Developing risk management framework to guide off-site manufacturing process: a Chinese perspective

Lin Zhang

PhD

October

2022

ABSTRACT

In China, demands for housing and infrastructure have increased significantly in recent years. However, such problems as extra costs, time overruns, and low quality still afflict the Chinese construction industry. It is imperative that the researcher find an alternative and novel method to solve the problem. Off-Site Construction (OSC) methods are often introduced to address quality, cost, and delivery (QCD) problems in the current situation. Many such OSC organisations have been established in China over the past decade, providing good practice for Chinese OSC industry development. In order to implement the OSC method successfully, the process and features of the OSC method need to be elucidated. It is also necessary to understand the differences arising between traditional construction methods and those of OSC, the application of which may result in unique risk factors arising within the OSC approach. Previous articles presented many risks associated with OSC projects. However, only a few articles have thus far considered the risk factors that influence off-site manufacturing (OSM) processes, and there is currently no risk response method for OSM. Therefore, this research aims to develop a risk management framework to reduce the negative effect(s) caused by OSM risk in China.

In this research, a mixed-methods approach, combining qualitative method and quantitative method was employed. Through the review of article, an introduction to OSC and OSM was presented. Semi-structured interviews were conducted as part of the qualitative research process. Thirty participants were interviewed. Based on the interview data, 3 sub-types, 13 groups, and 77 risk factors were identified and defined for the OSM process in China. As a consequence, a risk influence diagram reflecting the relationships arising between risk factors and QCD was developed. In order to identify the significant risk factors for the OSM process, a questionnaire survey was then developed based on the 77 risk factors identified from the interviews. 436 OSC practitioners participated in this quantitative research aspect and the researcher was able to identify the significant risk factors by evaluating the probability and impact of each risk via a five-point Likert Scale. The questionnaire identified 28 significant risk

factors that could cause QCD problems to arise within OSC projects. Based on the interviews and questionnaire data, a risk management framework was developed. In order to validate the significant risk factors and response methods, the OSM risk management framework was validated by case studies conducted for 2 OSC organisations. After the case study process had concluded, the OSM risk management framework was refined and presented.

This research identified 3 risk types, 11 risk groups and 28 risk factors for OSM risk management. The significant OSM risk factor in China is caused by high initial cost, consultant lack of OSC experience and contract bidding problems. The risk management framework was divided into 4 groups: principles, framework development, process, and participant.

The proposed OSM risk management framework seeks to help OSM organisations in China deal with risks pertaining to the OSC projects. This framework could help to identify those risk factors within the OSM process that may adversely affect QCD on the OSC project and presents the proposed response methods for each significant risk factor. Based on the type of organisation, the appropriate risk response method can be chosen from avoidance, transfer, reduction and retention. Thus, this framework is suitable for Chinese OSM organisations in helping them to understand the major barriers pertaining to the current situation. It may also have the potential to become a risk management guide for global OSM organisations.

ACKNOWLEDGEMENTS

I would like to appreciate all those who have supported and helped in my PhD research. Without them, it would have been impossible for me to finish my research.

First, I would like to express my special appreciation to my supervisor, Dr. Andrew Agapiou for his supervision, guidance, and support. During my study process, he gave me a lot of helpful advice and feedback for my research and also helped to improve my grammar. When I had doubts, he always encouraged me and pointed out better solutions. I owe my deepest gratitude for his support, guidance and patience which helped to hone my thinking and brought my work to a higher level.

I would also like to express my appreciation to my previous supervisor, Dr. Farzad Pour Rahimian, as he guided me towards PhD level. He shared his expertise, knowledge and experience at the beginning of my research. He gave insightful comments and suggestions for my research ideas and supported me to survive my early days in Strathclyde.

In addition, I owe a very important debt to the lecturers and colleagues at the research office of Architecture in Strathclyde. I want to thank the participants of the interviews, the questionnaire survey, and also the organisations that participated in the case studies.

I cannot express in words my thanks to my parents and family for their motivation, beliefs, prayers, willingness to listen and continuous support, both emotional and financial, throughout this journey.

Special thanks to all my friends. Last but not least, thanks are due to my best friends Cong Niu, Jianlin Cao, Mutian Li, Shangkun, Li, Xun Xi for their loyal friendship and the memories they have created.

DECLARATION

This thesis has not been previously submitted to meet the requirements for an award at this or any other institution of higher education. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Parts of this thesis have been published in the following conferences or journals:

Zhang, L., Rahimian, F.P., Agapiou, A. and Goulding, J., (2017). “Offsite construction: An opportunity for improving risk management”. *In international research conference 2017: shaping tomorrow’s built environment.*

Zhang, L. and Agapiou, A., (2019). “Risk definition for construction: risk, uncertainty, hazard, opportunity”. *In CIB World Building Congress 2019: Constructing Smart Cities.*

Zhang, L. and Agapiou, A., (2020). “Influence diagrams for off-site construction manufacturing risk assessment in China”. *Proceedings of the Institution of Civil Engineers-Management, Procurement and Law*, pp.1-18.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ABBREVIATION

Abbreviation	Explanation
AHP	Analytical Hierarchy Process
ANOVA	One-way Analysis of Variance
BBN	Bayesian Belief Network
CIM	Computer Integrated Manufacturing
DSS	decision support systems
EMV	Expected monetary value
FMEA	Failure mode and effects analysis
FMS	Flexible Manufacturing Systems
FST	Fuzzy Set Theory
FTA	Fault tree analysis
GDP	Gross Domestic Product
GT	Group technology
HMM	Hidden Markov Model
JIT	Just-In-Time
KMO	Kaiser Meyer-Olkin
MRP II	Manufacturing Resource Planning
OPT	Optimised Production Technology
OSC	Off-Site Construction
OSM	Off-Site Manufacturing
P-I	Probability and impact
PMBoK	Project Management Body of Knowledge
QCD	quality, Cost, Delivery
SWIFT	Structured what-if technique
TQM	Total quality management

GLOSSARY

Glossary	Explanation
External risk	Risks are produced by a non-human source and are beyond human control.
Internal risk	Risks are happened during the project process and caused by the feature of the project.
OSC	A construction method that produces component in OSC manufactory, transfer the component to the construction site, then assemble the component on-site.
OSM	A process in the OSC project, which is from the OSC manufacturer gets the requirement for the OSC project, to the OSC manufacturer gets payment for the OSC project.
Project member	Organisations that participate in OSC projects include the owner, consultant, manufacturer, transporter, and contractor.
Project process	OSC project process, includes project planning, design, production, logistic, and building.
Participant risk	. Risks are from within the organization and arise during normal operations.
Risk	A phenomenon or situation that has a negative effect on the objective.
Risk management	A process performed by management to identify, assess, manage, and control potential events or situations to provide reasonable assurance

List of appendixes

CHAPTER 1 - INTRODUCTION

1.1 Background

The construction industry is considered the most valuable asset of a country (Lam et al., 2010). However, the specific features of the construction industry result in lag behind other industries in the development process (Fulford et al., 2014; Latham, 1994; Winch, 1998). The construction industry has not changed since the last century. It is still a relatively low technology industry even in the most developed countries (Arif et al., 2009).

Due to the locations, workers, building types, time requirements, and governing policies, construction buildings are unique and built only once. It is thus almost impossible to summarise a general standard for the construction industry (Sousa et al., 2014). However, most construction projects have a similar process in that they start with a definition of need, followed by a design process, subcontracting, and then and then a whole building construction process, and last the time for project completion. In each construction phase, different processes should be considered (Hughes et al., 2001).

Traditional construction methods have been proposed for many years. It is still the most widely used methodology in the construction industry. Over three-quarters of all new housing in the UK is currently provided by the private sector using mainly traditional, site-based construction methods (Lang et al., 2016). Traditional construction methods provide a flexible production approach that encourages the housebuilder to use traditional materials and subcontract labour (Payne, 2009).

During long-term operations, traditional construction methods expose many problems. Yahya et al. (2012) concluded that the primary problems of traditional construction are that they require many workers, contribute less profit, entail many unnecessary activities, and frequently fail in terms of their timely completion. Schatteman et al. (2008) held the same view and emphasised that many construction projects fail to be completed on time, within budget, and quality goals. Zhang et al. (2016) defined that traditional construction methods lead to many issues such as low field productivity, unreliable quality, high resource allocations, excessive energy consumption, frequent safety accidents, and significant environmental pollution.

John et al. (2005) explained that the process of traditional construction comprised four stages, namely conceptual design, construction, operation, and maintenance. It would be simple in theory and construction projects would finish on time if they were strictly defined in terms of stages. However, two-thirds of projects in the UK are late due to their fragmented, complicated, risky and uncertain nature (Arayici et al., 2012). This suggests that a new approach to construction is necessary.

No two construction projects are the same, which causes each project to require a unique risk management process (Mills, 2001). However, it is possible to reduce the differentiation of different construction projects, which could keep the risk management method consist in the construction method. In that case, it is necessary to have a new construction method to solve the problem.

Off-site construction (OSC), or called modular construction, has been proposed in recent years (Doran et al., 2011). It differs from traditional construction in that the process of OSC includes off-site module prefabrication, component transportation, and on-site component installation (Nadim et al., 2009). Compared with traditional construction methods, OSC offers significant savings in terms of costs, time, quality control, waste, safety improvement, hazards and injury mitigation (H. X. Li et al., 2013).

Although OSC is relatively new, the use of construction components has existed for centuries. For example, Brunel developed standardised and prefabricated hospitals for the Crimean war in the middle of the 19th century, resolving the dearth of army treatment centres. Arif et al. (2010) argued that, in the pyramid construction process, the use of big boulders instead of smaller bricks was another example of OSC.

OSC is valued by many governments. Arif et al. (2009) found that Japanese housebuilders used OSC to produce attractive, customised and affordable homes. H.

X. Li et al. (2013) demonstrated that OSC was widely accepted across North America as an efficient construction method for accommodation. Blismas et al. (2006) indicated that OSC would become the primary means of improving the Australian construction industry in the ensuing decade. The UK government also considered OSC as the main route to improving construction in the twenty-first century (Arif et al., 2010). This view has since become a general consensus around the world, as the Chinese (Jiang et al., 2017), Singaporean (Park et al., 2011), and American (Nadim et al., 2011) governments have all presented similar white papers in support of OSC.

OSC differs from traditional construction through its four principal steps, namely design, manufacture, cross-border logistics, and on-site assembly (Li et al., 2016). The differences in the process necessitate a new risk management method. Previous articles have identified the new risks associated with OSC, including high component transportation fees (Hong et al., 2018), lack of experience (Wuni, Shen, et al., 2019), and lack of governmental support (Wang et al., 2019).

During the last decade, China's increasing population and economic progress have led to a rapid annual increase in the rate of urbanisation. According to the National New-type Urbanisation Plan (2014–2020), around 30 billion square meters of building area were newly constructed in China in 2020 (Taylor, 2015). It is impossible to meet the huge demand for building structures in China using a purely conventional approach. Better control of the construction process and working environment can only be achieved through predictable site conditions and by moving away from on-site manufacturing. The OSC method could help China to meet the requirements of both sustainability and housing demand (Zhai et al., 2013).

OSC is widely practised by the Chinese construction industry. Over the next decade, OSC is expected to account for 30% of total construction in China (Taylor, 2015). According to the 13th Five-Year Prefabricated Building Action Plan, 15% of new buildings should be OSC and more than 200 OSC industry bases should be established by 2020 (MOHURD, 2017).

Moreover, an increasing number of Chinese government standards and policies promote more effective Chinese OSC (Wu et al., 2015). Hong et al. (2018) summarised a number of relevant Chinese standards and policies at the provincial level, which could suggest that Chinese demand for OSC is increasing.

To achieve the aim of this research, the methods to be used for the current study comprised a comprehensive literature review which was followed by semi-structured interviews. The findings of these were subsequently transferred into a wider questionnaire survey and two case studies were used for the validation of the research.

OSC process transfers the on-site material building process into the component manufacturing process. The manufacturer's contribution is crucial from the outset. The risk in OSC arises during the early stage and becomes inherent in the project (Arabiat, 2013). Communication and coordination between the manufacturer and contractor are based on delivery orders, which are closely correlated to the progress of manufacturing and construction (Xiong et al., 2018). This presented that the Off-site manufacturing (OSM) process in the off-site manufactory is a relatively important process, especially for the component developing and producing process in the manufactory.

Due to the incessant problems arising with OSC projects, OSM risk should be considered. However, the OSM process is relatively new to construction companies, and the current method of risk identification may not recognise those risks that are specific to OSM. For example, the manufacturer usually processes orders from serial contractors because the frequent change in the type of prefabricated components during production entails significant equipment adjustments and operating changes (Yang et al., 2016). Large quantities of prefabricated components are stockpiled in a factory awaiting delivery as it takes a long time to produce a single component order. Additionally, the prefabricated components produced are usually voluminous, large and heavy, and require large storage areas (Kong et al., 2017). In this case, the roots of these risks require further investigation. There is also a need to consider the type of risk, its impact and probability. As risk management is a continuous process, the formulation of a risk framework for off-site manufactory is necessary. This framework should be generic for the off-site manufactory. It is also necessary for the framework to identify the key risks arising through the OSC project, especially in terms of the OSM process.

1.2 Problem statement

Schatteman et al. (2008) identified that one risk could cause at least one source of project delay. As resources were often shared among different projects, this disruption could lead to a complete project moratorium. Kaplinski (2013) identified that risk would have a significant influence during the management process as it also influenced operational strategy. Nonetheless, McGeorge et al. (2012) pointed out that traditional construction used few formal techniques of risk analysis and management due to a lack of familiarity with such approaches.

In China, as a crucial pillar of the Chinese economy, the construction industry has contributed between 14% and 28% of Chinese GDP over recent years (Du et al., 2019). However, problems such as rework, delay, and additional costs still recur in China. For example, many news outlets reported that significant quantities of grain were lost due to storage delays, which was ultimately attributed to construction delays in grain elevator projects (Chen et al., 2019). Z. Wu et al. (2017) identified that the construction risks were usually associated with delays and cost overruns. Thus construction risks in China have been a source of concern in recent years.

Risk management has developed over recent years. Edwards et al. (1998) identified the main features of risk management as a systematic means of managing risks. An effective risk management system should:

1. Establish an appropriate context.
2. Set goals and objectives.
3. Identify and analyse risks.
4. Influence risk decision making.

5. Monitor and review risk responses.

The primary advantage of using construction risk management for practices was in providing an understanding of and a degree of control in terms of identifying and managing inherent project risks. Dziadosz et al. (2015) demonstrated that risk management in traditional construction sought to identify undesirable factors, determine their impact on various elements of a construction project, and ultimately develop a solution to respond the risk factors identified. These risks might change during the project life cycle causing them to become a cumbersome challenge (Zavadskas et al., 2010). Risk management was designated as one of the eight principal areas by the Project Management Institute (Dziadosz et al., 2015).

OSC was also defined by many articles as an off-site environment, such as a manufactory, in which the manufacture and assembly of a building or parts of buildings take place for later installation on-site. However, OSC was not adopted by many housebuilders. Arif et al. (2009) reported that OSC accounted for approximately 2% of all UK construction and, of the top 100 housebuilders, few used OSC as their primary construction method.

As traditional construction and OSC employ very different processes, the OSC risk management process needs to be considered. However, the current OSC risk management process still uses those of traditional construction (Arashpour et al., 2015). In order to identify the new OSC risks and manage them, the specific features of OSC need to be addressed. For example, OSC issues such as health, safety, quality, human and environmental factors have not been considered (Blismas et al., 2006). Thus the OSC risk management method process remains unclear and needs to be improved.

OSC is a combination of material processing, manufacturing, mechanical engineering, installation services, construction and civil engineering activities, and all off-site practitioners are required to cooperate. As such, there are no single overarching contributors in the OSC sector (Taylor, 2010). The OSC process requires more attention to be paid to it, as the risks inherent within the process can adversely influence project cost, time and quality (Hashemi, 2015). As a part of the OSC process, OSM risk may interfere with the whole project. However, few articles have considered unique OSM risks or how other practitioners influence the OSM process. Therefore, it is necessary to first identify OSM risks and assess them to avoid the time wastages, quality issues and extra costs inherent in OSC projects.

The OSM process causes a variety of risks. Previous articles have presented risk rankings for OSC processes such as cost (Pan and Sidwell, 2011), environment (Lu et al., 2013), housebuilders (Pan et al., 2007), designers, contractors (Lu, 2007), and owners (Gan et al., 2015). These ranking processes give OSC risk management an appropriate and necessary point of reference. Although this research discusses the risks intrinsic to OSM, whole life cycle practitioners of OSC including the owners, consultants, and contractors should still be involved. As the OSC process is considered to be a continuous process, the influence of other practitioners' may increase the risks of the OSM process.

In order to develop a suitable risk framework for the OSM process, risk ranking is necessary to identify those risk factors of greatest significance. Risk ranking methods are based on probability and impact, and risk probability and impact matrices are used as per previous articles (Kassem et al., 2019). Therefore, this research attempted to reduce the risks inherent in a Chinese OSC project by developing a framework that specifically linked to particular areas of the OSM process that have been shown to cause delays, extra cost, or low quality.

1.3 Research question

Previous articles have highlighted the problems inherent in Chinese OSC projects. They also emphasise that the OSM process has a significant influence on successful OSC project completion. It is thus necessary to present a risk management method for OSM. Based on the problem statement above, the research questions are as presented below:

1. How does risk factor affect the OSM process in the Chinese OSC project?
2. Which risk factor has a stronger influence on OSM performance?
3. How can the risk factor be managed for the OSM process?

1.4 Aim and objectives

The review of the articles presented address identified risks and assess their relevance to OSM. Therefore, the aim and objectives of this thesis are as presented in Table 1.1.

1.4.1 Aim

The aim of this research is to develop a framework that provides a suitable risk management method for OSC projects in China.

1.4.2 Objectives

The objectives of this research are as follows:

1. To evaluate the existing risk and risk management processes.
2. To explore the main features of OSC and OSM.
3. To investigate the risks inherent within each phase of the OSM process in China.
4. To assess the significant risks of the OSM process in China.
5. To develop and validate a suitable framework for implementing risk influence analysis.

Table 1.1: Structure of the thesis - development of aim and objectives

Aim	**To develop a framework that provides a suitable risk management method for OSC projects in China**				
Objectives	Tasks	Methodology	Chapter	Output	Papers
1- To evaluate the existing risk and risk management processes	To cover the themes of risk and risk management methods	Secondary data	2-3	Literature review	‘Risk Definition for Construction: Risk, Uncertainty, Hazard, Opportunity’. Published in Hong Kong, CIB WBC 2019 conference.
2- To explore the main features of OSC and OSM	To understand the differences between traditional construction and OSC, and define the process of OSC	Secondary data	4	Literature review	‘OSC: an opportunity for improving risk management’. Published in Salford, IRC 2017 conference.

3- To investigate the risks inherent within each phase of the OSM process in China	To obtain qualitative data for the data analysis and uncover the risk for OSM processes	Primary data	6	Interview	‘Influence diagrams for OSC manufacturing risk assessment’. Published in MLP journal.
4- To assess the significant risks of the OSM process in China	To obtain quantitative data for analysis and rank the risk factors for the OSM process	Primary data	7	Questionnaire	‘Risk ranking for OSC manufacturing process’. Waiting for publishing.
5- To develop and validate a suitable framework for implementing risk influence analysis	To develop the framework for the OSM process and validate the framework.	Structured the analysis	8	Framework	‘A framework for OSM risk management’ In development.

1.5 Research methodology

The research methodology is necessarily influenced by which types of data need to be collected (Collis et al., 2013). This research used a mixed method as the methodology, and divided the process into four phases:

1.5.1 Literature review

The first step was desktop research via a systematic literature review of published articles in order to understand the current risk and risk management approach. This review helped to identify what the risks are and how they influence OSC projects. It also presents the role of the manufacturer in the risk management process. The knowledge gap in OSM risk is established during the literature review.

1.5.2 Semi-structured interviews

Semi-structured interviews were established with experts who have profound professional knowledge of OSM risks. The questions for the interviews were developed through the preview articles. The semi-structured interview included several standard questions plus some appended questions that were developed during the interview process. These interviews identify the specific risks associated with the OSM process and separate them from general OSC project risks. The interviews show the influence of off-site practitioners within the OSM project process.

1.5.3 Questionnaire

After the interviews concluded, a questionnaire survey was developed for the quantitative data collection. The result of the interviews provided the main source for questionnaire development. The questionnaire was distributed to current OSC practitioners. The purpose of this process was to give insight into OSM risks and identify the significant risk factors inherent within the OSM process.

1.5.4 Framework development

Based on the interview and questionnaire feedback, a framework was subsequently developed to rank and respond to the risks inherent within the OSM process. This framework presents the detail of the risk management process, and presents guidance based on the significant risk factors. After the significant risk factors were identified, the risk response method was identified based on the type of organisation. Two case studies were used to validate the risk management framework within the OSM process.

1.6 Limitations in research

This research focused on the Chinese OSC industry and the OSM process in particular. This research specifically addresses OSC manufactory in both the private and public sectors across China. The goal was to understand the features of risk in the OSM process and to rank the risks accordingly to measure the impact of how these influence OSC.

The manufacturer is defined as the organisation which is accountable for off-site project component production. In some instances, this would be conducted in parallel to a private company that was hired by the owner. In others, it would correspond to those branch offices which form part of the assigned engineering, procurement and construction (EPC) company.

Further to this, the scope of the present research only includes participants from mainland China. Taiwan was excluded due to differences in OSC industry standards. Hong Kong and Macao also have dissimilar OSC policies and development, as these two cities adopted different OSC development processes and this may affect the consistency of the research. In order to obtain more accurate findings, this research thus excluded these two cities. In order to avoid the potential dissimilarities arising due to the difference in the Chinese provinces, data were collected from major OSC locations in China, including Hubei, Guangdong, and Beijing. This should keep the data as uniform as possible.

1.7 Thesis structure

This thesis includes nine chapters which are as follows:

Chapter 1 – Introduction

The chapter presents the background of the research, leading to the extant gap in the current knowledge. It defines the concept of both OSC and OSM to give an understanding of the principle theories at the outset of the research. It also provides background and key questions underpinning the reasons for choosing this topic. The aims and objectives of the research are outlined. This chapter also briefly introduces the methodology of this research. The key findings of the study are highlighted at the end of this chapter.

Chapter 2 – Concepts of risk and risk management

The first part of this chapter presents an extensive literature review covering the concept of risk. It concludes with the theoretical background and definition of risk. It defines and explains the background and concept of risk. It also classifies the differences between risk, uncertainty, hazard, and opportunity. In conclusion, it explains three types of risk, namely internal risk, external risk, and project risk.

The second part of this chapter presents an extensive literature review that addresses the concept of risk management. It concludes the theoretical background for risk management and how best to implement risk management successfully. It defines and explains the background and concepts underlying risk management. It also introduces the process of risk management itself. In summary, it presents both the benefits and limitations of risk management.

Chapter 3 – Risk management method

This chapter presents an extensive literature review covering the risk management methods used, which are categorised according to the identification of specific risks, their assessment, analysis, and appropriate response. Both quantitative and qualitative methods for risk management are identified and explained.

Chapter 4 – OSC and OSM

The chapter presents an extensive literature review covering the concepts of OSC and OSM. The background and definition of OSC are introduced. The unique features of the OSC industry and the appropriate risk management methods are considered carefully. Also, this chapter includes the benefits and barriers of OSC. As a part of the OSC process, OSM is identified and analysed within this chapter. From previous articles deploying risk management strategies in OSC projects, all risk management methods are duly classified and evaluated. This presents a gap in that there are few articles that consider OSM risk management. By analysing the features of OSC and OSM, an appropriate methodology is selected for the project.

Chapter 5 – Methodology

This chapter introduces the methodology underpinning this research. The advantages and limitations of each method are defined and, in this case, a mixed methodology was chosen. The data collection process and limitations are presented as well as the reasons for the adoption of such software as NVivo and SPSS. Semi-structured interviews are employed for the qualitative methodology and a questionnaire survey was formulated for the quantitative aspects of this research. This chapter explains the construction of interviews and questionnaires and explains the pilot study for the data collection process. This chapter also explains how and why the research method was selected.

Chapter 6 – Qualitative results

This chapter introduces the findings from the qualitative methodology. The data presented within this chapter was derived from semi-structured interviews. The interviewees' backgrounds and affiliations are explained in detail. Based on the data presented, the risk factors that influence OSM processes are identified. In order to classify the various risks pertaining to project members and processes and external factors are presented. Each risk results in at least one potential problem for project quality, cost and delivery (QCD). Thus, the QCD influences for each risk are identified.

Chapter 7 – Quantitative results

This chapter introduces the results of the quantitative methodology. The data presented in this chapter is derived from the questionnaires. The participants' backgrounds and organisations are outlined. The pilot study itself is analysed to identify which risk factors were deemed suitable for formal research. The formal research is analysed to identify the significant risk factors associated with OSM. Based on the data obtained, the significant risk factors affecting OSM are identified.

Chapter 8 – Discussion and validation

This chapter presents the results of the research and validates the results. It explains the framework obtained from the interviews and questionnaires, validates the framework and seeks to refine it. This chapter describes the justification process for the research which was the case study method. It also presents the validation process for the framework using the two case studies. The framework is validated by means of the case study methodology which was enacted via interview, site visitations and document analysis.

Chapter 9 – Conclusion

The chapter summarises the main findings of this research. It presents the limitations of this research. The chapter also concludes with recommendations for off-site manufacture and future research.

1.8 Key findings

OSC has become a new method for the Chinese construction industry. It is thus necessary to develop an OSM risk management framework for Chinese construction companies. Furthermore, the research provides additional knowledge in identifying the significant risk factors associated with OSM in China and presents solutions. A risk management framework for OSM is developed based upon this research. The findings guide Chinese OSC organisations, particularly in relation to off-site manufacturing, to better understand the associated risks and implement improved responses.

CHAPTER 2 - RISK AND RISK MANAGEMENT DEFINITION

2.1 Introduction

The first part of this chapter explores the background and concept of risk, and how it influences both construction projects and projects more generally. Then, the differences arising between risk, uncertainty, hazard, and opportunity are presented. After risk is defined and discussed, its role in construction is addressed and presented for different aspects of the industry and then, finally, the chapter summarises the salient features of risk.

The second part focuses on the concept of risk management itself. It presents how the researcher implements risk management in both general and construction projects. By introducing the background to risk management, its development process is presented from a historiographical perspective. It also introduces the different types of the risk management process and presents the benefits of deploying risk management mitigation strategies.

2.2 Risk background and history

2.2.1 Risk history

In our everyday language, the concept of risk is frequently used and easily understood by the general population (Morgan et al., 1990). From an etymological analysis of the European notion, risk derives from the Greek nautical term ‘Rhizikon’ describing the need to avoid ‘difficulties at sea’ (Rivza et al., 2012). Another explanation is that risk was originally from a sailor’s term and meant ‘To run into danger or to go against a rock’ (Jannadi et al., 2003). More than 2,400 years ago, the Athenians offered the capacity to assess risk before making decisions (Aven, 2016). In that sense, the best approximation of risk would be fear of adventure. The fear refers to commercial activities and implies physical and mental distress, while the (ad)venture implies pecuniary ventures as a strategy by which to expand self-worth (Heckmann et al., 2015).

In the 14th century, the renaissance brought more in the way of maritime trade opportunities for European countries. Those merchants accepted risk as a way of expressing the dangers of losing their ships. These risks not only came from external threats such as adverse weather or piracy, but also from internal sources such as the ship's construction quality or the experience of sailors. The problems are inherent within the navigation process present potential developments and consequences (Klibi et al., 2012). These problems had to be considered by the merchants in order to find a solution by which to respond to these risks. Today this approach is widely used in planning and is commonly referred to as scenario analysis (Chermack, 2004). Within this context, risk definition changes with the fear that economic activities might lead to the loss or devaluation of an important asset or to a decrease in the performance of the business (Heckmann et al., 2015).

At the beginning of the 17th century, risk analysis became a predominant theme in mathematics, which concentrated on the probability of events that resulted in a loss. Mathematicians focused on uncertainties in gambling, which led to the development of Probability Theory which, in turn, became the main concept of risk (Frosdick, 1997). In the 20th century, risk analysis took a further development as many different kinds of risk are now discussed including business risk, social risk, economic risk, safety risk, investment risk, military risk, political risk, and so on. In these scenarios, risk is defined as a measure of the probability and severity of adverse effects, which has the probability and consequence for the project (Lowrance, 1976). In the 21st century, risk definitions have further evolved to disambiguate the meaning of probability and the adverse effects of risk definition. In the previous definition, the phrase 'Probability and severity of adverse effects could be interpreted in two ways at the same time. The first was in terms of the probability of the occurrence of adverse effects, and the second was in relation to the probability of the severity of these adverse effects, given their occurrence (Haimes, 2009). By using a systems engineering approach, risk can be identified by answering four questions, namely 'What can go wrong?', 'What is the likelihood?', 'What are the consequences?' and

‘Over what time frame?’ (Haimes, 2009).

2.2.2 Risk background

In the UK, a third of all projects were delivered late and over budget, and two-thirds were delivered late (Mulholland et al., 1999). In the USA, the health and safety problem resulted in small employers (<20 employees), which account for 37.5% of employment, being responsible for 57% of all fatalities (Ringen et al., 2018). The Alberta oil sands in Canada cost overruns of up to 100% (Jergeas et al., 2010). This problem is not unique to western countries. In China, old-fashioned construction methods led to many issues and the loss of time and money (Zhang et al., 2016). In Malaysia, delay is the most common, costly, complex and risky problem encountered in construction projects (Alaghbari et al., 2007). In South Korea, The average final cost at completion has increased by 122.4% compared to the original budgeted cost since the 1990s (Han et al., 2009). Mustafa et al. (1991) considered the reasons as coming from the lack of a rational, straightforward approach to combine all the facets of risk system into a single prioritised and manageable scheme. Nowadays, risk is recognised and perceived across many areas. In medical science, risk is defined for those people who are at risk of developing eating disorders (Striegel-Moore et al., 2007). In economics, risk is monitored to find the reasons for small business failures (Everett et al., 1998). In agriculture, risk is analysed to avoid fatal accidents in the planting process (Arana et al., 2010). However, before the 1960s, risk had not appeared in relation to a construction article (Edwards et al., 2013). Latham (1994) presented the notion that no construction project is risk-free and the body of research considering construction risk is increasing annually. However, the construction industry has a poor reputation for risk analysis as compared to other industries such as finance or insurance (Laryea, 2008). In a construction project, risk exists through the life cycle, which may result in losses of life and property (Ji et al., 2022). The dynamic environments of construction project increase the amount of risk, which increase the difficulty to manage construction risk (Monzer et al., 2019).

2.3 Risk features

2.3.1 Risk definition

For most people, risk is a negative response to a given project or process and many articles offer similar definitions. The Oxford-Dictionary (2017) defined risk as a situation involving exposure to danger. Jannadi et al. (2003) defined risk as a measure of the probability, severity, and exposure to all the hazards of an activity. Serpella et al. (2014) agreed with this view and emphasised that risk is the probability of a damaging event occurring during a project. For the project manager, risk is the issue of the problem that might happen while performing the project (Cervone, 2006). Many articles pointed out risk has a negative impact on achieving project objectives, and risk may cause schedule delays, cost overruns and safety and quality problems (El-Sayegh et al., 2018; Ghasemi et al., 2018; Li et al., 2019; Unver et al., 2021).

However, risk is not always associated with a negative outcome. Some articles contend that risk can be treated as an uncertain event with possible positive or negative outcomes. Zavadskas et al. (2010) described risk as an uncertain or conditional event with a positive or negative effect on at least one project objective, if it occurs. Lichtenberg (2000) defined this duality of risk as a possible event that could have a negative or positive impact.

The Project Management Body of Knowledge (PMBoK) stated that project risk is an uncertain event or condition that, if it occurs, has a positive or a negative effect on a project objective (PMI, 2017). For example, when General Electric launched Ecomagination, many people only saw the risk of solving environmental threats. Nonetheless, GE still captured the opportunity of environmental protection, an act that was highly praised by society (Bekefi et al., 2008).

Risk has been defined by many international and national-level standards. The definition of risk in the standards was found in varying terminologies. Table 2.1 presents the risk definition from the standards.

Table 2.1: Risk definition divided from standards

DOCUMENT	DEFINITION	KEYWORDS

ISO 31000:2018 (ISO, 2018b)	"Effect of uncertainty on objectives" and an effect is a positive or negative deviation from what is expected.	Uncertainty, positive or negative
PAS 7000:2014 (BSI, 2014)	Situation determined by the likelihood and impact of an incident arising from a particular threat scenario.	Likelihood, impact
BS EN ISO 14971:2019 (ISO, 2019)	The probability of occurrence of harm, and the consequences of that harm, that is, how severe it might be.	Probability, consequence
ANSI/ASSP Z690 (ASSP, 2011)	Effect of uncertainty on objectives.	Uncertainty, objective
CAN/CSA-Q850-97 (R2009) (CSA, 2009a)	The chance of injury or loss as defined as a measure of the probability and severity of an adverse effect to health, property, the environment, or other things of value.	Loss, probability
GB/T 23694-2013 (SAC, 2013)	Effect of uncertainty on objectives.	Uncertainty, objective

The professional bodies or societies also have a definition for risk. Table 2.2 presents the risk definition from the professional bodies or societies.

Table 2.2: Risk definition divided from societies

INSTITUTION	DEFINITION	KEYWORDS
Association for Project Management (APM) (APM, 2018)	Risk can be perceived either positively (upside opportunities) or negatively (downside threats). A risk is the potential of a situation or event to impact on the achievement of specific objectives	Positively, negatively, potential, objectives
Project Management Institute (PMI) (PMI, 2009)	An uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives.	Uncertain event, positive or negative, objectives
Institution of Civil Engineers (ICE) (ICE, 2020)	The possibility of outcomes different from those expected.	Possibility, outcomes
Australian Institute of Project Management (AIPM) (AIPM, 2021)	Factors that might adversely affect project outcomes.	Factors, adverse effect, outcomes
Project Management Research	An uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives.	Uncertain event, positive or negative,

Committee (PMRC) (PMRC, 2002)		objectives

The various definitions of risks are presented in Table 2.3, although risk may have different definitions across the literature. There is, however, a consensus that risk can influence at least one project objective. The influence on project objectives may result in extra cost or time delay.

Table 2.3: Risk definition divided from articles

AUTHOR	DEFINITION	KEYWORDS
Oxford-Dictionary (2017)	A situation involving exposure to danger	Situation, exposure, danger
Jannadi et al. (2003)	A measure of the probability, severity, and exposure of all the hazards of an activity	Probability, severity, exposure, hazard
Zavadskas et al. (2010)	Risk is an uncertain event or condition. It has a positive or negative effect on at least one project objective, if it occurs	Uncertain, positive, negative, project objective
PMI (2017)	Project risk is an uncertain event or condition that, if it occurs, has a positive or a negative effect on a project objective	Uncertain, positive, negative, project objective
Lichtenberg (2000)	Risk is defined as the exposure to loss or gain, or the probability of occurrence of loss or gain multiplied by its respective magnitude	Exposure, loss/gain, probability, magnitude
Serpella et al. (2014)	Most of the risk usually has negative outcomes leading individuals to consider only the negative side of risk	Negative result

In Chinese articles, there are also many research defined risks. (Huang et al., 2007) defined risk has a negative influence on the project. (Li, 2013) focused on the risk factor which has negative outcomes for the objective. Chen et al. (2017) agreed risk might have a positive influence on the project objective, but most articles consider risk only a negative aspect.

2.3.2 Risk features

Risk may have one or more causes and, if it occurs, may have one or more impacts which, in turn, may have positive and negative effects on the project objective. A cause may be a requirement, assumption, constraint, or condition that creates the possibility of negative or positive outcomes (PMI, 2017). Risk may also represent opportunities, but the fact that most of the risks detailed usually have negative outcomes has led individuals only to consider the negative side of risk (Kasa et al., 2018).

From a qualitative perspective, risk could be understood as (Aven et al., 2015):

1. The possibility of an unfortunate occurrence.
2. The potential for realisation of unwanted, negative consequences of an event.
3. Exposure to a proposition of which one is uncertain.
4. The consequences of the activity and associated uncertainties.
5. Uncertainty about and severity of the consequences of activity with respect to something that humans value.
6. The occurrences of some specified consequences of the activity and associated uncertainties.
7. The deviation from a reference value and associated uncertainties.

Another similar risk definition is shown below (Chia, 2006):

1. A risk is a future event that may or may not occur.
2. A risk must also be an uncertain event or condition that, if it occurs, has an effect on at least one of the project objectives, such as scope, schedule, cost or quality.
3. The probability of the future event occurring must be greater than 0% but less than 100%. Future events that have a 0% or 100% chance of occurrence are not considered risks.
4. The impact or consequence of the future event must be unexpected or unplanned for.

Risk descriptions could also be (Aven et al., 2015):

1. The combination of probability and magnitude/severity of consequences.
2. The combination of the probability of a hazard occurring and a vulnerability metric given the occurrence of the hazard.
3. A scenario, the probability of that scenario, the consequence of that scenario.

4. Some specified consequences and a measure of uncertainty associated with those consequences, with the background knowledge that supports the consequences and uncertainty.
5. Expected consequences.
6. A probability distribution for the associated damage.

These various risk definitions present the commonalities associated with risk, wherein risk can be considered to comprise two elements, namely impact and probability. In order to calculate how a given risk can influence the project, a formula is often presented as follows (Dziadosz et al., 2015):

$$CRI = I * P$$

In this formula, CRI represents Composite Risk Index, I represents the impact of the risk event, and P represents the probability of the risk occurrence. However, Sumner (2009) considered preparedness another variable for risk in influencing the outcome of the project. Although some risks have a low impact and low probability, the lack of preparation for such project risk could still result in the project objective being adversely affected.

In terms of construction, risk often constrains the main project objectives, namely timely delivery, cost, and quality (Zou et al., 2007). Similar ideas are presented by Abujnah (2010), who identified the project as being subject to interference in three crucial dimensions:

1. The number of possible outcomes.
2. The value (magnitude) of each outcome.
3. The probability of the occurrence of each outcome.

For a construction project, the Marsh Risk Universe can be used to define risk types (Visser et al., 2008). The Marsh Risk Universe is divided into internally driven risks, externally driven risks (stakeholder) risks. The bands, in turn, are divided into four quadrants, representing Financial, Strategic, Hazard and Operational risks.

2.4 Risk differentiation

Various definitions concur that risk is based on project uncertainty. However, the definition of construction risk remains unclear and is easy to confuse with uncertainty. Taroun (2014) identified that definitions are needed, not only for the risk management process itself, but also for construction risk in general.

2.4.1 Risk

After the Second World War, risk management underwent a significant improvement (Chapman et al., 2003). Many project management textbooks now contain definitions of project risk. A consensus of opinion on risk can be taken from the Guide to the PMBOK, which defines risk as an uncertain event or condition that, if it occurs, has a positive or negative effect on a given project objective (PMI, 2017). In the UK, a similar official risk management book called the Project Risk Analysis and Management Guide, developed by the Association for Project Management, defines risk as an uncertain event or set of circumstances which, should it arise, will likely have an adverse effect on the achievement of the project's objectives (Bartlett, 2004).

1. Risk is occurrence- or event-based

Jablonowski (2006) defined risk as the chance or likelihood of events occurring with negative consequences, such as injury or loss. Busby et al. (2008) agreed with this opinion and emphasised project risk as the statistical concept of the probabilities and consequences of threatening conditions and events, contingent on the project event and its having either a positive or negative influence. Construction risk could be financial, technical, political or organisational, and may have internal, external or project-related influences on construction projects (Zhang et al., 2017). All risks must have at least one source and one subsequent event which may occur as a result of that underlying state of affairs (Winch, 2010).

2. Risk is quantifiable and solvable

Cervone (2006) defined risk through a simple and understandable question: What are the problems the project manager might encounter while performing this project and how the project manager avoids them? This means that risk must be quantifiable and solvable. Many risk identification tools have been developed based on this assumption including brainstorming, interviews, checklists, scenario analysis, and fault tree analysis. However, most risks that have caused serious consequences had not been identified before the project process commenced (Dziadosz et al., 2015). Edwards et al. (2013) emphasised that if the risk could be found by a risk manager, the consequences of uncertainty could be avoided.

3. Risk is the consequence of uncertainty

Dziadosz et al. (2015) treat risk as a measurable component of uncertainty so that the occurrence probability and the extent of damage can be estimated. This view is shared, in turn, by Aven (2016) and Cleden (2017), who contend that risk is uncertainty about and severity of the consequences of activity with respect to something that humans value. The probability of the future event occurring must be greater than 0% but less than 100%, although the impact or consequence of the future event may be unexpected or unplanned (Chia, 2006).

2.4.2 Uncertainty

In the social sciences, uncertainty has most commonly been paired with risk. Beck (2014) pointed out that uncertainty has a strong relationship with risk. The Oxford-Dictionary (2017) defined uncertainty as the state of being not able to be relied on or not known or definite.

Compared with risk, uncertainty has fewer relevant definitions within the literature. Most articles conflate definitions of risk and uncertainty. However, some sources point out the differences between them. Jaafari (2001) defined uncertainty as the probability that an objective function will not reach its planned target value, or as an unknown probability of occurrence of an event. Winch (2010) pointed out that uncertainty in the plain English sense of ‘lack of certainty’ is in part about ‘variability’ in relation to such performance measurements as cost, duration, or ‘quality’. It is also about ‘ambiguity’.

1. Uncertainty is a ‘state of unknowing’

Morris (2013) emphasised that uncertainty really reflects unknowns. Uncertainty is the state of mind of someone deciding on a course of action without a clear outcome (Wakeham, 2015). As argued by Howell et al. (2010), the core concept of uncertainty is a lack of certainty over the parameters, context or possible outcomes of a particular set of circumstances. Therefore, the project is unknown due to this uncertainty and the project managers do not know that they do not know (NicholasTaleb, 2015).

2. Uncertainty is a lack of information

Frank (1999) divided uncertainty into either aleatory or epistemic uncertainty. Aleatory uncertainty is that uncertainty that cannot be foreseen in advance, and epistemic uncertainty is described as uncertainty deriving from a lack of knowledge. Either a deficit in information or knowledge will cause uncertainty (Grote, 2015).

3. Uncertainty cannot be measured

Unlike risk, uncertainty cannot be measured (Serpella et al., 2014). Knight (2012) stated that risk pertains to those events which are subject to known or knowable probability, whereas uncertainty refers to events for which it is impossible to specify numerical probabilities. Uncertainty always comes from some set of objective environmental characteristics, and most of them are unmeasured (Jauch et al., 1986). This feature of uncertainty causes the manager to be unable to control it, and thus they have to ignore it (Nowotny et al., 2001).

4. Uncertainty is the context for risk

Uncertainty should be treated as a context for risks, which risk causes a negative impact on the project's objective (Perminova et al., 2008).

5. Uncertainty can be positive and negative

Hillson (2002) divided uncertainty into two categories: (i) risk referring exclusively to a threat, and (ii) opportunity which is uncertainty with positive effects. Perminova *et al.* (2008) explained that when the fact is questioned, uncertainty arises, and risks or opportunities happen in the project. Similar ideas can be found in several different sources (Cleden, 2017; Morris, 2013; Ward et al., 2003).

2.4.3 Hazard

In the Oxford English Dictionary, a hazard is defined as a danger or risk (Oxford-Dictionary, 2017). However, some sources have pointed out that the distinction between risk and hazard is clear (Lofstedt, 2011). Hazard is associated with the intrinsic ability of an agent or situation to cause adverse effects on a target (Renn, 2008).

1. Hazard is a potential event of risk

Renn (2008) suggested that if a project is not exposed to hazards or has a solution for the corresponding risk, the condition of hazard may never materialise. The German Federal Institute for Risk Assessment (BfR), meanwhile, described hazard as the potential of a substance in toxicology to cause an adverse effect, while risk is the product of the scale and probable occurrence of damage (Spielmann et al., 2008).

2. Hazard is negative

Hazard is always negative. It is a potentially damaging physical event, phenomenon, or human activity, which may cause loss of life or injury, property damage, social and economic disruption, or environmental degradation (UN, 2004). A paper from the International Risk Governance Council (IRGC) provided a similar notion that hazard is the potential for harm or other consequences of interest (IRGC, 2005). The most authoritative view may come from the International Organisation for Standardisation (ISO), which provides the simplest and clearest idea of hazard as being a source of potential harm (ISO, 2018a).

3. Hazard is associated with intrinsic abilities

Although hazard is always negative, it would not be transferable to risk if there were no sensitive targets (Andretta, 2014). For example, there is a poisonous mushroom and, if somebody eats it, there will be a risk of him or her becoming poisoned. If nobody eats it, it will not be a risk (i.e., there are no sensitive targets), yet it remains a hazard. Hazard is associated only with the intrinsic ability of an agent, stressor, or situation to cause adverse effects to a target population or receptor (Asante-Duah, 2017).

2.4.4 Opportunity

In general, opportunity is defined as a time or set of circumstances that makes it possible to do something (Oxford-Dictionary, 2017). Opportunity and threat are thus always considered elements of the relative possibility of risk (Hillson, 2002).

However, the inner feature of opportunity is still unclear.

1. Opportunity is a dual risk

Risk exposure could be understood as Probability (loss) multiplied by Impact (loss). Opportunity exposure could also be treated as Probability (gain) multiplied by Impact (gain). Opportunity could thus be treated as a dual risk. If seized, it can have a positive impact on a project, but if ignored, it will have a negative influence (Boehm, 2014).

2. Opportunity has positive influences on a project

As with threats, opportunities also can involve uncertainty, with the potential to affect project objectives (Hillson, 2002). Chapman et al. (2011) provided a similar definition to support the idea that opportunities have a positive influence on a given project.

3. Opportunity may increase risk

Kendrick (2015) divided opportunities into three types: those related to project specifications, those related to planning decisions, and those related to beneficial uncertainties. Although some opportunities may reduce overall project risk, most will actually increase overall project risk and serve as sources of potential project problems. This is because the positive utility magnitude of improving an expected outcome is generally less than the negative utility magnitude of failing to meet an expected outcome (Pyster et al., 2012).

From the literature cited above, a flowchart can be developed to explain the relationship arising between risk, uncertainty, hazard, and opportunity:

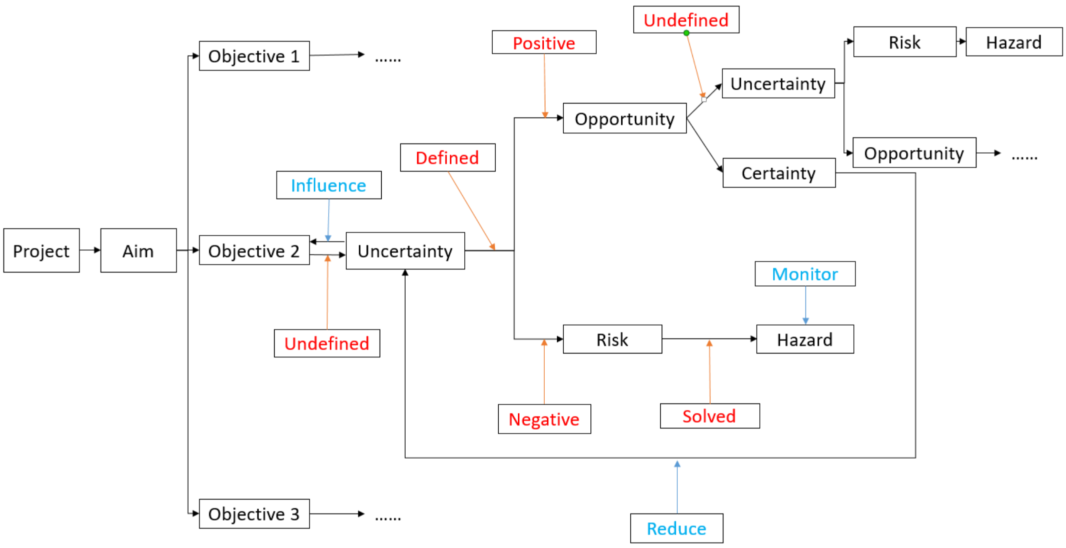


Figure 2.1: Uncertainty, risk, hazard, opportunity flowchart

In order to understand the process of Figure 2.1, the project manager could follow seven steps to divide the project, as follows:

1. A project begins, and the project manager defines the project into aims and objectives.
2. Each objective has its uncertainty. At this stage, the project manager knows that the uncertainty could influence the project, although they do not know when, where, why, to whom, or how such uncertainty may arise.
3. The project manager needs to use risk identification and risk assessment to know how the uncertainty may influence the project. Negative uncertainty transfers to risk, and positive uncertainty transfers to opportunity.
4. For risks, the project manager needs to use risk analysis and risk response to understand how to manage the risk and how to respond to it. After this, the risk transfers to hazard, and the project manager needs to monitor the hazard, but does not need to take further action if the hazard is not exposed. If the hazard exposes, it means the hazard transfers back to risk, which requires managing the risk.
5. For opportunities, the project manager needs to divide each opportunity into two parts: uncertainty and certainty. Uncertainty from the opportunity may

bring new risks or opportunities, and certainty can reduce the uncertainty of this objective.

6. All the objectives can be broken down using a similar structure through steps 1 to 5.
7. After all objectives are achieved, the aim can be achieved, and the project can be completed.

Figure 2.1 provides the interesting idea that each project can be treated as an opportunity. As each project has its own aim and several objectives, each objective could be treated as a smaller project. If the objective is seized, it could then be treated as the positive influence on the aim. If it is known that an opportunity has a positive influence on the project, if seized, then the relationship between objective, aim and project could be treated as depicted in Figure 2.2.

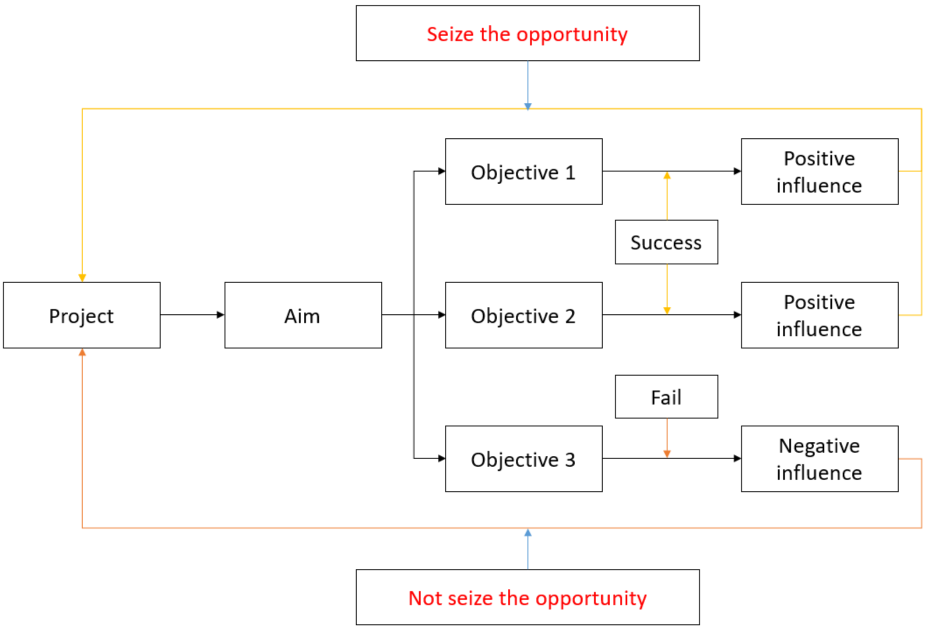


Figure 2.2: Opportunity flowchart

Figure 2.1 and Figure 2.2 provide the link between risk, uncertainty, hazard and opportunity. As presented, most construction project uncertainty can be divided into risks and opportunities. Those risks which are resolved will become hazards. Opportunities have a given uncertainty and could, in part, influence the outcome of the construction project.

2.5 Risk Type

Risk is defined into three categories: risk group, risk type, and risk factor. Risk factor is defined as a variable associated with an increased risk of disease or infection, risk type is defined as a set that several risk factors have a similar source, and risk group is defined as the set that several risk types have a similar environment. The relationship between them is risk group includes risk type, and risk type includes risk factor (Parritz et al., 2013). Risk type for the construction business has been defined by many articles.

El-Sayegh (2008) subdivided construction risk into two types: internal risk and external risk. Aleshin (2001) defined that internal risks are initiated inside the project, while external risks originate due to the project's environment. Internal risks are then divided according to the party who might be the originator of such risk events, such as the owner, designer, contractor, etc. External risks are those initiated at the macro level.

Renault et al. (2016) assigned construction risk into ten categories, namely:

1. Design: Defective design; inaccurate quantities; an uncoordinated design; a rushed design; the awarding of a design contract to unqualified designers; a lack of consistency between the bill of quantities, drawings, and specifications are all potential design risks.
2. Physical: Occurrence of accidents because of poor safety procedures, the supply of defective materials, insecurity of material and equipment, public insecurity, or varied labour.
3. Logistics: Improper site investigations; inaccurate project programmes; unavailable labour; inadequate materials or equipment; high degrees of competition in bids; undefined scope for labour; poor communications arising between the home and field offices all constitute logistical risks.
4. Legal: Ambiguity of work legislations; difficulties in obtaining permits; delayed dispute resolutions; legal disputes arising during the construction

phase among the parties to the contract; and no specialised arbitrators to help settle disputes fast all constitute legal risk factors.

5. Environmental: Adverse weather conditions and difficulties in accessing the site are just two environmental risk factors.
6. Construction: Gaps between implementation and specified completion dates due to a misunderstanding of drawings or specifications; actual quantities differing from contracted quantities; design changes; lower work quality due to time constraints; rush bidding; and undocumented changes to orders are some risks inherent in the construction process.
7. Management: Including poor communication arising between involved parties; ambiguous planning due to unanticipated project complexity; changes in management styles; lack of availability of information; resource mismanagement, *inter alia*.
8. Cultural: Religious, cultural customs clashing with schedules or requirements.
9. Financial: Delayed payments on contract, unmanaged cash flow, inflation, financial failure of the contractor, exchange rate fluctuations, monopolising of materials due to closure, and other unexpected political conditions can create financial risk.
10. Political: New governmental acts or legislation, inflation, and unstable security circumstances.

A risk breakdown structure for sustainable construction has been developed by El-Sayegh et al. (2018), which includes five categories, as follows:

1. Management risks: risk would occur when managing the construction project.
2. Technical risks: risk might occur during construction due to design changes, or insufficient/incorrect sustainable design information.
3. Stakeholders risks: risks are only those that affect sustainable construction and have no effect upon traditional construction projects.
4. Materials and technology risks: risks that relate to shortages, handling or quality of construction materials.

5. Regulatory and economic risks: such risk involve any codes or regulations enforced by the government and any economic crisis that might arise.

Zavadskas et al. (2010) streamlined construction risk into three types, namely internal risk, external risk, and project risk.

2.5.1 Internal risk

Internal risk is that risk that is influenced by project participants. It includes resource risk, project member risk, construction site risk, documentation and information risk (Zavadskas et al., 2010).

1. Resource risk: Materials and equipment involve considerable risks. The availability and productivity of the resources necessary to construct the project are risks that are proper for the contractor to assume.
2. Project member risk: Team risk refers to those issues associated with the project team members which can increase the uncertainty of a project's outcome, such as team member turnover, staff build up, insufficient knowledge among team members, a lack of cooperation, poor motivation, or team communication issues.
3. Construction site risk: Exposures to accidents in the workplace are an inherent risk and are best assessed by the contractors and their insurance and safety advisors.
4. Documents and information risk: Contradictions arising in documents, pretermission, legal and communication, changed order of negotiation and delayed dispute resolution are all significant risks arising during project construction. Communication is very important at all stages of construction and after completion.

Lehtiranta (2014) asserted that internal risks are related to the project organisers' ability to work together effectively. They represent the prominent face of the project's organisation and serve as a potential source of risks and opportunities.

2.5.2 External risk

External risk is a risk that the risk management team cannot control. It includes political risk, economic risk, social risk, and meteorological risk (Zavadskas et al., 2010).

1. Political risks: There are potential changes in government laws pertaining to the legislative system, regulations, policy and improper administration system, etc.
2. Economic risks: There may be economic instability in the country, repayment issues as regards manufacture, uncontrolled inflation, and funding deficits. Considering the current economic situation, such factors can be reasonably anticipated. Economic disasters are periodic crises of such magnitude that a contractor is unable to properly assess its probability or impact on costs.
3. Social risks: These are of growing importance to any effort in terms of risk allocation. It is an area in which political and social pressures from parties having little interest in a project, yet having a great impact on its completion, can greatly influence its outcome. The impact of financial aid on social and economic development within a region and the communication of risk in organisations can be analysed.
4. Weather risk: Except for extreme conditions, this is a risk that the contractor may accommodate, as its impact on construction methods can be readily assessed by the contractor.

These external risks all involve all other events or actors that the project's organisation may encounter. Their influence and impact are determined by how the organisation is able to harness its resources and attribute them to risk management.

2.5.3 Project risk

Project risk is that risk which only arises during the period of construction. It includes time risk, cost risk, work quality risk, construction risk, and technological risk (Zavadskas et al., 2010).

1. Time risk: Appraisal of delays in construction, technology and all other works.
2. Cost risk: The cost of opportunity product rises due to the neglect of management.

3. Work quality: Deflective workmanship is considered a significant risk factor in this category, not only because it results in construction delays and additional costs to the contractor, but also because it leads easily to disputes as to the liability for the delays.
4. Construction risk: Such risks are associated with construction delay, changes in work schedule and issues with construction technology.
5. Technological risk: Includes design errors, a lack of appropriate technology, management errors, and shortages of qualified labour.

2.6 Risk management background

2.6.1 Risk management history

The first evidence of risk analysis can be traced back as far as 3,200 BC within the Tigris-Euphrates valleys within a group of people known as the Asipu. The Asipu identified important dimensions of a given problem, proposing alternative actions and collecting data on likely outcomes (Baker et al., 1999b). During the Egyptian era, the construction process of the pyramids applied project management principles (Kwak, 2005). In 1730, the Japanese Dojima rice market used contracts to mitigate trading risks (Schaede, 1989). This approach provided the trader with a competitive protection tool that complemented several other risk management strategies.

The era of modern risk management began after World War II. Harrington et al. (2003) dated the origins of modern risk management to the period from 1955 to 1964. Snider (1956) observed that there were no risk management books available at that time and that none of the universities offered risk management courses. The first academic book pertaining to risk management was published by Mehr et al. (1963), and the first scholar to use risk analysis as a part of risk management was Hertz (1964), who generated probabilistic distributions of investment project rates of return. Since the commencement of the 1970s, the concept of financial risk management has evolved considerably (Dionne, 2013). Meanwhile, large companies began to develop self-insurance to mitigate risk, providing effective coverage as insurers against many forms of small exposure. This insurance covered the consequences of an adverse event or losses from an accident (Dionne et al., 1985). From the 1980s onwards, however, risk management became a well-established project management function (Taroun, 2014). Technological risk management models were developed, and pure risk management was considered. Risk management developed very quickly because companies began to actively consider financial management and portfolio management as separate entities (Dionne, 2013).

2.6.2 Risk management method history

The risk management method also entailed different stages over different decades. Before the 1950s, when project management and risk management were regarded as a single discipline, Henry Gantt developed the Gantt Chart in 1917 which became the most common tool for project risk management. Fayol (1949) later synthesised the fourteen principles of management and the five functions of a manager, a scientific management framework that became widely used within project risk management. In 1950, the critical path method, project evaluation and review techniques were devised as a risk management method. In 1962, the work breakdown structure (WBS) was invented through project evaluations and review techniques (DOD et al., 1962). In 1980, constraints theory was developed to improve the Critical Path method (Goldratt, 1990). Barnes (1983) first modelled risk in terms of probability and impact (P–I). Around 1985, fuzzy sets theory (FST) was introduced to address subjectivity within the evaluation of construction-related risks. By 1990, the analytical hierarchy process (AHP) had been widely adopted within the risk management process, replacing Project Evaluation and Review Techniques (Mustafa et al., 1991). After 1997, Goldratt (1997) developed the concept of the critical chain which could provide a rigid project schedule for a given project.

Since 2000, with the development of computer technology, personal computing has become a preferred tool for the modelling and assessment of construction risk. Decision support systems (DSS) were first used for risk assessment during this period. In the meantime, FST and AHP became the predominant approaches to solving the complex problem of risk management (Taroun, 2014). The disadvantages of P-I have since been exposed in that excessive streamlining of risk probability and impact estimates increase the level of unnecessary uncertainty (Chapman et al., 2000). Hastak et al. (2000) tried to combine AHP and P-I to develop a risk management model. However, the method was still overly simplistic for risk management. Tah et al. (2000) accessed FST and P-I through specifying ranges instead of single scores, but this solution might not serve as an appropriate choice for every project. Ward et al. (2003) suggested using the term project uncertainty management instead of project risk management. Jannadi et al. (2003) developed the Risk Assessor Model that defines risk from three angles: risk probability of occurrence, severity of impact, and exposure to hazards. Choi et al. (2004) integrated FST and DSS for underground construction project risk management, enabling managers to handle different types of risk through frequencies and subjective judgements.

After 2005, the sharp increase in the number of risk management issues marked the growing demand for suitable risk management approaches. For example, Cervone (2006) developed a new risk management model which intimated that risk discrimination should also be involved. Under this P-I risk analysis approach, risks are deemed to be independent of their environment, which is not the case in the context of a project. Nieto-Morote et al. (2011) considered a similar idea for risk interdependency issues. Dikmen et al. (2007) addressed the issue that risk manageability, or ‘controllability’, should also be brought into the P-I model. Zeng et al. (2007) suggested that the P-I model should add another factor index, one which reflects the surrounding environment and the influences arising between the identified risks. Other methodologies offered different forms of improvement. Zhang et al. (2007) combined the strengths of FST and AHP for assessing risks in joint venture construction projects in China. However, the limitations of FST and AHP do not necessarily overcome this challenge. New risk management models have since been developed. Zayed et al. (2008) proposed a risk model that computed the risk level of the project to prioritise a given set of projects, identifying the risks at both the macro- and micro levels, wherein the multiplier number is the project risk. The improvement in machine learning approaches reinforced such improvements to the risk management method. In 2009, the Bayesian Belief Network (BBN) was first used in risk management. It models the relationships arising between the risks in causing delays to the project and quantifies the likelihood of a delay in construction (Kim et al., 2009).

2.6.3 Risk management in construction background

Risk did not appear in the construction literature until the 1960s. Before the 1970s, most risk analysis processes employed statistical methods instead of Monte Carlo Simulations (Edwards et al., 1998). After project risk management became an essential element of project management in the late 1970s, most construction sites began to view risk management as being independent management of the project.

Nowadays, the risk literature shows that many methods are available to treat risk at an early stage. Risk management could entail both time and cost savings for the project. However, the degree of risk management implementation in small projects was still relatively low, so risk management was more likely to be applied to those projects with higher costs (Hwang et al., 2014). The reason for this is that managing smaller projects may cost a premium and, when compared with the project duration, it is not a cost-effective solution (Griffith et al., 1998). Risk management in construction project plays an important role irrespective of measure, activity, and organisation (Kumar et al., 2021). This results that construction risk management requiring a comprehensive risk framework to identify, analyse, evaluate, and control the risks (X. Zhang et al., 2020).

2.7 Risk management definition

2.7.1 Risk management situation

Cooper (2004) defined risk management in terms of the culture, processes and structures that aim to realise opportunities while managing negative impacts. The Project Management Institute differentiated project management into integration, scope, time, cost, quality, human resources, communications, risk, procurement and stakeholders. Thus, risk management is considered to be one of the ten designated project management areas (PMI, 2017). Zou et al. (2007) alternatively defined risk management as identifying, analysing and dealing with risk to achieve the project objectives without the negative impacts of risk. BSI (2008) presented risk management as a process. In this process, the risk can be accepted, or choose response method to mitigate probability or impact of risk. Risk management could improve the decision-making outcome (Mills, 2001), help the projects to be completed on time (Rashed, 2005), and keep costs within the agreed budget (Klemetti, 2006a). Akintoye et al. (1997) pointed out that many industries have since recognised the increasing importance of risk management and of developing risk management departments to control risk. However, risk management in construction projects only applied a simple approach which was unsuitable for quality project management (Serpella et al., 2014). The risk manager could, in theory, define all internal, external and project risks if the information was available. Unfortunately, it is impossible to obtain every detail for a given project. Also, the lack of time is another impediment to risk management (Tchankova, 2002). Not all the variables of the project can be defined and, during the project life cycle, new variables may be found or their probability may change (Jaafari, 2001). Another problem that should be considered to determine what the project's risks are and how they should be prioritised (Serpella et al., 2014).

2.7.2 Risk management definition

Project management should be viewed as a continuous process rather than as a planning tool, with a focus on actual performance rather than compliance with schedule, scope, quality and budget (Perminova et al., 2008). Where it differs from project management is that risk management is usually described as being a process applied to a respective function (Olsson, 2007). It should be clear that it is impossible to gather all the relevant information and develop a comprehensive risk management plan. In this case, most risk management plans should remain open to change and seek to minimise the impacts on project objectives (Jaafari, 2001). As such, each project should consider all the risks and have a solution for each of them.

Risk management has been defined by many international and national-level standards. The definition of risk management in the standards was found in varying terminologies. Table 2.4 presents the risk management definition from the standards.

Table 2.4: Risk definition divided from standards

DOCUMENT	DEFINITION	KEYWORDS
ISO 31000:2018 (ISO, 2018b)	Coordinated activities to direct and control an organization with regard to risk	Coordinated activities, direct, control.
BS EN ISO 14971:2019 (BSI, 2014)	Systematic application of management policies, procedures, and practices to the tasks of analysing, evaluating, controlling and monitoring risk.	Systematic, management, procedures, practices, identify, analyse, evaluate, monitor.
ANSI/ASSP Z690 (ASSP, 2011)	Coordinated activities to direct and control an organization with regard to risk.	Coordinated activities, direct, control.
CAN/CSA-Q850-97 (R2009) (CSA, 2009a)	The systematic application of management policies, procedures, and practices to the tasks of analysing, evaluating, controlling, and communicating about risk issues	Systematic, management, procedures, practices, identify, analyse, evaluate, monitor.
GB/T 23694-2013 (SAC, 2013)	Guide and control the coordination activities of the organization with regard to risk.	Coordinated activities, control

The professional bodies or societies also have a definition for risk management. Table 2.5 presents the risk management definition from the professional bodies or societies.

Table 2.5: Risk definition divided from societies

INSTITUTION	DEFINITION	KEYWORDS
APM (APM, 2018)	Risk management is focused on anticipating what might not go to plan and putting in place actions to reduce uncertainty to a tolerable level.	Plan, reduce, uncertainty
PMI (PMI, 2009)	The process concerned with conducting risk management planning, identification, analysis, responses, and monitoring and control on a project	Process, plan, identify, analyse, response, monitor, control
ICE (ICE, 2020)	The process to identify, evaluate and mitigate risks to increase the project's likelihood of success.	Process, identify, evaluate, mitigate
AIPM (AIPM, 2021)	The processes concerned with identifying, analysing and minimising the consequences of adverse events. The risk	Process, identify, analyse, consequences, review,

	management process is completed through review of the plan and recording of lessons learnt	record
PMRC (PMRC, 2002)	The process concerned with conducting risk management planning, identification, analysis, responses, and monitoring and control on a project.	Process, plan, identify, analyse, response, monitor, control

Risk management is defined as a process that can identify risks and analyse them. By using a suitable method and presenting the appropriate response to eliminate or reduce a given risk, the potential success of a project and its objectives can be augmented (Taylor et al., 1997). The primary goal of project risk management is thus to identify, evaluate and control the risks pertaining to project success (Lee et al., 2009). Risk management has thus become an integral part of an organisation's activities, as it can help an organisation to maintain a project and its aims directly and efficiently. Risk management is thus a continuous process that is directly linked to changes both inside and outside the organisation (Tchankova, 2002). Risk management mainly considers how the risk may cause effects and how to reduce the adverse effects (Flanagan et al., 1993). Risk management is a process through which to ensure that a project can be completed within its agreed constraints (Clark et al., 1990). The purpose of risk management is thus to quantify previously identified unwanted random factors, determine their potential impact on the time and costs of a building project, and then find solutions to reduce or avoid these factors (Skorupka, 2008).

In Chinese articles, there are also presented definition for risk management. M. He et al. (2021) defined risk management as a process to reduce risk negative influence for the project objective. Zheng (2021) presented risk management main focus on how to keep the time, cost, and quality of the project consistent with expectations. Yang (2021) emphasized the importance of risk management in construction project.

2.8 Risk management process

Risk management is defined as a continuous process, all the stages of the project should be considered during the risk management process (Veryzer Jr, 1998). During the construction project life cycle, it is necessary to analyse the risks for the whole process, and present a solution to respond to the risks. The construction project manager is required to realise the project and decrease the level of uncertainty inherent within the project. Thus, risk management should be considered concurrently with project management.

The risk management process has been defined by many articles. Risk management consists of three phases (Buchan, 1994):

1. Risk identification: recognising and documenting associated risks.
2. Risk assessment: examining the identified risks; refining the description of the risks; and estimating their respective probabilities and impacts.
3. Risk response: identifying, evaluating, selecting, and implementing actions in order to reduce the likelihood of occurrence of risk events and/or lower the negative impact of those risks.

Risk management process includes seven main steps (ISO, 2009a):

1. Risk planning.
2. Risk identification.
3. Risk assessment (qualitative and quantitative).
4. Risk analysis.
5. Risk response.
6. Risk monitoring.
7. Recording the risk management process.

Through the Project Management Institute (PMI, 2017), the PMBOK has been developed which consists of the six risk management processes:

1. Plan risk management.
2. Identify risks.
3. Perform qualitative risk analysis.
4. Perform quantitative risk analysis.
5. Plan risk responses.
6. Monitor and control risks.

According to Perry (1985), the risk management process comprises three phases:

1. Risk identification.

2. Risk analysis.
3. Risk response.

Kliem et al. (1997) divided the risk management process into four phases:

1. Risk identification.
2. Risk analysis.
3. Risk control.
4. Risk reporting.

Ponniah et al. (1998) divided the risk management process into five phases:

1. Risk identification.
2. Risk estimation.
3. Risk evaluation.
4. Risk response.
5. Risk monitoring.

Hallikas et al. (2004) divided risk management into four phases:

1. Risk identification.
2. Risk assessment.
3. Decision and implementation of risk management actions.
4. Risk monitoring.

Schieg (2006) identified six different phases for risk management:

1. Identifying risks.
2. Analysing risks.
3. Assessing risks.
4. Controlling risks.
5. Controlling goals.

Tummala et al. (2011) divided risk management into six phases:

1. Risk identification.
2. Risk measurement.
3. Risk assessment.
4. Risk evaluation.

5. Risk mitigation & contingency plans.
6. Risk control & monitoring.

As concluded from the preceding articles, the risk management process can be divided into four phases for the purposes of this research:

1. Risk Identification.
2. Risk assessment.
3. Risk analysis.
4. Risk response.

2.9 Risk management benefit

Risk management could serve to improve the quality of cost estimation and decision-making (Mills, 2001), helping projects to be completed on time and within budget (Rashed, 2005), lowering transaction costs and facilitating better risk allocation (Klemetti, 2006b).

Risk management may though require additional time and cost to complete the project. However, the cost and time savings were higher than the improvement in quality. Some organisations may ignore the potential benefits of risk management and instead emphasise the costs involved in the process. Actually, the implementation of risk management in small projects would bring more in the way of benefits than costs in the long-term (Hwang et al., 2014).

In construction projects, the main achievement is the triangle of money, time, and quality (Rwelamila et al., 1995). Unmitigated risk could adversely influence the project causing a failure to deliver in relation to this triangle. Risk management thus provides both a forecast and a solution for project uncertainty. This process provides a clear outcome for the project manager through which to understand the influence of uncertainty.

2.10 Chapter summary

Based on the articles presented above, risk type identification is presented in Table 2.6.

Table 2.6: Identification of risk types

LITERATURE	RISK	RISK GROUP

	TYPE	
Mustafa et al. (1991)		Acts of God risks, physical risks, financial and economic risks, political and environmental risks, design risks, job site-related risks.
El-Sayegh (2008)	Internal risk	Owners, designers, contractors, sub-contractors, suppliers.
	External risk	Political, social & cultural, economic, natural, other.
Renault et al. (2016)		Design, physical, logistical, legal, environmental, construction, management, cultural, financial, political.
El-Sayegh et al. (2018)		Management risks, technical risks, green team (stakeholders) risks, green materials and technology risks, regulatory and economic risks.
Zavadskas et al. (2010)	Internal risk	Resource risk, project member risk, construction site risk, documents and information risk.
	External risk	Political risk, economic risk, social risk, weather risk.
	Project risk	Time risk, cost risk, work quality, construction risk, technological risk.

Table 2.6 shows that most articles have presented construction project risks in terms of internal, external, and project factors. Although some articles did not classify the types of risk, some risk groups such as cost, political, and design were commonly identified within the different articles. Thus, this research has categorised risk into three types:

1. Internal risk: risk as affected by project participants.
2. Project risk: risk arising in the project process.
3. External risk: risk caused by other factors that cannot be controlled.

Based on the articles presented above, risk management process identification is presented in Table 2.7:

Table 2.7: Risk management process identification

LITERATURE	RISK MANAGEMENT PROCESS
Buchan (1994)	● Risk identification. ● Risk assessment. ● Risk response.
ISO (2009a)	● Risk planning. ● Risk identification. ● Risk assessment (qualitative and quantitative).

	● Risk analysis. ● Risk response. ● Risk monitoring. ● Recording the risk management process.
PMI (2017)	● Plan risk management. ● Identify risks. ● Perform qualitative risk analysis. ● Perform quantitative risk analysis. ● Plan risk responses. ● Monitor and control risks.
Perry (1985)	● Risk identification. ● Risk analysis. ● Risk response.
Kliem et al. (1997)	● Risk identification. ● Risk analysis. ● Risk control. ● Risk reporting.
Ponniah et al. (1998)	● Risk identification. ● Risk estimation. ● Risk evaluation. ● Risk response. ● Risk monitoring
Hallikas et al. (2004)	● Risk identification. ● Risk assessment. ● Decision and implementation of risk management actions. ● Risk monitoring.
Schieg (2006)	● Identifying risks. ● Analysing risks. ● Assessing risks. ● Controlling risks. ● Controlling goals.
Tummala et al. (2011)	● Risk identification. ● Risk measurement. ● Risk assessment. ● Risk evaluation. ● Risk mitigation & contingency plans. ● Risk control & monitoring.

Table 2.7 presents the identification of risk, its assessment, analysis (or evaluation), and response (or control) within the risk management process as identified by most articles. Accordingly, for the purposes of this research have divided risk management into four processes:

1. Risk identification: to identify the risk inherent in the project.
2. Risk assessment: to assess the risk and explain how it occurs.
3. Risk analysis: to analyse how risk influences the project.
4. Risk response: to respond to the risk to reduce its negative influence.

This chapter includes two major parts: risk and risk management.

The first part of this chapter introduced the concepts of risk, including its history and background, before identifying its behaviours. Risk would necessarily cause project delay if it arises. Compared with uncertainty, hazard and opportunity, risk presents a unique feature that should be considered. However, the current practice shows that the risk classification process remains unclear, and thus it is necessary to understand how risk is managed within the construction process.

The second part of this chapter covered the background and definitions of risk management. It divided risk management into its identification, assessment, analysis, and appropriate response. Risk could objectively cause project delay, in which case the potential risk sources should be identified. It is necessary to assess the risk probability and impact of each and every risk factor. In order to mitigate risk, the risk response method selected should combine the project objectives so as to minimise its negative influences. The benefits of risk management are presented to show that it is necessary to manage risk in a given project, and therefore risk management forms an integral part of project management and cannot be viewed as a separate entity. However, which method can be used in the risk management process and the advantage and disadvantage of each method is still unclear. In that case, the next chapter will explain the detail of how to manage risk.

CHAPTER 3 - RISK MANAGEMENT METHODS

3.1 Introduction

This chapter highlights the related research that explains various approaches to risk management. By dividing risk management into four processes, namely risk identification, risk assessment, risk analysis, and risk response, it is possible to assign a process to each that may include one or more of several quantitative or qualitative methods. The explanation for each method is provided in this chapter.

3.2 Risk identification definition

Risk identification determines what could go wrong within the development process of a project. The process must include an investigation of all potential sources of project risk and the influences of those risks. It is important to have a risk identification approach, as the rest of the steps may only be performed on the potential risks identified (Nieto-Morote et al., 2011). During the project life cycle, the risk may evolve or new risks may become known, which means that risk identification is an iterative process. Different projects have different iteration frequencies during each cycle.

Risk identification is the first step for risk management (Baker et al., 1998). For risk identification, a list of significant risk factors that influence the particular project should be developed during this process. In order to develop the list, the risk factors, the sources of the risk factors, and the potential effect of the risk factors. However, risk identification is influenced by external influences, such as educational background, practical experience, an individual's cognitive characteristics, the availability of information, peer group influence, etc. (Ritchie et al., 1993). Most risk identification methodologies revolve around a particular mathematical model, which sometimes causes the risk identification process to exclude human or social phenomena (Warner, 1992). Risk identification requires the cooperation of all parties in the project (Suharyanto et al., 2020).

According to Tchankova (2002), the risk management process includes risk identification, assessment, analysis and response. If done properly, this ensures efficient risk management. Therefore, risk identification needs to be seen more broadly and not merely in terms of what can be insured or mitigated (Tchankova, 2002). It should begin with the basic questions:

1. How can project resources be threatened?
2. What adverse effects can prevent the project from achieving its goals?
3. What favourable possibility can be revealed?

3.3 Risk identification method

The risk identification method includes but not limited to: brainstorming, interviewing, checklists, Structured 'What-if' Technique (SWIFT), scenario analysis, fault tree analysis (FTA), bow tie analysis, and direct observations.

3.3.1 Brainstorming

Raz et al. (2001) identified that brainstorming is the most frequently used tool. Akintoye et al. (1997) agreed with this opinion and pointed out that intuition, judgement and experience are the most frequently used assets in risk assessment. Brainstorming is a term borrowed from enterprise management and is not specifically designed for risk management. The brainstorming process consists of redefining the problem, generating ideas, identifying possible solutions, developing them and conducting evaluations. Brainstorming is a method that asks its participants to discuss possible sources of risk within the project, how to identify the risk factors, and how to solve these risks within an open discussion environment (Smith et al., 2009). Brainstorming requires the high skill of the practitioners to identify the risks(Kobo-Greenhut et al., 2019).

In the early 1950s, Osborn (1963) presented brainstorming as a problem solving method, as this method could yield a much greater number of ideas in a shorter time. Osborn (1963) argued that the effectiveness of brainstorming requires two essential components. The first is group thinking which is deemed more productive than individual thinking, and the second is the avoidance of criticism to improve the production of ideas.

For the first component, the generation of more ideas by group activity as opposed to individuals occurs as the free associations are more frequent within the group setting. Social facilitation can be found within the process, as other group members' suggestions can elicit further ideas. For the second component, all suggestions made should be reinforced and criticisms should be suppressed as this could result in yet more suggestions. Osborn (1963) explained that the deferment of judgement is the essence of group brainstorming. The basis of suspended judgement is the deliberate alteration of the thought process. In other words, one should turn on his valuing mind at one time and his creative mind at another, instead of trying to think both critically and imaginatively at the same time.

Two problems may occur in the brainstorming method. The first is that some participants may be very authoritarian and have domineering personalities, forcing the group to change the process of ideation. The second is that the number of participants may be incorrect, in that a small group may result in few suggestions while a large group may become inefficient and consume too much time.

3.3.2 Interview

The aim of the interview is to record and analyse the answers to questions. The interview consists of answering the developed questions and discussing the issues involved (Carter et al., 1994). The structured interview asks the participant to answer the question from certain options. The unstructured interview allows the participant to answer the question freely. There are two primary forms of interview: one-to-one and several-to-one. The one-to-one interview comprises one interviewer and one interviewee and may help to understand each aspect of risk at a deeper level. The several-to-one interview comprises one interviewer and several interviewees and can understand the knowledge of participants from several angles. The problem of the interview method is that it is very time consuming, as each interview takes time and their results have to be systematised and analysed. Accordingly, unduly confusing questions must be avoided and the questions should be well-structured so as to glean more effective feedback from the interviewees (Chapman, 2001).

3.3.3 Checklist

The checklist is developed by listing items, steps, or tasks required for the project and then analysing this against selection criteria to determine if the procedure is completed correctly. Historical information or experience from previous projects should be considered during the checklist development process (Safeopedia, 2018).

The checklist is analysed to determine the risks inherent within a particular project management plan. The checklist is usually developed based on prior knowledge gained from previous projects which were similar in nature to the pending project and historiographical information (PMI, 2017). The benefits of the checklist are appropriate for team members with lower experience. However, building an exhaustive checklist can be challenging as projects, each project has unique and different risks. If the checklist is not suitable for the project, the team members to review and prune the checklist. Lastly, the checklist should be reviewed during the closure of the project to improve future projects by incorporating valuable lessons learned (PMI, 2017).

However, the checklist approach has a number of potentially serious disadvantages according to Chapman (Chapman et al., 2003):

1. Important interdependencies between sources are not readily highlighted.
2. A list, particularly a long one, provides limited guidance as to the relative importance of individual sources.
3. Individual entries may encompass a number of important, separate sources implicitly.
4. Sources not on the list are likely to be ignored.
5. The list of sources may be more appropriate for some projects than others.
6. Individual sources may be described in insufficient detail to avoid ambiguity and varying interpretations.
7. A checklist presents an overly simplistic view of the potential effects of individual sources.

8. A checklist does not encourage the development of a more sophisticated attitude towards assessing and quantifying uncertainty.

3.3.4 Structured ‘What-if’ Technique (SWIFT)

The structured what-if technique (SWIFT) is a risk identification approach which employs structured brainstorming with the use of such pre-developed guide words as timing or amount, combined with similar phrases like ‘What if. . .’ or ‘How could. . .’ The participants may proceed to examine risk and hazard in the project (Card et al., 2012).

It is important to assemble the right team and to find suitable participants for the SWIFT method, as it is a workshop-based technique wherein participants may pose potential risks. Thus, the participants should encompass the representation of all stakeholder groups and those people who have the most intimate knowledge of the project. SWIFT is dependent on utilising the participants’ knowledge of the systems and processes being assessed. Using SWIFT not only helps to identify the risk, but also helps the participants to enhance their commitment to both new and pre-existing risk controls (ISO, 2009b).

12 procedures are presented for using SWIFT in risk management (Card et al., 2012):

1. Prepare the guide word: The facilitator should select a set of guide words to be used in the SWIFT analysis.
2. Assemble the team: Participants for the SWIFT workshop should be selected based on their knowledge of the system and/or process.
3. Background: Describe the trigger word for the SWIFT.
4. Articulate the purpose: Clearly explain the purpose to be served by the SWIFT.
5. Define the requirements: Articulate the criteria for success.
6. Describe the system: Provide high-level contextual and graphical descriptions of the system or process to be risk assessed. Do not get bogged down in detail.
7. Identify the risks/hazards: This is where the SWIFT is applied. Use the guide words/headings allocated to each system, high-level subsystem, or process step in turn. Participants should use prompts starting with phrases like “What

if…” or “How could…” to elicit potential risks/hazards associated with the guide word.

8. Assess the risks: With the use of either a generic approach or a supporting risk analysis technique, estimate the risk associated with the identified hazards. In light of existing controls, assess the likelihood that they could lead to harm and also the severity of harm that they might cause. Evaluate the acceptability of these risk levels and identify any aspects of the system that may require a more detailed risk identification and analysis.
9. Propose actions: Propose risk control action plans to reduce the identified risks to an acceptable level.
10. Review the process: Determine if the SWIFT met its objectives or whether a more detailed risk assessment is required for some parts of the system.
11. Overview: Produce a brief overview document to communicate the results of the SWIFT analysis.
12. Additional risk assessment: Conduct additional risk assessments using more detailed or quantitative techniques, if so required.

3.3.5 Scenario analysis

Scenario analysis could support the entire strategic management process, enclosing aspects as varied as the generation of options, the building of consensus or even the process of strategy implementation (Van der Heijden, 2011).

Ringland et al. (1998) defined the process for scenario analysis as follows:

1. Identify focal issue or decision.
2. Key forces in the local environment.
3. Driving forces.
4. Ranking by importance and uncertainty.
5. Selecting the scenario logics.
6. Fleshing out the scenarios.
7. Implications for strategy.
8. Selection of leading indicators and signposts.

9. Feed the scenarios back to those consulted.
10. Discuss the strategic options.
11. Agree the implementation plan.
12. Publicise the scenarios.

Mietzner et al. (2005) defined the advantages of scenario analysis:

1. The strength of scenarios is that they do not describe just one future, but that several realisable or desirable futures are placed side by side.
2. Scenarios open up the mind to hitherto unimaginable possibilities and challenge the long-held internal beliefs of an organisation.
3. Scenarios are an appropriate way to recognise 'weak signals', technological discontinuities or disruptive events and include them into long-range planning.
4. Scenarios can lead to the creation of a common language for dealing with strategic issues by opening up a strategic conversation within an organisation.
5. During the scenario process the aims, opportunities, risks, and strategies are shared between the participants which support the coordination and implementation of actions.
6. The ways of building a scenario are very flexible and can be adjusted to the specific task/situation at hand.

However, Mietzner et al. (2005) also introduced the disadvantages for scenario analysis:

1. The practice of scenario analysis is very time-consuming.
2. A more qualitative approach has to place a strong emphasis on the selection of suitable participants/experts and, in practice, this could not be an easy task to fulfil.
3. Data and information from different sources have to be collected and interpreted which makes scenario building even more time-consuming.
4. It could be difficult not to focus on black and white scenarios or the most likely scenario (wishful thinking) during the scenario-building process.

3.3.6 Fault tree analysis (FTA)

In 1961, Fault tree analysis (FTA) was first developed by H. A. Watson of Bell Telephone Laboratories to study the Minuteman missile launch control system for the US air force (Lee et al., 1985). Then FTA was adopted by the nuclear power plant industry to qualify and quantify the hazards and risks involved in nuclear power generation (Baig et al., 2013). FTA is basically a cause-and-effect analysis which breaks down potential project failure into one or more failings at the lower levels. The fundamental concept of FTA is to translate a physical system into a structured logic diagram. One specified top event is caused by a certain sequence of basic events. The FTA is a deductive procedure for determining combinations of component failures and human errors, which may in turn lead to the occurrence of system-specific adverse events (Gupta et al., 2007).

In order to construct an FTA, the process normally begins with the top event and proceeds in a top-down manner (Harms-Ringdahl, 2003). The AND-gate and OR-gates are used to provide logical connections between the basic events. The fault tree symbol OR-gate, which is equivalent to the Boolean symbol '+' represents the union of the events attached to the gate. One or more of the input events must occur to cause the event above the OR-gate to occur. The fault tree symbol AND-gate which is equivalent to the Boolean symbol '•' represents the intersection of the events attached to the gate. All of the input events attached to the AND-gate must exist in order for the event above the gate to occur

Eight procedures are presented for using FTA in risk management (Ayyub, 2014), as follows:

1. Define the system of interest: the boundaries of interest are defined in this step on which analysis is to be made along with the conditions of the system.
2. Define the top event of the system: Specify the problem on which the analysis will be based such as shutdown, pipe rupture etc.
3. Define tree top Structure: Define the events and the conditions that lead to the top event.

4. Explore each branch in successive levels of detail: Determine the events and conditions that lead to the intermediate event and keep repeating this process at different successive levels unless the fault tree is completed.
5. Solve the fault tree for the combination of events contributing to the top event: Examine all the event and conditions that are necessary for the top event to occur and develop a minimal cut set.
6. Identify important dependent failure potentials and adjust the model appropriately: Study the event and find the dependencies amongst the events that can cause single or multiple events/conditions to occur simultaneously.
7. Perform quantitative analysis: Use the past statistical data to evaluate or predict the future performance of the system.
8. Use the results in decision making: Find the conditions in which the system is at greatest potential hazard and place appropriate measures and recommendations to counter such risks.

The advantages of using FTA are that it starts from a top event which enables risk management to focus on the event. However, it is hard to get the failure data for all the eventualities within the fault tree, which may lower the credibility of the analysis (Baig et al., 2013).

3.3.7 Bow tie analysis.

Bow tie analysis is a graphical approach to representing a complete accident scenario, starting from accident causes and ending with its consequences. The left-hand side is a fault tree identifying the possible events that might cause the critical event, and the right-hand side is an event tree showing the possible consequences of the critical event itself based on the failure or success of safety functions. The fault tree and event tree are combined by a critical event (Delvosalle et al., 2006). Bow tie is an integrated concept which combines both techniques within a common platform, considering the top-event and initiating event as being linked to a common event called a critical event (Markowski et al., 2009).

However, the bow-tie analysis requires the probability of input events to be provided as precise crisp data or as defined probability density functions (Markowski et al., 2009). However, given the variant failure modes, design faults, and poor understanding of failure mechanisms, it is hard to obtain crisp data or probability density functions for the project (Ferdous et al., 2011).

3.3.8 Direct observation

Direct observation is a method by which to observe the project to figure out the potential risks or uncertainties. For accurate data, observers should be reliable in making the necessary assessment judgments, documenting their findings and participating in the analysis. Based on the perceived purpose of study, the observability and frequency of events, the observers should adapt their observations process accordingly (Catchpole et al., 2017). The process of direct observations includes:

1. An event, or events of interest that need to occur in the presence of the observer.
2. They need to be detected by the observer.
3. They need to be recorded.
4. It will usually need to be classified either immediately or post-hoc.
5. Then analysed in order to reach a higher level of understanding.

One problem arising is that, although observers are treated as the instrument of detection during the direct observation process, the subjectivity of observers may respond to social and situational factors that may, in turn, affect the quality of the observations. In order to reduce such biases, critiques of observational data after observation are suitable which may be achieved by asking participants to share their views of the observed behaviours. Another problem is that the noise of an event may disturb the observation process. The clearer the ability of the observer to detect signal from noise, the more risk and uncertainty that can be detected.

3.4 Risk assessment definition

Differing from risk identification, risk assessment is a process by which to record the risks and explain the risk factors. This process requires the recording of the risks and assigning each risk a brief description to ensure that it is clearly understood. After the risks have been described and descripted, each should be classified by category according to the risk source (Taylan et al., 2014). After risk identification, risk assessment provides both quantitative and qualitative assessment for each risk factor addressed (Lyu et al., 2020). The risk assessment could identify possible hazards, analyse the causes and consequences of the hazards, or describe risk with a proper representation of uncertainties. By making assumptions and simplifications, collecting and analysing data, and developing and using models, risk factors can be presented within the risk assessment process (Zio, 2018). It should be clear that risk assessment is treated as a scientific activity limited only by the available knowledge and the uncertainty inherent in risk, with the outcomes of risk assessment being one type of input, but never the sole basis for decision making (NRC, 1983).

Based on risk assessment, there may be four types of accident events or scenarios in the project (Flage et al., 2015):

1. Unknown-unknown: Identifies those events and scenarios that were unknown to everyone at the time of the risk assessment.
2. Unknown-known: Indicates those events and scenarios unknown to the risk analysts performing the assessment, but known to someone else.
3. Known-unknown: Identifies those situations of awareness in which the background knowledge is weak, but there are indications or justified beliefs that a new, hitherto unknown type of event or scenario (new in the context of the activity posing the risk) could occur in the future.
4. Known-known: Indicates those events and scenarios that are known to the analysts performing the risk assessment, and for which evidence exists.

Risk assessment is a method of systematic and structured effort through which to organise the knowledge available in those events, processes and scenarios that affect specific decisions in the management of risk. Risk assessment provides the framework for organising available knowledge within the system, to aid understanding of how the system can fail and to prioritise failure modes so that good decisions can be made

(Flage et al., 2015). The risk manager could use risk assessment to understand the potential magnitude of entry, establishment, spread and impact as well as the effectiveness of risk management options, and thereby establish the risk management decision (Health et al., 2018).

3.5 Risk assessment qualitative method

The risk assessment qualitative method includes but not limited to: brainstorming (see chapter 3.3.1), interview (see chapter 3.3.2), expert elicitation, Delphi method, SWOT analysis, Probability and Impact (P-I), Structured "What-if" Technique (SWIFT) (see chapter 3.3.4), and fault tree analysis (FTA) (see chapter 3.3.6).

3.5.1 Expert elicitation

By using expert elicitation, the participants' knowledge and experience about earlier projects could help to identify potential risk factors (Carter et al., 1994). Expert elicitation has been used to discern risk ranking, uncertainty and risk management options (Larkin et al., 2019). Self-elicitation or interviewer-elicitation can be chosen to obtain expert beliefs for expert elicitation. For self-elicitation, the participants estimate risk either alone or within a group. For interviewer-elicitation, an interviewer should participate to estimate risk either alone or within a group. Generally, weighted aggregates of subjective individual estimates are more accurate than the individual estimates that comprise the aggregates (Ashton et al., 1985). Although expert elicitation may not expose all risks, it could find risk in the early stage of project. The advantage of expert elicitation is that the participants could explain how risk could be solved.

3.5.2 Delphi method

In the early 1950s, the Delphi method was developed by the Rand Corporation for the US Air Force. This method is used to gather expert opinion (Robinson John, 1991). The Delphi method is a group communication process in which the group is treated as a whole in order to deal with complex problems. The Delphi method provides a series of intensive questionnaires for a group of experts to elicit a more reliable consensus (Linstone et al., 1975). The Delphi method is commonly used by academic researchers in the field of construction engineering and management (Gunduz et al., 2020). The Delphi method has three salient features: anonymity, iteration with controlled feedback, and statistical response (Dickey et al., 1978). The process of the Delphi method is that the participants remain unknown to one another and respond to a series of questionnaires and then, based on the new information gathered from the participants in each round, the participants can modify the feedback. After several iterations, the results can represent the best forecast from the participants (Corotis et al., 1981).

The advantage of the Delphi method is that it solves the problem that some participants have strong personalities during the interview process which, in turn, reduces the chances of others to provide an opinion. Another advantage is that it can highlight topics of concern and evaluate uncertainty in the project (Robinson John, 1991). Although the group view has a higher probability of being correct than that of an individual, its success depends principally on the careful selection of the component and the formulation of questions. The major difficulties of Delphi, however, lie in maintaining the high level of responsivity and in reaching and implementing a consensus (Robinson John, 1991). The disadvantage of this method is that it can be very time-consuming.

3.5.3 SWOT analysis

A Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis is a commonly used tool for analysing internal and external environments (Wheelen et al., 2017).

The strategic factors include internal and external environments which are summarised within the SWOT analysis. SWOT analysis can be used in the early stage of a project and help the strategic planners to develop and adopt a strategy for the project.

Although SWOT analysis can be used in the strategy analysis, it requires further consideration, as SWOT analysis only points out the strengths, weaknesses, opportunities or threats of the project and it does not consider the most significant problem. The fact that a SWOT analysis is based on qualitative analysis and the capabilities and expertise of the participants means that a SWOT analysis only can provide an incomplete qualitative examination of internal and external factors.

3.5.4 Probability and impact (P-I)

Risk probability and risk impact are random variables with a certain distribution. By using the random variable, this statistical method can be used to calculate and evaluate the significant risk factor(s). In order to obtain the data for a P-I of risk factors, it requires a relevant database about similar past projects. Risk probability is the likelihood that a given risk will occur. Risk consequences are the effect on project objectives if that risk event occurs. Risk analysis using P-I helps to identify risks that need to be managed dynamically (Boyd, 2011). The advantage of P-I includes simplicity and it can assess the risk conveniently (Ward, 1999). However, it is hard to build a database for risk management, as most P-I definitions are based on the participants' experience and knowledge. Although quantitative data would be better for statistical analysis, however, it is often impossible to calculate P-I for risk factors, rather it is possible only to estimate P-I as being either very high, high, moderate, low or very low (Carter et al., 1994).

3.6 Risk assessment quantitative method

A quantitative risk assessment method includes but not limited to: questionnaire, analytic hierarchy process (AHP), decision support system (DSS), failure mode and effects analysis, Bayesian belief network (BBN), and Markov chain analysis.

3.6.1 Questionnaire

The questionnaire is a method that always involves a list of questions to collect quantitative data from practitioners. Generally a questionnaire uses both open and closed questions to obtain data which may be of potential benefit to both qualitative and quantitative analyses (Gillham, 2008).

The advantages of questionnaire include (Gillham, 2008):

1. An efficient way to collect data.
2. Utility in collecting information on sensitive matters.
3. Research efforts are economical.

However, the disadvantages of questionnaire include (Gillham, 2008):

1. Response rates are often low.
2. They may only provide a snapshot.
3. They tend to elicit socially desirable responses.

3.6.2 Analytic hierarchy process (AHP)

Wind et al. (1980) developed an analytic hierarchy process (AHP) method. For this method, the decision problem should first be formulated. Generally, there are three levels for AHP, and each element at an equivalent level must be related to some or all of the elements within the next higher level. The top level includes the element guiding the overall objective of the decision problem; the intermediate level includes those elements that affect the decision, and the lowest level includes those elements for the decision options. After the hierarchy has been constructed, the relative importance of the elements at each level should be determined. From the top level to the lowest level, comparing the elements of that level to the level above, several square matrices are formed. After the square matrices have been formed, the relative weightings for the various elements should be considered. The decision making process is based on the weights of the elements throughout the hierarchy (Wind et al., 1980).

3.6.3 Decision support system (DSS)

Decision support systems (DSS) were recently used as a risk management method for a complex project (Menzel et al., 2012). DSS provides a computer-based environment to solve complex problems. In order to analyse the risk, it is first necessary to gather enough data and information to support the DSS as it is an automated system, providing all the information required to understand the problem; the possibility of exploring the data from different viewpoints; and the possibility of other options. DSS uses both the measured data and the knowledge of the participants (Torretta et al., 2017).

DSS comprises the following modules (Torretta et al., 2017):

1. Graphical User Interface.

2. Data Base Management System.
3. Model Base Management System.
4. Generator of alternatives.
5. Decision Model – Multi Criteria Decision Aid.

3.6.4 Failure mode and effects analysis (FMEA)

Failure mode and effects analysis (FMEA) includes three factors used to identify risk:

1. Occurrence: The frequency of the risks.
2. Detectability: The possibility of predicting risks before they occur.
3. Severity: The seriousness of the risk to the system.

The three factors are scored using a 10-point scale. The risk priority number is the product of the three factors ranking the failure modes. After multiplying the 3 factors, the highest risk priority number should be considered to analyse the failures and the reasons for this eventuality (Dağsuyu et al., 2016).

FMEA is a method designed to (Lipol et al., 2011):

1. Identify potential failure modes for a product or process.
2. Assess the risk associated with those failure modes and prioritise issues for corrective action.
3. Identify and carry out corrective actions to address the most serious concerns.

The disadvantage of FMEA includes (Khasha et al., 2013):

1. Different combinations of occurrence, detectability and severity may lead to an identical risk priority number value. However, failure modes with an identical risk priority number may correspond to different risk factors.
2. In traditional FMEA, the occurrence, detectability and severity are assumed to be of the same significance. However, in reality, the degree of their importance may vary.
3. RPN is simply calculated by multiplying the three input factors together, and the possible indirect relationships between these factors are not considered.

4. The three factors used in FMEA calculations do not encompass the entire range of causative factors leading to a failure mode, which may include mistakes, contradictions, uncertainties and ambiguities.

3.6.5 Bayesian belief network (BBN)

Bayesian Belief Networks (BBN) are a method that provides a deeper analysis of the interrelationships arising between each risk factor and the risk driver for each risk factor (Rechenthin, 2004). BBN becomes a framework by which to reduce the disadvantages of human reliability analysis from participants (Groth et al., 2013). The framework is presented as a unicycle graph as it only has one direction and cannot make up closed cycles. The nodes represent random variables and the arcs represent a direct dependency between variables. The arcs' direction represents the cause and effect relation arising between variables (Pereira et al., 2016).

BBN is based on two structural model components:

1. A directed acyclic graph that denotes dependencies and independencies between the model's constituent variables (Kekolahti, 2011).
2. Conditional probability tables denoting the strengths of the links in the graph (Aguilera et al., 2011).

3.6.6 Markov analysis

Markov analysis is a mathematical method by which to analyse risk in a project where it is well specified and has strong component dependencies (Diebel et al., 2005). Markov analysis presents a system with a number of discrete states with possible transitions arising among the states. The states are graphically presented as nodes in a directed graph, wherein the edges represent the probabilities of going from one node to another. According to the probability distribution, the system transits from its current state to the next state (Kwan et al., 2011).

Hidden Markov Model (HMM) is a finite state machine that has some fixed number of states, providing a probabilistic framework for modelling a time series of multivariate observations (Hassan et al., 2006). This method is part of a Markov analysis which can be treated as Markov chain as viewed through a memoryless noisy channel (Gallager, 1970).

HMM is characterised by the following (Hassan et al., 2006):

1. Number of states in the model.
2. Number of observation symbols.
3. State transition probabilities.
4. Observation emission probability distribution that characterizes each state.
5. Initial state distribution.

The advantage of HMM includes (Li et al., 2005):

1. HMM has strong statistical foundation.
2. It is able to handle new data robustly.
3. It is computationally efficient in developing and evaluating risk (due to the existence of established training algorithms).
4. It is able to predict similar patterns efficiently.

3.7 Risk analysis definition

Risk analysis is a process through which to analyse both the probabilities and consequences of risk factors. This process is inspired by thinking in economics (Sjöberg, 1980). In construction projects, risk analysis mainly depends on intuition, judgement, and experience (Akintoye et al., 1997). Risk analysis can quantify some of the identified risk to help the project manager minimize the negative influence (Issa et al., 2020).

Traditionally, a systematic risk analysis process is comprised of three steps (Purdy, 2010):

1. Identification of risk scenarios.
2. Likelihood analysis.
3. Effect analysis.

There are 62 accepted methodologies for risk analysis. These methodologies are separated into three different phases (Tixier et al., 2002):

1. An identification phase based on a site description. Such data are necessary to develop the processes of the methodologies.

2. An evaluation phase to realise a quantification of the risk. There are two ways to lead this; a deterministic approach and/or a probabilistic approach. This evaluation gives the previously identified consequences of scenarios and enables their impacts on the industrial site or on its vicinity to be taken into account.
3. A hierarchisation phase, which seeks to rank results, is obtained via the two previous phases in order to put preponderant risks forward. This phase helps us to identify the most important risks and to solve them first.

For input data, there are seven defined types (Tixier et al., 2002):

1. Plans or diagrams: the description of the site, installation, units, fluid networks, safety barriers and storage.
2. Process and reactions: operations and tasks description, physical and chemical features of process, kinetic and calorimetric parameters, operating conditions and normal functioning conditions.
3. Substances: the type of substance, physical and chemical properties, quantities and their toxicological data.
4. Probability and frequency: the type of failure, probability and frequency of failure, human failure, failure rate and the exposure probability.
5. Policy and Management: maintenance, organisation, safety policy, safety management system, transport management, and equipment cost.
6. Environment: the site environment, topographical data and population density.
7. Text and historical knowledge: standards, regulations, and historical knowledge.

From the review of 62 methods, four classes of output data are proposed (Tixier et al., 2002):

1. Management: actions, recommendations, modifications, and formation or operation procedures.

2. Lists: lists of errors, hazards, domino effects, causes/consequences, failures and damages, critical activities, failure mode, accident initiators, vulnerable places and major accident scenarios.
3. Probabilistic: failure rate, reliability, scenarios or damages probability, and accident frequency.
4. Hierarchisation: level risk index, severity and criticality, fire, explosion, toxic leakage index, organisational index, classification according to the type of risk.

The chapter below explains a common risk analysis method divided into qualitative and quantitative components.

3.8 Risk analysis qualitative method

Risk assessment qualitative method includes but not limited to: P-I (see chapter 3.5.4), project assumption testing, data precision ranking, risk categorisation, risk urgency assessment, and expert judgement.

3.8.1 Project assumption testing

Assumption is defined as a factor in the planning process where it is variously considered to be true, real, or certain, without available proof or evident demonstration (PMI, 2017). Assumptions Analysis is a technique that explores the accuracy of assumptions and identifies risks to the project from the inaccuracy, inconsistency, or incompleteness of assumptions (PMI, 2017). Two criteria should be tested for project assumption testing, specifically assumption stability and the consequences to a given project if the assumption is proven to be false. In the qualitative risk analysis process, alternative assumptions should be identified and tested in relation to their consequences for the project objectives (PMI, 2017). An assumption is a decision to proceed on the basis that one option will turn out to be correct and the other scenarios will not arise (Hillson, 2004).

A problem in the assumption is that it may not always be current. As the realistic outcome may change, misjudgements as the facts underlying the assumption might potentially cause a problem for the project. To solve this problem, Hillson (2004) designed a simple method called the “IF–THEN ” statement. The statement is that the

IF side tests how likely the assumption is to be unsafe, and the THEN side tests whether it matters. The example is: 'IF this assumption proved to be false, THEN the effect on the project would be …' If the assumption is false, then it could have a significant effect on at least one of the project objectives in a manner akin to risk. In this case, the assumption can be turned into risk.

3.8.2 Data precision ranking

Data precision describes the extent to which risk is known and understood. It measures the scope of the available data and the reliability of that data. An assessment must be made of the source of the data used in determining the risk (Chinbat, 2009).

Data precision ranking is a qualitative risk analysis approach that requires accurate and unbiased data if it is to be helpful to project management. Data precision ranking is a technique through which to evaluate the degree to which the data about risks is useful for risk management. It involves examining the extent of our understanding of the risk, the available data about the risk, the quality of that data, its reliability and integrity.

During the risk collection step, the Risk Management team may ask such questions (VijayaKumar, 2013b):

1. Is the data credible?
2. Is the data used of high quality?
3. Is the data and/or information accurate?
4. Is the risk itself understood properly?

Sometimes, the process of data gathering for risk analysis may go wrong, resulting in the data being unsuitable for the risk analysis. Risk data quality assessment is a technique for evaluating the utility of risk data employed for risk management. It involves examining the degree to which the risk is understood and also the accuracy, quality, reliability, and integrity of the data pertaining to the risk (PMI, 2017). If the information is not reliable, then fixing it is far less costly as compared to the impact of risk if it materialises (Knowledge, 2018).

3.8.3 Risk Categorisation

Risks can be categorised into many types such as sources of risk, the aspect of the project affected, or common root causes. Risk categorisation helps to determine work packages, activities, project phases or even roles in the project, which can in turn lead to the development of effective risk responses (PMI, 2017). For example, risks are sorted by organisational areas, technical areas, or contract areas. These risks could be treated as risk breakdown structures (Hillson, 2003). The selection of categories is often based operationally on the purposes of risk reduction in a given project (Hillson, 2003).

3.8.4 Risk Urgency Assessment

Risk urgency assessment seeks to identify near term risks that require immediate attention (VijayaKumar, 2013c). In order to identify near-term risks, three factors should be considered (PMI, 2017):

1. The time available to put a risk response into motion: some risks require response within a certain time, otherwise the risk itself may become irrelevant. If the risk is implemented within a certain timeline, then the risk could be solved whereas, if the timeline is missed, only the response can mitigate the risk.
2. The symptoms or warning signs of the risk: symptoms or warning signs are also known as risk triggers. Risk triggers could serve to identify which risk(s) require an immediate response.
3. Risk rating score: Risks that have a higher score are typically those risks that may occur relatively soon and thus require more action.

Indicators of priority of risk factor may include the probability of detecting the risk, the time required to affect a risk response, symptoms and warning signs, and the risk rating. In some qualitative analyses, the assessment of risk urgency is combined with risk ranking which is predetermined from the probability and impact matrix to give a final risk severity rating (PMI, 2017).

3.8.5 Expert judgement

Similar to expert elicitation, expert judgment requires the recruitment of experts having experience with similar recent projects. This method is often accomplished through workshops or interviews. The experts' bias should be taken into account in this process (PMI, 2017). Such an expert may be provided by any group or person with specialised education, knowledge, skill, experience, or training. It is common to seek an external group or person with a specific relevant skill set or knowledge for expert judgment (Sotille, 2016).

The expert could include (VijayaKumar, 2013a):

1. Individuals with similar project experience.
2. Project team members who contribute to project planning and management activities.
3. Specialists in risk management from outside the project.

3.9 Risk analysis: quantitative methods

Risk assessment qualitative method includes but not limited to: sensitivity analysis, decision tree, Monte Carlo simulation, influence diagrams, and criticality analysis.

3.9.1 Sensitivity analysis

Sensitivity analysis presents the impact of each risk factor (Flanagan et al., 1993). It can present the relationship between project's objectives and risks. It examines how the risk may change if the objectives change.

The purposes of sensitivity analysis are (Iloiu et al., 2009):

1. To help identify the key variables which influence the project cost and benefit streams.
2. To investigate the consequences of likely adverse changes in these key variables.
3. To assess whether project decisions are likely to be affected by such changes.
4. To identify those actions that could mitigate possible adverse effects on the project.

The process of sensitivity analysis includes (Iloiu et al., 2009):

1. Identifying key variables to which project decisions may be sensitive.

2. Calculating the effect of likely changes in these variables and a sensitivity indicator and/or switching value.
3. Considering possible combinations of variables that may change simultaneously in an adverse direction.
4. Analysing the direction and scale of likely changes for the key variables identified, involving the identification of the sources of change.

The tornado diagram presents an example of such a sensitivity analysis. A tornado diagram is a special type of bar chart used in sensitivity analysis for comparing the relative importance of the variables. The tornado diagram could, for instance, compare the relative importance and incidence of variables with a high degree of uncertainty to those that are more stable. It also could analyse risk-taking scenarios enabled for specific risks (PMI, 2017).

3.9.2 Decision trees

If there are several alternative choices in the project process, decisions need to be made. Each choice may include more sub-choices, which could be presented as a tree structure and present all possible paths to the point of decision (Song et al., 2015).

In order to implement such a decision tree, the process includes (Hulett, 2014):

1. Identifying the objective. Some trees will be constructed so as to make decisions to maximise value, such as Net Present Value or profit.
2. Identifying the major decisions to be made. In the decision tree this is called a decision node.
3. Identifying the major uncertainties. Uncertainties are specified within event nodes that relate to the consequences and their probabilities.
4. Constructing the structure of the decision and all of its (main) consequences. Because each decision or event node has at least two alternatives, the structure of the decision resembles a tree, although this is typically placed on its side with the root on the left and the branches on the right.
5. Solving the tree.

3.9.3 Monte Carlo Simulation

Monte Carlo simulation is a tool for estimating and analysing project risks. This simulation could be used in project time overruns (Hatmoko et al., 2010), project cost overruns (Karakas et al., 2013), and the level of project plan reliability (Rashki et al., 2014).

Monte Carlo simulation comprises a statistical simulation technique (Wall, 1997). To develop a Monte Carlo simulation method, first need to define the parameter that affects risk factor, then these parameters need to be treated as random variables. Each selected parameter is assigned a corresponding value rank and distributional probability function. The value of parameter is chosen randomly, the probability is determined by the distribution function. The values of the selected parameters, together with the corresponding probabilities, are used to calculate the corresponding exposure. This randomisation procedure is repeated 100 to 1000 times, when exposure itself also becomes a random variable. As the number of iterations increases, the mean and the standard deviation of the samples tend to converge (+/- S.D.) upon a normally distributed result (Smith, 1994).

Monte Carlo simulations have several advantages (Vose, 2008):

1. It allows model correlation between different dependent variables.
2. Simple mathematics is involved.
3. Calculation of the distribution functions is performed by computer.
4. Availability of several commercial software.
5. Treatment of linear and nonlinear models from simple to complex ones is achieved without great difficulty.
6. Changes and tests to the model can be performed quickly and easily.
7. Working with several independent variables simultaneously results in a probability distribution function for the output variable, aiding decisions in the acceptance of the risk of a particular action.

3.9.4 Influence Diagrams

An influence diagram is defined for formulating problems (Virtanen et al., 1998). Influence diagrams can aid the construction of models that expose the key influences or risk factors for the project.

Shachter (1986) defined an influence diagram as a framework through which to formulate problems combined with the knowledge of experts. Influence diagrams have been used for decision analysis, identifying probabilistic dependencies and characterising the flow of information (Agogino et al., 1987). An influence diagram normally includes 3 levels, namely relational, functional and numerical. The relational level is those interrelationships arising between the variables. The functional level is an inferential technique by which to manipulate risk (Tamimi et al., 1990).

Following influence diagram conventions, uncertain variables and events are typically shown as ellipses; variables are calculated from predecessors and presented as double ellipses; while decision nodes are shown as rectangles; and value nodes are depicted as diamonds (or hexagons). Influence diagrams are directed acyclic graphs in which an arrow connecting node A to node B is interpreted as follows (Ezell et al., 2010):

1. If node A is an event node and node B is a decision node, it means that “the event in A will be known prior to making the decision in B.”
2. If both nodes A and B are both chance nodes, it means that “knowing the event in node A affects the probabilities of events in node B.”
3. If node A is a chance or decision node and node B is an outcome node, it means that “the outcome depends on the predecessor nodes.”
4. If nodes A and A′ are chance nodes and node B is a node characterising a calculated variable, it means that the variable in node B is calculated from the numbers representing the uncertain variable in A and A′.

3.9.5 Criticality Analysis

By defining the critical path of each task of the project, criticality analysis defines which path could become critical without appropriate risk management. Criticality analysis also can present the sub-critical paths that should be concerned with the critical path. Some critical path analysis includes significant risks which require particular attention (Vanhoucke, 2011). The scope of criticality analysis is extended to cover interdependent infrastructures and possible threat(s). Generally, criticality analysis is performed for a large project and it usually involves higher impact scales (Theoharidou et al., 2009).

3.10 Risk response definition

After the risk factors have been identified, assessed and analysed, a risk response is required to deal with the risk factors identified. Risk response is a process by which to remove potential negative impacts and to increase the level of control over the risks (Zou et al., 2007). However, some risks cannot be eliminated, which means that these risks require more attention and the formulation of better strategies (Perry et al., 1985). Risk response is a process through which to enhance opportunities and reduce threats in projects. It could also create the essential conditions for optimal risk maturation in respect of the identification and assessment of risks (Motaleb et al., 2014). However, risk response always becomes the weakest part of the risk management process, and only a few projects stand to gain the full benefits of such risk management (Hillson, 1999).

The risk response process comprises four methodologies, namely risk avoidance, risk transfer, risk reduction, and risk retention (Hillson, 1999):

1. Avoidance: seeks to eliminate uncertainty either by making it impossible for the risk to occur or by executing the project in a different way that will achieve the same objectives while insulating the project from the effect of that risk.
2. Transfer: identifies another stakeholder who is better able to manage the risk and to whom the liability and responsibility for the action can be assigned.
3. Reduction: reducing the size of the risk in order to make it more acceptable to the project or organisation by reducing its probability and/or the impact.
4. Retention: recognising that residual risks must be taken and by responding either actively (by allocating the appropriate contingency) or passively (by doing nothing except monitoring the status of the risk).

In order to reduce the influence of risk, the contents and effects of all alternative methods should be considered (Wang et al., 2003) which could help the risk response process to choose a proper strategy to mitigate the negative impact of the risk (Miller et al., 2001).

Zhi (1995) classified risks into three broad channels according to how they can be addressed: via contract, insurance, or retention management. The contract and insurance allocate the risks to external parties, while retention management seeks to control risks through internal management processes. However, the decision for the risk response is determined by the project's characteristics (Fan et al., 2008).

3.11 Risk response method

Risk assessment qualitative method includes avoidance, transfer, retention, and reduction.

3.11.1 Avoidance

Risk avoidance means do not accept the risk and try to eliminate the risk (Flanagan et al., 1993). In order to avoid risk, the potential sources of each risk should be defined, and then all sources need to be solved. The most radical way to avoid risk is to refuse the contract and renounce the project. An alternative method is introducing a contract clause for some risk factors pertaining to risk avoidance. Risk avoidance should be used before the risk occurs, reducing the possibility and impact of a given risk factor to zero. However, risk avoidance should be considered as a negative coping method, because where there is no risk, there is also no opportunity (Bi et al., 2015).

3.11.2 Transfer

Risk transfer means transferring the risk to another project participant (Carter et al., 1994). Risk transfer can only reduce risk impact during the risk management process. Mostly, risk transfer pertains to financial risk. By signing contracts with other participants, this could result in a certain level of project performance. Insurance is another means of risk transfer. Which participant(s) are involved within the project to optimise risk control should thus be considered. This approach can compensate for disadvantages in terms of poor financial strength or small production scales (Bi et al., 2015).

3.11.3 Retention

Risk retention means taking no response to the risk (Tweeds, 1996). Still, the risk factor should be monitored and controlled during the project process. In general, there are two types of risk retention: active and passive. Active risk retention means that the risk has been estimated and a contingency plan prepared and implemented, while passive risk retention means that the risk has already arisen and caused only limited damage within an acceptable risk tolerance range. In fact, risk retention is the most common method for risk response, as risk retention achieves the final goal for risk management: namely reducing risk to an acceptable level (Bi et al., 2015).

3.11.4 Reduction

The goal of risk reduction is to decrease the probability of a given risk factor or else to decrease the impact of risk on the project (Baker et al., 1999a). However, the additional costs for risk reduction should be considered. The costs of risk reduction should be smaller than the costs should that risk materialise. Risk reduction methods often come from some alternative methods for executing the project.

3.12 Chapter summary

This chapter explained the method of the established risk management process. Table 3.1, Table 3.2, Table 3.3, Table 3.4, Table 3.5, Table 3.6 presented the methods of the risk management process.

Table 3.1: Risk identification methods

METHOD	FEATURE	ADVANTAGES	DISADVANTAGES
Brainstorm	Asking a group of people to consider the inherent risk in the project as far as possible, no matter whether the risk is reasonable or not.	• Could address a large amount of risk in a short time.	• May have bias if there is an authoritarian participant. • The number of group members should be considered carefully
Interview	Asking one or several people to answer the developed questions and discuss the issues involved.	• Can understand the knowledge of participants from several angles.	• A time-consuming method. • The results should be systematised and analysed.
Checklist	Listing items, steps, or tasks for the project, then analysing against criteria to determine if the procedure is completed correctly.	• Suitable for team members with less experience.	• Important interdependencies between sources are not readily highlighted. • Individual entries may encompass a number of important, separate sources implicitly. • Sources not on the list are likely to be ignored.
SWIFT	A structured brainstorming method. By combining similar phrases like 'What if. . .' or 'How could. . .' with the use of predeveloped guide words such as timing or amount.	• Could help the participants to enhance commitment to new and existing risk controls.	• Requires a group member with the most intimate knowledge of the system or process being assessed.
Scenario analysis	Estimating and analysing the scenario of the project in order to identify the risk in the project process.	• Scenarios that present realisable or desirable futures are placed side by side. • Building a scenario is very flexible and can be adjusted to a specific task. • Scenarios can lead to the	• The practice of scenario is very time-consuming. • Selection of suitable participants is required. • It can be difficult not to focus on black and white scenarios or the most likely scenario.

		creation of a common language for dealing with strategic issues.	
FTA	A cause-and-effect analysis which breaks down possible project failure into one or more failures at the lower levels.	● Can focus on the top risk factor from the lower levels.	● Hard to get the failure data of all the events in the fault tree.
Bow tie analysis	Combines fault tree method and event tree method to define the critical event.	● Could present accident causes and their consequences.	● Hard to obtain crisp data or probability density functions for the project.
Direct observations	Observes the project to figure out the potential risks or uncertainties.	● Could get the observed data, documenting the findings and participating in the analysis.	● Observers may respond to social and situational factors. ● Noise of event may disturb the observation process.

Table 3.2: Risk assessment qualitative methods

METHOD	FEATURE	ADVANTAGES	DISADVANTAGES
Brainstorm	Asking a group of people to consider the risk in the project as much as possible, no matter whether the risk is reasonable or not.	● Can address a large amount of risk in a short time.	● May have a bias if there is an authoritarian participant. ● The number of group members should be considered carefully
Interview	Asking one or several people to answer the developed questions and discussing the issues involved.	● Could understand the knowledge of participants from several angles.	● A time-consuming method. ● The results should be systematised and analysed.
Expert elicitation	Self-elicitation or interviewer-elicitation can be chosen to obtain expert beliefs.	● The participants could explain how risk could be solved. ● Could find risk in the early stages of project.	● May not expose all risk.
Delphi method	A group communication process in which the	● Solves the problem that some	● This method can be very

	group is treated as a whole to deal with complex problems.	participants have strong personalities during interview process. ● Can highlight topics of concern and evaluate uncertainty in the project	time-consuming.
SWOT analysis	Analyses the strengths, weaknesses, opportunities and threats of the project to develop and adopt suitable strategy.	● Could be used as a form of strategy analysis.	● Does not consider the most significant problems in the project.
P-I	By using random variables, the statistical method can be used to calculate and evaluate the significant risk factor(s).	● Could help to identify risks that need to be managed dynamically.	● Hard to build a database for P-I.
SWIFT	A structured brainstorming method combining similar phrases like 'What if. . .' or 'How could. . .' with the use of predeveloped guide words like timing or amount.	● Could help the participants to enhance commitment to new or existing risk controls.	● Requires a group member with the most intimate knowledge of the system or process being assessed.
FTA	A cause-and-effect analysis, which breaks down the project failure into one or more points of failure at the lower levels.	● Could focus on the top risk factor from the lower levels.	● Hard to get the failure data of all the events in the fault tree.

Table 3.3: Risk assessment quantitative methods

METHOD	**FEATURE**	**ADVANTAGE**	**DISADVANTAGE**
Questionnaire	Asks a group of people the same question and then analyses the frequency of the data.	● An economical method. ● Can collect sensitive data.	● The answer may not accurate because of social desirability.
AHP	Three related levels. Top level includes those elements for the overall objectives of the decision problem; intermediate level includes elements that affect the decision; and the lowest level include elements for the	● Requires a little quantitative data.	● Cannot provide solutions for risk factor(s).

	decision options.		
DSS	A computer-based environment to solve complex problems for a complex project.	• Could provide different viewpoints and the possibility of other options.	• Requires gathering enough data and information to support DSS.
FMEA	A 10-point scale includes occurrence detectability, severity of the risk factor, and multiplying 3 factors to obtain the significant risk(s).	• Could identify potential failure modes for a product or process. • Can identify and carry out corrective actions to address the most serious concerns.	• The importance of occurrence, detectability and severity may vary. • Does not encompass the entire range of causative factors leading to a failure mode.
BBN	A unicycle graph has one direction and cannot make up closed cycles. The node represents random variables and arcs represent direct dependency between variables.	• Easy to maintain and implement the data.	• Cannot get the result if the input variables are related.
Markov chain analysis	A probabilistic framework for modelling a time series of multivariate observations.	• Could handle new data robustly. • Could predict similar patterns efficiently.	• Only rely on the current stature and the observer objective. • Could not connect previous or future factor.

Table 3.4: Risk analysis qualitative methods

METHOD	FEATURE	ADVANTAGE	DISADVANTAGE
P-I	By using the random variable, the statistical method can be used to calculate and evaluate the significant risk factor(s).	• Could help identify risks that need to be managed dynamically.	• Hard to build a database for P-I.
Project assumption testing	Explores the accuracy of assumptions and identifies risks to the project arising from inaccuracies, inconsistencies, or incompleteness of assumptions.	• Suitable for projects with insufficient data.	• The realistic and assumptions may not be the same.

Data precision ranking	Measures the scope of available data and the reliability of the data to understand the risk factor.	• Improves the understanding of risk.	• Requires accurate and unbiased data.
Risk categorisation	Categorises the risks posed by many types of category, such as sources of risk, the areas of the project affected, or common root causes.	• Determines work packages, activities, project phases & even roles in the project, leading to the development of effective risk response.	• Requires experts to define and group categories.
Risk urgency assessment	Identifies near term risks that require immediate attention.	• Can identify the primary risk that needs to be solved.	• May ignore some risk factors which are not urgent but important.
Expert judgement	Like expert elicitation this method gathers the data and information from project experts.	• Could define the risk based on the experience thereby improving accuracy.	• Requires many experts to participate.

Table 3.5: Risk analysis quantitative methods

METHOD	FEATURE	ADVANTAGES	DISADVANTAGES
Sensitivity analysis	Presents the impact of each risk factor and investigate the consequences of likely adverse changes in key variables.	• Able to examine how the risk may change if the objectives change.	• The results may have subjectivity.
Decision tree	A tree structure includes alternative choices and sub-choices for the project.	• May observe the decision process for the project. • The structure of the tree is easy to maintain and understand.	• May result in a complex structure.
Monte Carlo simulation	A statistical simulation technique that treats parameters that affect a particular risk factor as a random variable, and randomly chooses parameters to calculate.	• Changes and tests in the model can be performed quickly and easily. • Allows model correlation between different dependent variables.	• Requires a lot of time to improve accuracy.

Influence diagrams	Framework to formulate problems combined with the knowledge of experts.	● Could provide a visible diagram. ● Could be used for decision analysis, identifying probabilistic dependence and characterising the flow of information.	● Cannot determine which risk factors are more significant.
Criticality analysis	Defines the critical path for each task in the project.	● Could define which path could become critical without risk management.	● A small project may it hard to find the critical path.

Table 3.6: Risk response methods

METHOD	FEATURE	ADVANTAGES	DISADVANTAGES
Avoidance	Refusing to accept any risk.	● Could reduce the possibility and impact of the risk factor to zero.	● Also erases the opportunity.
Transfer	Transferring the risk to another project participant.	● Could reduce risk impact on the risk-taker.	● The risk only changes taker, but still exists.
Retention	Taking no response to the risk.	● Could save on the cost of risk management.	● Risk still exists in the project.
Reduction	Decreases the probability of risk or decreases its impact.	● Could mitigate the risk of negative influence.	● Additional cost may arise in risk reduction process.

Based on the table presented above, the respective advantages and disadvantages of each risk management method are presented. In this research, one of the primary risk management methods was chosen for the research.

1. Risk identification: Interview is used in this research as a risk identification method. As an OSC project requires all OSC stakeholders to participate, it is first necessary to identify the OSM risk factor from all OSC participants. In this case, the interview is the method that is employed to collect data from owners, consultants, manufacturers, transporters, and contractors.
2. Risk assessment: Expert judgement is used in this research as a risk assessment method. After risk factors are identified, experts could help to define how the risk influences the project through their experiences. After risk assessment, the risk factors can be divided into different risk types and risk groups.
3. Risk analysis: An influence diagram is used in this research as a risk analysis method. As the OSC project is a lifecycle project, the interrelationship between each risk factor needs to be confirmed. An influence diagram could provide a visible diagram to help us to understand the risk factors and prepare a suitable risk response method.
4. Risk response: All risk response methods are utilised in this research as risk response methods, including risk avoidance, risk transfer, risk retention, and risk reduction. The appropriate risk response method is determined by many reasons, according to the types of company, material, and country, all of which impact the selection process.

By viewing articles, this chapter shows the method for risk management, divided by risk identification, risk assessment, risk analysis, and risk response, both qualitative and quantitative methods are presented. It also presents the advantage and disadvantage of the risk management method, and conclude certain risk management method would be used in this research. Risk management methods for the OSC project are explained in this chapter. However, it is necessary to distinguish traditional construction method and the OSC method. In the next chapter, the definition of OSC and OSM will be explained.

CHAPTER 4 - OSC AND OSM

4.1 Introduction

This chapter presents the background and history of OSC. It also presents those specific features of the OSC process which differentiate it from traditional construction processes. By breaking down the OSC process into discrete phases, OSM is defined in terms of its significant differences compared to traditional construction methods. It emphasises the importance of the OSM process in the OSC project and presents the relationship arising between traditional construction and OSC.

4.2 History of OSC

Although OSC is a relatively new method for construction projects, its related methodology dates back to ancient times. In order to understand the process of OSC development, the historical background of OSC must first be explained.

4.2.1 Early off-site stage

It seems that the earliest OSC prototypes can be traced back to the iron age with the use of timber crucks for barns (Hill, 2005). Arif (2009) argued that the use of big boulders instead of smaller bricks in pyramids is no different from using prefabricated wall components, methods which could be deemed OSC. The Roman Army also used OSC to build a 600-bed hospital in the UK between AD 83 and 86 (Gibb, 1999).

4.2.2 Before 1945

In the 17th century, the global expansion of the United Kingdom necessitated rapid construction across its various colonies, particularly in Africa, Australia, New Zealand, and Canada. This was relatively new for the UK, as components were manufactured in England and shipped by boat to various locations worldwide. The earliest case recorded was in 1624, when the UK assembled a house in England and sent it to the fishing village of Cape Anne which is now a city in Massachusetts (Arieff, 2002). In 1851, a three-storey exhibition hall was built in London. The components were made in a manufactory and relocated from the original site (Gibb, 2001). In the 18th century, some hospitals, storehouses and cottages were built and shipped to Sydney. These simple shelters were timber framed, with wooden components for the roofs, floors and walls (Herbert et al., 1978). This method was widely used by the UK, and such portable colonial cottages were delivered to many of its colonies. The timber frame used by the UK led to the balloon frame in the USA (Smith, 2009). However, in 1871, a large fire in Chicago destroyed most of the light frame timber houses causing the introduction of the steel frame house in the USA (Davies, 2005).

Corrugated iron was developed after the timber house fell from favour. Compared with the timber frame, corrugated iron is not only transportable, but also non-flammable. The features of corrugated iron caused it is widely adopted as a building material (Mornement et al., 2007). Corrugated iron houses could be ordered through magazines and other publications by patrons and it became a popular material of the time (Peterson, 1965). During the Second World War, corrugated iron was used to build Quonset huts and OSC became a widely used method in the UK following the First World War. The acute need for housing in the UK and shortages in labour and materials resulted in 50,000 houses being made by the OSC method between 1919 and 1939 (Marshall et al., 2013). In other European regions, more than 20 manufacturers offered pre-cut kit housing kits, including framing and enclosure houses (Smith, 2009).

4.2.3 1945-1990

The demand for housing increased around the world after the Second World War. For example, in 1947, 17,500 houses were constructed by the OSC method in Sweden (Waern, 2008). OSC was not only considered as a component provider for the housing sector, but also included integrated systems for electricity and plumbing at that time (Smith, 2009). In the UK, around 500,000 houses were systematically built by the OSC method during the period from 1945-1955 (Marshall et al., 2013). However, the collapse at Ronan Point caused societal concerns in relation to a non-traditional building method and OSC fell out of favour in the 1970s (Forum, 2002). In China, a similar disaster occurred in Tangshan. In the 1976 Tangshan earthquake, over 95% of the houses in the city collapsed, and more than 600,000 residents were either killed or wounded, many of whom lived in OSC buildings. Therefore, the public nicknamed prefabricated components as ‘coffin boards’ after the disaster (Wang et al., 2019).

4.2.4 After 1990

Although Japan had few OSC buildings during the 1950s-60s, it became the world’s most successful OSC exponent after the 1970s. In 2004, 1 in every 7 new homes in Japan was built using OSC methods (Noguchi, 2005). By 2004, OSC provided 2.1% of the total value of the UK construction sector (Goodier et al., 2005). For instance, the Uxbridge Travelodge hotel comprised 86 containers. These containers were built in China and shipped to Uxbridge and installed by bolting them together (Robinson et al., 2012). Although OSC is uneconomic, the increase in quality and the reduction in on-site construction time lead to the method being widely considered.

Different from developed countries, Chinese OSC has developed in recent years. After Tangshan earthquake, OSC had been dormant for a while in China. However, during the last decade, Chinese increasing population and economic progress led to a rapid annual increase in the rate of urbanisation. According to the National New-type Urbanisation Plan (2014–2020), around 30 billion square metres of buildings will be newly constructed in 2020 across China (Taylor, 2015). OSC is now widely practised by the Chinese construction industry. Over the next decade, OSC is expected to account for 30% of total construction in China (Taylor, 2015). According to the 13th Five-Year Prefabricated Building Action Plan, 15% of new buildings should use OSC, and more than 200 OSC industry bases were to be established by 2020 (MOHURD, 2017).

Azman et al. (2010a) presented the differences in components used in OSC from 1960 until 2010. They presented the significant changes in the technology and the material used for off-site components. It presented that the OSC project is not limited to the certain material to build the component. However, building code is the same regardless of material and production in the OSC project (Johnsson et al., 2009).

4.3 Definition and classification of OSC

4.3.1 OSC definition

OSC, or so-called pre-assembly, encompassing industrialised building, system building, off-site fabrication, off-site production and other modern methods of construction (Kamar et al., 2011), is a method whereby construction components are produced in the factory, transported to a site, and finally assembled on-site (Pan et al., 2012).

Many articles have offered a definition of OSC. Goodier et al. (2005) presented OSC as the manufacture and pre-assembly of components, elements or modules before installation at their final location. Lu et al. (2008) defined OSC techniques so as including a spectrum of applications wherein buildings, structures, or parts thereof are manufactured and assembled remotely from the building site prior to their installation *in situ*. Arif et al. (2010) explained the philosophy behind OSC as the amount of effort needed to achieve the same result would be significantly less if some activities were moved to a manufacturing facility rather than being performed on a construction site where the workers would be exposed to the elements. Pan and Goodier (2011) defined OSC as the manufacture and preassembly of building components, elements, or modules prior to installation in their final locations. Hashemi (2015) defined OSC as a term used to describe a spectrum of applications wherein buildings, structures or parts are manufactured and assembled remotely from a building site prior to their installation in their final positions or, in other words, moving operations that are traditionally completed on-site to a manufacturing environment.

In Chinese articles, OSC has been considered in recent years. L. Li et al. (2013) presented OSC as manufacturing of the precast component then assembling on-site construction method. Wang et al. (2017) explained OSC has three steps including design, manufacture and assembly. Guo et al. (2017) considered OSC as a new method to replace the traditional construction method.

4.3.2 Classification of OSC

Gibb et al. (2003) classify OSC into four categories:

1. Component manufacture and sub-assembly: the components have always been made in a factory and would never be considered for on-site production. These components include bricks, tiles etc.
2. Non-volumetric pre-assembly: some components, like pre-fabricated wall components, are created in the manufactory and cannot become a usable space there. The non-volumetric units are then brought onto the construction site and installed onto a steel, concrete, or wooden frame structure.
3. Volumetric pre-assembly: the manufacturing process produces usable space and is finally installed on the construction site onto an independent structural frame. This type of technique is used to manufacture plant rooms, toilet pods, shower rooms etc.
4. Modular building: this type of construction produces all the actual structure and fabric of the building in a factory which is then transported onto the site to be assembled. The majority of effort is concentrated in the manufacturing process, and only the final assembly and the finishing activities are performed on a construction site.

However, Arif et al. (2010) detailed 5 categories in their hybrid system. The hybrid system can be configured by the categories derived. For hybrid systems, Arashpour et al. (2017) presented a WBS for hybrid infrastructure projects as off-site/coordination/on-site triads.

On the basis of the increasing amounts of pre-assembly and standardisation involved, Sharma et al. (2017) divided OSC into 4 levels:

1. Component manufacture and sub-assembly.
2. Non-volumetric pre-assembly.
3. Volumetric pre-assembly.
4. Whole buildings.

Azman et al. (2012) presented OSC as 4 subtypes:

1. Component manufacture & sub-assembly: Items are always made in a factory and never considered for on-site production.
2. Non-volumetric preassembly: Pre-assembled units which do not enclose usable space.
3. Volumetric pre-assembly: Pre-assembled units which enclose usable space and are typically fully factory finished internally, but do not form the building's structure.
4. Modular building: Pre-assembled volumetric units which also form the actual structure and fabric.

Across different countries the off-site system has slight differences. For example, Azman et al. (2010a) compared the US, the UK, Australia, and Malaysia, showing the differences arising between the pattern and the degree of technology changes in these countries (see

Table *4.1*). Although different countries have different OSC standards, Hashemi (2015) suggested that developing countries could learn OSC experience from other developed countries.

Table 4.1: OSC types in different countries (Azman et al., 2010a)

COUNTRIES	CATEGORISATION OF OSC SYSTEM
US	● Off-site pre-assembly ● Hybrid system ● Componentised system ● Modular building
UK	● Component manufacture & sub-assembly ● Non-volumetric pre-assembly ● Volumetric pre-assembly ● Modular building
Australia	● Non-volumetric pre-assembly ● Volumetric pre-assembly ● Modular building
Malaysia	● Pre-cast concrete systems ● Formworks systems ● Steel framing systems ● Prefabricated timber framing systems ● Block work systems ● Innovative product systems

4.4 OSC processes

Li et al. (2016) defined OSC processes in Hong Kong according to 4 categories:

1. Design
2. Manufacture
3. Cross-border logistics
4. On-site assembly

The overseer of the OSC project in Hong Kong is the Housing Authority, as the client hires designers for architectural and engineering design and then transfers the design information to the manufacturer to produce components. The whole off-site manufacturing sector of Hong Kong has since been moved to the Pearl River Delta region in China. After the components are produced, they can be transported to the construction site in Hong Kong or else stored temporarily in Lok Ma Chau. Finally, the components are installed by the assembly company (Li et al., 2016)

Aris et al. (2019) presented the OSC development process. First, the developer, as the owner of the housing project, acquires the proposed land. The designer, the manufacturer supplier, the transporter and the contractor are all involved in the OSC process from the design stage until the final assembly of components on-site. After the houses are handed over to the purchaser the maintenance of some housing projects, such as high-rise apartments, will be taken care of by the subsidised company with the developer's cooperation.

For the contractor on-site assembly process, Gong et al. (2019) presented the three steps to show the different statuses of pre-fabricated products:

1. The expeditor delivers the daily order to the manufacturing factory. When the pre-fabricated products are produced and prepared well, they are then delivered to the construction site with an on-site check by the quality inspector.
2. The pre-fabricated products are arranged by the buffer foreman before being lifted by tower crane. The tower crane will be maintained regularly by the tower foreman to guarantee the safe operation of the crane. During the on-site

assembly process, the crane banksman and the prefabricated products installer are essential in providing accurate information during the lifting and placing process. General workers will help to handle some temporary work on site.

3. The assembled pre-fabricated products will then be checked by the quality inspector again. Substandard products will be returned to the factory for reworking. The site superintendent and the safety supervisor conduct the general planning and control and supervise safety issues on site.

The OSC on-site assembly process is divided into four steps (Li et al., 2018):

1. This phase beings when the pre-fabricated components arrive at the construction site and are checked by the on-site foreman after being delivered by the third-party logistics company.
2. Inputs are the delivery of pre-fabricated components and relevant documentation.
3. Concludes when the delivered pre-fabricated components are assembled and pass their respective inspections.
4. Completion of the superstructure work ends phase four.

4.5 OSC benefits and barriers

4.5.1 OSC benefits

As compared with traditional construction, OSC has proven to solve such issues as excessive project time (Arashpour et al., 2016); resource wastage (Lu et al., 2013); excessive project cost (Mao et al., 2016); and employee safety (Pan et al., 2008) and also improves project quality (Hashemi, 2015).

As a new methodology for construction, OSC solved many risks which arise in traditional construction projects. The advantages of OSC can be divided into six categories.

1. Cost: Gibb (2001) pointed out that the project team prefers to have a standard process which will simplify the overall construction process. It also reduced

wastage and resources. OSC could reduce the costs of construction project, reducing the burden during an economic downturn (Tam et al., 2007).

2. Environment: Gibb (2001) found that OSC produces less waste and less impact on the environment. Li et al. (2016) agreed with that and considered that OSC reduces material waste, air and water pollution, dust and noise, and overall energy costs, so that the on-site environment could improve. Tam et al. (2007) determined that OSC was a means of reducing long-term waste.
3. Health and safety: Gibb (2001) considered that if OSC participants understand more about the materials and components during the OSC project, then safety, health, productivity and quality performance should all increase. Gibb and Isack (2003) gave an example as to how OSC could improve safety for the construction project as, when working in prison, traditional construction participants have to have vetted and escorted to ensure their safety. OSC could easily employ workers, thereby reducing the cost of security. Li et al. (2016) proved that OSC gives more controlled conditions for weather, improves quality control and supervision of labour, affords easier access to tools, and means fewer material deliveries.
4. Quality: Arif et al. (2009) indicated that well engineered OSC projects could also produce high performance products by using innovative materials and designs. Gibb (2001) agreed that OSC could improve the quality of construction projects and certified that OSC can be conducted reliably, be more easily maintained, and requires fewer spare parts.
5. Time: Gibb and Isack (2003) worried about traditional construction projects, especially airports, roads, rail and prison projects, as there are too many participants working on-site at same time which may cause congestion and delay. Hashemi (2015) investigated several construction practitioners and gave them a solution for their risk in the form of OSC.

6. Work conditions: As OSC projects always hire only one company for construction, traditional construction methods which employ various sub-contractors are no longer needed, providing better job security for workers (Arif et al., 2009). Li et al. (2016) noted that on-site material storage areas could be reduced, as many materials are stored inside the manufactory.

4.5.2 OSC barriers

Although the OSC method brings a variety of benefits to the construction industry, there are still many barriers to implementing an OSC project. H. X. Li et al. (2013) believed that OSC risk is constituted by the following elements: engineering, occupational, cultural, socioeconomic, and financial. There are many risks that become barriers to OSC.

1. Cost: Li et al. (2014) pointed out that the project team prefers to have standard processes to simplify the overall construction process. Standard process also reduces waste and the use of resources. OSC could reduce the cost of a construction project, reducing the burden during an economic downturn (Tam et al., 2007). Although OSC could reduce building maintenance costs, the high initial capital expenditures, high design costs, and transport costs often deter developers (Arif et al., 2009). Blismas et al. (2005) worried that OSC always magnifies the advantages in terms of materials, labour and transportation costs, while neglecting other cost-related items such as site facilities, crane use and the rectification of works. For example, during OSC, manufacturing costs must also be considered, forcing developers to compress their costs before construction begins (Li et al., 2014). Blismas et al. (2006) pointed out that, given the high cost of initial investment, many construction industries refused to fully embrace OSC.
2. Culture: There was still a bias that OSC could only produce low-cost products (Arif et al., 2009). However, Nawi et al. (2014) considered that if there were

excellence in design for an OSC project, it could provide higher levels of productivity.

3. Flexibility: Blismas et al. (2005) considered that, although OSC could provide the design and specification before the construction process began, many clients and designers might change their demands during the construction process itself. Tam et al. (2007) considered the same risk that if the design of traditional construction had not been frozen in the development stage, it could affect the adoption of OSC. Nevertheless, many construction parties considered the inefficient design data and weak communications between the participating parties, and tried to use OSC to solve this problem (Li et al., 2016).
4. Health and safety: McKay (2010) considered that if OSC participants understand more about the materials and components employed during the OSC project, then safety, health, productivity and quality performance should all improve. Azman et al. (2010b) gave an example that OSC could improve the safety of a construction project in relation to working in prison, wherein traditional construction participants have to have vetted and escorted to ensure their safety. OSC could easily send employees to assembly plants, thereby reducing the cost of security. Li et al. (2016) proved that OSC affords more control over weather conditions, quality, supervision of labour, access to tools, and material deliveries. Most OSC projects used larger and heavier components for on-site assembly, which means regular mobile cranes are unsuitable for off-site components (Arif et al., 2009). Further, the heavy nature of OSC products increases potential hazards in the event of earthquake (Hashemi, 2015).
5. Knowledge: Arif et al. (2009) considered that the lack of adequate knowledge was the main constraint for further development of OSC. Research also showed that architects needed to know more about OSC (Hashemi, 2015).

6. Supply chain: Arif et al. (2009) identified that the import of OSC products from a foreign country led to lower quality and non-compliance with standards. Blismas et al. (2005) emphasized that the OSC developer only prefers a supplier who has established a high degree of trust.

4.5.3 OSC and traditional construction comparison

By comparing OSC and traditional construction methods, the difference between OSC risk and traditional construction risk is outlined in the tables below. In order to clarify the differences arising in terms of risk between each, three risk categories are presented (Zavadskas *et al*., 2010).

1. Internal risk comparison

Internal risk is influenced by project participants. It includes resource risk, project member risk, construction site risk, document and information risk (Zavadskas *et al*., 2010).

Table 4.2 presents the internal risk comparisons between OSC and traditional methods. The italics in the table mean risk in the construction method.

Table 4.2: Internal risk comparison

RISK TYPE	TRADITIONAL CONSTRUCTION	OSC
Resource risk	Many materials are small packages.	*More large load supply needs to be transported (Aburas, 2011)*
Project member risk	The client can place different order from multiple suppliers.	*The client only places order from single-point supplier who has the highest degree of trust (Blismas et al., 2005)*
Construction site risk	*More possible congestion on construction site.*	Less likely congestion on construction site (McKay, 2010)
	The on-site environment has more hazard in control and design process.	Factory environments could provide better control and design workplace (Meiling, 2010)
Documents and information risk	*More information confusion during construction process.*	Less information confusion during construction process (Azhar, 2011).

2. External risk comparison

External risk is that risk which the management team is not able to control. It includes such aspects as political risk, economic risk, social risk, and weather risk (Zavadskas *et al*., 2010). Table 4.3 presents the external risk comparisons between OSC and traditional methods. The italics in the table mean risk.

Table 4.3: External risk comparison

RISK TYPE	TRADITIONAL CONSTRUCTION	OSC
Political risk	*Traditional construction is a normal method for construction.*	Government encourages to use OSC (Nadim et al., 2009).
Economic risk	*Later income generation for clients.*	Clients get income earlier (Arif et al., 2009).
Social risk	*More waste and more impact on the environment.*	Less waste and less impact on the environment (Jaillon et al., 2009).
	Society agrees that traditional construction can build a variety of building structures.	*Society biased against OSC in that it can only provide low-cost building (Lu, 2007).*
Weather risk	*Hard to operate in bad weather.*	Compensates for local weather conditions (Lu et al., 2008).

3. Project risk comparison

Project risk is that risk which only arises during the period of construction itself. It includes time risk, cost risk, work quality, construction risk, and technological risk (Zavadskas *et al*., 2010). Table 4.4 presents the project risk comparison between OSC and traditional methods. The italics in the table mean risk.

Table 4.4: Project risk comparison

RISK TYPE	TRADITIONAL CONSTRUCTION	OSC
Time risk	*Lower speed of construction.*	Higher speed of construction (Goodier et al., 2007).
	The process of construction is to step by step.	Allows on-site building and OSM to run concurrently (Vernikos et al., 2012)
Cost risk	*Higher site-related costs.*	Lower site-related costs (Boyd et al., 2013).
	Lower initial capital outlay, lower design and transport costs.	*Higher initial capital outlay, higher design and transport costs (Pan and Goodier, 2011).*
Work quality	*Complicated construction process.*	Streamlines the overall construction process (Aburas, 2011).
	Harder to maintain and requires more spare parts.	Easier to maintain and require fewer spare parts (Alvanchi et al., 2011).
Construction	*More construction delays or*	Less construction delay/changes

risk	*changes to work schedule.*	to work schedule (Pan and Sidwell, 2011).
	The design process is not frozen in the development stage.	*The design process is frozen in the development stage (Li et al., 2011).*
Technological risk	Perennial technology development.	*Lack of adequate knowledge in terms of OSC (Mao et al., 2015).*

4.6 OSM

4.6.1 Traditional manufacturing features

Some articles did not classify the differences arising between OSC and OSM. For example, Hashemi (2015) considered OSC and OSM to be the same, as both represent construction methods in which prefabricated and standardised components are manufactured within a controlled factory environment and then transported and assembled into the on-site structure. However, this does not distinguish the processes arising within off-site manufactories and the entire OSC process. To clarify the features of OSC and its denominations in terms of precast construction, prefabricated manufacturing, prefabricated construction, and so on. This research defines OSM as 'the process that is responsible by the off-site manufacturer, which may include building material buying, component manufacturing, component transporting, and so forth'. Other processes are not deemed to be the responsibility of the off-site manufacturer and are not considered further.

Figure 4.1 presents a comparison between the traditional construction process and the OSC process (Salama et al., 2017). Compared with traditional construction methods, the OSC process involves component manufacturing and transportation and, as a consequence, OSC is more complex, dynamic and non-linear (Liu et al., 2016). OSC creates a ripple of secondary and tertiary impacts, which increase the complexity of the construction process (Slaughter, 2000). Therefore, it is imperative to understand the risks inherent within the off-site manufacture and transportation process, so that effective strategies can be developed accordingly. Previous studies also suggested that various contextual factors be considered (Gan et al., 2015).

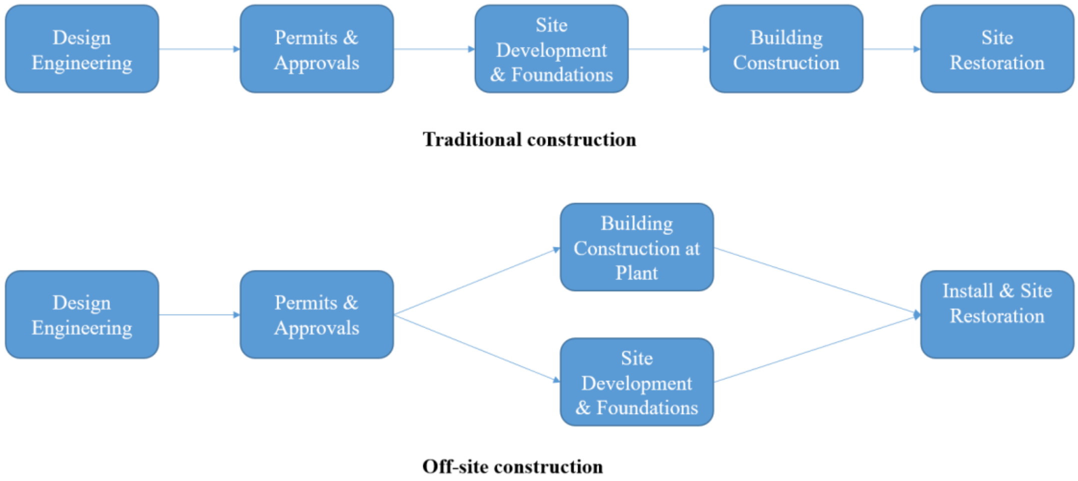


Figure 4.1: Process comparison for different construction methods

Before identifying OSM, it is first necessary to explain traditional manufacturing processes. Traditional manufacturing and OSM share many similarities which could serve to provide a greater understanding of the OSM process itself.

Traditional manufacturing is defined as high volume production on a relatively simple, standardised and autonomous assembly line (Gann, 1996). Chryssolouris (2013) defined manufacturing as the process of transforming materials and information into goods to meet human needs. Lanigan (1992) defined manufacturing as the application of technology to wealth creation by providing cost-effective solutions to human needs and problems. This definition contends that manufacturing is a process intended for mass production.

Over the past 40 years, many innovations have emerged to improve the traditional manufacturing process, as shown in Table 4.5 (Gann, 1996):

Table 4.5: Traditional manufacturing management methods (Gann, 1996)

TYPE	METHOD
Quality systems	● Statistical Quality Control (SQC) ● Total Quality Control (TQC) ● Total Quality Management (TQM)
Planning and scheduling systems	● Materials Resource Planning (MRP) ● Manufacturing Resource Planning (MRP II) ● Optimized Production Technology (OPT) ● Just-In-Time (JIT)
Manufacturing systems	● Group Technology (GT)

	- Cellular Manufacturing (CM) - Flexible Manufacturing Systems (FMS) - Computer Integrated Manufacturing (CIM)

These various methods solved the limitations and inflexibility of traditional mass production, and provided alternative solutions to achieving high quality, low cost and delivery on time (Atkinson, 1999). These methods are discussed in more detail below.

4.6.2 Quality systems

Statistical quality control (SQC) and total quality control (TQC) evolved into total quality management (TQM), which means TQM is the primary quality management method for manufacturing processes (Gann, 1996). TQM is an integrated management philosophy aimed at continuously improving the performance of products, processes, and services to achieve and surpass customer expectations (Woon, 2000). Samson et al. (1999) pointed out TQM has been a widely applied process for improving competitiveness around the world, albeit with mixed success. The process requires assessing the attitudes with benefits and deploying these attitudes. The six most frequent TQM practices are: continuous improvement and innovation; information and performance measures; process management; strategic planning; process control; and product and service design (Lewis et al., 2006). The advantages of implementing TQM lie in increasing productivity and decreasing costs by improving products or services to customers (Psomas et al., 2014). In order to measure the operational performance of TQM, nine constructs were used as follows (Saleh et al., 2018):

1. Improved product/service quality.
2. Increased productivity.
3. Reduced costs of defects and rework.
4. Reduced delivery lead time of finished products/services to customers.
5. Reduced customer complaints.
6. Improved customer satisfaction level and a decline in the number of warranty claims.
7. Purchase material turnover.

8. Total inventory turnover.
9. Reduced inventory obsolescence costs.

4.6.3 Planning and scheduling systems

Materials Resource Planning (MRP) has been expanded, not only for materials, but also in scope to encompass the entire manufacturing process, including master production scheduling, material requirements planning, capacity requirements planning, production monitoring and control, in addition to the more traditional accounting, financial, and marketing functions of the organisation. Together these become Manufacturing Resource Planning (MRP II). At the end of 1970s, MRP II was born in America. Now it has become the core of Enterprise Resource Planning (ERP) Systems which have been widely used in manufacturing (Jiang et al., 2009). MRP II systems are computer-based manufacturing information programmes, originally designed to provide component parts exploration and production ordering (Burns et al., 1991). However, the limitations for traditional MRP II include (Jiang et al., 2009):

1. The System Administrator has the tendency to set a longer lead-time which used to form the basis of manufacturing plans.
2. Used fixed lead-time parameters that do not satisfy the requirements of building an adaptability manufacturing system.
3. The precondition of forming the manufacturing plans is the assumption of Infinite Manufacturing Capability.
4. Lack of restriction on Secure Stocks.

In some cases, manufactories have moved from MRP II to Just-In-Time (JIT) to reduce the risk of the above eventualities (Rao et al., 1988). JIT was developed by Japanese car manufacturer Toyota as a method by which to control the company’s internal operations and relationships with suppliers. Although JIT is a production system, it involves all levels of the organisation and requires some modifications from top to bottom (Lee et al., 1984). The core practices of JIT include (Nakamura et al., 1998):

1. Set-up time reduction.
2. Schedule flexibility.
3. JIT maintenance.
4. Specific equipment layout configurations.
5. Kanban.
6. Pull system support.
7. JIT supplier relationships.

The JIT method provides numerous benefits (Goyal et al., 1992), as follows:

1. Better quality.
2. Less scrap.
3. Less wip.
4. Increased teamwork.
5. Increased productivity.

Bottlenecks are the key factor in Optimized Production Technology (OPT). OPT defines bottlenecks as those parts of the production system that have the lowest production potential. Such bottlenecks are the decisive factor in determining the production system's effectiveness (Iveta et al., 2010). The OPT process includes 10 rules (Iveta et al., 2010):

1. Balancing materials flow rather than balancing capacity leads to more efficient production management.
2. The level of resource utilisation in areas other than at production system bottlenecks is defined by system limitations and not the potential at that specific location.
3. Utilisation and activation of resources are not synonymous.
4. An hour lost at a bottleneck is an hour lost for the entire system.
5. An hour saved at a non-bottleneck does not provide any value for the system.

6. Bottlenecks determine throughput as well as the level of inventory in the system.
7. The transport batch does not have and often should not be the same as the production batch.
8. The production batch should be variable over time along the entire production process schedule.
9. Production schedule should be created with respect to all limitations of the production system.
10. Lead times are a product of the schedule and cannot be established in advance.

4.6.4 Manufacturing systems

Cellular Manufacturing (CM) is an application of Group technology (GT) in manufacturing (Singh, 1993). GT is an attractive strategy which is employed to achieve economic efficiency within flexible manufacturing systems. The idea of GT is to group machines and parts together to save time and cost. The objectives for the GT are (Wang et al., 2006):

1. To reduce the number of duplicated machines.
2. To reduce the number of exceptional elements.
3. To increase machine utilisation rates.

The advantages of GT include (Wang et al., 2006):

4. Shortening throughput times.
5. Providing better quality.
6. Reducing material handling costs.
7. Keeping loads balanced, thereby increasing capacity due to shorter set-up times.
8. Bringing better job satisfaction due to increased teamwork.

A Flexible Manufacturing Systems (FMS) process includes (Suri, 1985):

1. Planning for the FMS.
2. Initial design & detailed design.

3. Installation & production planning.
4. Scheduling.
5. Operation.
6. Ongoing modifications.

FMS is suitable for complicated design, planning, and operational problems, and also became the reason FMS is more difficult to operate (Saygin et al., 1999).

Computer Integrated Manufacturing (CIM) is a system that involves the development of a digital computer database which integrates manufacturing, design, and business functions into a single cohesive system. CIM could help the manufacturer to obtain a computer-oriented system. CIM could be used to collect data from across the company and develop a corporation-wide computer database that could design and manufacture parts without disruption. The result would be reduced design and manufacturing lead times and this is often cited as a driver of greater market share and improved profitability (Bozdağ et al., 2003).

The advantages of CIM include (Kahraman et al., 2004):

1. Greater process flexibility.
2. Reduced inventory.
3. Reduced floor space.
4. Faster responses to shifts in market demand.
5. Lower lead times.
6. A longer useful life of equipment over successive generations of products.

4.6.5 OSM gap

Traditional methods provide innovations and changes for traditional manufacturing. However, the adoption of these methods in traditional construction is relatively hard. The reason for this derives from the specific features of the construction industry.

In traditional construction, each building is unique and designed by a consultant. These unique design aspects reduce the effectiveness of the building and become a source of inefficiency (Gann, 1996).

In order to solve the problem, Gann (1996) presented two solutions:

1. To standardise buildings as per the systems building technique.
2. To make the production process as flexible as possible, allowing a large variety of buildings to be made up of a small number of standard components.

Also, component standardisation should be considered. The more components that are standardised and designed to be assembled in a simple and routine manner, the more productivity gains will likely result.

These ideas point to OSM as a feasible solution for current construction issues. In OSC, the OSM process increases demand to transfer the traditional manufacturing method to the OSM process. However, solutions from traditional manufacturing industries cannot be simply transposed to the problems of OSM, and such solutions should be re-engineered (Gann, 1996).

As OSM is a process of an OSC project, OSC risk and its risk management method could be considered as the reference resources for OSM risk and risk management development. In order to identify OSC risks, many articles divided OSC risks based on the participants, specifically the owner, consultant, manufacturer, and contractor.

For an owner or developer, the most significant risk comes from 'governmental support'. Research by Mao et al. (2015) involved a survey of Chinese developers. The respondents emphasised that a 'lack of governmental regulations and incentives' were the greatest obstacles inhibiting the adoption of OSC approaches. Wu et al. (2019) collected 112 questionnaires and found that 'insufficiently developed regulation and policies to promote OSC' was seen as a general risk in OSC. Using an online survey method to collect questionnaires from 19 different provinces, Ji et al. (2017) identified how policy support needs to be considered to promote the construction industrialisation process. In the absence of this, the owner is less willing to use OSC methods.

For a consultant, the most significant risk comes from 'off-site features'. Sutrisna and Goulding (2019) analysed two OSC cases in the UK and found that adopting 'OSC techniques in a project at an early stage' was the main risk. As the off-site construction requires a freeze in the design process in its early stages, subsequent changes to design in OSC cause more problems than for traditional construction projects, including delays and time wastage. To avoid the risk of design change, some consultants provide a standardised design model for OSC buildings. However, this solution results in the other risk of 'limited design options' (Lu et al., 2008). Using an interview and questionnaire survey, Vernikos et al. (2012) pointed out that, although OSC improves the health and safety of on-site workers, which can reduce time and cost, this advantage has limited influence on the consultant. The complexity of OSC projects enhances the difficulty for consultants to realise the benefits of OSC.

For a contractor, the most significant risk comes from 'cost'. Pan et al. (2007) carried out combined phone interviews and questionnaires to identify the major risks for off-site contractors. The main risk was found to be 'high capital cost' as, compared with traditional construction, OSC requires longer lead-in times, costing more during the preparation process (Mao et al., 2016). This view of high off-site costs is supported by Hong et al. (2018), who suggested that the provision of financial support should be considered when implementing OSC.

In a review of manufacturers, L. Zhang et al. (2020) showed that the off-site manufacturing process risk could be divided into 77 different factors. These factors include several that differ from other OSC process risks, including 'high component model fees' and 'rigid prefabricated rate requirements'. This research considered 'design error' to be the most dominant risk within the off-site manufacturing process. These risks influenced at least one off-site manufacturing project's QCD.

Although some articles present the risks of the off-site manufacturing process, the relative importance of each risk still needs to be examined. Considering the whole life cycle of OSC, the manufacturing process requires more attention as it provides the production function for OSC. Risk analysis for the off-site manufacturing process is necessary to help manufacturers understand which risks need to be urgently solved and which could be ignored. Therefore, conducting a study focused specifically on a mathematical method for considering an off-site manufacturing process risk analysis is worthwhile.

Chapter 3.12 presented the risk management method that is generally used in OSC projects. Table 4.6 presents the articles cited in relation to OSC projects.

Table 4.6: Risk management methods employed in OSC projects

RISK MANAGEMENT METHOD	LITERATURE	AIM OF LITERATURE
Risk identification method		
Brainstorm		
Interview	(Ahn et al., 2020)	OSC health and safety risk identification.
Checklist	(Wuni and Shen, 2019)	OSC supply chain risk identification.
SWIFT		
Scenario analysis	(Mostafa et al., 2016)	OSC system analysis, supply chain improvement.
FTA	(Hsu et al., 2017)	Delay factor of OSC project.
Bow tie analysis		
Direct observations	(Xue et al., 2018a, 2018b)	OSC collaborative management for cost performance
Risk assessment method		
Brainstorm		
Interview	(Ahn et al., 2020)	OSC health and safety risk identification.
Expert elicitation		
Delphi method	(Arashpour et al., 2017)	OSC uncertainty integrated management.
SWOT analysis	(Jiang et al., 2018)	OSC method promotion in China
P-I	(Wu et al., 2019)	OSC integrated design & construction project delivery risk identification.
SWIFT		
FTA	(Hsu et al., 2017)	Delay factors in OSC projects.
Questionnaire	(Hashemi, 2015)	OSC risk assessment in Iran.
AHP	(H. X. Li et al., 2013)	OSC risk identification and assessment.
DSS	(Pan, 2006)	Optimising OSC project process.
FMEA		
BBN	(Yu et al., 2019)	The influence of stakeholders in OSC quality risk.
Markov chain analysis		
Risk analysis method		
P-I	(Wu et al., 2019)	OSC integrated design &

		construction project delivery risk identification.
Project assumption testing		
Data precision ranking		
Risk categorisation		
Risk urgency assessment		
Expert judgement	(McKay, 2010)	OSC influence on health and safety.
Sensitivity analysis		OSC optimisation for time schedule.
Decision tree	(Arashpour et al., 2018)	Optimal process integration architectures design for OSC project.
Monte Carlo simulation	(Rausch et al., 2019)	Tolerance analysis for OSC project.
Influence diagrams	(L. Zhang et al., 2020)	Risk assessment and analysis for OSC project.
Criticality analysis		
Risk response method		
Avoidance	(Pan and Goodier, 2011; Rausch et al., 2017; Wang et al., 2018)	Risk response for OSC project.
Transfer		
Retention		
Reduction		

Table 4.6 presents those risk management methods used for OSC, explaining how the current OSC project has established several risk management methods to manage OSC risk. As OSM is a part of the OSC process, the risk management method deployed in an OSC project may become a solution by which to solve OSM risks. However, it seems that the OSM process had been ignored in the previous article. Thus, as a result, risk and risk management for OSM processes have suffered from insufficient research.

In order to fill the gap, this research focuses on the use of current risk management methods for OSM processes to identify and respond to risk and develop a risk management framework for OSM processes within OSC projects.

4.7 Chapter summary

For risk management, the method of the process must first be identified, as it has been proven that such a method could help to manage project risk more effectively. This research has tried to combine a variety of methods for OSM risk management. To this end, this research selected a specific method as detailed in Table 4.7.

Table 4.7: The risk management methods employed in this research

RISK MANAGEMENT PROCESS	RISK MANAGEMENT METHOD
Risk identification	Interview
Risk assessment	Interview, Questionnaire
Risk analysis	Influence diagram
Risk response	Avoidance, Transfer, Retention, Reduction

This research combined attempted to merge the methods of each risk management process and thereby create a risk management framework. In that case, the reason to choose each risk management method is presented:

1. Risk identification: interview is chosen for this process. As OSC project requires all parties to participate, it is necessary to understand the risk from different angles such as owner, consultant or contractor. Interview could get data from different angles, which is the most suitable method for risk identification.
2. Risk assessment: interview and questionnaire are chosen for this process. As the risk group and risk type should be divided in this process, it is necessary to get the detail for risk factor from more OSC practitioners. Questionnaire is a method to collect data from a large amount of people. Combining interview and questionnaire method, these methods could specify the groups and types of each risk factor.
3. Risk analysis: influence diagram is chosen for this process. How risk factor influence QCD in OSC project is concerned in this process. Influence diagram could provide a visible diagram for the relationship between risk factor and QCD, which could be used for risk analysis process.
4. Risk response: avoidance, transfer, retention, and reduction are chosen for this process. As all risk factors should have at least one risk response method, these methods could cover most situation in risk management process.

This chapter showed the specific features of the OSC process as compared to traditional construction processes. By breaking down the OSC project into the constituent phases which the OSM process (found in every OSC project) must first pass through during its realisation, it becomes clear that the risk implicit within the OSM process needs significant consideration as it may cause a negative impact upon cost, time and quality.

CHAPTER 5 - METHODOLOGY

5.1 Introduction

This chapter explains the research design and provides a methodological comparison between different approaches. It presents a general review of research methodologies and considers a methodology suitable for this research. It also presents the rationale for the selection of the methodology used in this research. In order to achieve the aims and objectives, a mixed methodology was selected for this research. Semi-structured interviews were employed for qualitative research and questionnaire for the quantitative aspect of the study.

5.2 Research Concept

5.2.1 Fundamental concepts

Research philosophy serves to explain the underlying theory of various research approaches (Maylor et al., 2016). Easterby-Smith et al. (2012) defined three benefits that an understanding of philosophical issues imparts:

1. It helps to clarify research designs, and clarify what kind of evidence is required for the research.
2. It helps to point out the limitation of approach, and identify which design is suitable for the research.
3. It helps to identify or create a new design for the research.

To define the philosophy behind the design of this research, epistemology, ontology, methodology and axiology are explained. Four sets of assumptions are defined by Creswell et al. (2017) in terms of the pursuit of acquisition of knowledge:

1. What values go into it (epistemology)?
2. How do we know that it is true (ontology)?
3. How do we write about it (axiology)?
4. How do we study it (methodology)?

5.2.2 Epistemological position

Epistemology is a description of how an individual’s cognition becomes stable (Keeney, 2017). Baron (2019) used epistemology to refer to the nature of the observer’s knowledge. It is held that epistemology can be conceptualised in one of two ways (Hofer, 2001):

1. As a systematic progression in the development of one’s ideas about knowledge and knowing.
2. Personal epistemology is a system of more-or-less independent beliefs.

Bryman (2016) explained epistemology as concerning the question of what is regarded as acceptable knowledge in a discipline. One central issue in this context is the question of whether the social world can and should be studied according to the same principles, procedures, and ethos as the natural sciences. The position that affirms the importance of imitating the natural sciences is invariably associated with an epistemological position known as positivism. MacIntyre (2013) believed that one’s worldview influences the interpretation and understanding of new information. Epistemology and worldview are, therefore, subjects that are closely linked in representing how one comes to know and the combined framework of one's individual knowledge.

There are many epistemological branches, including essentialism, historical perspective, perennialism, progressivism, empiricism, idealism, rationalism, constructivism, and pragmatism, etc. For example, pragmatism chooses either or both observable phenomena and subjective meanings can provide acceptable knowledge which is dependent upon the research question and its focus on practical applied research, integrating different perspectives to help interpret the data (Saunders et al., 2009). Realism chooses observable phenomena to provide credible data and instead focuses on explaining within a context or contexts (Saunders et al., 2009).

The two major types of epistemological branches are positivism and interpretivism (Eldabi et al., 2001). Positivism is a method which considers that the world is constructed by concrete and external processes and thus the resulting world reflects an objective, independent reality, and this reality provides the foundation for human knowledge (Weber, 2004). Hence positivistic research uses quantitative methods for data collection and analysis (Hovorka et al., 2010). Interpretivism is a method which considers the world to be based on culture, experience, history, and so forth. This knowledge of this world is thus built through social construction (Weber, 2004). In this case, human behaviour and feelings should be considered and monitored through this method (Rivas, 2010).

The principal data for this research was collected from Chinese OSC practitioners, which means that it is based on their feelings and experiences. Further, the site observations, expert views, and literature review were also necessary for this research, which requires it to be explained from a personal standpoint. Also, the initial primary data for this research was generated from interviews, all of which followed research data (e.g. questionnaire, case study) that was developed based on the outcomes of the interviews. The differences arise between people and OSC organisations should be identifiable in the data analysis process. Thus, this research is mainly based on interpretivism.

5.2.3 Ontological position

Ontology stems from the Greek word 'onto' meaning being and 'logos' for word. It was developed by 19^{th} Century German philosophers to distinguish various kinds of beings within the natural sciences (Sowa, 2001). Bunge (1977) defined ontology as a method through which the world can be organised in an orderly fashion. Heidegger (2008) alternatively defined ontology as interpreting the factual world.

There are many ontological branches, including realism, idealism, materialism, objectivism and subjectivism. For example, realism contends that there is an external reality that is independent of what people may think or understand it to be, whereas, idealism maintains that reality can only be understood via the human mind and socially constructed meanings. Similar to realism, materialism also claims that there is a real world, but only the material or physical world is considered to be real (Snape et al., 2003).

The two major types of ontological branches are objectivism and subjectivism (Hamati-Ataya et al., 2014). Subjectivism contends that reality is based on the observer's perspective, which means that our perceptions about the world are inextricably bound to our stream of experiences (Weber, 2004). Objectivism argues that reality is separate from the individual who observes it, and thus it cannot change between observers. Positivistic ontology is therefore argued to be dualistic in nature (Weber, 2004).

This research aims to develop an OSM risk management framework for the Chinese OSC industry. This requires that the research be focused on feedback from current OSC practitioners which is, in turn, related to the experience of those practitioners. It also requires us to observe the current practices and actions from such projects. As the research attempt to choose interview for data collection method, it requires observing the current practices such as awareness and people's perception of OSM risk. This means that this research primarily obtains data from a subjectivistic perspective.

5.2.4 Axiological position

Biddle et al. (2015) defined axiology as the nature of ethics and its values. Houston (2014) defined axiology (for scientific investigation) as being neutral and value-free. Axiology is an objective format for the measurement of intangible values and attitudes, it focuses on measuring the level of development, it also considers the type of perceptual bias arising within thought (Brown et al., 2007).

There are many axiological branches including positivism, realism, interpretivism, and pragmatism. Positivism means that the research is undertaken in a value-free way in which the researcher is independent of the data and maintains an objective stance. Realism means that the research is value-laden, in that the researcher introduces bias based on their world views, cultural experiences and upbringing. Interpretivism means research is value bound, in that the researcher is part of what is being researched and thus cannot be separated and so will be subjective. Pragmatism means that values play a large role in interpreting the results, given that the researcher adopts both objective and subjective points of view (Saunders et al., 2009).

5.2.5 Methodological position

Methodology explains the what, when, where, why, to whom, and how of the data collection process (Collis et al., 2013). Therefore, this research methodology needs to solve (Leedy et al., 2014):

1. What data are needed?
2. When the data are collected?
3. Where the data are located?
4. Why the data should be collected?
5. From whom to collect data?
6. How data is obtained and analysed?

The methodological approach determines the primary focus of the research (Pathirage et al., 2008). The research approach is an interconnection of processes at a conceptual and empirical level (Maylor et al., 2016). To ensure that the data collection methods can solve the problem of the research question, the research approach itself should concern the data collection process. Three types of research design are commonly presented (Trochim et al., 2008):

1. True experiment.
2. Quasi-experiment.
3. Non-experiment.

The types of research design are chosen according to the features of the research in relation to the research aim, type of participant, or personal experiences of the researcher. There are many methodological branches, namely deductive (deduction), inductive (induction), abductive, analogical, cause-and-effect, critical thinking and metaphoric inference. For example, abduction uses an observation or set of observations to reach a logical conclusion, and this permits making the best guesses to arrive at the simplest possible conclusions (Walton, 2014). Analogical thinking finds similarities between two or more things and then uses these characteristics to find other qualities common to both (Gentner et al., 2012).

Generally, the two major types of methodological branches are deduction and induction.

Deduction entails moving from the general towards the particular, whereas induction entails moving from the particular to the general. Deduction considers the theories and derived hypotheses, and then tests those hypotheses. Induction observes a phenomenon of interest and then considers theories based on the analysis of the phenomenon (Locke, 2007). Aristotle considered that induction was necessary to develop valid theories but also that deduction was needed to test and further refine those theories (Harriman, 2010). In this case, induction and deduction are viewed as complementary. There are five consecutive stages of deductive research (Saunders et al., 2009):

1. Deduce the hypothesis from the theory.
2. Articulate the hypothesis in functioning stipulations which recommend an association between the concept and variable.
3. Test the functioning hypothesis.
4. Examine the precise result of the investigation.
5. If needed, adjust the theory to correspond to the findings.

The characteristic of deduction is that it requires the evidence to be quantified and statistically generalised in line with human social behaviour. This means that the sample size of the data collection should be considered (Saunders et al., 2009). The feature of induction is that it requires the background of the event to be considered in detail. This results in focus on a small sample of subjects in the induction process (Saunders et al., 2009).

The deductive approach is deployed in this research, as it focuses on developing an OSM risk management framework. In accordance the approach of this research includes four steps:

1. Reviewing the current literature and OSC practices in China with a view to understanding the current situation by means of an analysis of primary and secondary data.
2. Developing an OSM risk management preliminary framework via data analysis from the previous step.
3. Testing and validating the preliminary framework.
4. Refining and documenting the final OSM risk management framework.

Based on the philosophy identification, the research concept is concluded below. This research takes the stance of interpretivism for epistemology, subjectivistic perspective for ontology, deductive approach for methodology. Interpretivism and subjectivistic perspective results the research needs to collect data from Chinese OSC practitioners. The deductive approach requires to analyse data by quantify and statistically generalised the OSC practitioners' behaviour. In order to collect and analyse the data, interview and questionnaire are deployed in this research. In that case, mixed method is selected as the research method.

5.3 Research methods

In considering the research methods, qualitative, quantitative and mixed methods were contemplated.

5.3.1 Qualitative method

Qualitative methods have been defined by many articles:

1. Qualitative method is the application of observational techniques and/or the analysis of documents as the principal means of learning individuals or groups. Sometimes qualitative research is referred to as fieldwork, referring to the immersion of researchers in the life and world of those being studied (Hagan, 1997).
2. Qualitative method, as a field of inquiry in its own right, cuts across disciplines, fields, and subject matter. Qualitative researchers study things in

their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them (Falconer et al., 1999).

3. The phrase qualitative method refers in the broadest sense to research that produces descriptive data – people's own written and spoken words and observable behaviour (Taylor et al., 2015).
4. A qualitative method collects open and emerging data primarily to develop themes based on the data (Creswell et al., 2017).

From the definitions presented above, a qualitative method may fall into one of two domains (Maruna, 2010):

1. Data collection techniques which include engagement, textual analysis and open-ended interviews.
2. Involving the discovery of patterns in textual and linguistic data collected, often with phenomenological purposes.

The advantages of a qualitative methodology include:

1. Flexible and responsive interactions between the interviewer and respondents (Sykes, 1990).
2. Useful when one needs to supplement, validate, explain, illuminate, or reinterpret quantitative data gathered from the same setting (Maruna, 2010).

However, the qualitative method also has several disadvantages. It always relies on the interview as a principal means of methodology and, as a result, the data may lack diversity (Williamson, 2006). Another problem is that the size of samples is limited in qualitative methodologies, which will cause the research findings to lack universality (Castro et al., 2010).

5.3.2 Quantitative method

Quantitative methods have also been defined by many articles:

1. Quantitative method is the application of statistical procedures and techniques to data collected through surveys, including interviews and questionnaire administration (Hagan, 1997).

2. In quantitative method, concepts are assigned a numerical value. This empirical orientation suggests that the same approach applicable to studying and explaining physical reality can be used in the social sciences (Hagan, 1997).
3. Quantitative method refers to counts and measures of things (Lune et al., 2017)
4. A quantitative method is one in which the investigator primarily uses postpositivist claims for developing knowledge (i.e., cause and effect thinking, reduction to specific variables and hypotheses and questions, use of measurement and observation, and the test of theories), employs strategies of inquiry such as experiments and surveys, and collects data on predetermined instruments that yield statistical data (Creswell et al., 2017).

From the definition offered above, a qualitative methodology can be defined as having two dimensions, as follows (Maruna, 2010):

1. Data collection from surveys or quantitative records.
2. Analysis involving some kind of statistical analysis to test hypotheses in a manner similar to the physical sciences.

The advantages of quantitative methods include (Amaratunga et al., 2002):

1. Comparison and replication are allowable.
2. Independence of the observer from the subject being observed.
3. Subject under analysis is measured through objective methods rather than being inferred subjectively through sensation, reflection or intuition.
4. Reliability and validity may be determined more objectively than qualitative techniques.
5. Emphasises the need to formulate hypothesis for subsequent verification.
6. Helps to search for causal explanations and fundamental laws, and generally reduces the whole to the simplest possible elements in order to facilitate analysis.

However, the disadvantages of quantitative research include that it may not concern social or cultural aspects of the organisations (Myers, 2019). Another disadvantage is that it only measures variables at a specific moment in time, wherein the variables may change in the future (Amaratunga et al., 2002).

5.3.3 Mixed methods

Comparing qualitative and quantitative methods, qualitative research is exploratory and better for new or unexpected research and can provide better illustration than quantitative methods. However, the quantitative method is more replicable, precise, and generalisable than qualitative research, as it generally focuses on mathematical data. The statistical techniques used in quantitative methodology could reduce the influence of participants' subjective opinion or bias (Maruna, 2010).

Mixed methods research, variously called multi-method research, mixed model research, or mixed methodology, combines the advantages of both qualitative and quantitative methods to increase the breadth and depth of understanding (Johnson et al., 2007).

Rossman et al. (1994) presented reasons to link qualitative and quantitative data:

1. To enable confirmation or corroboration of one another via triangulation.
2. To elaborate or develop analysis, providing richer details.
3. To initiate new lines of thinking through attention to surprises or paradoxes, thereby 'turning ideas around' and providing fresh insights.

The fundamental principle of mixed methods research should be its complementary strengths and non-overlapping weaknesses (Johnson et al., 2003).

Mixed methods are appropriate in the following situations (Greene et al., 1989):

1. When researchers would like to converge different methods or use one method to corroborate the findings of another about a single phenomenon.
2. When researchers would like to use one method to elaborate, illustrate, enhance, or clarify the results from another method.
3. When researchers would like to use results from one method to inform another method, such as in creating a measure.

4. When researchers would like to use one method to discover paradoxes and contradictions in findings from another method that can suggest reframing research questions.
5. When researchers seek to expand the breadth and depth of the study by using different methods for different research components.

For mixed methods, although they combine the feature of qualitative and quantitative methods, the proportion of each method still should be considered. Morse (2016) presented eight mixed methods modes:

1. Inductive-simultaneous design, the core component is qualitative, and the supplemental component is quantitative.
2. Inductive-sequential design, the core component is qualitative, and the supplemental component is quantitative.
3. Deductive-simultaneous design, the core component is quantitative, and the supplemental component is qualitative.
4. Deductive-sequential design, the core component is quantitative, and the supplemental component is qualitative.
5. Inductive-simultaneous design, both components are qualitative.
6. Inductive-sequential design, both components are qualitative.
7. Deductive-simultaneous design, both components are quantitative.
8. Deductive-sequential design, both components are quantitative.

Another mixed methods process definition was developed by Teddlie et al. (2009):

1. Parallel mixed designs: The quantitative and qualitative methods start at same time with parallel strands. The strand results are integrated into meta-inferences after separate analyses are conducted. The quantitative and qualitative results are used to answer the same research question.
2. Sequential mixed designs: The quantitative and qualitative strands start chronological phases, with start for the later strand depending on the previous

strand. The research questions are interrelated and sometimes evolve during the study.

3. Conversion mixed designs: Transfer of one type of data to another type for subsequent analysis. The additional findings are then added to the results. The quantitative and qualitative results seek to answer the same research question.
4. Multilevel mixed designs: Combined parallel mixed designs and sequential mixed designs to answer the same question.
5. Fully integrated mixed designs: In these designs, mixing occurs in an interactive manner at all stages of the study. At each stage, one approach affects the formulation of the other, and multiple types of implementation processes can occur.

As mentioned above, mixed methods combine the advantages of both quantitative and qualitative methods. Many articles used mixed methods for construction risk management or OSC projects (Arabiat, 2013; Mehdizadeh, 2012; Odimabo, 2016). Mixed methods have proven useful, particularly in construction research. For this research, mixed methods are used.

Deductive-sequential design is used in this research. This research aims to develop an OSM risk management framework, which requires to define the significant risk factor for OSM process. The order of research method is qualitative then quantitative. First interview is used as qualitative method, which is the supplemental component for the research. The interview aims to define the risk factor for OSM process. Second, questionnaire is used as quantitative method, which is the core component for the research. The questionnaire aims to define the significant risk factor for the OSM process.

5.4 Research process

5.4.1 Sampling method

For both the interview and the questionnaires, the snowball sampling method was used in this research. Snowball sampling is defined as collecting a sample from a population in which a standard sampling approach is otherwise either impossible or prohibitively expensive, for the purpose of studying those characteristics of individuals within the population (Handcock et al., 2011). Snowball sampling is deemed suitable when the research subjects are difficult to access. Although snowball sampling may introduce bias because the sampling units are not independent and projecting data beyond the sample is not justified, it is nonetheless useful in specific circumstances and for locating rare populations (Acharya et al., 2013). The process of snowball sampling asks current subjects to recruit future subjects until data saturation is achieved (Grove et al., 2012). Snowball sampling is an alternative method when random sampling is otherwise not possible (Cohen et al., 2005). The advantage of snowball sampling is that it takes less time and provides the opportunity to communicate better with future subjects (Polit et al., 1994). In this research, the participant comes from OSC practitioners, which is a specific group in the construction industry, and this group has a relatively close internal relationship. For example, every Chinese province has OSC association, only OSC practitioners can join the association. This means OSC practitioners meet the requirement of snowball sampling subjects: rare populations and difficult to access. In that case, compared with random sampling, the snowball sampling method could get access with OSC practitioners in easier way.

OSC practitioners were invited to participate in this research. As mentioned in the literature review, OSC is a new construction method in China which results in the population of OSC practitioners being relatively low in China. This means that snowball sampling would be a suitable method for the data collection process.

The first-tier participants included the off-site owner, consultant, manufacturer, transporter, and contractor on the Chinese mainland. Then the chain method was used to ask the first-tier participants to invite more OSC industry participants and, as the second-tier participants have existing links to the first-tier participants, it also links them to the researcher (Naderifar et al., 2017).

5.4.2 Ethical approval

Ethical approval should be concerned with reducing the ethical issues during the data collection process. The USA presented suitable criteria for approval of research by an institutional review board (Kanter, 2009):

1. How are the risks to human participants minimised?
2. Why are the risks reasonable in relation to the anticipated benefits?
3. How is the selection of participants equitable?
4. Are adequate procedures in place to ensure the privacy and confidentiality of participants?
5. Is the plan used to monitor the data and safety of the participants?
6. How is informed consent sought and documented?
7. If applicable, what safeguards are used to protect vulnerable populations?
8. Other relevant information.

In the UK's research ethics application process, the questions listed below should be answered to avoid ethical pitfalls (Smajdor et al., 2009):

1. Is the research likely to provide useful new information? Is it investigating an area in which there is a compelling need for further research?
2. Is the design of the study adequate to fulfil what it sets out to establish?
3. Are patients likely to be harmed physically or psychologically as a result of participating? Are the potential harms proportionate to the likely benefits of the study? Have all possible means of reducing risk been explored?
4. Does the study involve children, prisoners, or those who lack the capacity to make informed decisions? If so, is their inclusion justified?
5. How are potential participants being identified? Is there a risk of coercion?
6. Are adequate procedures in place for gaining consent?
7. Is clear, comprehensible, and honest information provided?
8. Who will be accessing records or data? Will it be anonymised? Where will it be kept?

9. Participants have a stake in the research. What arrangements have been made for reporting findings back to them? (Participants are unlikely to have access to medical journals in which studies are published, and such studies are unlikely to be readily understood by them.)
10. How long will tissue samples or patient data be kept? Will it be used in future research?

In order to protect the privacy of the participants, ethical approval is sought for both semi-structured interviews and the questionnaire process. To keep the participants anonymous, all necessary steps were taken to protect the process. Ethical clearance was granted for this research in advance of any data collection to ensure strict compliance with data management requirements and procedures.

During the interview process, a consent form (see Appendix 1) was designed and distributed to interviewees. All interviewees read and signed the consent form by understanding that their data would be anonymised and only used for the purposes of this research.

For the questionnaire process, a participant information sheet (see Appendix 2) was put in front of the questionnaire for download purposes and any participant could download the sheet and contact the researcher. The participant could leave the questionnaire survey at any time.

5.5 Qualitative research: interviews

5.5.1 Interview context

In this part, the interview was developed and proceeded for collection of the qualitative data. This part contributed to the achievement of the purpose which was to understand the risks in the OSM process. To achieve this, the steps were:

1. To provide the background of OSC.
2. To identify participants for interview.
3. To understand the activities and risks involved.

5.5.2 Interview preparation

It is necessary to prepare for interviews as this could help to streamline the process and alleviate problematic circumstances that could potentially arise once the research is implemented (Turner III, 2010). For interview preparation, there were eight prerequisite principles (Turner III, 2010):

1. Choose a setting with little distraction.
2. Explain the purpose of the interview.
3. Address terms of confidentiality.
4. Explain the format of the interview.
5. Indicate how long the interview usually takes.
6. Tell the interviewee how to get in touch with the researcher later.
7. Ask the interviewee if there are any questions before getting started with the interview.
8. Don't count on the researcher’s memory to recall the interviewees’ answers.

To this end, a pilot study was developed. A pilot study assists the research by determining the possibility of flaws, limitations, or other weaknesses within the interview design, enabling the researcher to make necessary revisions prior to the implementation of the study (Brinkmann et al., 2018).

Effective research questions could serve to reduce time wastage and help to focus on the research objectives. Turner III (2010) explained what a good interview question requires:

1. Wording should be open-ended.
2. Questions should be as neutral as possible.
3. Questions should be asked one at a time.
4. Questions should be worded clearly.
5. Be careful asking ‘why’ questions.

The questions for the pilot study were based on the literature review and are presented in Appendix 3.

In order to determine the questions for the interview, 15 people from academia and industry were asked to identify whether the interview questions were suitable for interview. This pilot study was completed during the period from March 2019 to April 2019, and the initial contact was through email. Four instances of feedback were given, representing a response rate of 26.7%. The feedback received is detailed in Table 5.1.

Table 5.1: Pilot interviews - participant feedback

NAME	INSTITUTION	ROLE	SUGGESTION
TP1	University	Professor	● It would be better to cover focus on general contractors, not only suppliers. ● 'Could you please define the process of [the] off-site manufacture phase?' This question could be presented as background knowledge rather than as a question. ● Details of interview expect hypothesis and objectives are also necessary.
TP2	University	Senior lecturer	● Not only the title, but also the sub-title should contain numbers, which could help the interviewee to understand the process of the questions. ● Several questions are not clear enough. This should be presented in more detail to help the interviewee to understand. ● It would be better to divide the risk management process and to use risk management process to design the questions.
TP3	Off-site manufacturer	Chairman	● As risk is a very wide ranging area, more detail could be presented to introduce which kind of risk you want to address. ● Several examples of risk could be provided to give the interviewee a hint.
TP4	Off-site contractor	Chairman	● This participant misunderstood the request and gave the interview answers directly.

Three of the four instances of feedback were valid and offered various advice. All advice was evaluated and incorporated within the interview questions. Based on the pilot study, the second version of the interview questions is presented in Appendix 4.

5.5.3 Interview process

Creswell et al. (2017) discussed the importance of selecting appropriate participants for interviews. An appropriate participant could provide the most credible information for the research. It is also important to conduct the interviews in a comfortable environment, as the participants could share more information in an environment without restrictions.

In order to collect data, a series of semi-structured interviews with selected practitioners was conducted. These practitioners derived from four different areas, namely Yichang, Wuhan, Beijing, and Foshan. The main reason for interviewing practitioners from different areas was that China is a relatively large landmass, leading to considerable diversity in the location of OSM (Wang et al., 2013). Ji et al. (2017) introduced a ranking for Chinese OSC across different provinces and indicated that east China and central China had developed large-scale construction industrialisation. The disparity in OSM between different provinces, however, is significant. Therefore, interviewees' locations should be taken into consideration, as they may lead to a different emphasis on risks. The gross domestic product (GDP) *per capita* in Beijing (north of China), Hubei (middle of China), and Guangzhou (south of China) are relatively high (IMF, 2019). Beijing is ranked 12th in China and ranked 2nd in the north of China in terms of its GDP. Hubei is ranked 8th in China and 3rd in central China. Guangzhou GDP is currently ranked 1st in China (NBS, 2021). For the total output value of construction in China, Beijing is ranked 9th (1.19 billion RMB); Hubei is ranked 3rd (1.69 billion RMB), and Guangdong 4th (1.66 billion RMB) (CCIA, 2021). These three places also are identified as being priority areas for the promotion of OSC (SCGO, 2016). In this case, these places were selected for the interview location. The top three OSC companies for each province were selected and prioritised as the main off-site manufactories.

The interviewees included not only manufacturer, but also a consultant, a contractor, and EPC (Engineering, Procurement, Construction) company. The reason for this is that OSC features relationships between clients, designers, developers, contractors, manufacturers and suppliers which are long term and necessarily amalgamated (Zhai et al., 2014).

5.5.4 Sampling method

As the amount of information obtainable from qualitative research do not necessarily increase because more data is obtained, the size of this research sample was determined by ‘saturation’ in terms of interviews (Mason, 2010). For example, Charmaz (2006) suggested that 25 participants are adequate for smaller projects. Ritchie et al. (2013) identified that qualitative samples under 50 were misleading. Green et al. (2018) explained that it was unnecessary to interview more than 20 participants.

From other articles within similar research areas, the number of interviewees is typically around 10-40. For example, Yu et al. (2019) interviewed 12 managers (or engineers) to establish the structure of the Bayesian network and evaluate the probabilities of the node states for evaluating different stakeholder impacts on the occurrence of quality defects. Venables et al. (2004) interviewed 27 key participants in both manufacturing and housing development, suggested that the uptake of OSC is influenced by the perceptions of developers and by wider market and regulatory factors. Love et al. (2011) interviewed 29 construction practitioners from 8 civil infrastructure projects, revealing that a risk/reward model can influence stakeholders' behaviour. Li et al. (2017) conducted interviews with 10 experts to understand current practices, challenges, and opportunities of piping prefabrication.

Snowball sampling is often used for interview sample definition. In order to qualify for the interview, all respondents were required to be active OSC industry practitioners. The top five respondents were contacted via e-mail or phone, and then further respondents were introduced by the top five. After these participants provided more respondents within similar organisations, and these participants had given referrals (though not all were from the same type of organisation), the total number of respondents was 30. All interviewees had experience in OSC projects. However, some interviewees were not willing to be recorded and 5 of the instances of interviewee feedback were not valid. The interviewees are marked from P1 to P25 for the benefit of further study (see Table 5.2).

Table 5.2: Participants' personal details for the interview

NUMBER	PLACE	COMPANY ROLE	POSITION	EXPERIENCE (YEARS)	DATE
P1	Yichang, Hubei province	Manufacturer	Engineer manager	14	09/05/2019
P2			Factory director	18	09/05/2019
P3		Contractor	Project manager	13	10/05/2019
P4			Technical director	11	10/05/2019
P5			Chief engineer	4	10/05/2019
P6	Wuhan, Hubei province	EPC	Vice general manager	12	16/05/2019
P7			General manager	23	16/05/2019
P8			Chief engineer	32	16/05/2019
P9			Structural designer	6	16/05/2019
P10			Vice general manager	3	16/05/2019
P11		Consultant	Vice chief engineer	19	17/05/2019
P12		Manufacturer	Production manager	5	18/05/2019
P13			Chief engineer	10	20/05/2019
P14		Manufacturer	Chief engineer	5	21/05/2019
P15			Factory manager	7	21/05/2019
P16			Production manager	6	21/05/2019
P17	Beijing	Manufacturer	Chief engineer	6	03/06/2019
P18		Manufacturer	Technical director	20	04/06/2019
P19	Foshan, Guangdong province	Manufacturer	General manager	6	11/06/2019
P20		Manufacturer	Assistant general manager	3	11/06/2019
P21			Material manager	2	11/06/2019
P22			General manager	19	12/06/2019
P23			Vice technology minister	6	12/06/2019
P24			Production manager	2	13/06/2019
P25			Outsourcing manager	20	13/06/2019

The interviews were conducted individually at a face-to-face level. To further encourage commitment, interviews were carried out at those venues most convenient to the respondents, and all interviews were conducted in interviewees' offices as the time could be set in accordance with their convenience. All interviewees had experience with OSC, and all were working on at least one off-site project during the interview process, which increased the likelihood that interviewees had a clear understanding of OSC and its risks. In order to avoid bias, interviewees from multiple sources were contacted and not only managers at different levels from the same company, but also at the same level across different companies (including entrepreneurial companies, multinationals, state-owned and private companies) were interviewed. In order to contact more interviewees, the snowball sampling method was employed by the researcher. The chief managers of the company were first contacted and then their company colleagues, and so on. To avoid ethical issues, all interviewees agreed to sign an ethical consent form which informed them that their name and that of their company would not be revealed and reassured them that the interview could be terminated at any time.

As Mandarin is the mother-tongue language in China and English is not widely spoken, it was more comfortable for the interviewees to speak Chinese. As there are many dialects in China, some interviewees preferred certain dialects for their responses. Many participants do not know how to speak English which would become a significant barrier if the researcher only chose participants who understood English. The interviewees were permitted to choose any kind of language.

Creswell et al. (2017) introduced the notion that respondents in an interview will not necessarily answer the question being asked by the researcher and, in fact, many answers a question that is asked in another question later in the interview. Sometimes the interviewees may misunderstand the question or else do not wish to answer the questions directly. In order to solve this problem, some questions may be reconstructed during the interview process to reduce this problem.

The interviews were typically 60 to 90 minutes in length. They began with background information and then interviewees were asked open-ended questions in six sections. Examples of questions included: ‘Could you please define the risk for each phase of the OSM process?’, ‘Is there a specific person on this project in charge of risk management?’, ‘Do you have any suggestions for the current risk management process?’ Interviews were conducted between 27/04/2019 and 13/06/2019.

During the interviews, details of this study, the ethical approval form, and the purpose of the interview were presented and explained to the interviewees. After the interviewees had understood and agreed to participate, interviewees were asked to answer the interview questions, although other opinions and points of view were welcome.

All interviews were recorded and transcribed. The transcriptions totalled 109 single-space pages in Chinese. After the transcription was finished, the transcription was successfully delivered to 24 interviewees to get approval and further feedback, this activity was conducted from 29/09/2019 to 02/10/2019. Some further advice and detail were given by interviewees during this time as they had an opportunity to respond to the feedback and to clarify any understandings of the research objectives. The interview recordings were then transcribed, their meanings were extracted, translated into English and then presented.

All interview data were processed through NVivo, a qualitative data analysis software that simplifies a significant number of manual tasks and gives the researcher more time to discover underlying trends, recognise themes and derive conclusions (Wong, 2008). NVivo is widely used in qualitative data analysis, and its value has been proven by many articles (Chileshe et al., 2016; Sepasgozar et al., 2018). It creates an environment for the researcher to use notes to indicate that a particular passage belongs to a certain theme or topic in the interview. Code created in NVivo involves the desegregation of textual data into segments, examining data similarities and differences, and grouping them together conceptually as similar data in their respective nodes (Wong, 2008).

5.5.5 Data analysis process

The purpose of the interview was to find out and categorisation the risk from OSM. The interviewees' ideas should be transferred into sections or groups of information, also known as themes or codes (Creswell et al., 2017). In order to achieve our purpose, the data analysis for this research followed a linear path involving three steps:

NVivo codes and notes were defined based on categories/themes identified from literature review. Zhang et al. (2017) identified three nodes in OSC, namely internal, project, and external. Internal is further divided into four nodes, specifically resource risk, project member risk, construction site risk, and document/information risk. The project was then sub-divided into four nodes of time, cost, construction, and technological risk. External risk was divided into four risk nodes, namely political, economic, social, and weather.

The interview result was then transferred to NVivo by node and code. All feedback transcripts were read by the researcher to identify whether extra code was needed. As each interview result was read, some nodes and codes were identified and retroactively created or erased. Table 5.3 presents a node diagram for interview feedback. In this research, interview feedback was divided into three nodes, specifically project member, project process, and external. The Project Member node was divided into five codes, namely owner, consultant, manufacturer, transporter, and contractor. The Project Process node was divided into four codes: cost, time, feature of project, and project management. The external node was divided into four codes, specifically environment, resource, policy, and society. After the nodes and codes were identified, an NVivo analysis was developed, going through all the feedback for each transcript.

Table 5.3: A node diagram for interview feedback

NODE	CODE
Project member	Owner
	Consultant
	Manufacturer

	Transporter
	Contractor
Project process	Cost
	Time
	Feature of project
	Project management
External	Environment
	Resource
	Policy
	Society

Third, some interviewees had contradictory or unusual feedback in the judgement of the researcher. Such feedback is related mainly to the external node, especially the social and political codes. This feedback is presented and explained in the following section.

5.6 Quantitative research: questionnaire

5.6.1 Questionnaire context

In this part, the questionnaire is developed and processed for the purposes of quantitative data collection. This part contributes to the achievement of the purpose to define and rank the risks inherent within the OSM process. To achieve this, the steps are:

1. To develop a suitable questionnaire through interview.
2. To identify the impact and possibility of each risk.
3. To rank each risk of the OSM process.

5.6.2 Quantitative data types

Generally, there are four types of quantitative data. Different types of data have different meanings in the research (Maylor et al., 2016):

1. Nominal data: Any number assigned to a nominal variable is arbitrary, rather than essential of that variable. Many qualitative variables are converted to nominal values in scientific research.
2. Ordinal data: Items on an ordinal scale are set into some kind of order by their position on the scale. This may indicate such as temporal position, superiority,

etc. Ordinal measures are often associated with attitude measures, such as the familiar ranked-order responses known as a Likert-type scale.

3. Interval data: Interval data is measured along a scale in which each position is equidistant from one another. This allows for the distance between two pairs to be equivalent in some way. This is often used in psychological experiments that measure attributes along an arbitrary scale between two extremes.
4. Ratio data: Ratio data is similar like interval data. However, ratio data has a zero point for the scale, which means there is no data in the zero point. In a ratio scale, numbers can be compared as multiples of one another. Ratio data can be multiplied and divided because not only is the difference between 1 and 2 the same as between 3 and 4, but also that 4 is twice as much as 2.

5.6.3 Questionnaire preparation

Based on the purpose and steps of the quantitative data collection process, two types of data need to be collected, namely nominal and ordinal data. Nominal data includes the participants' personal information, including that pertaining to the core business of the company, how many OSC projects they completed, etc. Ordinal data includes the impact and probability of each OSM risk, which requires knowing the attitude of questionnaire participants. In order to obtain ordinal data, a Likert scale is employed.

A Likert scale or frequency scales which use fixed choice response formats were adopted and these were designed to measure attitudes or opinions (Rattray et al., 2007). A close-ended questionnaire was developed with a certain selection in this research, and a Likert scale was used to measure the extent of each risk factor. Generally, a Likert scale is a measure of the degree of agreement or disagreement on a particular statement (Pimentel, 2019). There are two major types of Likert scale, even and odd. Even Likert scales are generally used to collect extreme feedback without providing a neutral option, whereas odd Likert scales could give the participant the option of responding neutrally (Brown, 2000). Dawes (2008) proved that no significant differences arose in terms of the mean score, variance, skewness or kurtosis when using five-, seven- or ten-point Likert scales. However, five- or seven-point Likert scales are considered to be typical ordinal Likert scales (Sullivan et al., 2013) and so an odd Likert scale was used for this research.

Commonly, a five- or seven-point Likert scale is suitable for such analysis (Van Laerhoven et al., 2004). The articles, which pertain to similar research areas, also used a Likert Scale as their questionnaire method. For example, Meiling et al. (2012) used a five-point Likert scale to measure the extent of respondent agreement with each statement to manage continuous improvement in off-site construction. Pan et al. (2008) presented a five-point Likert scale survey to investigate the extent and strategies for OSC utilisation amongst large housebuilders. Lu et al. (2008) designed a seven-point Likert scale to identify how architects and contractors perceived the benefits and barriers of using OSC techniques.

In this research, a five-point scale was used to identify OSM risk impacts and likelihoods. For risk impact, the scale was:

1. Very Low impact.
2. Low impact.
3. Average impact.
4. High impact.
5. Very High impact.

For risk possibility, the scale was:

1. Very Low possibility.
2. Low possibility.
3. Average possibility.
4. High possibility.
5. Very High possibility.

In order to avoid bias, a pilot study was designed and distributed from September 2019 to October 2019 (see Appendix 5). The sample for the pilot study was selected from the interviewees from the qualitative study, as these interviewees had the necessary research experience and could provide better feedback for the questionnaire. 250 questionnaires were distributed and 54 were received with feedback. After the pilot questionnaire process had concluded, all pilot feedback was recorded in SPSS to identify the validity and reliability of the questionnaire.

Validity is defined as the extent to which a concept is accurately measured in a quantitative study. Three types of validity are presented by Heale et al. (2015) (see Table 5.4).

Table 5.4: Research validity types (Heale et al., 2015)

TYPE OF VALIDITY	DESCRIPTION
Content validity	The extent to which a research instrument accurately measures all aspects of a construct.
Construct validity	The extent to which a research instrument (or tool) measures the intended construct.
Criterion validity	The extent to which a research instrument is related to other instruments that measure the same variables.

Content validity is designed to check whether the instrument adequately covers all the content that it should with respect to the variable (Heale et al., 2015). There are 3 types of evidence that can be used to demonstrate that a research instrument has construct validity (Heale et al., 2015):

1. Homogeneity: The instrument measures one construct.
2. Convergence: This occurs when the instrument measures concepts similar to that of other instruments.
3. Theory evidence: This is evident when behaviour is similar to theoretical propositions of the construct measured in the instrument.

Criterion validity applies to any other instrument that measures the same variable. Criterion validity is measured in 3 ways (Heale et al., 2015):

1. Convergent validity: An instrument is highly correlated with instruments measuring similar variables.
2. Divergent validity: An instrument is poorly correlated to instruments that measure different variables.

3. Predictive validity: The instrument should have high correlations with future criteria.

Reliability relates to the consistency of a measure. A participant completing an instrument meant to measure motivation should receive approximately the same responses each time the test is completed. Reliability is measured in 3 ways (Heale et al., 2015):

1. Homogeneity: The extent to which all the items on a scale measure one construct.
2. Stability: The consistency of results using an instrument with repeated testing.
3. Equivalence: Consistency among responses of multiple users of an instrument, or among alternate forms of an instrument

Homogeneity is assessed using item-to-total correlation, split-half reliability, the Kuder-Richardson coefficient and Cronbach's Alpha. In split-half reliability, the results of a test, or instrument, are divided in half. Cronbach's Alpha is the most commonly used test used to determine the internal consistency of an instrument (Heale et al., 2015).

Stability was tested using test-retest and parallel or alternate-form reliability testing. Test-retest reliability is assessed when an instrument is given to the same participants more than once under similar circumstances (Heale et al., 2015).

Equivalence is assessed through inter-rater reliability. This test includes a process for qualitatively determining the level of agreement between two or more observers (Heale et al., 2015).

After the pilot questionnaire study is completed, the validity and reliability tests are implemented. The 77 risk factors in questionnaire were reduced to 61 risk factors, and the reasons why the risks were erased or changed are presented in Table 5.5.

Table 5.5: Reason for reduction in risk factors

TYPE OF VALIDITY OR RELIABILITY	RISK ERASE OR CHANGE QUANTITY	REASON
Content validity	4 (includes question change)	Based on the feedback, these questions are

		unclear.
Construct validity	3	Rotated Component Matrix lower than 0.6
	5	Rotated Component Matrix presented two components.
Homogeneity (or internal consistency)	2	Cronbach's Alpha if the item deleted, the number would rise to 0.9.
	4	Reliability Statistics number lower than 0.8.

Based on the qualitative interview feedback, a questionnaire was developed. Risk is then divided into 3 types and 13 groups (see Table 5.6):

Table 5.6: Risk group and risk types for qualitative study

RISK TYPE	RISK GROUP
Internal risk	Cost
	Off-site feature
	Project management
	Time
Participant risk	Owner
	Consultant
	Manufacturer
	Transporter
	Contractor
External risk	Environment
	Government policy
	Resource
	Society

5.6.4 Main questionnaire development

Based on the pilot study, the questionnaire was divided into five sections. These were background information, internal risk, participant risk, external risk and extra risk (see Appendix 6).

The first section was designed to capture participant demographics such as their position; the nature of the organisation, and the number of years of experience in the construction industry. It could help to ensure the relevance of the responder to obtain a comparison of different perspectives from different organisations. The background information includes the classification of each participant from 5 aspects; namely construction experience, OSC experience, OSC project, company area, and component material. As the OSC constitutes the whole life cycle process and requires participant cooperation; the company area includes the owner, consultant, manufacturer, transporter, and contractor. It also addresses precast, steel and wooden components.

From the second to the fourth sections, a number of risk factors identified from interviews are presented. These sections aim to identify the main risk factors in OSM. The risks are divided into 3 groups, 13 types and 61 factors. A five-point Likert scale was used by respondents to rate the impact and probability of each risk factor.

The fifth section aimed to present a space for extra risks and to identify the impact and probability of additional risk. The general open-ended questions may help to identify those issues not covered by the closed questions, either by elaborating and explaining some of the findings from closed questions, or through identifying new issues (O'Cathain et al., 2004). However, the general open-ended question is hard to define in terms of whether it constitutes qualitative or quantitative data (O'Cathain et al., 2004). In order to avoid this issue, this section provides a semi-open question for the participants to provide more ideas as to the risks and to rank additional risks. In this case, these risks can be treated as quantitative data.

5.6.5 Sampling methods

To identify the sample size for the questionnaire, the sample size formula, or so-called Cochran's Formula, was used. Before this formula, several variables need to be identified.

1. Population size: The total size of the population involved in the research. The sample size formula was considered especially appropriate in situations with large populations (Woolson et al., 1986).
2. P value: The probability of finding the observed, or more extreme, results when the null hypothesis of a study question is true (Greenland et al., 2016).
3. Type one error (or so-called false positive): Occurs when a researcher incorrectly rejects a true null hypothesis (Mecklin et al., 2005).

4. Type two error (or so-called false negative): Occurs when a researcher fails to reject a null hypothesis which is really false (Mecklin et al., 2005).
5. Standard deviation: This determines how much the responses will vary from each other and from the mean. A low standard deviation means that all the values will be clustered around the mean, whereas a high standard deviation means that they are spread out across a much wider range with very small and very large outlying figures (Kadam et al., 2010). In general, the standard deviation is presented as sigma, the most common number include one sigma (68%), two sigma (95%), three sigma (99.7%) (Greenland et al., 2016). In this research, two sigma was used as the standard deviation.
6. Confidence level: The variety is the average value of the attributed variable obtained from those samples and is equal to the true population value. It is obtained by the samples which are distributed normally around the true level, with some samples having a higher value and some obtaining a lower score than the true population value. If the confidence level is set too high, it may result more type one error. If the confidence level is set too low, it may result more type two error. (Israel, 1992). In that case, based on the standard deviation, 95% confidence level is set in this research. The 95% confidence level is two sided, which it excludes not only the one-sided p value 2.5% above the upper limit but also the one-sided p value 2.5% below the lower limit, which result the total p value is 5%. This cause there is a 5% chance test results are the result of a type one error (Greenland et al., 2016).
7. Z-score: The Z-score, or so-called standard score, is a measure of how many standard deviations below or above the population mean a raw score is. For a confidence level of 95%, the Z-score is 1.96 (Cheadle et al., 2003).
8. Margin of error (or so-called confidence interval): The number can determine how much of a difference arises between the mean of a sample and the mean population. In order to minimize both type one error and type two error, The

margin of error equal the Z-score multiple the standard deviation score. In that case, the result of margin of error is 5%.

Figure 5.1 presents the formula (Glen., 2020):

$$n_0 = \frac{Z^2pq}{e^2}$$

Figure 5.1: Sample size formula (Glen., 2020)

where:

1. e is the desired level of precision (the margin of error);
2. p is the estimated proportion of the population that has the attribute in question; and
3. q is 1 – p.

The value of each variable is defined below. The number of those involved in the Chinese construction industry is approximately 55.63 million people (Thomala, 2019). The percentage of those in the OSC industry is around 9% (PIRI, 2019), which means that the population size of the OSC industry is some 5,006,700. The confidence level is 95% and the margin of error is 5% and, based on this formula, the ideal sample size is 385.

The questionnaire collection process took place from September 1st, 2020 to October 9th, 2020. The researcher invited 438 professionals to participate in the questionnaire survey as first-tier participants. In total, 120 participated in this questionnaire survey as first-tier participants. Thus, the response rate of the questionnaire survey was 27.40%. After the first-tier participants had finished the questionnaire, a web-based questionnaire with a link was sent to them and they were asked to distribute the link to others OSC practitioners. After a snowball sampling process was enacted, 436 questionnaires samples were collected during the process. All questionnaires that were returned were filled in completely.

5.6.6 Data collection process

As the questionnaire is published online, several potential risks should be considered.

Differing from face-to-face or phone calls, online questionnaires may be opened by the same participants. In order to avoid bias in this questionnaire, each participant was only allowed to complete the questionnaire once and the control is based on that of 'wenjuan.com' which provides a monitor that only one Internet Protocol (IP) can complete the questionnaire and only on one occasion. However, many companies share one IP address (Kavisankar et al., 2011) and this sometimes can cause those participants who come from the same company to be unable to complete the questionnaire. In such a case, a single WeChat account can also complete the questionnaire only once. The participants who could pass one of the monitors could complete the questionnaire. To ensure the validation of questionnaires, only complete responses could be submitted online.

Compared with the use of anonymous questionnaires, questionnaires with less perceived anonymity could result in more frequent terminations during the questionnaire process (Alvik et al., 2005). To protect the anonymity of participants, the questionnaires did not collect personal field data such as the company name, the level of the participants in the company, etc. A personal information sheet and informed consent were however provided at the top of the questionnaire with a downloadable link for the participants. The participants could thus quit the questionnaire without any consequence.

Once questionnaires were comprehensive and free from ambiguity, qualified participants were invited to participate in the survey. To identify qualified participants, the questionnaires were distributed only through the snowball sampling method. Possible first-tier participants were identified and contacted at the beginning of data collection. The first-tier participants came from four sources, namely an OSC society, an OSC company, an OSC conference, or an OSC online group. The list of first-tier participant companies was identified through a local OSC society website which provides the company contact details of top-tier off-sites. Then a phone call, WeChat message, e-mail, or walk-in was used to connect with the companies. Table 5.7

presents the number of participants who were contacted as first-tier participants for this research questionnaire. Table 5.8 presents the participants who agreed to participate in the research.

Table 5.7: Number of first-tier participants approached

Participant group	**First-tier Participant (Approached / Contacted)**				
	Phone	**WeChat**	**E-mail**	**Walk-in**	**Total**
Owner	22	32	18	7	79
Consultant	15	21	14	5	55
Manufacturer	40	65	33	17	210
Transporter	4	7	1	1	13
Contractor	23	27	16	15	81
Total	104	152	82	45	438

Table 5.8: Number of first-tier participant agreed

Participant group	**First-tier Participant (Agreed)**					
	Phone	**WeChat**	**E-mail**	**Walk-in**	**Total**	**Receptiveness Rate**
Owner	3	15	0	6	24	37%
Consultant	5	12	1	3	21	38%
Manufacturer	5	22	2	11	40	19%
Transporter	1	3	0	1	5	38%
Contractor	2	18	0	10	30	37%
Total	15	70	3	31	120	33%

In order to avoid bias in pilot questionnaire results, the main questionnaire process only invited participants who did not fill the pilot questionnaire. Overall, acceptance rates were quite high given the sector in which manufacturers typically only respond favourably 19% of the time. This showed that trust problems were probably the result of fewer manufacturers wishing to participate. Nevertheless, first-tier participants numbered 120. They were then given a questionnaire website URL or questionnaire QR code to complete the questionnaire online. The questionnaire was created and maintained on a professional questionnaire data collection website ‘wenjuan.com’.

These first-tier participants were used to contact other participants. The first-tier participants were asked to suggest or recommend any other organisations that would qualify to take part in this questionnaire and were asked to distribute the questionnaire through WeChat. Most of them were willing to provide more participants and agreed to publish the questionnaire in their respective online OSC groups.

In many cases, both the website URL and questionnaire QR codes were provided to participants. The reason for doing this was to give participants the opportunity to distribute the questionnaire across their social circles. The average completion time for each participant to finish the questionnaire was 7 minutes and 56 seconds.

All questionnaires had to be filled in properly and completely, otherwise the results could not be submitted online.

In China, e-mail is not a common contact method and e-mails drew few responses. However, although the number was small, it was still important to gather as many first-tier participants as possible. WeChat is an alternative method of contacting off-site companies which has a better response rate. Walk-in has the highest response rate of all, as it has the most human feeling of contact, which results in the participants having a positive reaction. The telephone call is an alternative method for walk-ins which could save time.

This research was conducted with the following data collection process to ensure that the data could be as objective as possible:

1. All participants fully completed the questionnaire and so all of them could be used for analysis.
2. Before the questionnaire was completed, some participants had been contacted.
3. Multiple approaches were used to reach respondents and to send questionnaires.
4. The participants' views were sought after the questionnaire was finished.
5. Providing ethics forms and participant information sheets to all participants, detailing all research information and aspects of confidentiality.

5.6.7 Data analysis – Group factors and subfactors

Factor analysis was first attempted to group these factors and sub-factors pertaining to OSC risk. It is a method used to identify the common factors that explain order and structure among the measured variables (Watkins, 2018). A factor is an unobservable variable that influences more than one observed measure and which accounts for the correlations arising among these observed measures. If the latent construct was partitioned out, then the intercorrelations among the observed measures would be zero (Brown, 2015). As this research focused on the risks inherent within the OSM process, factor analysis was first considered.

The factor analysis was based on the pilot questionnaire study, as it is the first step in identifying risks and categorising them. The sample size of the pilot study should be considered. While generally larger samples have been recommended, as larger samples can provide more precise results (MacCallum et al., 1999), Hair et al. (1998) considered that the minimum condition sample size would be 50 and so the pilot questionnaire study sample size (65) exceeded the recommended base value. Two methods could test the strength of correlations arising, namely Bartlett's test of sphericity (less than 0.05), and the Kaiser Meyer-Olkin (KMO) test (with a minimum of 0.6) (Gliem et al., 2003). In this research, factor analysis is needed to divide OSM risk factors into different risk groups. Bartlett's test of sphericity and KMO could help to identify whether the data is suitable for factor analysis.

5.6.8 Data analysis – Main factors

The Statistical Package of Social Science (SPSS) software was used to analyse the questionnaire results. Before the risk factor analysis, the details of all the participants involved in the project were extracted. Participant information included working experience, type of organisation, number of projects, and the type of component involved.

The main section of questionnaire was dedicated to determining the ranking for each identified risk factor. In this case, the mean values in ranking each risk factor were employed. However, these rankings were not yet conclusive, as more statistical analyses should be used for the risk analysis process.

Many articles considered the Likert scale to be an ordinal measure, which means that the response categories have a rank order and yet the intervals between values cannot be presumed to be equal (Jamieson, 2004). However, an ordinal scale measure, sometimes in the form of a Likert scale, may violate the basic assumptions of an ordinal level measure as the Likert scale can perform arithmetic operations which are not otherwise permitted as ordinal level measurements (H. Wu et al., 2017). In that case, there are arguments which consider the Likert scale to be a continuous interval scale. Knapp (1990) considered treating ordinals as interval scales which resulted in many fruitful and meaningful findings. For example, Rosenberg's Self-Esteem Scale is still widely used to measure global self-esteem (Rosenberg, 2015). Harwell et al. (2001) pointed out that many educational researchers analyse ordinal scale data using the interval scales method. Carifio et al. (2008) pointed out that the Likert response format empirically produces interval data at the scale level, and considered the Likert scale to be an ordinal scale that rarely considers abundant empirical findings. In order to incorporate parametric data analysis techniques within the Likert scale, Harpe (2015) presented five recommendations, namely:

1. Scales which have been developed to be used as a group must be analysed as a group, and only as a group.
2. Aggregated rating scales can be treated as continuous data.
3. Individual rating items with numerical response formats at least five categories in length may generally be treated as continuous data.
4. One should consider nonparametric or categorical data analysis approaches for individual rating items with numerical response formats containing four or fewer categories or for adjectival scales.
5. One should remember the benefits of statistical models.

Parametric statistics can be used in conjunction with Likert data, with small sample sizes, unequal variances, and non-normal distributions, with no fear of coming to the wrong conclusion (Norman, 2010). In this research, five-point Likert scale with numerical response formats is developed. For example, the risk probability in the questionnaire is presented from 1 to 5 to represent from very unlikely to very likely, which may generally be treated as continuous data. The continuous data can be analysed by parametric method. In such a case, it is appropriate to use a parametric method to analyse Likert scales.

The homogeneity of participant feedback should be addressed first. An independent samples T-test was used when comparisons involved only two levels, while a one-way Analysis of Variance (ANOVA) test was more suitable for more than two levels (Arifin et al., 2017). In general, a significance level of less than or equivalent to 0.05 means a violation of the assumption of homogeneity of variance (Tabachnick et al., 2007). In general, there are two types of error in statistical hypothesis testing. These are known as Type I and type II errors. A Type I error is the rejection of a true null hypothesis, while a type II error is the non-rejection of a false null hypothesis (Banerjee et al., 2009). To avoid a Type I error, family wise error correction procedures and false discovery rate techniques are the most commonly used statistical methods (Genovese et al., 2002). Family wise error approaches are based on Monte Carlo simulations and/or Gaussian field theory using various cluster size corrections and are conceptually similar to Bonferroni. In contrast, formal false discovery rate analyses take the distribution of *P*-values from analysis into account and end up being less conservative than family wise error (Lieberman et al., 2009).

After the data was collected, the data was analysed by two statistical methods: descriptive statistics and inferential statistics. The descriptive statistic includes means and standard deviation and the inferential statistic includes ANOVA and regression analysis.

The Pearson Correlation should be considered for the correlation arising between risk impact and risk probability for the OSM process. By checking the R-values for the variables, the linear associations arising between risk probability and risk impact can be presented (Benesty et al., 2009).

5.7 Framework development and validation

This research aims to develop a framework for OSM risk management. A Framework could help to improve the consistency, robustness and reporting of the activity (Rodgers et al., 2016). Based on previous literature, the methods to develop framework are concluded in Table 5.9.

Table 5.9: framework data collection method

METHOD	DEFINITION	EXAMPLE
Existing methods and guidelines	Developing framework based on previous published framework or guidance.	(Tserng et al., 2009)
Refined and validated	Refining and validating previous framework.	(Walker et al., 2011)
Experience and expertise	Getting data or experience from experts in the field.	(Monzer et al., 2019)
Literature review	Getting data from published articles.	(Cagliano et al., 2015)

The process to develop a framework can be broadly divided into three phases (McMeekin et al., 2020) :

1. Identifying data to inform the framework.
2. Developing the framework.
3. Validating, testing, and refining the framework.

In this research, the framework development also includes three phases:

1. Identifying data from experience and expertise, by using interview and questionnaire methods.
2. Developing the framework based on existing methods and guidelines, such as ISO standards.
3. Validating, testing, and refining the framework, by using the case study method.

This research needs to validate the framework, which could ensure the quality of the research (Lucko et al., 2010). Validation could make this reference table valuable to society (Kennedy et al., 2005). Verification can be explained as doing things right and doing the right things (Lucko et al., 2010). The validation process could also help the research to ensure the highest standards of quality (Lucko et al., 2010).

In general, the validation process can be divided into two main areas, specifically internal validity and external validity when testing cause-and-effect relationships (Parsian et al., 2009). Internal validity is interrelated with the concept of causality, while external validity is interrelated with the concept of induction (Leedy et al., 2014). Internal validity is defined as the degree of confidence that the causal relationship being tested is trustworthy and not influenced by other factors or variables, and external validity is the extent to which results from a study can be applied to other situations, groups or events (Trousselard et al., 2010). There is a trade-off between internal and external validity: Better internal validity often comes at the expense of external validity. A general solution is to conduct the research in a controlled environment, then a field experiment to analyse whether the research result is accurate in the real world (Lopes et al., 2015).

There are several threats to internal validity, such as history, maturation, instrumentation, testing, selection bias, regression to the mean, social interaction, and attrition. In order to counter internal validity threats, methods like adding a comparable control group, larger sampling group, random assignment of participants, or blinding participants (Steyerberg et al., 2016).

External validity also has threats, for example, sampling bias, history, experimenter effect, Hawthorne effect, testing effect, aptitude-treatment, and situation effect. In order to counter external validity threats, methods like replications studying, field experiments, probability sampling, or recalibration (Steyerberg et al., 2016).

Therefore, the validation of framework includes two parts: internal validation and external validation. For internal validation, this research used different testing groups in the pilot study and formal study for both interview and questionnaire process. This research also used a large sampling group in both interview and questionnaire process to keep the result less sensitive.

For external validation, this research collected both interview and questionnaire data from different areas in China to enhance generalizability in the different Chinese provinces. This research also used case study to evaluate the result, which could prove the result is not only suitable in the specific situation.

5.8 Chapter summary

In this chapter, the detailed methodological aspects of this research are presented. Based on articles that introduce the research methodologies, an appropriate methodology for this research was identified. Mix methods were employed for the purposes of this research which includes semi-structured interviews for qualitative analysis and questionnaire survey for quantitative analysis. Snowball sampling was used to gather respondents. Content analysis was used to address the qualitative data while statistical analytical tools were used for the quantitative data.

CHAPTER 6 - QUALITATIVE RESULT

6.1 Introduction

In this chapter, the qualitative data obtained from interviews will be analysed through NVivo to present the salient risk factors for OSM. The interviews involved some 25 OSC experts who took part in OSC projects. At the end of this chapter, a summary of the findings is presented.

6.2 Risk factor and variety

6.2.1 Interview background

The investigation commenced with a semi-structured interview to identify the main activities and risks associated with the OSM process and the relevant risks arising among the various OSC process that may influence the off-site manufactory. The semi-structured interview process drew upon expert opinions from the OSC project. The schedule of interview includes:

1. Introductions: Participant introduction, background, and interest in the research.
2. Introduction to project: This includes an overview of the aims and objectives of the research.
3. Areas to be covered: Identifying the main building elements for analysis. Activities associated with the methods of each off-site manufacture phase are verified along with the risks arising for each phase of off-site manufacture. Opinion/evidence is presented for each risk. Identify the current solution for off-site manufacture process risk and discuss whether the current solution could solve these risks.
4. Further discussion needs to be added.
5. Close.

All interviews were conducted in quiet, comfortable areas within the interviewees' offices. During the semi-structured interviews, the interviewer recorded the audio for subsequent transcription and analysis. The interviews lasted between half an hour and one hour. The participants could provide any aspects of the risk factors pertaining to OSM or OSC. After the interview process, a tour of the manufactory was implemented, during which the interviewer could discuss further questions.

6.2.2 Risk breakdown structure

After the interview, the feedback was transferred into NVivo and the OSM risks arising are listed in a table. A risk breakdown structure is used to identify the risks arising within the OSM process.

Based on the feedback from the interviews, a breakdown of the risk factors was developed and presented. After comparison with risk factors identified in other articles, the interviewee alludes to several new risks which are presented in Table 6.1, Table 6.2, Table 6.3, Table 6.4 in italics. In order to define the risk by criteria, the criteria for the risks identified were divided into 4 groupings, namely site condition, resources, project parties, and project features.

Table 6.1: Risk breakdown structure from interview: site conditions

RISK GROUP	**RISK SUB-GROUP**	**RISK FACTOR**	**RISK STATEMENT**
Environment	Unpredicted weather	*Strong wind/gale*	Bad on-site weather such as a strong wind causes a pause to on-site activities and manufactory.
	Temperature	*High temperature affects labour*	Manufactory environment too hot affecting worker productivity.
		High temperature affects material	Temperatures may influence component quality.
	Seasonal changes	*Labour number changed*	Worker numbers fluctuate seasonally. Insufficient number of workers during holidays or very hot days.
	Pollution	*Pollution limitation*	When smog occurs, the manufactory needs to stop to reduce levels of pollution.

Table 6.2: Risk breakdown structure from interviews: resource

RISK GROUP	RISK SUB-GROUP	RISK FACTOR	RISK STATEMENT
Labour	Labour skill level	*Lack of skilled labour*	Lack of experienced manufactory workers.
			Lack of experienced manager.
			Lack of experienced on-site workers.
	Labour availability	*Sub-contractor continuity*	Outsourcing workers - lack of continuity.
	Labour accidents	*Manufacture worker operation fault*	Worker operation error.
			Component binding is not firm enough.
		Driver operation fault	Driver may exceed the speed limit.
	Labour responsibility	*Labour lack of responsibility*	Manufactory workers lack responsibility.
			On-site workers lack responsibility.
	Human resource planning	Rapid growth of skilled labour cost	Manager training cost is very high.
		Poor labour planning	Too many workers in manufactory.
		Poor fleet management	Hard to find who should take responsibility in owner transport group.
			Outsourcing transport group may cause component split.
Equipment	Equipment maintenance	Incompetence of technology and equipment	Reuse rate of PC component model is very low.
	Equipment malfunctions	Equipment limitation	Foreign assembly line is not suitable for China.
Material	Material delivery	*Delivery not on time*	Supplies not delivered on time.
	Material shortage	Shortage of material supply	Lack of materials.
	Material procurement	Poor material quality	Material quality is not good enough.

Table 6.3: Risk breakdown structure from interview: project member

RISK GROUP	RISK SUB-GROUP	RISK FACTOR	RISK STATEMENT
Owner	Management strategy	Unrealistic prefabrication schedule	Planning is too late, causing insufficient time for further development.
Engineering and design	Team experience	Incompetence of designer of prefabricated components	Architects lack knowledge of OSC.
	Project goal	Conflicting designer interests	Consultant does not have notion to do a better drawing.
	Complexity of design	*Support of prefabricated components interference*	Assemble component is very complex, and there is limited operable space.
	Design change	Change to orders	Owner demands change.
	Design errors	Errors and defects arising due to poor design ability of designers	Conceptual design phase did not consider design development phase.
			Insufficient development design.
			Developing design did not consider the whole off-site process.
		Design limitations	Design is too conservative.
		Design not suitable for assembly and installation	Unreasonable lifting point design.
			Component joint is not suitable for assembly.
		Unreasonable model design for prefabricated components	Poor model design, causes assembly and disassembly to be very difficult.
Manufacturer	Preliminary preparation	*Manufactory design error*	Manufactory design bad.
		Insufficient project evaluation	Project evaluation is not good enough.
		Manufactory size limitation	Manufactory size limitation cause some components to be unable to be produced.
		Longer lead-in time during design stage	OSC needs a lot of time to prepare before beginning to build.
		Cost disadvantages due to higher	Cost to build a manufactory is very high.

		preparation costs	
	Change of manufactory	*Manufacturer changes in late stage*	Manufacturer may change after conceptual design is finished.
	Number of projects	*Projects exhibit mutual interference*	Too many concurrent projects due to manufactory confusion.
	Number of manufactories	*Insufficient off-site manufacturers*	Not enough off-site manufacturers.
	Management experience	Lack of management practices and experiences	Lack of component classification method.
			Insufficient assembly line control.
		Incompetence of manufacturers of prefabricated components	The process could become more effective.
	Process control	*Unrealistic manufactory project schedule*	Manufactory produce process cannot catch up with on-site building process.
	Production error	*Irregular prefabricated components*	Components are too high or too wide.
			Component does not follow the drawing.
	Management strategy	*New management method shortage*	Lean production cost is too high.
			Lean production is not suitable for complex component.
Transporter	Road problem	*Traffic restrictions*	Transportation limitations of road network.
		Road damage	Road bumps cause component split.
	Transportation cost	Transportation cost	Transportation fee is high.
	Transportation damage	Damage of prefabricated elements during transportation access to the building site	Components may collide during transportation.
	Transportation distance	Long distance of factory to site	Component cannot be transported long distances.
Contractor	New technology	*Technology change*	On-site construction method change may cause production process to change.
		Technical faults in installation	Cannot check whether grout sleeve is grouting well.
	Defective work	Lack of experience of current contractors	On-site construction process bad.

		in assembly of prefabricated components	
	Number of manufactories	*Manufactory mutual interference*	Contractor uses different manufactory components at the same time, causing some components to be unable to be assembled.
	Process control	Unrealistic on–site project schedule	On-site process too slow. Causes components to be kept long in stock.
	Labour cost	Rapid growth of skilled labour cost	On-site worker cost is high.
Project management	Quality control process	Lack of a quality monitoring mechanism for the production process	Lack of quality management method.
	Type of contract	Poor cooperation between multiple interfaces	The whole chain lacks transparency.
	Management strategy	*New management method shortage*	EPC could not make sure everybody is collaborating.
			EPC promotion is not good enough.
			BIM model lacks on-site process explanation.

Table 6.4: Risk breakdown structure from interview: project features

RISK GROUP	RISK SUB-GROUP	RISK FACTOR	RISK STATEMENT
Finance	Type of funds	High-cost pressure without economics scale effect	Manufactory only gets profit from subsidy.
	Payment process	*Unreasonable payment process*	Financial pressure from contractor, manufactory can only get payment after the project is finished, which may be more than 1 year.
Politics	*Improper law and policy*	Loss due to insufficient laws pertaining to industrialised building	Some places are not suitable for OSC, but still use OSC, because government has lowest OSC requirement.
		Inappropriate design codes and standards for industrialised buildings	Government developed a development design standard, but it is not suitable for realistic.
			The standard of OSC does not have enough detail for OSC process.
	Insufficient government policy	*Few chances to get support from facility*	Insufficient supporting facilities.
		Few chances to get preferential policies on tax, loans, or subsidy	Lack of policy subsidy.
		Lack of compliance to requirements/standards	Lack of construction specification.
		Standard difference	Different places have different industry standards.
		Incompetence of supervisor of prefabricated components	Supervisor does not understand OSC.
		Lack of standardisation	House type lacks standardisation.
			Transport lacks standardisation.
			Lack of appropriate specification or guidance.
Schedule	Project duration	*Longer on-site building time*	OSC needs more time to build than on-site during main structure building process.
Society	*Socioeconomic*	Socioeconomic environment downturn.	Real estate downturn lasts for years.

	environment		
	Social habit	*Unreasonable contract bid winning reason*	Only the lowest construction budget company can get the contract from owner.
		Projects discontinuous	Projects suffer from discontinuity. Some have to wait after June to have more projects.
	Social prejudice	High quality/performance expectations	Component exterior requested to be more beautiful, although it is unnecessary to make it beautiful.
		Terminal user's conservatism and scepticism	Because there was an off-site building falling down, society lacks trust in OSC.
		Inefficient cost estimating for prefabrication	OSC product price is higher.

6.3 QCD and risk factor

6.3.1 Quality, cost, and delivery

Once the grouping of the risk breakdown structure has been created, the influence of risk should be identified. The influence diagram is an acyclic graphical network of nodes connected with directed arcs (Varis et al., 1990). An influence diagram is simply a diagram that consists of nodes reflecting 'variables' and 'decisions' and 'influence' reflected by arrows (Dikmen et al., 2007). It provides a clear directional graphic of how these nodes are interconnected and provides a convenient way of expressing the nature of the research target to others. The influence diagram is used by Ashley et al. (1987) in a construction project to explain the status and interactive relationships of underlying risk factors. The influence diagram is then applied to the risk analysis, decision analysis, and probabilistic inference in the construction project. The influence diagram is used to organise risk factors so as to describe the interrelationship arising between risk and risk stakeholders, which could provide a clear outcome for OSM risks. Lin et al. (2011) identified that an influence diagram is a suitable risk analysis method for construction, and a similar idea was presented by Zhi et al. (2010) who contended that construction risk could be assessed via the influence diagram. In this study, the influence diagram is used to produce a risk model which incorporates the interrelationships arising between project members, project risks and their influencing factors. It is the main approach used in developing an in-depth understanding of OSM.

To address how these risks influence OSM in the influence diagram; quality, cost and delivery (QCD) are incorporated, as these are the three elements that today's company must consider. Sometimes QCD expanded to QCDMS (Quality, Cost, Delivery, Morale, Safety), it is a project management method, which is developed to help companies within the UK automobile sector (Imai, 2007). QCD method is used to assess different components of the production process, which could help managers make logical decisions (Kannan et al., 2006). Soin (1992) defined QCD as follows:

1. Quality that includes customer satisfaction issues and product/process quality.

2. Cost which includes all costs, such as administrative expenses, manufacturing costs, and productivity issues.
3. Delivery which includes the introduction of new product designs, research, development and manufacturing product commitments as well as the delivery of products to the customer.

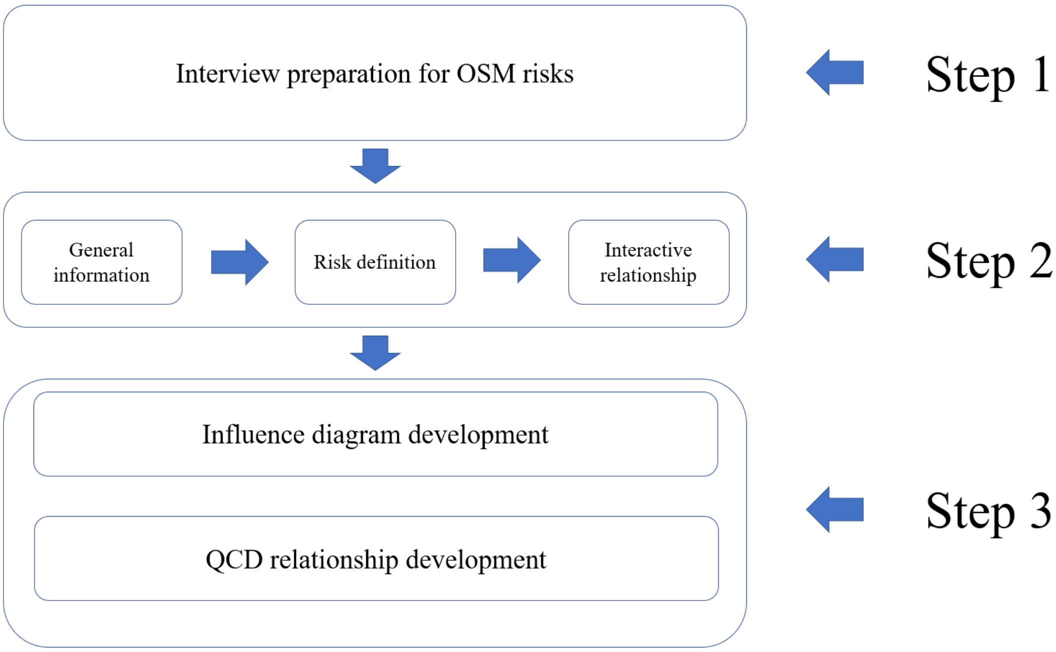
Many construction projects regard QCD as a direct result of the effectiveness of project management. Tayur et al. (2012) considered it to be based on teamwork, cooperation and effective coordination throughout the construction supply chain. Carpenter et al. (2016) analysed the public school construction project QCD over two years to understand the risks inherent within the project. QCD can be used in risk management to maintain sustainable project management (Krause et al., 2009). In this research, QCD was used to identify risk, and the influence diagram was employed to represent the influence of risks arising in the project.

Figure 6.1 presents the methodology development process, which involves three steps. Step 1 is the interview preparation process itself, developing semi-structured interview questions for the evaluation of OSM risks. The variables and questions were based on the existing literature (Dalton et al., 2011; Pan et al., 2007; Shahzad et al., 2013; Shang et al., 2013) which presented interviews as an effective and robust method for OSC risk identification.

Step 2 is the interview process which incorporates three sections. Section 1 is the collation of general information about each interviewee, including their professional qualifications, industry experience and the specific characteristics of their respective industry organisation. Section 2 is the examination of their perception of OSM risks. Section 3 includes their response to the interactive relationships arising amongst these risks.

Step 3, the influence diagram process which is separated into two sections. Section 1 develops the influence diagram based on risks and interrelationships arising from Step 2. Section 2 analyses how these risks influence the project by using the QCD model.

Figure 6.1: Process of qualitative data development process



6.3.2 Risk factor and risk assessment framework

Based on the risk breakdown structure, the risk type, risk group and risk factors for OSM are defined. As the risk breakdown structure provides a wider view of the risk factors, several risk factors are integrated into one risk to develop the risk framework. The risk assessment framework is presented in Table 6.5.

The three types are defined within this framework as follows: Project Member, Project Process, and External. Project Members means the organisation which participates OSC project, including the owner, consultant, manufacturer, transporter, and contractor. Project Process means the situation that happened during OSC project process, including cost, project features, project management, and time. External means the situation OSC project manager cannot control, including environment, politic, resource, and society.

Table 6.5: Risk assessment framework used in qualitative research

Risk type	Risk group	Risk factor
Project Member	Owner	Demand change Partner
	Consultant	Design error Experience Responsibility Standardisation Technology
	Manufacturer	Experience Component quality Participant Production process Project complexity Responsibility Size of factory
	Transporter	Experience Responsibility Standardisation Storage process Transportation limitation
	Contractor	Experience On-site complexity Participant Responsibility Standardisation Technology
Project Process	Cost	Initial cost Labour cost Resource cost
	Feature of project	Concrete feature Off-site feature
	Project management	Cooperation New management method Risk management method
	Time	On-site operation Preparation time
External	Environment	Factory environment Natural disaster
	Politic	Standard Support
	Resources	Quality Shortage Standardisation Usability
	Society	Prejudice for off-site Social convention Socioeconomic environment

The details for each risk are presented below to explain the risk based on the interview feedback.

6.3.3 Project member risk

1. Project Member – Owner risk

P13 said: *'Many owners have their plan for the off-site project. However, they do not follow their plan, they always delay their plan. This causes our components to have to be put in our storage yards, which is a waste of our time and money.'*

It is understood that the owner may change their decision during the construction project process. The main decisive change comes from design demand. Arif et al. (2009) explained that OSC could benefit in terms of time and cost, but these advantages can only be realised when incorporated into the central approach from the design stage. This is particularly pertinent in the conceptual design phase when an owner makes a change, as it means that the whole OSC process has to change. Such changes will inevitably involve additional cost and time, especially in the OSM process.

In traditional construction in China, other participants (e.g. contractor, consultant, supplier, etc.) come from different companies, and the fragmented nature of the construction industry leads to the power of decision making residing with the owners (Mao et al., 2015). This owner-led approach is central to OSC projects. However, current owners lack adequate knowledge of OSC, which causes them to make incorrect decisions at an early stage.

2. Project Member – Consultant risk

P10 said: *'Many Chinese designers do not know the on-site process, and they do not know the off-site process. They do not consider whether the design can be implemented for the construction project. As most of them only need to operate on the computer, it is hard for them to think about the tool or solution for the project.'*

McCarney et al. (2012) explain that OSC requires an early design freeze to be effective, which requires a consultant with a high degree of expertise in the marketplace. However, Chinese consultants lack not only off-site experience but also on-site process experience. In the traditional method, the consultant only needs to be responsible to the owner, restricting the opportunity for designers to cooperate with other participants.

P1 said: *'Sometimes the consultants need to do the design development phase for us. However, when the design needs to change, as this can reduce the cost for the manufacturer, the consultants can only get more risk and responsibility from changing. The willingness for them to change the design is very low.'*

The consultant's allocation of responsibility also brings with it another problem. The consultant has no responsibility for helping the manufacturer to improve component design. For example, if a consultant improves the quality of the design development phase, it will become a time-consuming process for consultants, and this design change is the main driver of both time and cost overruns in construction projects (Hwang et al., 2009). The consultant needs to take extra responsibility for the risk of design change. Haller et al. (2015) explain that the change in design may decrease OSC design quality (i.e., time, cost and product quality). However, consultants gain no profit from this phase, as only the manufacturer can take advantage of it.

P14 said: *'In general, the standardisation of off-site building construction is relatively low. Different owners require different types of building, which leads to the design of various types.'*

Consultants lack experience and responsibility, with the result that current off-site design standardisation and technology are relatively low. Goulding et al. (2015) explain that the technical problem in off-site design should be considered as a medium-term priority (6-10 years).

3. Project Member – Manufacturer risk

P12 said: *'The main problem comes from the manufactory workers. Currently our degree of automation is insufficient, and the project is complex. Sometimes the manufactory workers may make some mistakes.'*

P15 said: 'there are a few people choose to become off-site managers, most of them are less than 30 years old. This causes our management team to not have much *experience, we have to use standard to solve this problem.'*

P25 said: *'Some managers do not understand the off-site project. Some of them are just graduate students. They only follow the theory from the class, and do not know how to solve the real problem.'*

As with consultants, the manufacturer also has insufficient experience of OSC methods and, as Vernikos et al. (2013) explain, the manufacturing workforce's lack of experience is the main reason for time delays. There is a difference however, between the lack of experience of the consultant and the manufacturer. The manufacturer needs to take responsibility for component quality and needs to fix the problems with components. However, as OSC is a relatively new method in China, most manufacturing managers are around 25-35 years old, which means that they lack not only OSC experience, but also traditional construction experience.

P13 said: *'If you found a problem and report it, it means you have the responsibility to solve the problem. So, the workers do not want to report a potential problem to the manager.'*

OSM workers' lack of responsibility is also an issue for the manufactory. In traditional construction, it is unnecessary to hire formal workers, as most traditional construction projects are discontinuous in nature and the flexibility of outsourcing workers can help the construction company to save on costs. Therefore, some manufacturers prefer to outsource workers so as to reduce costs. However, it is impossible to retain the responsibility for outsourced workers and this problem increases in the OSM environment.

P9 said: *'Sometimes the components are too complex, and the rebar workers have to use a lot of time binding the rebar. This causes a pause in the assembly line. If we have the experience, we should build more rebar assembly lines.'*

Such a lack of experience means that some manufacturers have insufficient assembly lines not only for component production, but also for the manufacturing building process or otherwise some assembly lines are unsuitable for component production. This may also increase the complexity of the production process. An inappropriate factory layout can cause chaos in the production process. For example, as the contractor requires more than one floor of components even before the on-site process begins, the manufacturer needs the components to be prepared in advance, and many factories have at least one yard for component storage. However, as the on-site construction process may be delayed, the current storage yard is always insufficient for OSM to such an extent that factories have to pause their production until the yard is empty.

P1 said: *'It is easier for us to build standard components. However, sometimes we have to produce only one component. This component may be very complex, and we have to build a mould for this component. It takes a lot of time to build it.'*

Pan and Arif (2011) explain that, compared with other manufactured products, housing and buildings have more complex components. Production of these complex components is a problem for OSM. As with other factories, the off-site manufacturer also needs to reduce costs through mass production. However, most construction projects only need a few complex components and it is unnecessary to produce these complex components in the factory.

P7 said: *'Some deviation of components is allowed and in line with national standards. However, during the assembly process, these deviations are magnified. For a single component it is okay, but several deviant components cannot be assembled together."*

P19 said: *'When some quality inspection agency checks traditional construction component, they have a government standard to follow. However, in OSC, they do not have a standard, and are always knit-picking over tiny details like the surface smoothness.'*

OSM production problems will increase in the on-site construction process, which means that off-site components have a higher quality requirement. However, the standard of off-site components is still unclear, which causes some misunderstandings in quality certification departments regarding quality definition. For example, some quality certification departments pay excessive attention to a surface feature of components, which is unnecessary.

4. Project Member – Transporter risk

P2 said: *'Safety is the most important thing in off-site component transportation, as the component may weigh more than 4 tons.'*

P21 said: *'Our truck can transfer more than 30 tons of components. However, the irregular shape of components, like bay windows, increases our loading time, and decreases our loading amount.'*

As OSC components are heavier than traditional construction materials, heavy off-site components increase risk in the transportation process (Motaleb et al., 2014). Heavy components mean a relatively higher cost to transport components over a long-distance than for traditional construction. Even worse, most components have an irregular shape, which decreases the total volume of components transported for each truck. This problem happens more often in southern China, as southern Chinese temperatures are higher than those in the north, and more prefabricated bay windows are needed. The shape of prefabricated bay windows is such that fewer can be loaded at the same time.

P16 said: *'The off-site component transportation requires a better quality of road, also the width and height limitation."*

As mentioned above, the off-site component is always heavy and large, requiring transportation trucks of corresponding size. Many roads have height and weight limits, which means that trucks may have to take a detour. As component transportation trucks may cause environmental problems, including noise and dust, off-site component transportation is banned during the daytime, especially in the city centre. Most components have to be transported at night. However, most on-site work occurs in the daytime, leading to a significant inconvenience for the component transporter.

5. Project Member – Contractor risk

P5 said: *'The on-site workers are inadequate, especially off-site assembly workers. They do not have enough experience to cooperate, and only know how to do their own job.'*

As OSC is a relatively new method for many contractors, many workers in contracting companies do not have experience with OSC component assembly. The complexity of component assembly increases the challenge for the workers. In traditional construction, the contractor hires sub-contractors such as carpenters, electricians, and steelworkers. This process is well developed in traditional construction, as sub-contractors do not need to be concerned about others' work. However, OSC demands cooperation amongst all sub-contractors across the whole life cycle, and current sub-contractors have to learn how to avoid material or component collisions.

P19 said: *'When we produce the components, we treat them seriously. However, the on-site workers do not care about the quality of the components and may break them.'*

In traditional construction, over 90% of sub-contracted workers are migrant workers (Swider, 2015). Most are unregistered migrants, which means that they have no written contracts with their employers. This makes it almost impossible for the contractor to monitor which migrant worker is irresponsible. In OSC, this problem is amplified. Component assembly requires high precision working, especially in the component joint assembly process. However, some migrant workers do slapdash work, thus increasing the risk.

P10 said: *'Now we still cannot prove that the grouting process is 100% safe, and we still do not know how to solve this if there is a quality problem."*

P16 said: *'We are lacking experts for the checking of the grouting process. This technology problem should be solved.'*

Another problem with the grouting process is that it is currently impossible to check the quality of the grout coupler. The present alternative solution is to record the whole process of grouting. However, this solution requires the manager to monitor the process, which increases the cost and duration of the project.

Each influence diagram includes 4 parts:

1. The first is the cluster presented in the upper-left of a square, such as the 'Owner', 'Consultant', 'Manufacturer', etc.

2. The second is the feature that may happen in the OSM process in the green square, such as ‘Change demand’, ‘Wrong demand’, ‘Change partner’, etc.
3. The third is the risk in the blue oval, such as ‘Demand’, ‘Partner’, ‘Design error’, etc.
4. The fourth is QCD in the red hexagon, including ‘Quality’, ‘Cost’, and ‘Delivery’.

The fact that the cluster, feature, and risk are covered by a square means that they are in the same group. The arrow pointing from the feature to the risk means that the feature causes the risk. The arrow pointing from risk to QCD means that the risk causes the QCD problem. The identification of relationships is based on the interview feedback. The interviewees present the project influence of each risk which is defined for the QCD problem. As the risk causes the project delay, extra cost, or low quality, the relationships arising between risk and QCD lie in the unidirectional path.

For project participants, two influence diagrams are developed to explain the category for each risk, these influence diagrams present how project member risks influence OSM project (Figure 6.2 and Figure 6.3).

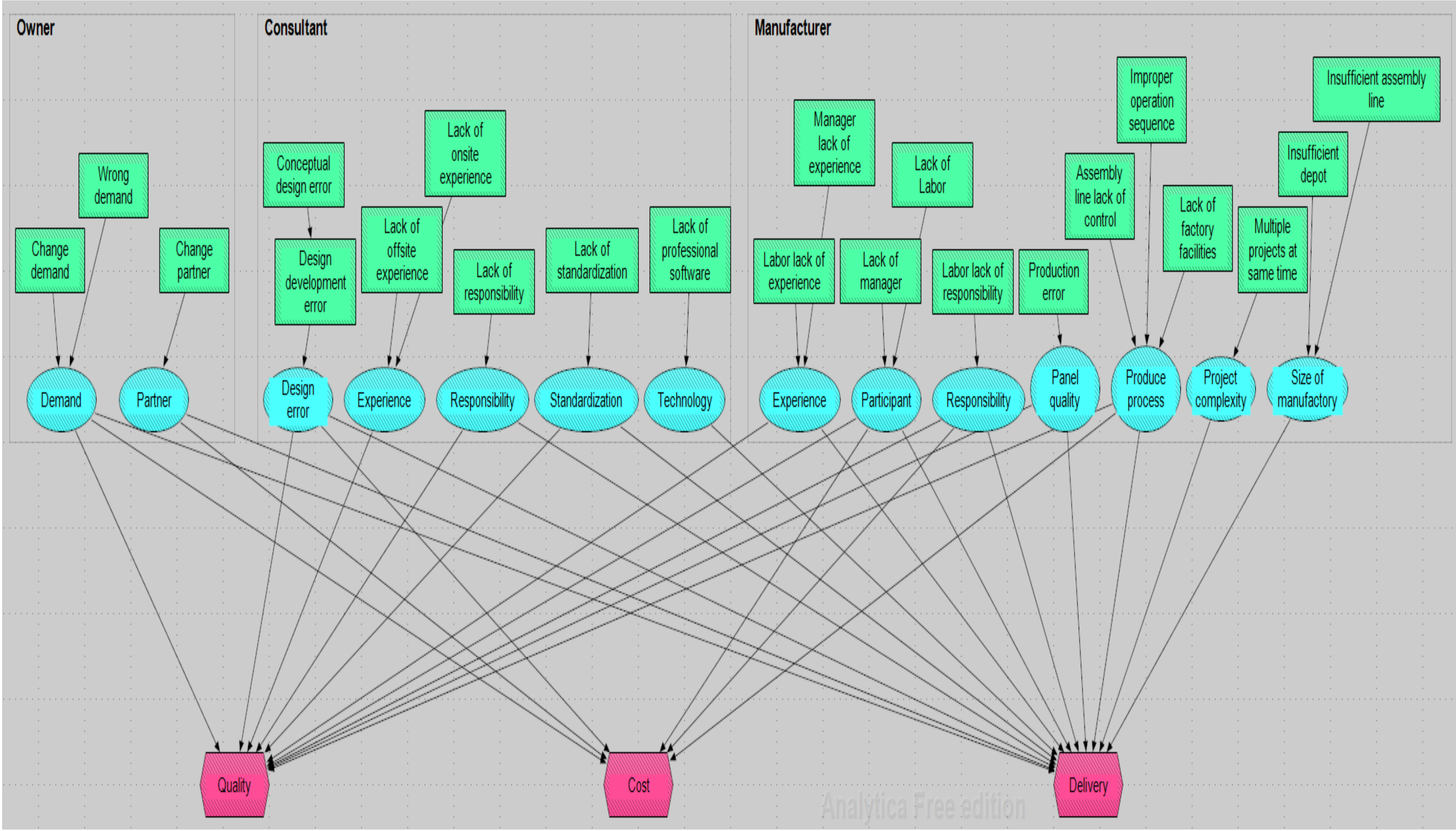


Figure 6.2: Influence diagram for Project Members by interview: part one

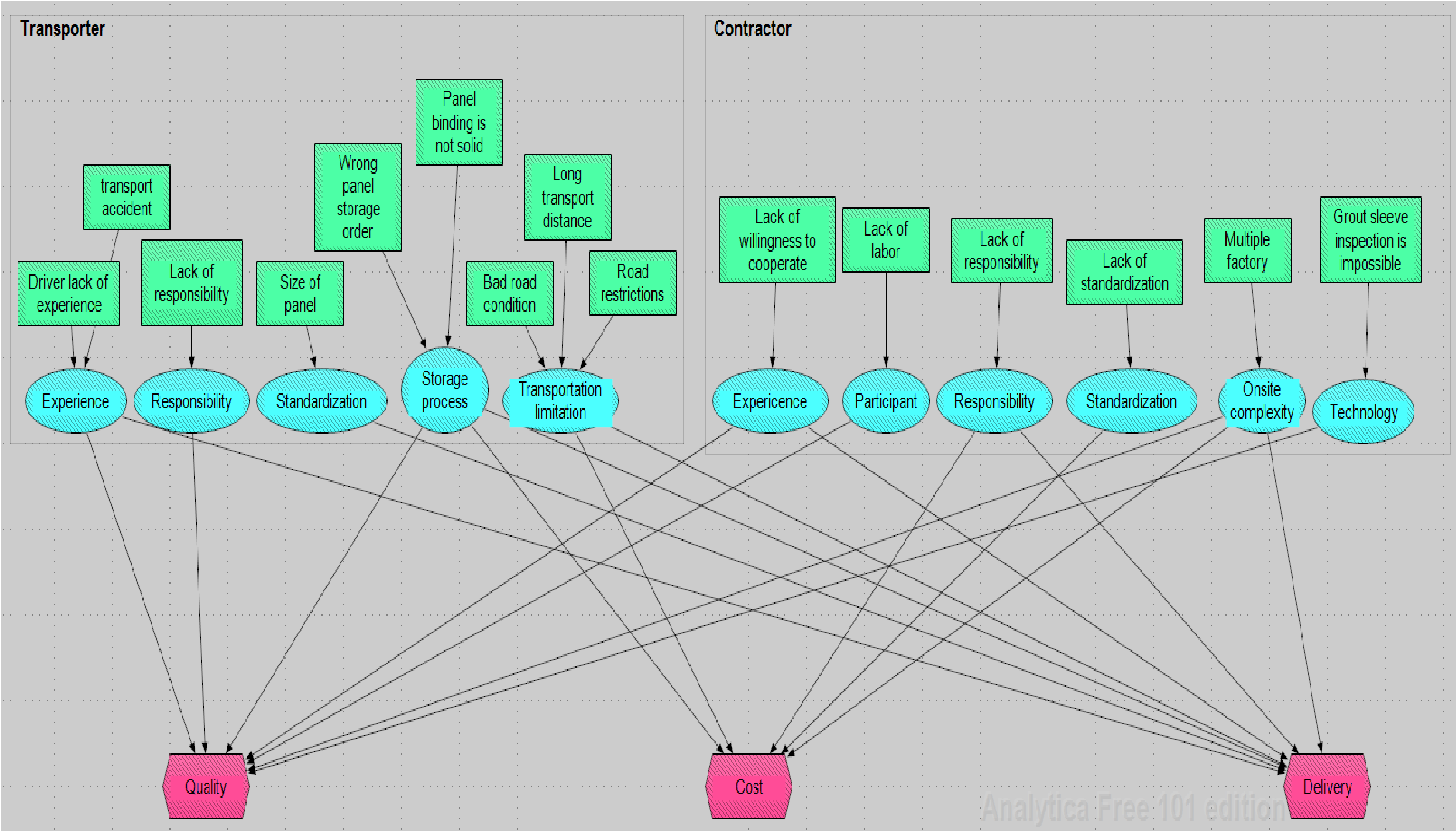


Figure 6.3: Influence diagram for Project Members by interview: part two

6.3.4 Project Process risk

1. Project Process – Cost

P22 said, *'If only the cost for component production is considered, our cost is lower than traditional construction. However, the costs of the manager's salary, fixed assets cost, tax fee, etc., these costs increase our initial cost.'*

Many previous articles have mentioned that the initial cost of OSC is higher than for traditional construction. For example, Goodier et al. (2007) presented a high initial cost as the reason why using off-site is more expensive than traditional construction. Pan et al. (2007) noted that higher initial costs were identified as the most significant barrier to the use of OSC methods.

Although Pan and Sidwell (2011) maintained that off-site is the most cost-effective method of building in the UK, they only considered on-site costs and their research is based on UK OSC. The initial costs for Chinese OSM include three parts, namely OSM, transportation, and post-delivery.

OSM costs include land, manufacturing and equipment. Although these costs can be decreased through apportioning across more PC components, an increased component rate will increase on-site costs including on-site pouring, more experienced on-site workers, and on-site management. If the contractor is not an 'Engineering, Procurement, Construction' (EPC) company, then the contractor and manufacturer cannot share these risks, as neither will be inclined to increase their own risk to decrease the other participant's risk and, if the contractor refuses to increase the component rate, the OSM building costs are hard to decrease.

Many manufacturers also agree to undertake the transportation of components as these costs should be the concern of the manufacturer. Lu (2009) noted that transportation constraints, including cost, impact negatively on OSC, while Lu et al. (2013) observed that transportation costs account for around 18–20% of total costs. Such costs depend on a range of factors, including component type, transportation distance, road quality, traffic jams, and time limits. It is difficult to reduce transport costs as they are largely externally determined.

During component production, manufacturers are not paid, as most contractors follow a 'pay after delivery' rule. The manufacturer thus has to prepay the cost of materials, component moulds and storage. The manufacturer also has to be prepared to avoid on-site emergencies, which adds to the burden of prepaid costs. Even when the project is finished, the manufacturer has to wait until the building works are finally signed off, and some manufacturers may not get paid for up to two years.

P18 said, *'We still have labour shortages. The reason for these shortages is that the cost of experienced labour is very expensive."*

As mentioned under the category of 'Project Member – Manufacturer', most manufacturing workers are around 25-30 years old and lack experience. Cross-training may be an appropriate way to improve experience in dealing with OSC projects (Nasirian et al., 2018). However, manufacturers then need to provide training courses for workers, adding to labour costs. After training, workers require higher salaries (Liu et al., 2012), which further increases the cost of manufacturing.

There are two types of labour involved in traditional construction. The first is formal labour and the second outsourced labour. However, in OSC, component production requires more experience and responsibility and, therefore, formal labour is more suitable. One problem is that formal labour requires monthly payments. However, as construction projects are discontinuous, sometimes the manufacturers will receive no projects for two or three months at a time and this may cause manufacturers to have to pay monthly salaries without receiving payment themselves.

P12 said, *'For example, some project contracts were signed in 2017. However, the project may begin in 2018. The material costs may see a significant increase during this time.'*

OSC requires higher quality materials than traditional construction, and these are harder to obtain, especially as more and more OSMs are established. It is estimated that, typically, there is a 2% wastage of raw materials and a 3% wastage of finished products within the production process (Peng et al., 2011), increasing the resource costs for materials.

Another resource cost comes from the PC moulds, one which varies depending on whether the material of the mould is steel, wood, glass fibre reinforced concrete (GRC), or polystyrene. Most manufacturing processes use a steel mould for standardised components and wood moulds for non-standardised components. The cost of the mould increases when the cost of different types of component increases and decreases when the number of the same type of component rises.

2. Project Process – Time

P4 said, *'The OSC grouting process requires more than 75% concrete strength before the next floor assembly. In traditional construction, we do not need to waste time for the grouting process."*

Previous articles indicate that OSC is a time-saving method for construction projects (Mao et al., 2015). However, many contractors responded that the OSC method is slower than traditional construction in the facade building process. For example, traditional construction can build at a rate of three days per floor, but OSC needs around five days per floor. The delays in the OSC method are due to a multitude of reasons.

For many PC components, the component joint connection has to be completed on-site, which is a very complex process for the on-site worker. As mentioned under 'Project member – contractor', many on-site workers lack experience and responsibility, exacerbating the difficulties of component joint connections. This causes the contractor to slow down the whole process of OSC. The component joint connection in on-site assembling also brings with it another problem, as it requires a concrete grouting process, necessitating additional on-site assemble time and increasing the time for the overall OSC process.

P23 said: *'If the preparation time is not sufficient, then there may be a greater time risk in the future. The limitation on time may cause design error to increase, and the manufacturer may have to do reworking.'*

Compared with traditional construction, OSC requires more preparation time. However, manufacturing rarely affords sufficient time for component production. For example, most off-site project preparation, including developing design, component design, component mould design, and component mould production requires two to three months to complete, yet most factories have only a month for preparation in China. Sometimes the plan is changed by the owner, placing more pressure on the manufacturer.

3. Project Process – Features of Project

P11 stated, *'The concrete component is very heavy, and it is hard to hoist on-site. Our current standard does not allow us to build PC components of more than 100 metres.'*

The current material used for PC components is concrete. Compared with other materials such as steel or wood, concrete requires more energy input to construct the same building (Glover et al., 2002). This increased energy cost for OSC arises because a steam heating kiln is needed to accelerate the setting of the concrete which, otherwise, would require a further five days. Even with a steam heating kiln the component still requires 12 hours for setting.

Another problem is that PC components are heavier than other materials, which causes two problems. First, it is hard to transfer components to another location and, second, this restricts the construction of high-rise buildings.

4. Project Process – Project Management

P20 said, *'Although we are in the leading position for the design process, there is still some risk. For example, we cannot make sure whether the plumber and electrician understand how to cooperate with us, and so we may change our design process.'*

Coordination and cooperation are necessary for OSC. However, the lack of transparency in the off-site chain often leads to delays in OSC projects. Such a lack of cooperation may result in many problems. Here are several examples:

Between the consultant and the manufacturer, if the consultant does not consider the simplicity of component production, then the manufacturer has to produce non-standardised moulds and components which cost more than the standardised component.

Between the contractor and the manufacturer, many off-site factories have a large yard for component storage so as to accommodate on-site process changes or delays. However, the yard imposes a substantial cost on the manufacturer.

P5 stated, *'We have nine different types of BIM models, based on construction, structure, assembly, etc. However, these models only consider the final phase of the project. They do not consider the process of the project.'*

New construction management methods, including BIM, lean construction, and EPC, could help OSM to reduce its risks. However, many factories are still unclear as to how to use these methods. The risks of each new construction management method are presented below:

EPC is a highly efficient method of integrating diverse design, procurement, and construction processes simultaneously (Guo et al., 2010). In China, most EPC companies are contractors (Zhang et al., 2011), but the design process itself can significantly affect project performance. As the contractor has to cooperate with the consultant, this leads to a further problem for traditional construction, as few contractors have EPC experience, especially in the design process. Some OSC projects are known as EPC projects, but consultants and contractors have no communication or cooperation in these.

BIM provides great potential to promote the industrialisation of construction and improve the performance of OSC (Zhang et al., 2016). However, the application of BIM occurs mostly in the design phase. Few consider the on-site building process, which means that the BIM model is useless for contractors.

Lean construction aims to maximise the use of materials and labour in construction and avoid any waste or non-value-added activities (Mostafa et al., 2016). However, extant Chinese off-site manufacturers have little experience of lean construction, and some of them treat lean construction as being equivalent to the off-site component designing process only.

For Project Process, an influence diagram is developed to explain the category for each risk, this influence diagram presents how project process risks influence OSM project (see Figure 6.4).

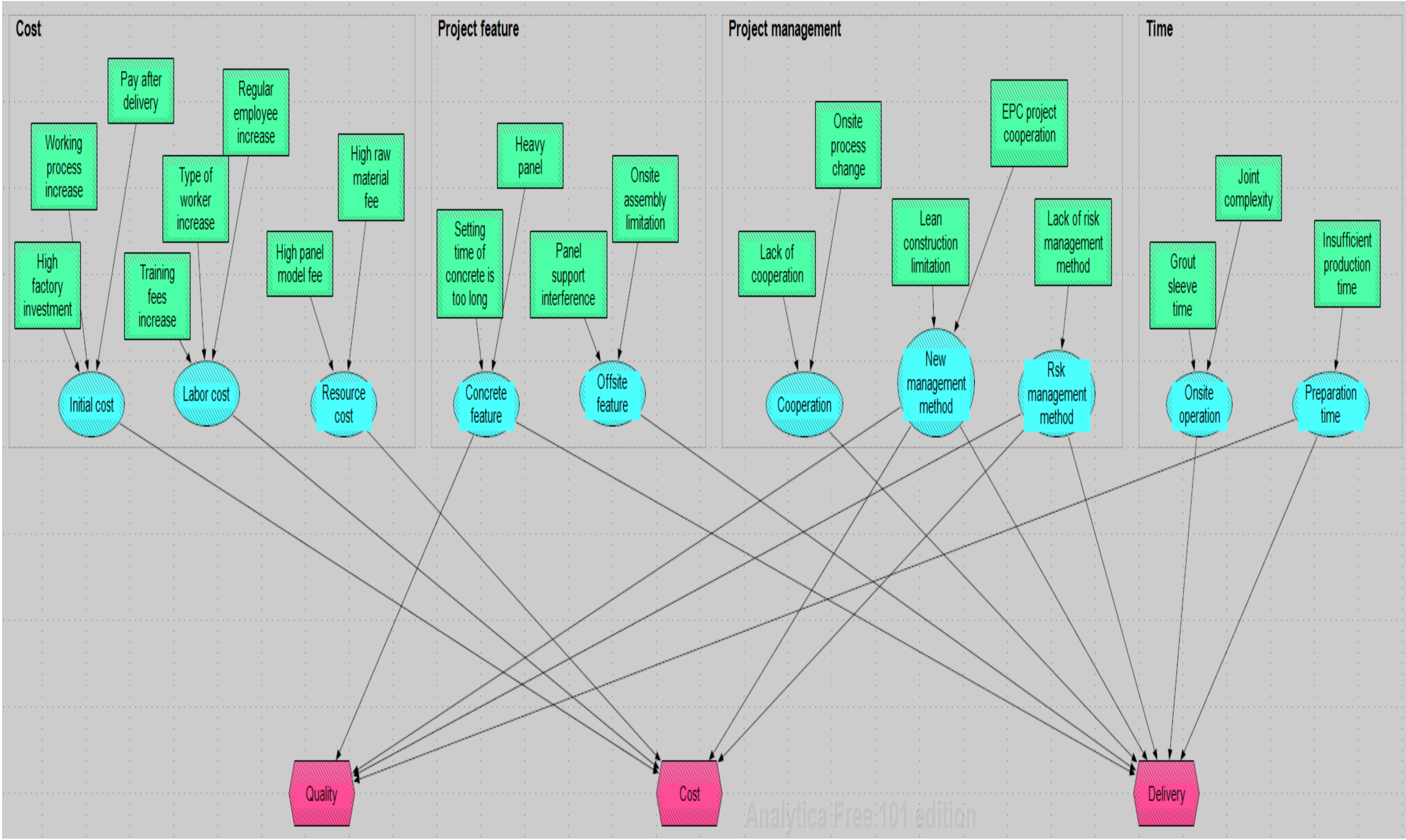


Figure 6.4: Influence diagram for Project Process by interview

6.3.5 External risk

1. External – Environment

P7 said: *'It is too hot in southern China. Many workers prefer to do another job rather stay in the off-site factory.'*

Although Arif et al. (2010) suggest that OSC provides better working conditions for workers as compared with traditional mass production manufacturing companies, the off-site factory often has poorer working conditions. As most off-site factories do not feature air conditioning or heaters, particularly in southern China, the temperatures in such factories may adversely influence workers' motivation.

In China, the number of building projects is seasonal. For example, in Guangdong province, rain is more frequent in the first half of the year, which means that more projects occur in the second half of the year and thus demand for labour is correspondingly seasonal.

P17 said, *'If the smog warning is orange in Beijing, then all OSM production is suspended.'*

Although Hong et al. (2018) suggest that OSC is less vulnerable to weather, it may still influence the OSC process. For example, in Beijing, the heavy smog caused by factory pollution resulted in Beijing suffering its highest average PM 2.5 concentration (Wang et al., 2014), which led to off-site manufacturers having to stop production to reduce the smog.

2. External – Resources

P25 said: *'A component mould production company does not consider whether the mould is easy to use. If the design of the mould is very bad, we will need a lot of time to demould the component.'*

Off-site resources require higher material and equipment quality than traditional construction. Regarding material quality, some suppliers cannot meet the requirements for OSC, and they lack awareness of how to improve their quality, thereby increasing component production time and reducing quality.

Regarding equipment quality, for example, some off-site manufacturers prefer to buy foreign component connectors than Chinese connectors, as the latter do not reach quality requirements.

P12 said, *'Some embedded parts require customisation, and these parts need time to produce.'*

Resource shortages may arise due to a lack of resources or resource delivery delays.

A lack of resources may lead to additional costs. For example, sand often contributes bulk, strength and stability to concrete and therefore is a necessary resource for PC components. However, to protect the biodiversity of the rivers and lakes, many sand mining operations are banned in China (Leeuw et al., 2010), resulting in an increase in the price of sand.

Resource delivery delays are also caused by other suppliers. Some component moulds require customisation and this is impossible for the supplier to prepare in advance.

P3 said, *'Our component moulds are customised by the supplier. If there is a deviation in the mould, it is impossible for us to assemble or demould the component.'*

Current supplier standardisation remains in chaos, especially in relation to component moulds. As mentioned under 'Project Member – Consultant', building designs may require a customised mould, and many of these may only be used once. Manufacturers cannot reuse these moulds.

Different suppliers have different standards for production of moulds. When manufacturing workers try to split or assemble a mould, it is often hard for them to learn new standards, forcing manufacturers to buy the mould from the same supplier.

3. External – Politic

P1 stated, *'For example, the national requirement is that a building should be more than 50% prefabricated. However, this [type of] building is not suitable for OSC. In order to meet the requirements, some parts are using off-site components unnecessarily.'*

The Chinese government has published several standards to promote OSC, and local authorities have been active in promoting its implementation (Jaillon et al., 2014). However, this may not be suitable for every type of building. For example, in Beijing, the aim is that 20% of new buildings should be fabricated via OSC (TPC, 2017). In order to reach this target, some local authorities are forcing contractors to use the off-site method. Contractors have to find the easiest method to achieve these assembly rates and, as the quality standard for off-site components is unclear, some contractors choose low-quality components so as to reduce costs and meet targets.

Another problem is that, as OSC is relatively new, design standards for such construction are conservative. This adds to the costs for materials.

P19 said, *'Unlike in northern China, where many decisions are made for political reasons, in our city, the owner prefers to choose the cheaper method. In the current situation, traditional construction is still cheaper than OSC.'*

Although the Chinese government gives support and subsidises OSC, the cost is still higher than for traditional construction. Many off-site companies fear that the subsidy promotion may stop, further reducing their willingness to operate OSC projects.

4. External – Society

P5 said, *'If you buy an OSC house, you may still have a concern whether the off-site building is reliable. The social understanding of OSC is still unclear.'*

Many people still have a bias against OSC. Aside from the current quality problem and the time aspects of OSC, another reason that should not be ignored is a historical one. In the 1950s, Chinese OSC was promoted across many areas. However, due to limitations of technology, equipment, and management, many quality problems arose (Wang et al., 2019). In the wake of the 1976 Tangshan earthquake, over 95% of the houses in the city collapsed, and more than 600,000 residents were either killed or wounded. Many of them lived in OSC-fabricated buildings. Therefore, the public called prefabricated components 'coffin boards' after the disaster (Wang et al., 2019). This historical problem is still an obstacle for an owner choosing OSC.

P2 said, *'Sometimes our price is very low, but some other company provides a much lower price, even lower than the cost. They can afford the price, but we cannot.'*

Contracting-out is a method whereby, after agreeing to a construction project, the contractor contracts out the construction project to others, either in its entirety or in part. The contracting-out of construction projects is forbidden in China. However, it still happens on occasion in some areas, especially in third-tier and fourth-tier cities in China. Thus, a contractor may win a contract at far below market price and then seek to contract-out to others in order to make a profit.

For External factors, an influence diagram has been developed to explain the categories arising for each aspect of risk, this influence diagram presents how external risks influence OSM project (see Figure 6.5).

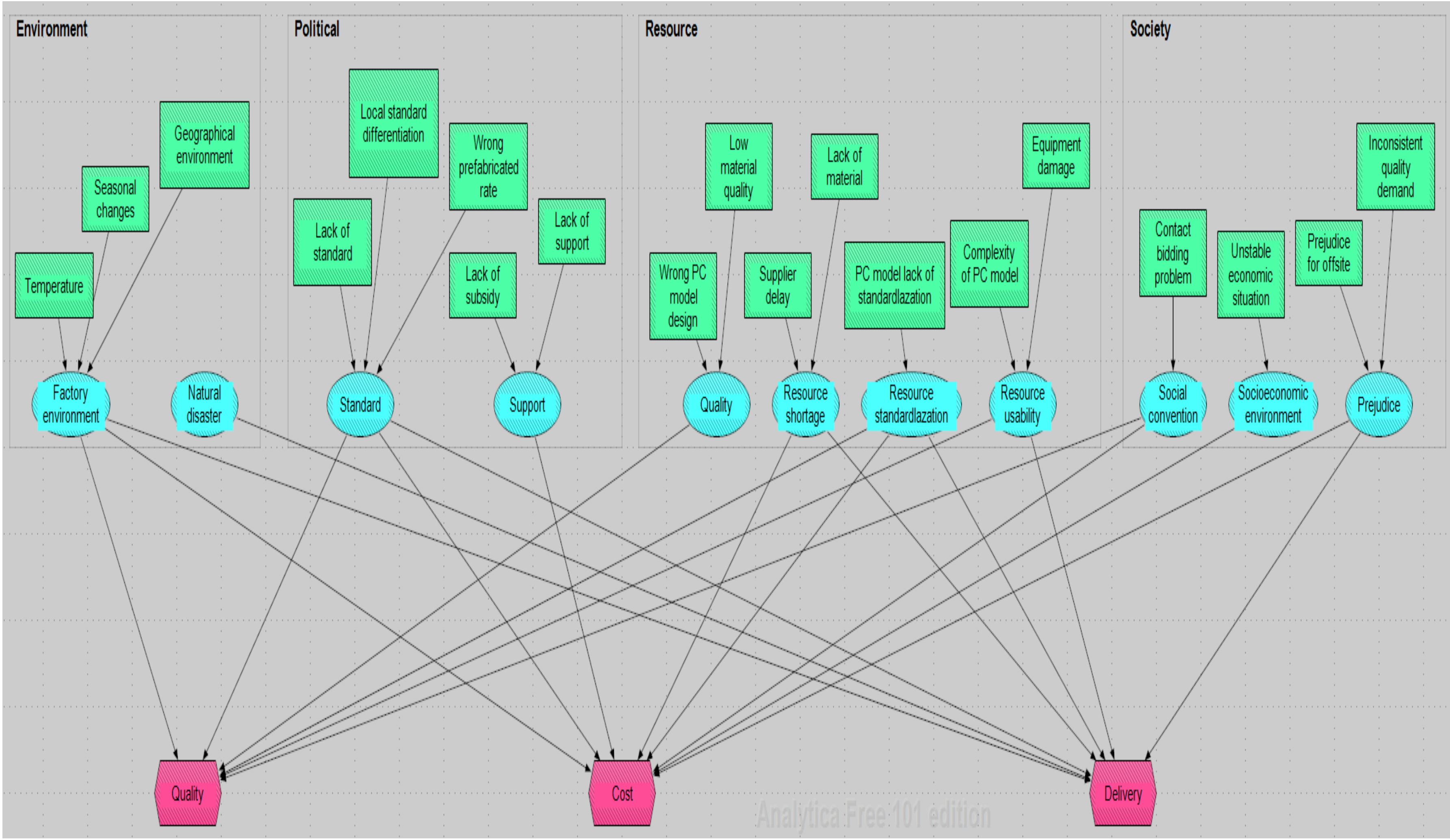


Figure 6.5: Influence diagram for External by interview

6.4 Risk explanation

After 77 risk factors are identified, the specification of each risk factor is presented in Table 6.6.

Table 6.6: Risk factor explanation for influence diagram

RISK FACTOR	EXPLANATION
Owner change demand	Owner may change demand during OSC project process.
Owner wrong demand	Owner may require the demand that not suitable for OSC project.
Change partner	Owner may change Manufacturer after conceptual design is finished.
Conceptual design error	Design error during conceptual design process.
Design development error	Design error during design development process.
Consultant lack of off-site experience	Consultant lacks of off-site design experience.
Consultant lack of on-site experience	Consultant lacks of off-site assembly experience.
Consultant lack of responsibility	Consultant lacks of OSC project design responsibility.
Consultant lack of standardization	Consultant lacks of OSC project design standardization.
Lack of professional software	Consultant lacks of OSC project design professional software
Manufacturer labour lack of experience	Manufacturer labour lacks of OSC component production experience
Manufacturer manager lack of experience	Manufacturer manager lacks of OSC component management experience
Manufacturer lack of manager	Manufacturer lacks of experienced OSC manager.
Manufacturer lack of labour	Manufacturer lacks of experienced OSC labour.
Manufacturer labour Lack of responsibility	Manufacturer lacks of OSC component production responsibility.
Production error	Error during component production process.
Assembly line lack of control	The Assembly line lack of control.
Improper operation sequence	Operation mistake during component production process.
Lack of factory facility	Manufacturer lacks of OSC component production facility.
Multiple projects at same time	Manufacturer have to do many OSC project at same time.
Insufficient depot	Manufacturer lacks of OSC depot to storage component.
Insufficient assembly line	Manufacturer lacks of OSC component production assembly line.

Driver lack of experience	Transporter's driver lack of logistics experience.
Transport accident	Sometime transport accident happened.
Transporter lack of responsibility	Transporter lacks of OSC component logistics responsibility.
Size of component	Component size is too big for the truck.
Wrong component storage order	Component has wrong storage order in depot cause had to transfer.
Component binding is not solid	Component may not bind solid on the truck.
Bad road condition	Road condition may be bad.
Long transport distance	On-site is too far away to the manufacturer.
Road restriction	Some roads do not allow truck to be transported during the day.
Contractor lack of willingness to cooperate	Contractor does not want to do OSC project, as they could not control the project process.
Contractor lack of labour	Contractor lacks of experienced on-site OSC labour.
Contractor lack of responsibility	Contractor lacks of OSC component assembly responsibility.
Contractor lack of standardization	Contractor lacks of OSC component assembly standardization.
Multiple manufactory	Multiple manufactories provide component to one project, which the component may not fit.
Grout sleeve inspection is impossible	Grout sleeve inspection process cannot be monitored.
High manufactory investment	Manufactory building investment is very expensive.
Working process increase	As more organization participate OSC project, more working process for all participant.
Pay after delivery	Manufacturer can only get pay after the OSC project is finished, which means the manufacturer have to wait a long time.
Training fee increase	Practitioner lack of experience means more training is required, which increase the training fee.
Type of worker increase	More types of workers are required as more process in OSC project.
Regular employee increase	The experienced practitioner requires to become contact worker, which increase the company cost.
High component model fee	Component production need model, which is a cost for the manufacturer.
High raw material fee	OSC component requires higher quality material, which is more experience.
Setting time of concrete is too long	On-site assembly requires Grout sleeve inspection process, which take time.
Heavy component	The component is very heavy during logistic process.
Component support interference	Component need support during on-site assembly process, which may interference the worker.
On-site assembly limitation	On-site assembly problem like tower crane cannot hoist the heavy component.

Lack of cooperation	Lack of cooperation between OSC organizations.
On-site process change	On-site process may change or pause like bad weather.
Lean construction limitation	Lean construction does not prove the benefit for OSC project.
EPC project cooperation	OSC organizations lack of cooperation in EPC project
Lack of risk management method	There are few risk management method for OSC project.
Grout sleeve time	Grout sleeve inspection process cost a lot of time.
Joint complexity	On-site joint assembly is very complex.
Insufficient production time	Component production cost a lot of time, but the manufacturer always has limit time.
Temperature	Temperature is too high or too low, make the working environment worse.
Seasonal change	Seasonal change, some workers do not want to work in certain season.
Geographical environment	Different geographical environment in different area of China, which result the manufactory need produce different types of component.
Lack of political standard	Lack of political standard from the government.
Local standard differentiation	Different provinces have different OSC standard, which cause some OSC organizations confusion.
Wrong prefabricated rate	Some prefabricated rate from government standard is not suitable for OSC project.
Lack of subsidy	Lack of subsidy from government.
Lack of support	Lack of support from government.
Wrong component model design	Component model may design wrong, which cause hard to produce component.
Low material quality	The material quality may not fit for OSC component production.
Supplier delay	Supplier may not delivery the material on time.
Lack of material	Lack of high stand material for OSC component.
Component model lack of standardization	Component model lack of design standardization.
Complexity of component model	Component model is complex to assemble.
Equipment damage	Some equipment may get damage.
Contract bidding problem	Always the lowest price wins the contract result there is no profit for manufacturer.
Unstable economic situation	Current global economic situation is unstable.
Prejudice of OSC	Many people have prejudice of OSC project and think it is unsafe.
Inconsistent quality requirement	Government quality requirement for OSC component is inconsistently.

6.5 Chapter summary

This chapter presented analysis and findings from a set of semi-structured interviews undertaken to develop questionnaire for the purposes of quantitative analysis. As a result, 3 types and 13 groups amounting to some 77 risk factors were defined, and an influence diagram was developed based on these to connect the risk internal relationship and external influences for QCD.

CHAPTER 7 - QUANTITATIVE RESULTS

7.1 Introduction

This chapter reports results obtained from the questionnaire survey and includes the identification of significant risks in the OSM process that delay OSC projects. The precise statistical methodology and the analytical process for the questionnaire analysis are also presented. The data for the questionnaire were derived from 436 OSC industry practitioners who engage in OSC projects. These findings are presented later in this chapter.

7.2 Participant details of pilot study

This section presents the personal details of the participants of the pilot study.

Table 7.1 presents the details of participants who took part in this questionnaire based on their respective roles in the company. In general, most participants came from 'manufacturing' companies (57.4%), followed by 'consultants' (25.9%) and 'contractors' (29.6%). There were a few 'owners' (13.0%) and a few 'transporters' (5.6%) who were willing to respond to this questionnaire. There was also one participant (1.85%) who came from a 'testing facility'. Considering that some of the companies were EPC companies, there may be more than one correct answer to this question.

Table 7.1: Participant details: quantitative pilot study

BUSINESS SCOPE OF COMPANY	NUMBER	RATE
Owner	7	12.96%
Consultant	14	25.93%
Manufacturer	31	57.41%
Transporter	3	5.56%
Contractor	16	29.63%
Other	1	1.85%
Total no. of participants	54	

Table 7.2 presents the type of company. Most companies were two types, namely 'state-owned companies' (59.3%) and 'private companies' (38.9%). Only one

company was a joint venture (1.85%). None of the companies was foreign.

Table 7.2: Type of company: quantitative pilot study

TYPES OF COMPANY	NUMBER	RATE
State-owned Company	32	59.26%
Private Company	21	38.89%
Foreign Company	0	0%
Joint Venture Company	1	1.85%
Other	0	0%
Total no. of participants	54	

Table 7.3 presents the numbers of employees in each company. Most companies were ‘small’ (44.4%). However, as compared with ‘medium-sized companies’ (24.1%) and ‘large companies’ (31.5%), the frequencies were notably similar.

Table 7.3: Employee numbers by company type in pilot study

EMPLOYEE NUMBERS IN COMPANY	NUMBER	RATE
Large (Employees > 1000)	17	31.48%
Medium (Employees 500~1000)	13	24.07%
Small (Employees < 500）	24	44.44%
Total number of participants	54	

Table 7.4 presents the level of experience of the participants within the construction industry. Most of the participants were relatively new, as only 51.9% of participants had ‘0~5 years’ of experience, while the other three groups were quite evenly divided with 18.5% of participants having ‘5~10 years’ of experience, 13.0% ‘10~15 years’ of experience, and 16.7% of participants over ‘15 years’ of experience.

Table 7.4: Experience levels of the participants of pilot study

YEARS OF EXPERIENCE	NUMBER	RATE
0~5 years	28	51.85%
5~10 years	10	18.52%
10~15 years	7	12.96%
> 15 years	9	16.67%
Total	54	

7.3 Research factor analysis – pilot study

7.3.1 Risk factor definition

In the questionnaire, the probability and impact of the risk factors on an OSC project, as determined by a five-point Likert scale, are shown in Table 7.5 and Table 7.6 (Chapman, 1999).

Table 7.5: Probability Likert scale (Chapman, 1999)

PROBABILITY	DESCRIPTION	SCALE VALUE	LEVEL
Frequent	Constant occurrence	5	Critical
Probable	Likely to occur regularly	4	
Occasional	Quite often occurs	3	Intermediate
Rarely	Little likelihood but could well happen	2	Not critical
Improbable	Unlikely but possible	1	

Table 7.6: Impact Likert scale (Chapman, 1999)

IMPACT	DESCRIPTION	SCALE VALUE	LEVEL
Extreme	Constant occurrence	5	Critical
Great	Likely to occur regularly	4	
Moderate	Quite often occurs	3	Intermediate
Little	Little likelihood but could well happen	2	Not critical
Negligible	Unlikely but possible	1	

In the pilot study, only risk impact is considered to reduce the time for the participant. In general, mean risk impact ratings from 3.0 to 5.0 could be considered an intermediate or critical level of risk, respectively, in terms of the risk analysis process. However, after the pilot study, the mean scores and rankings of the 77 risks identified are shown in Table 7.7.

Table 7.7: Risk factor definitions: pilot study

Risk factor	Mean	Std. Deviation
Conceptual design error	4.50	0.746
Wrong component model design	4.37	0.853
Consultant lack of off-site experience	4.35	0.677
Consultant lack of responsibility	4.31	0.886
Design development error	4.30	0.690
Illegal subcontracting problem	4.28	0.811
Low material quality	4.26	0.955
Participants lack cooperation	4.26	0.732
Lack of government support	4.26	0.851
Contractor lacks responsibility	4.22	0.769
Contractor lacks standardisation	4.20	0.833
Lack of material	4.20	0.939
Consultant lacks on-site experience	4.19	0.803
Lack of government standards	4.19	0.913
Component model lacks standardisation	4.17	0.841
Manufacturer lacks responsibility	4.17	0.863

Owner changes demands	4.13	0.825
Consultant lacks knowledge of standardisation	4.13	0.933
Supplier delay delivery	4.11	0.883
Equipment damage	4.09	0.957
Manufacturer labour force lacks experience	4.06	0.834
Transporter component binding is not solid	4.06	0.960
Complexity of component model	4.06	0.856
Unstable economic situation	4.06	0.998
On-site construction period changes	4.06	0.811
Manufacturer management lacks experience	4.06	0.920
Contractor lacks willingness to participate	4.04	0.910
Contractor lacks experience	4.04	0.823
Owner changes partners	4.04	0.846
Grout sleeve inspection is impossible	4.04	1.009
Owner demand not suitable for OSC	4.04	0.889
EPC lacks cooperation	4.02	0.879
Component production error	4.02	0.942
High factory investment	3.98	0.961
Contractor lacks labour force	3.98	0.901
Transporter placed wrong component storage order	3.94	0.920
Prejudice against OSC	3.94	0.960
Insufficient components in depot	3.94	0.899
Manufacturer lacks labour	3.94	0.940
Assembly line lacks control	3.93	0.949
Complexity of joint assembly	3.91	0.853
Lack of risk management method	3.89	0.904
Improper operation sequence	3.87	0.891
Manufacturer lacks factory facilities	3.87	1.029
Components paid after delivery	3.85	0.998
Consultants lack professional software	3.83	0.947
Local government standard differentiation	3.83	0.966
Rigid prefabricated rate requirement	3.83	0.927
Lack of government subsidy	3.80	1.016
Insufficient assembly line	3.78	0.984
High raw material fees	3.74	0.955
On-site component assembly limitation	3.74	0.915
Transporter lacks responsibility	3.74	1.067
Manufacturer lacks manager	3.74	0.955
Road restrictions	3.72	0.960
Insufficient production time	3.69	1.096
Geographical differences	3.69	0.843
High component model fee	3.69	0.948
Transport accident	3.65	1.049

Long transport distance	3.63	0.958
Excessive component quality demand	3.61	0.960
Component is too heavy	3.59	0.981
Contractor has multiple factory productions at the same time	3.57	1.039
Transporter driver lacks experience	3.54	1.004
Bad road conditions	3.52	0.863
Natural disaster	3.37	1.322
Grout sleeve time is long	3.31	1.043
Seasonal changes	3.30	0.944
Working processes increase	3.28	0.940
Temperature in manufactory too high	3.28	0.998
Component support interference	3.26	1.031
Setting time of concrete is too long	3.22	1.110
Manufacturer produces multiple projects at the same time	3.22	1.003
Lean construction limitation	3.15	1.204
Types of worker increase	3.07	1.007
Long-term contract worker numbers increase	3.06	0.960
Training fees increase	2.76	1.008

Of a total of 77 risk factors presented, 76 achieved a mean score over 3, thus indicating significant risk. However, other similar research (Baloi et al., 2003; Creedy et al., 2010; Rezakhani, 2012) contended that the number of significant risks was around 15-40. Thus, an alternative method was chosen to identify the significant risk arising in the research. Factors with mean scores higher than the average total value were identified as critical risks for Chinese OSM risk. This method was also used in the main questionnaire process.

7.3.2 Result of pilot factor analysis

A factor analysis was applied to determine the components of the OSM risk factors. Some risk factors were deleted for one or several of the following reasons: (1) The risk factor contributed to more than one component; (2) The component had only one risk factor; or (3) The risk factor exhibited a big difference as compared with the other risk factors in relation to the same component. After the improper risk factors were deleted, 35 risk factors were subsequently analysed. As the risks were divided according to three variables (project process, project member, and external), three types of factor analysis were performed for each variable. The results of Bartlett's sphericity test (and associated significance level) and the values for the KMO measures of sampling accuracy are presented for each variable in Table 7.8. The results of Bartlett's sphericity test were 129.158, 737.474, and 289.309, respectively with an associated significance level of 0.000. The values for the KMO measure of sampling accuracy were 0.751, 0.776, and 0.808, all of which are higher than 0.6. These results indicate that the sample set was suitable for factor analysis (Basto et al., 2012).

Table 7.8: KMO measure for each variable: pilot study

Variables	KMO Measure	Approx. Chi-Square	Sig.
Project process	0.751	129.158	0.000
Project member	0.776	737.474	0.000
External	0.808	289.309	0.000

For project process variables, only one component with eigenvalues greater than 1 was extracted through principal component analysis, accounting for 54.1% of the cumulative. As only one component was created, each of the project process's six critical risks belong to the same component (see Table 7.9).

Table 7.9: Component matrix for the project process: pilot study

RISK FACTOR	COMPONENT
	1
High factory investment	Only one component was extracted.
Components paid after delivery	
Participants lack cooperation	
On-site construction period change	
EPC lack of cooperation	
Lack of risk management method	
Eigenvalues	3.248
Variance (%)	54.130
Cumulative (%)	54.130

Component 1 (initial preparation work risk) comprises seven risks which focus on issues arising prior to the manufacturing process being established. These components include the initial cost and communication with other participants. Many articles present initial cost as the primary barrier to OSC's wider adoption (Arif et al., 2010; Hong et al., 2018; Pan and Sidwell, 2011; Rahman, 2014), as the cost of manufacturing buildings can be high. Even worse, the 'pay after delivery' method means that the manufacturing process needs very high levels of capital investment. This cost causes many companies to hesitate to establish OSM facilities. The initial communication with other participants is limited. As the construction industry is inherently fragmented, different participants have different demands and requirements (Rahman, 2014). This deters the adoption of OSC. To solve this problem, some companies have tried the Engineering Procurement Construction (EPC) method. EPC aims to integrate the construction industry (Ishii et al., 2014), but this method is relatively new in China and still lacks internal cooperation. This unclear risk management method for OSM further decreases confidence in OSC.

For the project member variables, four components with eigenvalues greater than 1 were extracted through a principal component analysis, accounting for 68.3% of the total. Each of the 20 critical risks belonged to only one of the four components, and the factor loading value exceeded 0.5 (see Table 7.10).

Table 7.10: Component matrix for project members: pilot study

RISK FACTOR	COMPONENT			
	2	3	4	5
Improper operation sequence	0.804			
Assembly line lacks control	0.761			
Component production error	0.752			
Manufacturer lacks factory facilities	0.720			
Manufacturer labour lacks experience	0.700			
Transporter component binding is not solid	0.644			
Transporter placed wrong component storage order	0.601			
Consultant lacks off-site experience		0.767		
Consultant lacks on-site experience		0.764		
Conceptual design error		0.702		
Consultant lacks responsibility		0.686		
Design development error		0.654		
Contractor lacks experience			0.817	
Contractor lacks labour			0.813	
Contractor lacks standardisation			0.692	
Contractor lacks responsibility			0.638	

Contractor lacks willingness to participate			0.605	
Owner demands not suitable for OSC				0.809
Owner changes partners				0.705
Owner changes demand				0.621
Eigenvalues	4.626	3.538	3.291	2.212
Variance (%)	23.132	17.692	16.453	11.059
Cumulative (%)	23.132	40.824	57.277	68.336

Component 2 (Manufacturer and Transporter risk) comprises seven risks which focus on issues relating to the manufacturer and the transporter. Many manufacturers are responsible for PC component transportation, which causes the manufacturer to share the risk with the transporter. As OSC is a relatively new method (Han et al., 2018), the inexperienced workers of off-site manufacturers cause many problems including erroneous component production and improper operation sequencing. The supporting facilities for OSM require more development, as the lack of such facilities influences the manufacturer in producing certified products. Although the PC components are certified, the transportation process may still damage components. As the storage and transport standards of OSC remain unclear (Boyd et al., 2013), transportation problems, such as incorrect PC component storage or component binding, can arise during this process.

Component 3 (Consultant risk) comprises five risks that focus on issues relating to consultancy. As mentioned above, consultancy risks are identified as the foremost obstacle in the ranking analysis of OSM, especially in relation to the conceptual design process. These conceptual design issues cause a domino effect so that the design development error probability also increases. Such design errors are derived from two factors. The first of these is a lack of experience and the second is a lack of responsibility. Some articles also cite OSC's lack of technology and experience (Pan et al., 2008; Vernikos et al., 2014; Wu et al., 2019).

Component 4 (Contractor risk) comprises five risks that focus on issues relating to the contractor, such as the consultant's lack of experience and lack of responsibility. It is also reflected in the contractor's lack of adequate skilled labour and lack of understanding of standardisation (Mao et al., 2016). In China, contractors and subcontractors receive the least profit from OSC methods, a reality that often deters contractors from participating.

Component 5 (Owner risk) comprises three risks that focus on issues relating to the owner. In traditional construction, owners can change their demands or partners during the construction project process following traditional construction methods. However, OSC requires the freezing of the design before the project begins (Pan et al., 2012). Many manufacturers complained that the owner changed their demands or partners during the OSC project process (M1, M3). If the owner lacks OSC experience, they tend to choose the more familiar and conventional method of traditional construction. However, OSC is not the same and this means the owners' demands are not suited to OSC.

In terms of external variables, two components with eigenvalues greater than 1 were extracted through a principal component analysis, accounting for 65.2% of the cumulative. Each of the ten critical risks belonged to only one of two components, and the factor loading value exceeded 0.50 (see Table 7.11).

Table 7.11: Component matrix for external variables: pilot study

Risk factor	**Component**	
	5	6
Lack of material	0.863	
Component model lacks standardisation	0.814	
Wrong component model design	0.789	
Supplier delay delivery	0.780	
Equipment damage	0.764	
Low material quality	0.747	
Complexity of component model	0.705	
Unstable economic situation		0.882
Prejudice against OSC		0.877
Lack of government standards		0.627
Eigenvalues	4.342	2.183
Variance (%)	43.421	21.832
Cumulative (%)	43.421	65.253

Component 6 (Material and Equipment risk) comprises seven risks that focus on

issues relating to the external supplier. The raw material suppliers remain within the traditional construction industry which requires lower quality materials than OSC. This means that many material suppliers cannot reach the requirements for OSC materials. The manufacturer's equipment is required to be of higher quality to produce off-site components, and broken or damaged equipment always delays the manufacturing process. For example, the component model quality defines the quality of off-site PC components. However, current component model suppliers lack standardisation, which often leads to the component design either being bad or too complex to assemble or break up.

Component 7 (Society and Government risk) comprises three risks that focus on issues relating to society and government supports. Chinese OSM lacks government support and appropriate codes and standards (Zhai et al., 2014). In China, the deviation in OSC standards across different provinces further aggravates this problem. In the last three years, the US-China trade war has led many Chinese companies to consider that the economic situation may take a turn for the worse (Itakura, 2020). This trepidation has also spread to OSM. Another problem comes from society. In the wake of the 1976 Tangshan earthquake, more than 600,000 residents were either killed or wounded, and many of them lived in OSC buildings. Therefore, customers are worried about the quality of such buildings (Wang et al., 2019) and, as a result of this prejudice, customers are refusing to buy off-site buildings.

7.3.3 Risk factor analysis conclusions

Based on the pilot study, the factors for the risk groups were defined to include seven components:

1. Initial preparation work risk.
2. Manufacturer and Transporter risk.
3. Consultant risk.
4. Contractor risk.
5. Owner risk.

6. Material and Equipment risk.
7. Society and Government risk.

This system of classification identified the appropriate risk groups and risk factors for the questionnaire. However, this pilot study only covered the impact of the risk, which is incomplete in terms of risk impact and probability analysis. In order to solve this problem, the probability and impact were both analysed in main research.

7.4 Participant detail – main study

This section presents the personal details of the participants of the main study. The reliability and validity of the questionnaire are tested in this section.

7.4.1 Reliability and Validity

This research used Cronbach's alpha to measure the internal consistency arising among the selected risk factors to evaluate the reliability of the scale. Cronbach's alpha is a test reliability technique that requires only a single test administration to provide a unique estimate of the reliability for a given test. Cronbach's alpha is the average value of the reliability coefficients one would obtain for all possible combinations of items when split into two half-tests. When using Likert-type scales it is imperative to calculate and report Cronbach's alpha coefficient for internal consistency reliability for any scales or subscales one may be using (Gliem et al., 2003). In order to identify the reliability of the questionnaire, Cronbach's coefficient alpha was used, and the test result was 0.991 (see Table 7.12), which is higher than the 0.7 threshold, indicating that the five-point scale measurement was reliable at the 5% significance level (Kline, 2000). The validity definition used the KMO test. The KMO criterion for the adequacy of the sample is an index comparing the size of the observed correlation coefficient and partial correlation coefficient. The KMO rate must be above 0.50. The higher the rate, the better the data set for factor analysis (Tastan et al., 2008). The KMO test result was 0.964 (see Table 7.13), which was higher than the 0.7 threshold for a reliable instrument (0.8 indicates a very reliable instrument; (Promsawad et al., 2014). Whether any given risk is significantly important is based on the mean scores presented against a test value of 3 (with a significance level of 0.05).

Table 7.12: Cronbach's coefficient alpha result

Reliability Statistics

Cronbach's Alpha	N of Items
.991	122

Table 7.13: KMO and Bartlett's Test results

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.964
Bartlett's Test of Sphericity	Approx. Chi-Square	65940.308
	df	7381
	Sig.	.000

7.4.2 Detail for participant

Table 7.14 presents the level of experience of the participants in the construction industry. Although the greatest number of participants only had '0~5 years' experience (35.78%); '5~10 years' experience (24.77%); or 'more than 15 years' experience (22.25%), there was also a significant number with '10~15 years' of experience (17.2%). This indicates that many of the participants had extensive experience in the construction industry, which results in the participants having the necessary experience to discuss risk management within the construction industry.

Table 7.14: Participant details

YEARS OF EXPERIENCE	NUMBER	RATE
0~5 years	156	35.78%
5~10 years	108	24.77%
10~15 years	75	17.2%
> 15 years	97	22.25%
Total	436	

Table 7.15 presents the experience levels of the participants in the OSC industry. Most participants are relatively new to the construction industry, 74.08% of participants had only '0~5 years' of experience. 18.52% of participants had '5~10 years' of experience, while the other two groups were quite evenly divided with 4.36% of participants having '10~15 years' of experience and 5.5% 'more than 15 years'. This represents the fact that the OSC sector is relatively new to China, and so most participants lack

experience. In this case, it is necessary to identify those risk arising in the OSM process to reduce the potential risk that may occur in the future of participants' projects.

Table 7.15: Experience in OSC industry

YEARS OF EXPERIENCE (OSC)	NUMBER	RATE
0~5 years	323	74.08%
5~10 years	70	16.06%
10~15 years	19	4.36%
> 15 years	24	5.5%
Total	436	

Table 7.16 presents the number of OSC projects in which the participants were involved. Although some of the participants were not involved in any OSC projects as of yet (28.67%), three-quarters of the participants were involved in at least 1 OSC project; whereas 35.09% of participants had participated in '1-3 projects'; 12.84% in '4-6 projects', and 5.5% in '7-9 projects'. A total of 78 participants claimed involvement in more than 10 projects, indicating a relatively high level of experience, which is important for a reliable response.

Table 7.16: Number of OSC projects participants were involved

NUMBER OF OSC PROJECTS	NUMBER	RATE
0	125	28.67%
1-3	153	35.09%
4-6	56	12.84%
7-9	24	5.5%
> 10	78	17.89%
Total	436	

Table 7.17 presents the details of participants who took part in this questionnaire in relation to their respective business involvement within the company. In contrast to the pilot study, most of the participants in the main study were 'Contractors' (36.01%). 'Consultants' (27.98%) or 'Manufacturers' (27.75%). 'Owners' comprised the lowest level of representation (17.2%) along with 'Transporters' (4.36%). For the 'other' participants, the details of the participants are presented in Table 7.18. The table indicates that some of the participants perhaps misunderstood the question (for instance, some participants thought that sub-contractors were not a subset of

‘contractor’, and thus considered sub-contractor as ‘other’). There were 14 participants who misunderstood the question. Other participant categories included ‘Business consulting’, ‘Software development’, ‘Research Unit’, ‘Insurance’, ‘Supervision’, and ‘Intermediary’. This proves that OSC is a whole life cycle progress, which requires support from other industries.

Table 7.17: Business scope of company

BUSINESS SCOPE OF COMPANY	NUMBER	RATE
Owner	75	17.2%
Consultant	122	27.98%
Manufacturer	121	27.75%
Transporter	19	4.36%
Contractor	157	36.01%
Other	33	7.57%
Total	436	

Table 7.18: Business scope of company (others)

BUSINESS SCOPE OF COMPANY (OTHERS)	NUMBER
Business consulting	5
Software development	4
Research Unit	3
Insurance	1
Supervision	5
Intermediary	1
Misunderstood the question	14
Total	33

Table 7.19 presents the type of off-site materials that the participants’ companies employed. Most companies are using ‘concrete structures’ as the main structure for their OSC projects (84.17%). In previous articles, only 5% were using steel structures for OSC projects (Mao et al., 2015). This represents a significant increase in ‘steel structures’ (22.71%). Only 5.0% of companies were using ‘wooden structures’ for OSC projects. Although 13 participants used ‘other’ structures, all these companies are support companies for the OSC industry (insurance, business consulting, etc.), which still constitutes a form of support for one or more of these three structures.

Table 7.19: Types of off-site material

TYPES OF OSC MATERIAL	NUMBER	RATE
Concrete structure	367	84.17%
Steel structure	99	22.71%

Wooden structure	22	5.05%
Other	13	2.98%
Total	436	

7.5 Main research mean – probability

This section of the questionnaire listed 61 risks factors identified within the interview process and asked the participants to evaluate the probability of each risk factor arising on a five-point Likert scale. The Likert scale spans the risk probability spectrum from improbable, rarely, occasionally, and probable to frequent.

Table 7.20 presents the mean scores on the instruments measuring the risk probability associated with the OSM risk group. Each risk factor within the questionnaire was rated on a scale of 1 to 5 which could be more readily analysed. The overall mean for the risk group was 3.30, which serves as the intermediate number for our analysis. In this case, cost (3.42), off-site features (3.40), project management (3.3), time (3.38), ownership (3.38), consultancy (3.35), government policy (3.32), and society (3.39) were all significant risk groups, while manufacturer (3.18), transporter (3.17), environment (3.00), and resources (3.13) were relatively improbable risk groups. The most significant risk group of all was project management, and the most improbable risk group was environment.

Table 7.20: Probability mean scores for risk groups

RISK GROUP	MEAN(P)	DECISION
Cost	3.42	Significant
Off-site feature	3.40	Significant
Project management	3.53	Significant
Time	3.38	Significant
Owner	3.38	Significant
Consultant	3.35	Significant
Manufacturer	3.18	Improbable
Transporter	3.17	Improbable
Environment	3.00	Improbable
Government policy	3.32	Significant
Resource	3.13	Improbable
Society	3.39	Significant
Total	3.30	

In terms of internal risk, the significant risk factors included high off-site manufactory building costs; overall increases in working processes; component pay after delivery;

more regular employees; high component models and material fees in cost group. Components may be too heavy and on-site assembly limitations exist in the off-site feature group. A lack of cooperation, adjustments or changes to on-site construction periods, the lack of an appropriate risk management method, or 'difficult to deploy' new management methods within project management groups were all cited. In addition, there was complexity arising in joint assembly and insufficient production times in the group.

Table 7.21 presents the mean scores for the internal risk factors identified. The highest mean factor in the cost group was 'high component model and material fees' (3.74). Whereas the highest mean factor in the off-site feature group was 'on-site assembly limitations' (3.52). The highest mean factor in the project management group was 'on-site construction period adjustments or changes' (3.61). And the highest mean factor in the time group was 'complexity of joint assembly' (3.43).

Table 7.21: Probability mean score for internal risks

RISK GROUP	RISK FACTORS	MEAN(P)	STD. DEVIATION	DECISION
Cost	High off-site manufactory building cost	3.72	1.166	Significant
	Overall working process increase	3.28	1.178	Significant
	Components paid after delivery	3.47	1.312	Significant
	High training cost	3.20	1.207	Improbable
	More types of workers	3.22	1.278	Improbable
	More regular employees	3.35	1.217	Significant
	High component model and material fees	3.74	1.139	Significant
	Grand Mean		3.42	
Off-site feature	Component is too heavy	3.47	1.177	Significant
	Component support interference	3.23	1.188	Improbable
	On-site assembly limitations	3.52	1.246	Significant
	Grand Mean		3.40	
Project management	Lack of cooperation	3.56	1.185	Significant
	On-site construction period adjustment or change	3.61	1.177	Significant

	Lack of risk management method	3.50	1.189	Significant
	Hard to deploy new management method	3.45	1.151	Significant
	Grand Mean		3.53	
Time	Complexity of joint assembly	3.43	1.155	Significant
	Insufficient production time	3.34	1.274	Significant
	Grand Mean		3.38	

In terms of participant risk within the owner group, the significant risk factors arising included owners changing demands and those demands not being suitable for off-site projects. Design error, consultants' lack of off-site experience, consultants' lack of on-site experience, and consultants' lack of standardisation were all significant risk factors within the consultant group. Manufacturers' lack of experience, unavoidable errors in component production, and insufficient component yard storage were the significant risk factors within the manufacturer group. Contractors' lack of experience, contractors' lack of experienced employees, and lack of on-site assembly standardisation were all identified as significant risk factors within the contractor group.

Table 7.22 presents the mean scores for the participants' risk factors. The highest mean factor within the owner group was 'owner changes demand' (3.49); the highest mean factor within the consultant group was 'consultant lacks on-site experience' (3.55); the highest mean factor within the manufacturer group was 'manufacturer lacks experience' (3.34); while the highest mean factor within the transporter group is 'transportation road problems' (3.23); and the highest mean factor within the contractor group was 'contractor lacks experienced employees' (3.45).

Table 7.22: Probability mean score for participant risks

RISK GROUP	**RISK FACTORS**	**MEAN(P)**	**STD. DEVIATION**	**DECISION**
Owner	Owner changes demand	3.49	1.132	Significant
	Demands not suitable for off-site project	3.46	1.143	Significant
	Owner changes project partners	3.21	1.116	Improbable
	Grand Mean		3.38	

Consultant	Design error	3.31	1.243	Significant
	Consultant lacks off-site experience	3.55	1.170	Significant
	Consultant lacks on-site experience	3.58	1.153	Significant
	Consultant lacks responsibility	3.2	1.342	Improbable
	Consultant lacks standardisation	3.31	1.266	Significant
	Consultant lacks suitable professional software	3.15	1.319	Improbable
	Grand Mean		3.35	
Manufacturer	Manufacturer lacks experience	3.34	1.258	Significant
	Manufacturer lacks employees	3.25	1.234	Improbable
	Manufacturer lacks responsibility	3.1	1.267	Improbable
	Unavoidable errors in component production	3.32	1.247	Significant
	Assembly line lacks control	3.16	1.281	Improbable
	Lack of off-site manufactory facilities and equipment	2.98	1.296	Improbable
	Producing different types of components at the same time	3.1	1.331	Improbable
	Insufficient component yard storage	3.31	1.293	Significant
	Insufficient assembly line	3.12	1.262	Improbable
	Grand Mean		3.18	
Transporter	Transporter lacks experience	3.21	1.297	Improbable
	Transporter lacks responsibility	3.02	1.322	Improbable
	Mistakes arise during the transfer process	3.18	1.279	Improbable
	Transportation road problems	3.23	1.304	Improbable
	Long transport distance	3.23	1.261	
	Grand Mean		3.17	
Contractor	Contractor has lack of willingness to participate in off-site project	3.28	1.236	Improbable
	Contractor lacks	3.42	1.215	Significant

	experience			
	Contractor lacks responsibility	3.15	1.273	Improbable
	Contractor lacks experienced employees	3.45	1.219	Significant
	Lack of on-site assembly standardisation	3.3	1.259	Significant
	Grand Mean		3.32	

In terms of external risks, the significant risk factors included differentiation in local government policy standards, rigid prefabricated rate requirements, and a lack of subsidy and support within government policy groups. For the resource group it was a lack of standardisation of component models. In the society group it was contract bidding issues, an unstable economic situation, public society prejudices against OSC, and inconsistent quality demands for OSC projects.

Table 7.23 presents the mean score for the external risk factors identified. The highest mean factor in the environment group was 'geographical environment' (3.16); for the government policy group it was a 'lack of subsidy and support' (3.39); for the resource group it was 'component model lacks standardisation' (3.35); and for the society group it was 'contract bidding problems' (3.56).

Table 7.23: Probability mean score for external risks

RISK GROUP	RISK FACTORS	MEAN(P)	STD. DEVIATION	DECISION
Environment	Geographical environment	3.16	1.226	Improbable
	Manufacturing indoor environment	2.97	1.235	Improbable
	Seasonal changes	3.00	1.241	Improbable
	Natural disaster	2.9	1.329	Improbable
	Grand Mean		3.00	
Government policy	Lack of government policy standards	3.24	1.262	Improbable
	Local government policy standard differentiation	3.33	1.204	Significant
	Rigid prefabricated rate requirement	3.33	1.208	Significant
	Lack of subsidy and support	3.39	1.245	Significant
	Grand Mean		3.32	

Resource	Low material quality	3.05	1.266	Improbable
	Supply delay or not on time	3.15	1.280	Improbable
	Lack of material	3.07	1.295	Improbable
	Component model lacks standardisation	3.35	1.277	Significant
	Manufactory equipment damage	3.06	1.263	Improbable
	Grand Mean		3.13	
Society	Contract bidding problem	3.56	1.255	Significant
	Unstable economic situation	3.31	1.249	Significant
	Public society prejudice for off-site building	3.36	1.202	Significant
	Inconsistent quality demand for OSC project	3.35	1.240	Significant
	Grand Mean		3.39	

7.6 Main research mean – impact

This section of the questionnaire listed 61 risks factors identified through the interview process and asked the participants to evaluate the impact of each risk factor on a five-point Likert scale. The Likert scale ranked the risks as being marginal, little, moderate, great, or extreme.

Table 7.24 presents the mean scores of the instruments measuring risk impact associated with OSM risk groups. Each risk factor in the questionnaire was evaluated on a scale of 1 to 5 in lieu of the Likert scale making statistical analysis easier. The overall mean score for the risk groups is 3.34, which is defined as the intermediate number for analysis. In this case, project management (3.48), time (3.35), owner (3.46), consultant (3.51), government policy (3.38), and society (3.45) all featured as significant risk groups, while cost (3.32), off-site feature (3.32), manufacturer (3.28), transporter (3.21), environment (3.05), and resource (3.31) were viewed as improbable risk groups. The most significant risk group was project management, and the most improbable risk group was environment.

Table 7.24: Impact mean scores for risk groups

RISK GROUP	MEAN(I)	DECISION

Cost	3.32	Improbable
Off-site feature	3.32	Improbable
Project management	3.48	Significant
Time	3.35	Significant
Owner	3.46	Significant
Consultant	3.51	Significant
Manufacturer	3.28	Improbable
Transporter	3.21	Improbable
Environment	3.05	Improbable
Government policy	3.38	Significant
Resource	3.31	Improbable
Society	3.45	Significant
All	3.34	

In terms of internal risk, the significant risk factors include high off-site manufactory building costs, component payment after delivery, high component model costs and high material fees. Components are often too heavy and this limits on-site assembly in the off-site feature group. A lack of cooperation, on-site construction period adjustments or change, the lack of an appropriate risk management method, and hard to deploy new management methods are significant factors within the project management group. Complexity of joint assembly featured significantly for the time group.

Table 7.24 presents the mean scores for internal risk factors. The highest mean factor in the cost group was the 'high off-site manufactory building cost' (3.59); the highest mean factor for the off-site feature group was 'on-site assembly limitation' (3.43); whereas the highest mean factor for the project management group was 'on-site construction period adjustment or change' (3.43); and the highest mean factor in the time group was 'complexity of joint assembly' (3.41).

Table 7.24: Impact mean scores for internal risks

RISK GROUP	RISK FACTORS	MEAN(I)	STD. DEVIATION	DECISION
Cost	High off-site manufactory building cost	3.59	1.183	Significant
	Overall working process increase	3.31	1.181	Improbable
	Component paid after delivery	3.45	1.292	Significant
	High training cost	3.09	1.251	Improbable
	More types of workers	3.10	1.276	Improbable

	More regular employee	3.20	1.242	Improbable
	High component model and material fee	3.56	1.178	Significant
	Grand Mean		3.32	
Off-site feature	Component is too heavy	3.39	1.182	Significant
	Component support interference	3.16	1.200	Improbable
	On-site assembly limitation	3.43	1.232	Significant
	Grand Mean		3.32	
Project management	Lack of cooperation	3.55	1.196	Significant
	On-site construction period adjustment or change	3.54	1.215	Significant
	Lack of risk management method	3.49	1.208	Significant
	Hard to deploy new management method	3.37	1.184	Significant
	Grand Mean		3.48	
Time	Complexity of joint assembly	3.41	1.189	Significant
	Insufficient production time	3.30	1.259	Improbable
	Grand Mean		3.35	

In terms of participant risk, the significant risk factors included the owner changing demands, those demands being unsuitable for off-site projects, and the owner changing project partners. In terms of the consultant group, risk factors included design error, a lack of off-site experience of consultants, the consultants lacking on-site experience, consultants lacking responsibility, and a lack of standardisation of approach. For the manufacturers' group it was the manufacturer's lack of experience. Within the contractor group the main risks were cited as a lack of experience, a dearth of experienced employees, and a lack of on-site assembly standardisation.

Table 7.25 presents the mean scores for participant risk factors. The highest mean factor recorded within owner group was 'owner changes demands' (3.53); for the consultant group it was that the 'consultant lacks on-site experience' (3.7); for the manufacturer group it was the 'manufacturer's lack of experience' (3.44); within the transporter group it was 'mistakes made during the transfer process' (3.29); whereas for the contractor group it was the 'contractor's lack of experienced employees' (3.48).

Table 7.25: Impact mean scores for participant risk

RISK GROUP	RISK FACTORS	MEAN(I)	STD. DEVIATION	DECISION
Owner	Owner change demand	3.53	1.206	Significant
	Demand not suitable for off-site project	3.49	1.162	Significant
	Owner change others project partner	3.37	1.176	Significant
	Grand Mean		3.46	
Consultant	Design error	3.55	1.274	Significant
	Consultant lacks off-site experience	3.7	1.192	Significant
	Consultant lacks on-site experience	3.65	1.160	Significant
	Consultant lacks responsibility	3.4	1.346	Significant
	Consultant lacks standardisation	3.51	1.258	Significant
	Consultant lacks professional software	3.27	1.311	Improbable
	Grand Mean		3.51	
Manufacturer	Manufacturer lacks experience	3.44	1.240	Significant
	Manufacturer lacks employees	3.31	1.234	Improbable
	Manufacturer lacks responsibility	3.31	1.311	Improbable
	Unavoidable errors in component production	3.29	1.257	Improbable
	Lack of control of assembly line	3.27	1.263	Improbable
	Lack of off-site manufactory facilities and equipment	3.14	1.293	Improbable
	Producing different types of components at the same time	3.22	1.328	Improbable
	Insufficient component storage yard facilities	3.33	1.272	Improbable
	Insufficient assembly line	3.25	1.278	Improbable
	Grand Mean		3.28	
Transporter	Transporter lacks experience	3.22	1.296	Improbable
	Transporter lacks responsibility	3.12	1.318	Improbable
	Mistakes made during the transfer process	3.29	1.288	Improbable

	Transportation road problems	3.24	1.292	Improbable
	Long transport distance	3.21	1.273	Improbable
	Grand Mean		3.21	
Contractor	Contractor lacks willingness to participate in off-site project	3.27	1.253	Improbable
	Contractor lacks experience	3.46	1.215	Significant
	Contractor lacks responsibility	3.27	1.276	Improbable
	Contractor lacks experienced employees	3.48	1.206	Significant
	Lack of on-site assembly standardisation	3.38	1.265	Significant
	Grand Mean		3.37	

In terms of external risk, the significant risk factors include differentiation in local government policy standards; rigid prefabricated rate requirements; and a lack of subsidy and support in relation to the government policy group. For the resource group these were supply delays or lateness, and a lack of component model standardisation. Contract bidding problems, unstable economic situations, public prejudice against off-site buildings, and inconsistent quality demand for OSC projects featured strongly for the society group.

Table 7.26 presents the mean score for external risk factor. The highest mean factor in environment group was ‘geographical environment’ (3.20), the highest mean factor in government policy group was ‘lack of government policy standards’ (3.39), the highest mean factor in resource group was ‘component model lack of standardization’ (3.44), the highest mean factor in society group was ‘contract bidding problem’ (3.65).

Table 7.26: Impact mean scores for external risk

RISK GROUP	RISK FACTORS	MEAN(I)	STD. DEVIATION	DECISION
Environment	Geographical environment	3.20	1.226	Improbable
	Manufacturing indoor environment	3.03	1.235	Improbable
	Seasonal changes	2.99	1.241	Improbable
	Natural disaster	3.01	1.329	Improbable
	Grand Mean		3.05	
Government	Lack of government	3.39	1.262	Significant

policy	policy standards			
	Local government policy standard differentiation	3.36	1.204	Significant
	Rigid prefabricated rate requirement	3.37	1.208	Significant
	Lack of subsidy and support	3.41	1.245	Significant
	Grand Mean		3.38	
Resource	Low material quality	3.3	1.266	Improbable
	Supply delay or not on time	3.37	1.280	Significant
	Lack of material	3.23	1.295	Improbable
	Component model lack of standardisation	3.44	1.277	Significant
	Manufactory equipment damage	3.24	1.263	Improbable
	Grand Mean		3.31	
Society	Contract bidding problem	3.65	1.255	Significant
	Unstable economic situation	3.38	1.249	Significant
	Public prejudice against off-site buildings	3.41	1.202	Significant
	Inconsistent quality demand for OSC project	3.37	1.240	Significant
	Grand Mean		3.45	

7.7 Main research – probability and impact

Based on the probability and impact of risk factors arising in OSC projects, the significant risk factors have been presented. In the next stage, it was necessary to understand the relationships arising between the impact and probability of risk factors. In order to check whether the data follows a normal distribution, the quantile-quantile plot (Q-Q plot) was deployed. A Q-Q plot is a plot of the order statistics of the sample against the theoretical quantiles. This tool is used to assess how close the empirical distribution is to the model distribution (Ben et al., 2004). The Q-Q plot should be approximately a straight line for normal data for a high positive correlation. Moreover, any outliers in the data are easily identified in the Q-Q plot (Andersen et al., 2018). Figure 7.1 and Figure 7.2 presented the Q-Q plot for risk probability and impact, revealing that the data constitute an approximately straight line. This proved that the quantitative data is approximately normally distributed, which demonstrates that the parametric analysis method can be used in this research.

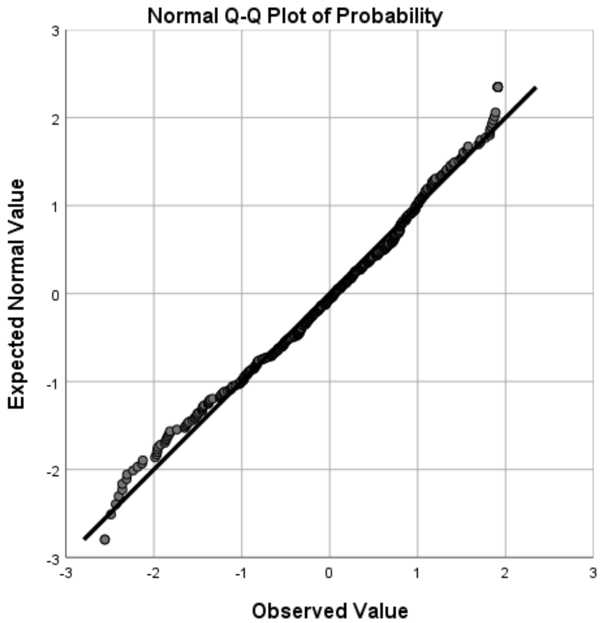


Figure 7.1: Probability Q-Q Pilot

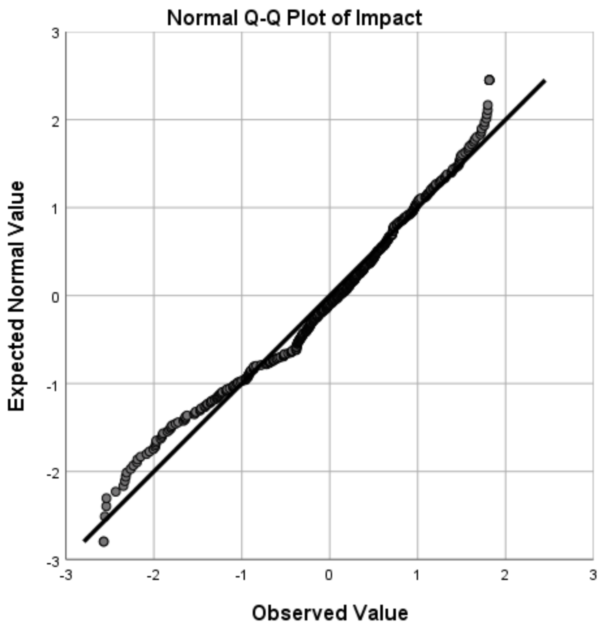


Figure 7.2: Impact Q-Q pilot

To this end, a linear regression analysis was employed for risk impact in order to regress the risk probability. Regression analysis is used to generate an equation so as to describe the statistical relationship arising between one or more predictors and the response variable to predict new observations. The result is explained as follows:

1. R^2-value and adjusted R^2-value: The R^2-value is the percentage of the response variable variation that can be explained by its relationship with one or more predictor variables. The adjusted R^2-value is the percentage of the response variable variation that is explained by its relationship with one or more predictor variables, adjusted for the number of predictors in the model (Akossou et al., 2013).
2. Standard error: The standard error is an estimate of the standard deviation of a statistic (Belia et al., 2005).
3. T-value: The t-value is a test statistic for t-tests that measures the difference arising between an observed sample statistic and its hypothesised population parameter in terms of units of standard error (Ross et al., 2017).
4. ANOVA: ANOVA is a statistical tool for studying the relationship between a response variable and one or more explanatory and predictor variables (Ross et al., 2017).
5. F-statistic: The F-statistic is a value derived when running an ANOVA test or regression analysis to find out if the means between two populations are significantly different (Prix, 2010).

Table 7.27 shows that the mean probability was 3.30, with a standard deviation of 1.238 while the mean impact was 3.34 with a standard deviation of 1.247.

Table 7.27: probability and impact mean and standard deviation.

	MEAN	**STD. DEVIATION**
Probability	3.30	1.238
Impact	3.34	1.247

In Table 7.28 an R-value of 0.89 indicates a strong influence arising between risk probability and risk impact. The adjusted R^2-value of 0.79 indicates that there is large positive linear correlation arising between risk probability and impact. The regression equation presented in Table 7.29 shows how the increase in the value of the risk impact increases in parallel with the value of risk probability. Further, Table 7.30 indicates that risk probability significantly influences impact ($p<0.001$).

Table 7.28: Questionnaire R-value result

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.890[a]	.792	.791	.45688363	1.959

a. Predictors: (Constant), impact

b. Dependent Variable: probability

Table 7.29: Questionnaire Coefficients calculated

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-1.703E-17	.022		.000	1.000	-.043	.043
	impact	.890	.022	.890	40.619	.000	.847	.933

a. Dependent Variable: probability

Table 7.30: Questionnaire ANOVA result

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	344.406	1	344.406	1649.906	.000[b]
	Residual	90.594	434	.209		
	Total	435.000	435			

a. Dependent Variable: probability

b. Predictors: (Constant), impact

Based on the linear regression equation, the risk impact and probability relationship formula are:

$$Probability = -1.703E\text{-}17 + (0.89 * impact)$$

Consequently, Table 7.31 shows that the business scope of the company ($F=1.758$, $p=0.120$) and types of off-site material ($F=1.076$, $p=0.359$) do not have a significant effect on their mean rating in terms of risk probability.

Table 7.31: Business scope of company and types of OSC material comparison: probability

Tests of Between-Subjects Effects

Dependent Variable: probability

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	25.017[a]	21	1.191	1.203	.244	.058
Intercept	.094	1	.094	.095	.758	.000
Business scope of company	8.706	5	1.741	1.758	.120	.021
Types of off-site material	3.198	3	1.066	1.076	.359	.008
Error	409.983	414	.990			
Total	435.000	436				
Corrected Total	435.000	435				

a. R Squared = .058 (Adjusted R Squared = .010)

Consequently, Table 7.32 shows that the business scope of the company (F=0.692, p=0. 630) and the types of off-site material used (F=2.188, p=0.089) do not have significant effect on their mean rating in terms of risk impact.

Table 7.32: Business scope of company and types of OSC material comparison: impact

Tests of Between-Subjects Effects

Dependent Variable: impact

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	28.143[a]	21	1.340	1.364	.131	.065
Intercept	.015	1	.015	.015	.903	.000
Business scope of company	3.400	5	.680	.692	.630	.008
Types of off-site material	6.451	3	2.150	2.188	.089	.016
Error	406.857	414	.983			
Total	435.000	436				
Corrected Total	435.000	435				

a. R Squared = .065 (Adjusted R Squared = .017)

Table 7.33 presents the observation that, based on the business scope of company, transporters considered all risk factors (internal risk, participants risk, and external risk) that weighed more heavily on probability than other groups. Finally, in terms of the probability of risk arising, other types were evaluated to be of lower risk.

Table 7.33: Probability divided by business scope of company

PROBABILITY				
Risk group	Internal	Participant	External	Total
Owner	3.35	3.33	3.31	3.33
Consultant	3.57	3.29	3.27	3.38
Manufacturer	3.57	3.38	3.24	3.40
Transporter	3.58	3.61	3.37	3.52
Contractor	3.34	3.17	3.12	3.21
Other	3.06	3.09	2.95	3.03

Table 7.34 shows clearly that, based on the business scope of the company, transporters evaluate OSC risk more in terms of impact on occurrence than do other groups. Finally, in terms of the impact of risk occurring, other groups weighed building construction risks less strongly as compared to other groups.

Table 7.34: Impact divided by business scope of company

IMPACT				
Risk group	Internal	Participant	External	Total
Owner	3.34	3.43	3.39	3.39
Consultant	3.49	3.35	3.37	3.40
Manufacturer	3.53	3.51	3.41	3.48
Transporter	3.56	3.57	3.47	3.53
Contractor	3.23	3.21	3.15	3.20
Other	2.97	3.25	3.09	3.10

Table 7.35 presents the findings based on different types of off-site structural material, and wood has a higher OSC risk probability rating than other materials.

Table 7.35: Probability divided by types of off-site material used

PROBABILITY				
Risk group	Internal	Participant	External	Total
Concrete	3.34	3.26	3.19	3.26
Steel	3.48	3.22	3.19	3.30
Wood	3.78	3.58	3.51	3.62
Other	3.30	2.79	3.02	3.04

Table 7.36 presents the findings based on different types of off-site structural material, and wood has a higher OSC risk impact rating than other materials.

Table 7.36: Impact divided by types of off-site material

IMPACT				
Risk group	Internal	Participant	External	Total
Concrete	3.36	3.33	3.27	3.32
Steel	3.37	3.34	3.29	3.33
Wood	3.71	3.77	3.77	3.75
Other	3.11	2.84	3.02	2.99

From the results presented above, all stakeholders that participate OSC projects have different perceptions of risk factors, as the objectives of each stakeholders are different, how the risk should be treated by the stakeholders are different. For the business scope of company, transporters have the highest mean ratings for OSM risk impact and probability. In relation to types of off-site material used, those companies using wood have the highest mean ratings for OSM risk impact and probability.

7.8 Chapter summary

This section presents the results derived from questionnaire surveys which were conducted based on the impact and probability of risk arising within the OSM process. Statistical approaches were undertaken to identify the main risks arising within the OSM process. Overall, the participants had similar responses, which means that the perceptions of risk factors are similar for all participants. Finally, 28 factors were accepted as being significant risk factors as these may have negative impacts on QCD.

CHAPTER 8 - DISCUSSION

8.1 Introduction

This chapter aims to present an OSM risk management framework and validate it using a case study approach. It was first necessary to validate the framework to guarantee that the findings and recommendations are reliable, as this could also prove the objectivity and reliability underlying the research.

8.2 Related research review

Previous articles presented many frameworks for the construction project. For example, The Royal Institute of British Architects (RIBA) Plan of Work organises the process of briefing, designing, constructing and operating building projects into eight stages and explains the stage outcomes, core tasks and information exchanges required at each stage (RIBA, 2020). Other organisations from different countries also presented a plan of work with different stages. For example, Architects' Council of Europe (ACE) divided construction processes into nine stages (ACE, 2020), American Institute of Architects (AIA) divided construction processes into four stages (AIA, 2020), and Association for Project Management (APM) divided construction processes into eight stages (APM, 2018). The process maps for a plan of work generally include six processes: pre-design, design, construction, handover, in use, and end of life. These plans of work provide the project team with a road map for promoting consistency from one stage to the next, and provide vital guidance to clients undertaking perhaps their first and only building project (RIBA, 2020).

During the construction industry development, Modern Methods of Construction (MMC), or called smart construction are changing how buildings are designed, manufactured and assembled (Shibani et al., 2021). This is a process which focuses on OSC techniques, it is a process to produce more, better quality homes in less time. For example, designing for manufacturing and assembly (DFMA) is considered in many countries, which is considered by owner as a faster and more effective way of making buildings, and contractors consider as a way to lower the costs of delivery and reduce risks (Bao et al., 2021). DFMA includes two mythologies: Design for Manufacture and Design for Assembly. This requires the OSC component should be designed for ease of manufacture process and ease of assembly (Zhafri et al., 2018).

Building information modelling (BIM) is introduced in many OSC project to improve the building quality and reduce cost. Generally, BIM is computer files which can be extracted, exchanged or networked to support decision-making regarding a built asset. BIM allows architects, engineers, real estate developers, contractors, manufacturers, and other construction professionals to plan, design, and construct a structure or building within one 3D model (Chan et al., 2019). In the traditional building design process, 2D technical drawings present plans, elevations, sections for building. However, 2D drawings cannot display the information clearly, so they are forced to physical prototyping (Chen et al., 2018). BIM can reduce or avoid the disadvantage of 2D drawing, and it can also include building information about time (4D BIM) or cost (5D BIM), it can cover spatial relationships, geospatial information, quantities and properties of building components for the building, it also presents the whole life cycle for the building from initial planning through to construction and then throughout its operational life (Lee et al., 2020).

As BIM requires computer files to monitor and maintain building data, it is necessary to combine computer technology with OSC project. Computer aided manufacturing (CAM) is the use of software and computer-controlled machinery to automate a manufacturing process. CAM requires a protected, predictable environment, it also requires repetition and high numbers of units to make the investment in the robotics technology required viable (R. He et al., 2021). In that case, CAM is suitable for OSC project, and could help to develop OSC component with higher quality. For example, the Building on Demand is the first 3D printing building house in Europe, which become an office hotel in Copenhagen, Nordhavn area (Pessoa et al., 2021).

In order to develop an OSM framework, the process of framework development includes four steps (Abduh et al., 2018):

1. Identification the key factor in OSM risk management process.
2. Identification of underlying relationship between factors.
3. Adaptation of OSC project, which means framework validation.
4. Comprehensive evaluation, which means framework improvement.

8.3 OSM Framework development

The Institution of Civil Engineers (ICE) presented a systems approach for OSC risk and risk management that is deemed necessary (Ruoheng et al., 2019). Many articles presented a risk framework to solve the risks arising in the project process. For example, ISO explained risk management as a project in the ISO 31000 standard (ISO, 2018b). Figure 8.1 presents the ISO 31000: 2018 standard risk management guidance, including its relationship with the risk management principles and processes. It is noted that many national bodies are adopting this model to develop or revise standards for risk management. For example, BS ISO 31000: 2018 in the UK (BSI, 2018), JIS Q 2001:2001 in Japan (JSA, 2001), CSA-Q850-97 (R2009) in Canada (CSA, 2009b), and AS/NZS 4360:2004 in New Zealand (NZS, 2004), all risk standards for those countries developing approaches are based on the ISO 31000 standard.

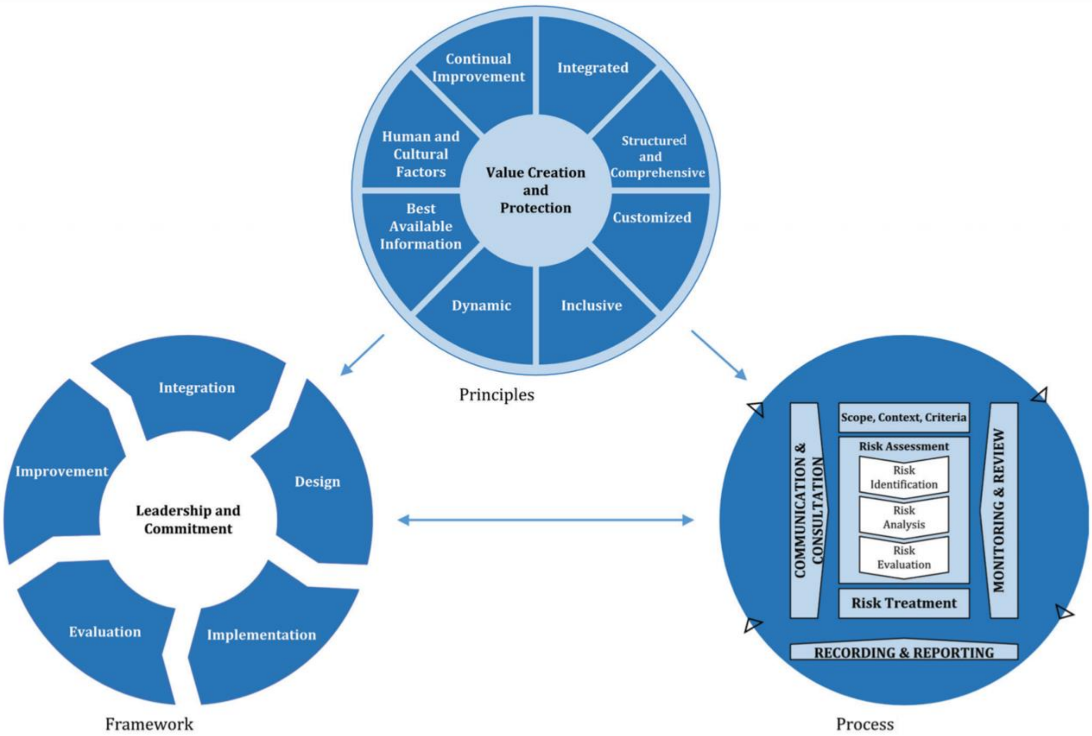


Figure 8.1: ISO 31000 principles, framework and process guidance (ISO, 2018b)

The principles of ISO risk management include integrated, structured and comprehensive, customised, inclusive, dynamic, best available information, human and cultural factors, and continual improvement. The purpose of risk management is the creation and protection of value. The principles guide the characteristics of effective and efficient risk management, communicating their value and explaining their intention and purpose (ISO, 2018b). This principle is the foundation of risk management (Luko, 2013). The principles of OSM risk management should be connected with the features of OSC projects. In this research, OSM risk management principles include:

1. Value creation and protection: To create and protect the value of Chinese OSC manufacturers.
2. Integrated: OSM risk management is an integral part of Chinese OSC manufacturing activities.

3. Structured and comprehensive: OSM risk management requires a structured and comprehensive approach, one which could be deployed or be referenced in other OSC projects.
4. Customised: Different OSC manufacturers require different types of OSM risk management approach, based on external and internal contexts relating to its objectives, such as the types of organisation, the types of OSC project, and the location of the project, etc.
5. Inclusive: For Chinese OSC manufacturers, it is necessary to consider OSM risk factors alongside other project participants, such as the owner, consultant, transporter and contractor. Especially with the consultant, which has the most significant influence on OSM risk factors.
6. Dynamic: Due to the external and internal context changes, OSM risk can emerge, change or disappear. Many OSM risk factors are caused or changed by other participants. For example, on-site bad weather results in the contractor having to pause the component assembly process, which in turn causes component production process delays.
7. Best available information: The inputs to risk management are based on historical and current information, as well as on future expectations. Additionally, OSM risk management is a relatively new area for risk management, as the input information or data for the risk management process may be insufficient or else damaged by other participants. OSC manufacturers need to explain the importance of sharing information promptly and clearly to other participants so as to improve the quality of information or data.
8. Human and cultural factors: OSC manufacturers need to be concerned about different human behaviours and cultures for different OSC projects. For example, OSM Risk management is deployed by a project manager of a Chinese OSC manufactory, which is inevitably affected by the Chinese culture and personal characteristics.

9. Continual improvement: OSM risk management needs continuous improvements through learning and experience as well as more communication of the risk management methods for different OSC manufacturers.

Figure 8.2 presents the principles of OSM risk management.

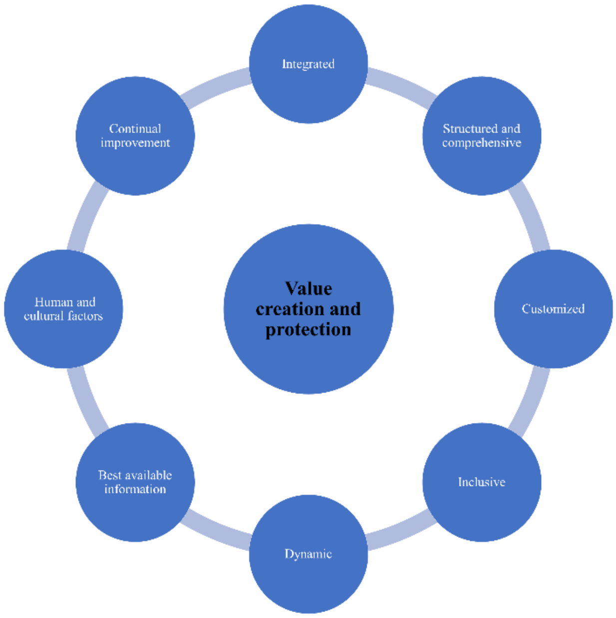


Figure 8.2: OSM risk management principles

Within the ISO risk management framework, it encompasses integrating, designing, implementing, evaluating and improving risk management across the organisation. It is worth noting that the ISO risk management framework follows and improves the plan-do-check-act (PDCA) cycle (Sousa et al., 2012). Others executing project planning also used similar PDCA cycles and, although the nomenclature may vary, the meaning remains substantially identical. For OSM risk management, it is also necessary to adopt PDCA as the ground framework methodology and to combine this with the features of OSC projects. In this research, the OSM risk management framework was divided into:

1. Leadership and commitment: Generally, a Chinese OSC project is led by an OSC owner and supervised by the Chinese government. In this case, OSM risk management should not only be considered by the top management of the

OSC manufacturer, but also by that of the OSC owner and the oversight body of the Chinese government.

2. Integration: An OSM risk management framework should be integrated into Chinese OSC manufacturing activities as well as how to integrate OSM risk management in accordance with the principles of OSM Risk management.
3. Design: The OSM risk management framework design should follow the risk management process and the features of OSC project. The details are explained in OSM risk management and by OSC project participants.
4. Implementation: OSM risk management framework implementation requires the engagement and awareness of all OSC participants. During the implementation process, OSC manufacturers should consider how to ensure effective communication with other participants and monitor whether the risk management framework is integrated within OSC manufacturing activities.
5. Evaluation: To evaluate the OSM risk management framework, the OSC manufacturer needs to consider whether this framework could help to achieve the aim of the project. Generally, an OSC manufacturer aims to create and protect value by producing components for an OSC project. An optional evaluation method is to check whether the OSM risk management framework improves the QCD of components effectively.
6. Improvement: The strengths and weaknesses of the OSM risk management framework are evaluated during the evaluation step, and the framework should be monitored and adapted to improve the suitability, adequacy, and effectiveness of the framework.

Figure 8.3 presents the framework of OSM risk management.

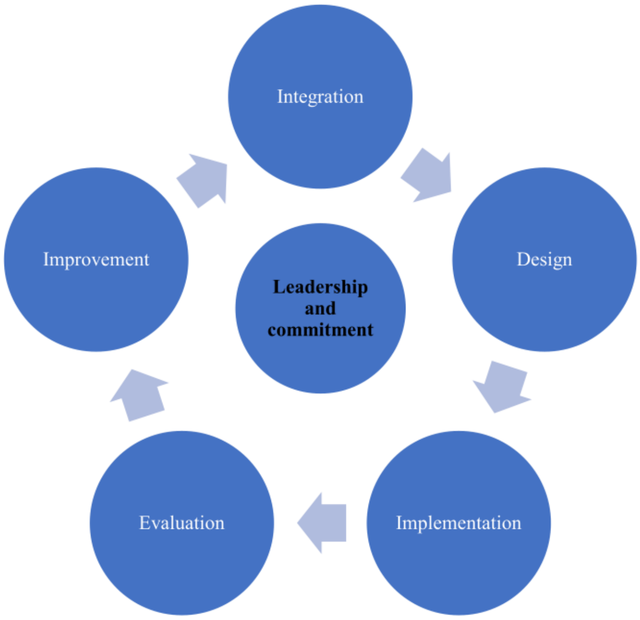


Figure 8.3: OSM risk management framework

The ISO risk management process involves the systematic application of policies, procedures and practices to the activities of communicating and consulting, establishing the context and assessing, treating, monitoring, reviewing, recording and reporting risk. In this research, a similar process is presented for OSM risk management:

1. Risk identification: Risk identification is the first step in the risk management process. If there is a phenomenon that delays the objective of the OSC project, it should be considered a risk. The identification process requires identifying the scope and context of risk factors.
2. Risk assessment: Each risk factor needs a brief description and should be classified by category according to the risk type and group in the risk assessment process. Risk assessment could provide a risk classification chart for the risk analysis process.
3. Risk analysis: How does the risk factor affect the project is analysed in the risk analysis process. The quantified risk factors provide input to the risk response to decide what is the most appropriate risk treatment strategy and methods.

4. Risk response: After the significant risk factors have been identified, the risk response method should be considered. Different risk factor requires different risk response methods, which depends in turn on the features of those risk factors. Risk response can also introduce new risk factors, and so risk response is a continuous process and requires change or updating as the project progresses.
5. Communication and consultation: The OSM risk management process requires effective communication with all OSC project participants, whereby communication seeks to promote awareness and understanding of risk. The consultation is also necessary for the OSM risk management process. It should be noted that experts from different areas could help in identifying the risk factor from different perspectives. For example, an expert from a university or a risk manager from large-scale manufacturing could be invited into the consultation process.
6. Monitoring and review: Monitoring and review should be considered during the OSM risk management process. In an OSC project, it should be mentioned that the OSC project requires cooperation from all participants, which results in monitoring and review from other participants as an optional choice. This process could improve the evaluation step in the OSM risk management framework.
7. Recording and reporting: All activity in the OSM risk management process should be recorded, whether it is a positive or negative result. Reporting quality can be improved by providing and supporting top management and oversight bodies such as an OSC owner or the Chinese government, and it is necessary to inform the results of the OSM risk management process to other participants. This process could enhance the improvement step in the OSM risk management framework.

Figure 8.4 presents the process of OSM risk management.

Figure 8.4: OSM risk management process

Although ISO risk management guidance does not include the project participants, it is necessary to emphasise the participants of OSC projects for OSM risk management and, as the OSC project is a whole industry chain project, OSM risk cannot be treated as an isolated phenomenon (Kamali et al., 2016). An OSC project generally includes five participants, namely the:

1. Owner: The organisation that owns a built asset. In a Chinese OSC project, it generally means the developer for the construction project who undertakes the costs of the OSC project.
2. Consultant: The professionals appointed by the owner to perform expert tasks on a project. In a Chinese OSC project, it generally means the designer for the construction project who provides design drawings and planning for an OSC project.
3. Manufacturer: The organisation that produces goods to sell them to a customer. In a Chinese OSC project, it generally means the manufacturer who produces an OSC component for an OSC project.

4. Transporter: The organisation that transfers the materials or goods to a customer. In a Chinese OSC project, it generally means the transporter who transfers OSC components from the OSC manufactory to the on-site location.
5. Contractor: The organisation appointed by owners to carry out construction works. In a Chinese OSC project, it generally means the contractor who assembles the OSC components at the construction site.

Figure 8.5 presents the participants of OSM risk management.

Figure 8.5: OSM risk management participants

Based on the preceding analysis, the OSM risk management framework is presented in Figure 8.6. However, this framework does not present the details of the risk management process for OSM risk, as it also lacks a connection with the results from quantitative research. In order to understand how to identify, analyse and respond to OSM risk, the case study method is used to validate and improve the framework.

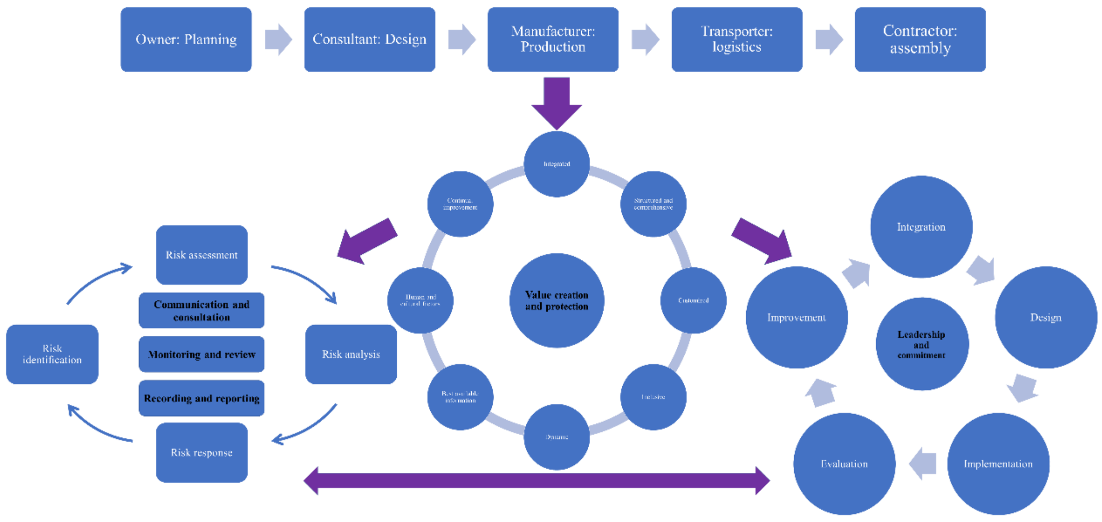


Figure 8.6: OSM risk management whole framework

8.4 Risk analysis for OSM

8.4.1 Identification of Risk in OSM

Based on past risk identification from the literature review and interviews, 77 risk factors were identified. In order to identify those of significance in the Chinese OSM sector, a questionnaire survey was developed and conducted on the Chinese mainland. After a pilot questionnaire study, 61 risk factors were shortlisted and other risk factors were either merged or erased. After a criticality decision, the cut-off point for risk probability was taken as 3.30 and for risk impact 3.34. These thresholds reduced the number of salient risk factors to 28. These 28 risk factors cause QCD problems within OSC projects. Four risk factors had a significant probability but an improbable impact; while four risk factors had a significant impact but were improbable. The other 35 risk factors were deemed improbable risks. These 28 significant risk factors were attributed to 11 risk groups. As shown in Table 8.1, Table 8.2, and Table 8.3, the minimum mean rating identified for risk probability was 3.31 for ‘unstable economic situation’, whereas the maximum mean rating was 3.74 for ‘high component model and material costs’. The minimum mean rating identified for risk impact was 3.36 for ‘local government policy standard differentiation’, whereas the maximum mean rating was 3.7 for ‘consultant lacks on-site experience’. For these 28 risk factors, 10 were considered to be internal risk, 10 were considered to be participant risk, and 8 were considered to be external risk.

Based on the interviews, questionnaire and visits made to the site, several risk factors were identified as the primary sources of risk for OSC projects. One risk factor was selected from each risk group as being the most significant risk:

1. Internal risk: High off-site manufactory building cost.
2. Participant risk: Consultant lacks off-site experience.
3. External risk: Contract bidding problems.

The explanation for the classification of these risk factors and risk groupings will be presented below.

8.4.2 Internal risk

Internal risk was identified as a major source of risk, as these risks were caused by those features intrinsic to off-site projects. These risk categories include cost, off-site featured, project management and time. These significant risks are presented in Table 8.1:

Table 8.1: Mean of internal significant risk factors

INTERNAL RISK MEAN				
Risk Group	**Factor**	**Probability**	**Impact**	**Total**
Cost	High off-site manufactory building cost	3.72	3.59	3.655
	Components paid after delivery	3.47	3.45	3.46
	High component model and material fees	3.74	3.56	3.65
Off-site feature	Component is too heavy	3.47	3.39	3.43
	On-site assembly limitation	3.52	3.43	3.475
Project management	Lack of cooperation	3.56	3.55	3.555
	On-site construction period adjustment or change	3.61	3.54	3.575
	Lack of risk management method	3.50	3.49	3.495
	Hard to deploy new management methods	3.45	3.37	3.41
Time	Complexity of joint assembly	3.43	3.41	3.42

For the internal risk group, the most significant risk was ‘high off-site manufactory building cost’, which also had the highest overall mean score in relation to the three risk groups. This risk was cited in previous articles. Sutrisna, Cooper-Cooke, et al. (2019) identified that off-site initial investment were the cause of some contractors refusing to use OSC method in Western Australia. Arif et al. (2009) worried that OSC could be the more expensive option because of perceived higher design, cranage and transportation costs. This cost was also mentioned by many interviewees during interview process. According to P3, '*High off-site manufactory building cost is a very serious problem. The amortisation fee of the manufactory is also relatively high. The cost includes land fees and factory structure which is all money. Sometimes our equipment is imported from abroad, which is more expensive.*' P7 said, '*Many companies only consider material costs as their true cost – this has always happened in traditional construction. However, in OSC, costs such as manufactory building costs should not be ignored. But many owners do not understand this and think that OSC is a cost saving methodology.*' From these comments and others, it was evident that many off-site manufacturers understand initial investment of OSC as a risk factor for these projects, despite the fact that risk is not perceived by other participants including owners and contractors. The off-site manufacturers suggest that the initial investment and amortisation fee should be considered as an off-site project cost.

8.4.3 Participant risk

Participant risk was identified as another major source of risk, as these risks are caused by the project participants themselves. This risk category includes the owners, consultants, manufacturers, and contractors. These significant risks are presented in Table 8.2:

Table 8.2: Mean of participant significant risk factors

PARTICIPANT RISK MEAN				
Risk Group	**Factor**	**Probability**	**Impact**	**Total**
Owner	Owner changes demand	3.49	3.53	3.51
	Demand not suitable for off-site project	3.46	3.49	3.475
Consultant	Design error	3.31	3.55	3.43
	Consultant lacks off-site experience	3.55	3.7	3.625
	Consultant lacks on-site experience	3.58	3.65	3.615
	Consultant lacks standardisation	3.31	3.51	3.41

Manufacturer	Manufacturer lacks experience	3.34	3.44	3.39
Contractor	Contractor lacks experience	3.42	3.46	3.44
	Contractor lacks experienced employees	3.45	3.48	3.465
	Lack of on-site assembly standardisation	3.3	3.38	3.34

For the participant risk group, the most significant risk was 'consultant lacks off-site experience', which also had the highest impact mean score among the 3 risk groups. It is interesting to note that all participants complained about the consultants' lack of off-site experience. For instance, P5 said, '*the contractor lacks not only off-site experience, but also on-site assembly experience. When they designed the building, they did not consider the constructability or implement-ability of the project. As most of the operations are performed on a computer in the consultancy company, it is difficult to consider which tools and measures are to be used on-site.*' P10 said, '*The consultant always follows traditional construction design processes and, as a result, the building cannot follow OSC guidance.*' P19 stated, '*Traditional consultants do not understand the construction process and construction costs. Nowadays, dealing with consultant is very difficult as they do not know how to control the costs. In that case, the owner will not be satisfied*.' It proves to be the case that the off-site project is a whole life cycle that requires all participants to cooperate effectively or, otherwise, the risk caused by the consultant will influence other participants such as manufacturers.

8.4.4 External risk

Some risk factors are neither the cause of the internal risks nor are the participants the cause of external risks, as these factors derive from wider macro-economic activities in China or other societal contexts. These risk categories include government policy, resources, and society. These significant risks are presented in Table 8.3:

Table 8.3: Mean of external significant risk factors

EXTERNAL RISK MEAN				
Risk Group	**Factor**	**Probability**	**Impact**	**Total**
Government policy	Local government policy standard differentiation	3.33	3.36	3.345
	Rigid prefabricated rate requirement	3.33	3.37	3.35

	Lack of subsidy and support	3.39	3.41	3.4
Resource	Component model lack of standardisation	3.35	3.44	3.395
Society	Contract bidding problem	3.56	3.65	3.605
	Unstable economic situation	3.31	3.38	3.345
	Public society prejudice against off-site building	3.36	3.41	3.385
	Inconsistent quality demand for OSC project	3.35	3.37	3.36

For the internal risk group, the most significant risk arising was 'contract bidding problems'. Only a few interviewees mentioned the 'contract bidding problem' as a salient risk, yet the questionnaire feedback indicated that it is a very serious risk. For example, P22 said, '*A big problem in our industry is low prices. The owner will pay more attention to who has the lowest price. Winning the bid at a low-price means that other good companies cannot survive.*' However, P22 mentioned a similar problem related to this risk, '*You have to settle some people before you get a project, and you also have also to settle some material gangdom. This is because we need the project as, without the project, we cannot afford the cost.*' This presents the vicious cycle in that competition leads the off-site manufacturer to have to compromise in accepting unfair contracts, even though the contract may ultimately cause them to lose money.

8.4.5 Conceptual framework

By concluding the risk rankings above, the risks inherent within the OSM process could be concluded in Table 8.4 (ranking by importance of the risk):

Table 8.4: Risk identification for OSM processes

RISK FOR OSM PROCESS		
Risk type	**Risk code**	**Risk factor**
Internal risk	IR1	High off-site manufactory building costs
	IR2	High component model and material fees
	IR3	On-site construction period adjustment or changes
	IR4	Lack of cooperation
	IR5	Lack of risk management methods
	IR6	On-site assembly limitations
	IR7	Components paid after delivery
	IR8	Component is too heavy
	IR9	Complexity of joint assembly
	IR10	Hard to deploy new management method
Participant risk	PR1	Consultant lacks off-site experience

	PR2	Consultant lacks on-site experience
	PR3	Owner changes demand
	PR4	Demands not suitable for off-site project
	PR5	Contractor lacks experienced employees
	PR6	Contractor lacks experience
	PR7	Design error
	PR8	Consultant lack of standardisation
	PR9	Manufacturer lacks experience
	PR10	Lack of on-site assembly in standardisation
External risk	ER1	Contract bidding problems
	ER2	Lack of subsidy and support
	ER3	Component model lacks standardisation
	ER4	Public society prejudice against off-site building
	ER5	Inconsistent quality demands for OSC project
	ER6	Rigid prefabricated rate requirement
	ER7	Unstable economic situation
	ER8	Local government policy standard differentiation

In order to develop a conceptual framework, this research undertook four steps:

1. Literature review: This research conducted a thorough review of the literature in order to understand the OSM process and its advantages. Further, various variables that affect the OSM process were identified. Similarly, the current risks and barriers to OSC projects were derived from the literature.
2. Interview: This research conducted interviews to identify the influential factors pertaining to OSM risk within OSC organisations across China. 77 risk factors were identified which influence OSC projects in China.
3. Questionnaire: This research conducted a questionnaire survey to rank the risks identified through interview. Based on 436 questionnaires, 28 risk factors were identified as being of significance to the OSM process.
4. Case study: By using case study, an OSM risk management reference table was developed and validated. The OSM risk management conceptual framework was developed based on the reference table, these will be discussed in detail in the following sections.

The literature review and data analysis were based on the interviews and questionnaire results as well as a list of significant risk factors identified within the OSM process (see Table 8.4). After the factor analysis had been completed, the risk factors were divided into certain risk types (see Table 8.5) and risk groups (see Table 8.6).

Table 8.5: Risk type explanations

RISK TYPE	EXPLANATION
Internal risk	The risk type comes from the OSC project itself. It includes cost, off-site features, project management, and time.
Participant risk	The risk type comes from OSC project participants. It includes owner, consultant, manufacturer, and contractor.
External risk	The risk type comes from outside of OSC project. It includes government policy, resource, and society.

Table 8.6: Risk group explanations

RISK GROUP	EXPLANATION
Cost	The group is affected by the OSC project cost, which deals with the strategies and financial preparedness of the OSC organisation.
Off-site feature	The group is affected by the features of the OSC project. This group stresses the inherent characteristics that only happen in OSC projects.
Project management	The group is affected by the project management methods selected for OSC and are caused by lack of project management method or lack a project manager.
Time	The group is affected by the effective use of time planning and scheduling for OSC projects.
Owner	The group is caused by the owners who focus on OSC project planning.
Consultant	The group is caused by consultants who focus on OSC project design.
Manufacturer	The group is caused by the manufacturers who focus on off-site component production.
Contractor	The group is caused by the contractors who focus on OSC component on-site assembly.
Government policy	The group is affected by the government, especially in relation to policy that may cause risk in OSC projects.
Resource	The group is affected by the cost, quality and delivery of OSC resources.
Society	The group is affected by the social environment, which includes public attitudes, the economic environment, and social customs.

Table 8.7: Risk factor explanations

RISK CODE	EXPLANATION
IR1	The high capital investment for off-site manufactories, especially manufactory building costs are a major cost for off-site manufacturers.
IR2	As the component models and materials lack standardisation, the cost is higher than the set price.
IR3	On-site period changes result in the manufacturer having to change their production plans.

IR4	Cooperation between project participants and inside the manufactory.
IR5	The new process in the OSC project requires new risk management methods.
IR6	On-site assembly limitations include extra support for the components, extra step for on-site assembly processes, and interference for the construction workers.
IR7	Manufacturers cannot get their funds until the project is finished which increase their costs.
IR8	Heavy components cause all transport processes to require more time.
IR9	The component joint assembly is still a new technology that needs more new technical support.
IR10	Project management methods like six sigma and lean production is still relatively new for off-site manufacturers, requiring more time to establish these methods.
PR1	The consultant has little knowledge of OSC processes, causing the design diagram to be unsuitable for off-site component production.
PR2	The consultant does not need to go on-site to learn how to work on-site, which cause the design diagram to be unsuitable for construction project.
PR3	Owners can change their demands during traditional construction projects. However, the feature of OSC projects mean that changes in demands require more time and cost.
PR4	Some owners still use traditional construction requirements for OSC projects.
PR5	There are two reasons why contractors lack experienced employees. First, there are few experienced OSC workers. Second, young people are unwilling to become on-site workers.
PR6	Only a few contractors have experience in OSC projects.
PR7	Design errors are caused by consultants, including conceptual design errors and design development errors.
PR8	The consultant lacks standardisation, resulting in other participants needing to change aspects of different projects.
PR9	The off-site manufacturer experience includes product experience, transport experience, manufactory design experience, etc.
PR10	Lack of on-site assembly standardisation causes the on-site assembly time to be extended, leading to the manufactory time being extended.
ER1	Current construction contract bidding methods favour the lowest prices which usually win the bids which may adversely affect quality.
ER2	Although government provides subsidy and support for OSC, many companies still think this support is insufficient.
ER3	Different component model companies have different standards, which means that the component differs from other component models and cannot be assembled.
ER4	OSC projects require much less time for on-site processes than traditional construction methods. However, many people think that it is too quick and cannot be safe.
ER5	OSC could increase the quality of buildings. However, as off-site manufacturers have similar production environments to general manufacturers (e.g., car, phone, etc.), some people think that the OSC

	process has similar quality to general manufacture.
ER6	The government policy gives off-site companies certain requirements for prefabricated rate. However, some buildings are unsuitable for OSC to reach the required prefabricated rate, and the OSC company has to pay extra costs.
ER7	The trade war and COVID-19 have worsened the economic outlook, reducing commitments to OSC projects.
ER8	Different provinces have different policies, which leads to OSC companies having to change their operation methods in a new province.

Further, this factor analysis enabled the researcher to group risks and identify how these risks influence quality, cost, and delivery (QCD) of the OSC project (see Table 8.8). Based on the literature review and interview feedback, the risk response method for each risk factor is presented in Table 8.9 to assess the suitability of the OSM risk assessment table for off-site manufacturer. The risk response method adopted includes avoidance, transfer, reduction and retention. In the validation process, the research data obtained via the case study method is used to refine the proposed OSM risk reference table.

Table 8.8: Risk assessment table for OSM processes

RISK TYPE	RISK GROUP	RISK FACTOR	RISK CODE	QCD INFLUENCE
Internal risk	Cost	High off-site manufactory building cost	IR1	C
		High component model and material fee	IR2	C
		Component paid after delivery	IR7	C
	Off-site feature	On-site assembly limitation	IR6	Q, C, D
		Component is too heavy	IR8	D
	Project management	On-site construction period adjustment or change	IR3	C, D
		Lack of cooperation	IR4	C, D
		Lack of risk management method	IR5	Q, C, D
		Hard to deploy new management method	IR10	Q, C, D
	Time	Complexity of joint assembly	IR9	D
Participant risk	Owner	Owner change demand	PR3	C, D
		Demand not suitable for off-site project	PR4	C, D
	Consultant	Consultant lacks off-site experience	PR1	C, D
		Consultant lacks on-site experience	PR2	C, D
		Design error	PR7	Q, C, D
		Consultant lack of standardisation	PR8	Q, C, D
	Manufacturer	Manufacturer lacks experience	PR9	Q, C, D
	Contractor	Contractor lacks experienced employees	PR5	Q, C, D
		Contractor lack of experience	PR6	Q, C, D
		Lack of on-site assembly standardisation	PR10	Q, C, D
External risk	Government policy	Lack of subsidy and support	ER2	C
		Rigid prefabricated rate requirement	ER6	Q, C
		Local government policy standard differentiation	ER8	C, D
	Resource	Component model lacks standardisation	ER3	Q, C, D
	Society	Contract bidding problem	ER1	Q, C, D
		Unstable economic situation	ER7	C

	Public society prejudice for off-site building	ER4	C, D
	Inconsistent quality demand for OSC project	ER5	C, D

Table 8.9: Risk response methods for OSM risks

RISK FACTOR	RESPONSE METHOD			
	Avoidance	Transfer	Reduction	Retention
High off-site manufactory building cost		Share the manufactory cost by becoming an EPC company.	Buy manufactory from general manufacturer and retrofit.	Consider as the unavoidable capital cost.
High component model and material fees		Share the manufactory cost by becoming an EPC company.	Establish mutual trust with suppliers through long-term cooperation, strive for preferential treatment.	Consider as the unavoidable capital cost.
Component paid after delivery	Place a backup plan to avoid negative effect by delayed payments.	Delay to pay other costs such as workers' salaries, material costs, etc.	Ensuring issues of payment are well documented at the start of projects. Ensuring payment arrangements made are executed according to plan. Obtain payment by instalments.	
On-site assembly limitation	Regular assessment of the working conditions and limitations should be considered.		Produce standard components to expedite on-site assembly process.	
Component is too heavy			Divided the components into smaller pieces and assemble on-site.	Contain this as a feature of OSC method.
On-site construction period adjustment	Proper planning of projects, taking into consideration emergencies (weather,	The contractor should pay extra costs if there is		

or change	government policy, etc.) to ensure the most appropriate conditions are provided for on-site period.	period adjustment or change.	
Lack of cooperation	Encouraging all participants to have good collaborations to ensure a common good is pursued for the project.		
Lack of risk management method	Cooperation with academia and industry to develop new risk management methods for OSC projects.		
Hard to deploy new management method			Construction managers should be given regular training to enable them to have current knowledge of practices in the industry.
Complexity of joint assembly		Assemble components in the manufactory to streamline on-site joint assembly process.	Regular training for on-site workers should be given for on-site assembly process.
Owner changes demand	Project planning at the initial stage of projects should be done. The plan needs to be strictly implemented.	The owner should pay extra costs if demands are changed.	Establish EPC company, reduce the information exchange lag during demand change.
Demand not suitable for off-site	An advanced announcement for demand should be published.		

project	Communication for the owner and other participants should have regular execution.			
Consultant lacks off-site experience			Designer should be given OSC training before designing.	
Consultant lacks on-site experience			Designer should go on-site and conduct field trips to understand the processes of on-site construction.	
Design error			The construction drawing review process should be done before being implemented by all participants.	
Consultant lack of standardisation	The consultants should cooperate and establish a common design mechanism.			
Manufacturer lacks experience			Ensuring manufacturing team are given the required training. Hire experienced workers.	
Contractor lacks experienced employees	Cooperate with colleges, encourage colleges to train more experienced employees.		Ensuring on-site workers are given required training.	
Contractor lacks experience			Ensuring on-site workers are given required training.	
Lack of on-site assembly standardisation	The contractors should cooperate and establish a common on-site assembly mechanism.			
Lack of subsidy and support			Pre-evaluate the cancellation of government subsidies to reduce	

			the impact of cancellation of policy support.	
Rigid prefabricated rate requirements			Follow the lowest prefabricated rate requirements for unsuitable construction projects.	
Local government policy standard differentiation			Due diligence and careful negotiations should be required before establishing the project in a new province.	
Component model lacks standardisation			Ensure only trusted suppliers are engaged in the supply of materials and component models.	
Contract bidding problem				Accept as the Chinese society feature.
Unstable economic situation			Project planning should be made well in advance and sufficient cash flow should be maintained.	
Public society prejudice against off-site building			High quality off-site project should be completed to reduce bias.	
Inconsistent quality demand for OSC projects				The problem with inconsistent quality demand is outside of control. It can only be changed by improving the inherent impression of OSC projects.

8.5 Case study preparation

In order to validate the reference table, a case study of the Chinese OSC organisations was chosen. Three main sources were used to validate the OSM risk reference table:

1. Documentary observations: By collecting data from OSC project documents, the documentary observations analyse data from the document to understand the project planning process for the project. It may also include relating government policy or standards for OSC as well as the construction drawings for the project.
2. Site observations: Site observations not only include observing in the manufactory, but also in other OSC processes such as the construction site, means of transport, or design office. This could help to understand features of the case based on the researcher's view.
3. Interview: During site observation process, various project team members were interviewed. These differed from interviews for the qualitative process, as these interviews focused on how to respond to the significant risks arising for OSC projects.

To identify the risk factors and risk response methods of the reference table, a guide of case studies was developed (see Table 8.10). This guide is divided into observable evidence and interview-based evidence. The observable evidence includes documentary observation data and site observation data, whereas the interview-based evidence includes interview data. Such a guide could help to find and define the appropriate response methods for risk factors identified during the cases.

Table 8.10: Risk reference table validation: a case study guide

RISK FACTOR	OBSERVABLE EVIDENCE	INTERVIEW BASED EVIDENCE
High off-site manufactory building cost	If possible, checking the bill of off-site manufactory building costs, including factory costs, land cost, equipment cost. etc.	By asking the interviewees how the organisation allocated funds to reduce the manufactory building cost.
High component model and material feed	If possible, checking the bill of off-site component model and material cost.	By asking the interviewees how the organisation allocated funds to reduce the component model and material costs.
Component paid after delivery	If possible, checking the income time of the off-site manufactory, and the contract of component payment schedule.	By asking the interviewees how to avoid capital chain rupture during payment delay situation.
On-site assembly limitations	If possible, observing the on-site worker assembly process, and checking the potential problems that cause assembly process delay.	By asking interviewees if there is a difficultly to assembling on-site and how to solve it.
Component is too heavy	If possible, checking the requirement of OSC transportation conveyance, such as component trucks, tower cranes, etc.	By asking interviewees whether the component weight influences their plans and how they respond to this problem.
On-site construction period adjustment or change	If possible, checking the planning of on-site period and whether plan has been followed.	By asking the interviewees how they plan and execute the activity and what to do if the plan has not been followed.
Lack of cooperation		By asking the interviewees, how often they hold meetings and how they solve disputes during the participant discussion process.
Lack of risk management method		By asking the interviewees if they considered the risk and how they intend to solve it.
Hard to deploy new management method	If possible, check with the new management planning of organisation and how it will be implemented.	By asking the interviewees if the worker follows the new management method how to correct the worker if they do not follow the rules.

Complexity of joint assembly	If possible, observing the on-site worker assembly process and checking for potential problems that cause assembly process delay.	By asking the interviewees if there is a difficulty to assembling on-site and how to solve it.
Owner changes demands	If possible, checking the initial plan of the project and monitoring whether the milestone finishes on time.	By asking the interviewees how much impact the owner changing demands has and how to reduce this risk.
Demand not suitable for off-site project		By asking the interviewees what types of demand would be not suitable for off-site project and how to judge whether the demand is reasonable.
Consultant lacks off-site experience		By asking the interviewees whether the designer is conversant with the techniques and methods of OSC.
Consultant lacks on-site experience		By asking the interviewees whether the designer is conversant with on-site processes.
Design error		By asking the interviewees which types of design would be not suitable for off-site projects and why the design error arose.
Consultant lack of standardisation		By asking the interviewees whether different consulting companies have similar design standardisations and how to coordinate the differences arising within the design process.
Manufacturer lacks experience		By asking the interviewees whether the manufacturer is conversant with the techniques and methods of OSC methods.
Contractor lacks experienced employees		By asking the interviewees which types of employees are required and how to get more employees if insufficient.
Contractor lacks experience		By asking the interviewees whether the contractor is conversant with the techniques and methods of

		OSC.
Lack of on-site assembly standardisation		By asking the interviewees whether different contractor companies have similar assembly standardisation processes and how to align these.
Lack of subsidy and support	If possible, check the government policy for OSC online.	By asking the interviewees if the government provides sufficient subsidy or support and how to prepare if the government stops these.
Rigid prefabricated rate requirement	If possible, check the government policy for prefabricated rate requirement online.	By asking the interviewees how to fit the prefabricated rate for unsuitable projects.
Local government policy standard differentiation	If possible, check the local government policy for OSC online, and compare the policy with other provinces.	By asking the interviewees how the different policies influence off-site projects and how to reduce their negative impacts.
Component model lacks standardisation		By asking the interviewees whether different supply companies have similar component models and how to coordinate differences in the production process.
Contract bidding problem		By asking the interviewees what percentage of losing bids are because the price is not the lowest and discussing how to respond this.
Unstable economic situation		By asking the interviewees how the economic war and COVID-19 influence their OSC projects and how to reduce negative impacts.
Public society prejudice against off-site building		By asking the interviewees whether society still has negative views of OSC and how to change this stereotype.
Inconsistent quality demand for OSC project		By asking the interviewees what reflects the inconsistent quality demand for OSC.

In this research, two case studies were employed. The types of cases are different, which could help to identify whether the appropriate risk response method varies for different organisations. The reference table for the risk factor and identified risk response was provided to the interviewees to determine the influences upon risk and how to respond to them.

8.6 Case study one

8.6.1 Sources of Data – Case One

For case study one, the background of the organisation is presented in Table 8.11.

Table 8.11: Profile of Case Study One

ORGANISATIONAL FEATURES	DETAIL
Year of establishment	2017
Type of organisation	State-owned company
Areas of specialisation	EPC company for OSC project, includes planning, design, production, transportation, and assembly.
Registered capital	90 million RMB (About 10 million pound)
Floor area	110 thousand square meters
Annual production capacity	220 thousand cubic meters per year
Production line	6 production lines, including 3 concrete component lines, 1 stell component line, 1 steel bar line, and 1 concrete component line (import from Germany).
Catchment areas	Shenzhen and Shantou. The OSC project is controlled by the head office, this company get the order from the head office.
Location	Shenzhen, Guangdong province, China.

Case Study One was a state-owned company established in 2017, which is a wholly-owned third-tier subsidiary company for the third ranked state-owned construction company. The aim of this company is to address the shortage of OSC companies in the local area, as a new economic development zone has developed over recent years. The company is able to plan, design, manufacture, transport and assemble for OSC projects. Several high-rise residential apartments were developed during the data collection period. These apartments adopted the components manufactured by the company. For data collection, the manufactory and the construction site were visited and observed by the researcher. A project manager, a general manager, and a purchasing manager from the manufactory were interviewed. A project manager from the construction site was also interviewed. Table 8.12 presented the detail of each interviewee in the case study one.

Table 8.12: Participant information for case one

CODE	POSITION	EXPERIENCE
CO1	Project manager from manufactory	6 years
CO2	General manager	10 years
CO3	Purchasing manager	4 years
CO4	Project manager from construction site	5 years

8.6.2 Evaluation of OSM risk reference table– Case One

During the case study data collection process the reference table was presented to the interviewees who were asked to identify how the risks identified influence their company and OSC projects. These risks were found to have a likely influence on quality, time, and cost, which means that the risk influences can be divided into QCD. Based on the interviews, the were documents analysed after visiting the manufactory and associated site, and the appropriate risk response method for each risk was ascertained and identified.

COST					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
IR1	C		Share the manufactory cost by becoming an EPC company.	Buy manufactory from general manufacturer and retrofit it.	Consider capital cost as unavoidable.
IR2	C		Share the manufactory cost by becoming an EPC company.	Establish mutual trust with suppliers through long-term cooperation, strive for preferential treatment.	Consider capital cost as unavoidable.
IR7	C	Place a backup plan to avoid negative effect of delayed payments.	Delayed payments to other costs such as worker salaries, material cost, etc.	Ensuring issues of payment are well documented at the start of projects. Ensuring that payment arrangements made are executed according to plan. Receive payment by	

				instalments.	

All interviewees agreed that the cost was prioritised across all the projects, especially in OSC. CO1 said, '*Many people think that OSC projects could save more money. Yes, but only in the condition of excluding the manufactory building cost.*' Most interviewees agreed that high off-site manufactory building costs (IR1) should be considered as the most significant barrier to establishing an off-site manufactory. As this company is an EPC company, the manufactory cost is apportioned by the head office. However, this cost is still relatively high for the construction company.

For this company, high component model and material fees (IR2) are considered to fall under the same risk category as IR1. Both risks are initial investments for OSC projects. During the site visitation process, the researcher observed 4 production lines, one of which was purchased from a German company at the cost of 150 million yuan. This cost is also apportioned to the head office, which is relatively high cost for a start-up company.

CO1 explained the influence of component payment after delivery (IR7): '*For off-site manufactories, the major income comes from components. However, the component needs to be assembled on-site and await project acceptance. Sometimes the owner delays this payment as they do not have enough money. We have to pre-pay the workers and materials.*' These delays in payment affect the cash flow of the manufacturer and lead to not only extra cost, but also project delay. However, as an EPC company, the payment process is documented and follows the schedule, reducing the IR7 risk for the manufactory.

OFF-SITE FEATURES					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
IR6	Q, C, D	Regular assessment of the working conditions and limitation should be considered.		Produce standard components to reduce on-site assembly process.	
IR8	D			Divide the components into smaller pieces and assemble on-site.	Contain this as the feature of OSC method.

Compared with traditional construction, OSC has several new features. During the researcher's constriction site visit, on-site assembly limitations (IR6) occurred quite often. For example, many components have irregular shapes, causing the hoisting process to require more steps than for a traditional construction project. Another problem comes from the use of steel bars in OSC projects, as the component needs a grout sleeve to connect with each other given that the steel bar is the connection point, which means that the steel bar effectively extends the size of the component, further limiting component assembly. Many posters and documents can be found on the construction site to inform the importance of safety for working conditions and regular inspections are performed for the OSC site.

CO2 stated, '*In the manufactory, the weight of the component is not that important as we could use equipment to transfer the component. This problem always happens during the on-site assembly process, as the heavy component requires better tower cranes.*' This company thinks that the component being too heavy (IR8) does not have a large influence on the manufacturing process, but for the on-site assembly process it is important. As an EPC company, the manufacturer has more opportunity to discuss with both consultant and contractor, and IR8 is discussed during the regular meetings and a suitable component is agreed upon.

PROJECT MANAGEMENT					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
IR3	C, D	Proper planning of projects taking into consideration emergencies (e.g., weather, government policy, etc.) to ensure that the most appropriate conditions are provided for on-site period.	The contractor should pay extra costs if the period is adjusted or changed.		
IR4	C, D	Encouraging all participants to have good collaborations to ensure that a common good is pursued.			
IR5	Q, C, D	Cooperate with academia and industry			

		to develop new risk management methods for OSC projects.	
IR10	Q, C, D		Construction manager should be given regular training to enable them to have current knowledge of practices in the industry.

On-site construction period adjustments or changes (IR3) not only influence OSC projects, but also traditional construction projects. As OSC project delay influences the industrial chain, the negative impact of IR3 is magnified. To solve this problem, the EPC company chooses to urge the contractor to follow the schedule. However, this solution has only a limited effect.

Although this company is an EPC company, a lack of cooperation (IR4) is still arising. CO4 said, '*It seems that we are an EPC company and internal competition still exists. As we cannot meet the needs of all people, sometimes we have to communicate with other participants to get want we want.*' For EPC companies, the competition is reduced but still exists. To solve this problem, regular meetings for all participants are required.

For cooperation with academia and industry, CO2 said, '*To be honest, our company has the best management methods in China and many companies want to learn our technology. As for academia, the problem is that some researchers retain obsolete or unrealistic ideas and it is hard to apply these methods to OSC.'* However, this company has a plan to cooperate with both academia and industry to develop the risk management method in the future to solve the lack of a suitable risk management method (IR5).

Within the manufactory, the researcher observed many signs and boards for lean manufacturing and lean construction. During the regular meeting process, the term lean manufacturing was mentioned several times. However, CO1 commented, '*It seems that we have some new management technology in our manufactory. However, we always do it in formalism. For example, we require regular reports every week to* *discover the problems arising in the production process. It works well for the first month, however, after this there are few problems that need to be reported, yet we still need to write the report.*' Another thing that should be recognised is that few people understand what six sigma is, and others think that Kanban is a signboard. It is hard to deploy new management methods (IR10), not only because of the lack the knowledge of new management methods, but also because such novel management methods are used inflexibly. To respond to IR10, this company religiously follows the training and up-skilling of the managers and organises that the manager visits off-site manufactories in Japan and Hong Kong.

TIME					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
IR9	D		Assemble the component in the manufactory to reduce on-site joint assembly process.	Regular training for on-site workers should be given for on-site assembly process.	

Complexity of joint assembly (IR9) is an identified construction site risk. CO4 said, '*This risk is similar, as an on-site assembly limitation (IR6), but more focus is on the component itself. Our company has assembly training for the on-site worker, and this could help them to assemble more quickly.*' This means that the solution for IR9 is to give regular training for on-site workers.

OWNER					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
PR3	C, D	Project planning at the initial stage of projects should be done. The plan needs to be strictly implemented.	The owner should pay extra costs if demand is changed.	Establish EPC company, reduce the information exchange lag during demand change.	
PR4	C, D	An advance announcement of demand should be published. Communication for the owner and other participants should have regular execution.			

For this company, an owner-related change in demand (PR3) happened during the first project. CO2 recalled, '*When we did our first project, we did not have much experience, which caused us have to change the planning during the project. After that, we began to build initial planning, and a BIM model was built in the early stages. This helps the off-site project to follow the schedule.*' It is evident that new management methods and new technology, such as BIM, could help the company to reduce PR3 risk.

The event that demand was not suitable for an off-site project (PR4) occurred at the same time for this company. As mentioned in PR3, the main reason for a change in demand is because of PR4. In this case, a suitable demand is necessary for an OSC project. In order to develop an appropriate requirement, regular meetings with the owner and other participants should be implemented regularly.

CONSULTANT					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
PR1	C, D			Designer should be given OSC training before designing.	
PR2	C, D			Designer should go on-site and conduct field trips to understand the process of on-site construction.	
PR7	Q, C, D			The construction drawing review process should be done before being implemented by all participants.	
PR8	Q, C, D	The consultants should cooperate and establish a common design mechanism.			

Although this company has a design team for OSC projects, consultants lacking off-site experience (PR1) is still an extant problem. CO2 said, '*The OSC project is relatively new for designers, but most of our designers are young people and they could learn this new methodology really fast if they had a good teacher. We give them many chances to go to manufactories and to learn the process of off-site component production.*' For this company, the response method for PR1 is providing more opportunity for designers to visit the manufactories and learn the off-site component production process.

Consultants' lack of on-site experience (PR2) was noted by the company, CO3 said, '*As the designer, they do not need to go on-site, which results in them not knowing the on-site process. The OSC project is a life cycle project, and so it is necessary to send them to learn the on-site process.*' Thus, the company sends the designer to learn the on-site assembly process.

Design error (PR7) arises because of PR1 and PR2. As CO4 said, '*The lack of experience results in PR7, if they understand how to design OSC project, there will not be any design error.*' In order to reduce design error, the experience of the contractor should be improved, which means general training for the designer is necessary.

This company has a solution for consultants' lack of standardisation (PR8). As CO2 said, '*We have cooperation with other companies, and we have an association in our area. Last year, we developed the design standardisation for concrete components for shear walls. We will develop more standardisation in the future.*' From CO2 response, PR8 will be reduced by more standardisation development in the future.

MANUFACTURER					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
PR9	Q, C, D			Ensuring manufacturer team are given the required training. Hire experienced worker.	

Although the rank of manufacturers lacking experience (PR9) seems relatively low in the participant risk category, it nonetheless still presents several problems. CO1 complained, '*The production line from Germany cost us 150 million. However, this production line has stopped working since January. The reason is that the supplier only provided 2 types of code for component production, and we want to do some other types of product. Since the COVID-19 outbreak, we have been unable to ask them to come here for coding. Now it is only a very expensive warehouse.*' During the researcher's observation process, a lot of steel bars and other components were placed on the production line, but no new components were produced. CO1 provided a solution for PR9: '*To solve this problem, we need to hire more experienced workers or train more workers to become expert. However, the production line problem is still existing, and there is still a big gap between our technology and that of foreign countries.*' Hiring more experienced workers or training the workers could reduce PR9, but the root of the problem is the lack of available high technology for OSC.

CONTRACTOR					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
PR5	Q, C, D	Cooperate with colleagues, encourage them to train more experienced employees.		Ensuring on-site workers are given the required training.	
PR6	Q, C, D			Ensuring on-site workers are given the required training.	
PR10	Q, C, D	The contractors should establish cooperation and a common on-site assembly mechanism.			

Contractors' lack of experienced employees (PR5) was agreed upon by CO4 who stated, '*In our project, we have insufficient experienced OSC workers. We tried to provide more training for the workers, but it takes time to be productive. Another thing is that we need more workers on-site, as many young people think it is too hard to work on-site and most of our on-site workers are aged from 35 to 55.*' PR5 caused the contractor to consume extra time and cost to train these workers. However, as few young people are willing to work on-site. This is the only solution for the company in the current situation.

From CO3 view, the contractor's lack of experience (PR6) is same as PR5, and the reason is that OSC is still a relatively new methodology and the contractor for OSC still needs more practice and training.

During the site visitation process, there was no generic on-site assembly standardisation (PR10) for the workers. For example, there was no clear assembly process guide for the workers on-site, as most of the workers were using their experience from traditional construction projects. Another problem observed was that the steel bar on the component was bent by the worker, damaging the connection point for the component and causing safety issues for the building structure. PR10 is duly recognised by the manager, but it is hard to change, CO3 said, '*We know there are a lot of problems during the on-site assembly process, not only because of the on-site limitations, but also because of a lack of on-site standardisation. Although we have monitors for the on-site assembly process, they cannot monitor every aspect.*' In order to solve PR10, two methods are chosen for this company. The first is giving regular training to on-site workers, and the second is monitoring the on-site assembly process.

GOVERNMENT POLICY					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
ER2	C			Pre-evaluate the cancellation of government subsidies to reduce the impact of cancellation of policy support.	
ER6	Q, C			Follow the lowest prefabricated rate requirement for unsuitable construction projects.	
ER8	C, D			Due diligence and careful negotiations should be required before establishing a project in a new province.	

As a new economic development zone, it seems that a lack of subsidy and support (ER2) has only a limited influence on this company. As CO2 said, '*We get a lot of support in this area as this is a new economic development zone and the government sector attaches great importance to OSC.*' After mentioning that the subsidy and support may be cancelled in the future, CO2 said, '*Yes, we forecast that the support will be cancelled in the future. However, as OSC has had vigorous promotion during these years, we could get a profit in these early years and then we do not need to worry about the support.*' For this company, it seems that the provision of government support has been treated properly.

On the construction site, the prefabricated rate for each building is 28%, which is higher than the lowest prefabricated rate requirement (20%). Rigid prefabricated rate requirements (ER6) affect the company little, although CT1 still commented: '*Some* *of the buildings are not that suitable for OSC methods, but we still use them, as these buildings are treated as an OSC demonstration*.' This suggested that some projects are unsuitable for the OSC method, but that ER6 may force them to deploy the method anyway.

CO1 said, '*We received a lot of support in this area as this is a new economic development zone and the government sector attaches great importance to OSC. However, some places do not have support like this, and sometimes the province thinks that OSC is a profitable new construction method and they do not understand that the initial costs for OSC are very high.*' Local government policy standard differentiation (ER8) seems to have only a limited effect on this company. However, the manufacturer recognises a differentiation in standards across different provinces. To reduce the risk of ER8, CO1 said, '*We always choose the province with enough support and a robust policy.*' This suggests that the provincial policy and standards are considered first by the company before establishing a project. During the data collection process, some government staff from another province came to this company to gain experience, establishing that the off-site experience across different provinces varies.

RESOURCE					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
ER3	Q, C, D			Ensure that only trusted suppliers are engaged in the supply of materials and component models.	

The component model for this manufactory is designed and developed by certain suppliers which reduce the risk of a lack of standardisation of component models (ER3). From CO3 view: '*Although we do not have any problem with component models, the model's lack of reuse is still a problem. If the model has a standardisation we could use the old model in the new component which could greatly reduce our cost.*' ER3 results in the manufacturer having to pay extra costs for component models and, to reduce this risk, only trusted suppliers are chosen for the supply of off-site component models.

SOCIETY					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
ER1	Q, C, D				Accept as the Chinese society feature.
ER7	C			Project planning should be made well in advance. Sufficient cash flow should be maintained.	
ER4	C, D			High quality off-site project should be done to reduce bias.	
ER5	C, D				The problem of inconsistent quality demand is outside of the sphere of control. It can only be changed by improving the inherent impression of OSC projects.

As an EPC company, the client is the headquarters which results in the manufacturer becoming a *de facto* 'local supplier' for the headquarters. However, contract bidding problems (ER1) still arise.CO1 stated, '*In a construction project, the lowest price company always win the contract, even for an OSC project. We could get a contract from our headquarters and become their component supplier. However, for our headquarters, they still need to balance the profit and win the contract.*' An EPC company could reduce the ER1 risk for the manufacturer. However, the risk is still extant and influences all construction projects.

The threat from an unstable economic situation (ER7) has increased in recent years. CO4 said, '*During these years, the economic war has had a significantly negative influence for the construction industry. We thought 2020 could go better, however, the COVID-19 issue has caused us to have to pause many projects in the first half of the year.*' These 'black swan events' were not considered by the company, resulting in a negative influence. In the future the company will set aside more cash flow to reduce its influence.

Although the OSC industry has been negatively affected by COVID-19 (ER7), the public's prejudice against off-site building (ER4) has declined during this period. CO2 stated, '*During COVID-19, the Leishenshan hospital and Huoshenshan hospital built in Wuhan used OSC methods. The building process was broadcast live online which increased the interest of the general public in OSC.*' Although the hospitals give more confidence to the public, the safety of OSC is still being questioned by the general public. The ER4 solution is based on the public's view, as CO2 said, '*It is hard to change the public perception. The only thing we can do is to produce better quality components and build better OSC buildings.*'

From CO2 viewpoint, an inconsistent demand in quality for OSC projects (ER5) is same as for ER4, as both risks stem from the public's attitude and the reason for this is because of the public's lack of understanding of OSC. As for ER4, the problem can only be solved by dispelling the public's prejudices, increasing its understanding of OSC, and developing more quality off-site buildings.

8.6.3 Risk response method - Case One

According to the interviewees' feedback, site visitations and document checking, the identification of each identified risk and its response is presented in Table 8.13.

Table 8.13: Summary for Case Study One

CODE	QCD	RESPONSE METHOD
IR1	C	**Transfer:** Share the manufactory's cost by becoming an EPC company.
IR2	C	**Transfer:** Share the manufactory's cost by becoming an EPC company.
IR7	C, D	**Reduction:** Ensuring issues of payment are well documented at the onset of projects. Ensuring payment arrangements made are executed according to plan. Get paid in instalments.
IR6	Q, C, D	**Avoidance:** Regular assessment of the working conditions and limitations should be considered.
IR8	D	**Reduction:** Discuss with other participants designing a suitable component.
IR3	C, D	**Reduction:** Urging the contractor to follow the construction plan.
IR4	C, D	**Reduction:** Have regular meetings for all participants.
IR5	Q, C, D	**Avoidance:** Cooperate with academia and industry to develop new risk management methods for OSC projects.
IR10	Q, C, D	**Reduction:** Construction manager is given regular training to enable them to have current knowledge of practices in the industry. Visiting other manufactories to gain more experience.
IR9	D	**Reduction:** A regular training for on-site workers should be given for the on-site assembly process.

PR3	C, D	**Avoidance:** Project planning at the initial stage of projects should be done. The plan needs to be strictly implemented.
PR4	C, D	**Avoidance:** Communication for the owner and other participants should be regularly executed.
PR1	C, D	**Reduction:** Designers should be given OSC training before designing.
PR2	C, D	**Reduction:** Designer should go on-site and conduct field trips to understand the process of on-site construction.
PR7	Q, C, D	**Reduction:** The construction drawing review process should be done before being implemented by all participants. Designer should have regular training for OSC projects.
PR8	Q, C, D	**Avoidance:** The consultants should cooperate and establish a common design mechanism.
PR9	Q, C, D	**Reduction:** Ensuring manufacturer teams are given the required training. Hire experienced workers.
PR5	Q, C, D	**Reduction:** Ensuring on-site workers are given the required training.
PR6	Q, C, D	**Reduction:** Ensuring on-site workers are given the required training.
PR10	Q, C, D	**Reduction:** Monitor the on-site assembly process and give regular training to on-site workers.
ER2	C	**Reduction:** Pre-evaluate the cancellation of government subsidies to reduce the impact of cancellation of policy support.
ER6	Q, C	**Reduction:** Follow the lowest prefabricated rate requirement for unsuitable construction projects.
ER8	C, D	**Reduction:** Due diligence and careful negotiations should be required before establishing the project in a new province.
ER3	Q, C, D	**Reduction:** Ensure only trusted suppliers are engaged in the supply of materials and component models.
ER1	Q, C, D	**Reduction:** Establish EPC company to obtain internal contracts.
ER7	C	**Reduction:** Project planning should be made well in advance. Sufficient cash flow should be maintained.
ER4	C, D	**Reduction:** High quality off-site projects should be completed to reduce bias.
ER5	C, D	**Reduction:** High quality off-site projects should be completed to reduce bias.

8.7 Case Study Two

8.7.1 Sources of Data – Case Two

For case study two, the background of the organisation is presented in Table 8.14.

Table 8.14: Profile of Case Study Two

ORGANISATION FEATURES	DETAIL
Year of establishment	2016
Type of organisation	Private company
Areas of specialisation	Manufactory for component production and

	transportation.
Registered capital	100 million HKD (About 9.5 million pound)
Floor area	85 thousand square meters
Annual production capacity	180 thousand cubic meters per year
Production line	4 production lines, include 3 concrete component lines, and 1 steel bar line.
Catchment areas	Foshan. This company has cooperation with local government, and the local government introduce OSC project to the company.
Location	Foshan, Guangdong province, China.

Case study two is a private company that was established in 2016 as a wholly-owned second-tier subsidiary company of a top-five Chinese private construction company. The main focus of this company is to provide off-site components for local OSC projects. The company is able to produce and transport such components. Several high-rise residential apartments were being developed during the data collection process, and this company also produces off-site components for the subway floor. For the purposes of data collection, the manufactory was visited and observed by the researcher. A project manager, a general manager, a purchasing manager, and a design manager from the manufactory were interviewed. Table 8.15 presents the detail of each interviewee in case study two.

Table 8.15: Participant information for case two

CODE	POSITION	EXPERIENCE
CT1	Project manager	4 years
CT2	General manager	8 years
CT3	Purchasing manager	4 years
CT4	Design manager	3 years

8.7.2 Evaluation of OSM risk reference table– Case Two

During the case study data collection process, the reference table was presented to the interviewees and each was asked to identify how the identified risk influences their company and OSC project. These risks were found to have a likely influence on quality, time, and cost, which means that the risk influence is divided into QCD. Based on the interviews, the documents were analysed and the manufactory site visited, whereupon the appropriate response method for each identified risk was ascertained.

COST					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
IR1	C		Share the manufactory cost by becoming an EPC company.	Buy manufactory from general manufacturer and retrofit it.	Consider capital cost as unavoidable.
IR2	C		Share the manufactory cost by becoming an EPC company.	Establish mutual trust with suppliers through long-term cooperation, strive for preferential treatment.	Consider capital cost as unavoidable.
IR7	C	Place a backup plan to avoid negative effect of delayed payments.	Delay paying other costs such as workers' salaries, material costs, etc.	Ensuring issues of payment are well documented at the start of projects. Ensuring payments arrangements made are executed according to plan. Receive payments in instalments.	

This company considered the high off-site manufactory building cost (IR1) as a major risk for off-site manufactory cost problems. CT2 said, '*The OSC project requires a nearby off-site manufactory, generally within 20 km. We need to build a lot of off-site manufactories in this area.*' Thus the causes of the costs of off-site manufactories cannot be avoided. Alternative solutions such as 'buying manufactories from general manufacturers and retrofitting them' are provided, but are generally refused by the interviewees, CT2 said, '*Although general manufactory looks like an off-site manufactory, the inside is different. The cost for the off-site manufactory building not only includes the manufactory, but also the location, area, production line, etc. it is hard to find a perfect place which is suitable for an off-site manufactory.'* Thus, this company accepts IR1 as a necessary cost.

For high component models and material fees (IR2), CT1 said, '*We think this is an essential cost. As you know, we also need to pay the materials and equipment costs in traditional construction, so it is very normal for us to pay the materials and component costs if we want to do an OSC project.*' Although this company agreed that IR2 is a risk for the off-site manufactory, it is unavoidable as the traditional construction sector is also exposed to similar risk.

Component payment after delivery (IR7) results in the company always lacking in terms of cash flow. CT2 explained, '*We always lack money. For example, our components are produced for other projects, but we are still waiting for the payment from the project we finished a year ago. It means our money has to be prepaid for the workers' salaries, which puts a lot of pressure on our cash flow.*' The company has to set aside more capital as a form of backup planning to respond to the IR7 risk. However, this backup plan requires a robust cash flow as well as a sufficient capital reserve, which results in an aggravated financial pressure on the off-site manufactory.

OFF-SITE FEATURE					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
IR6	Q, C, D	Regular assessment of the working conditions and their limitations should be considered.		Produce standard component to reduce on-site assembly process.	
IR8	D			Divide the components into smaller pieces and assemble on-site.	Contain this as a feature of the OSC method.

To a manufacturer, on-site assembly limitations (IR6) have limited influence. However, CT2 said, '*Although we do not do on-site assembly, the on-site assembly limitations could result in more time-consuming solutions, which lengthens the construction period and increases our cost.*' IR6 could result in a delay to the whole construction process, which in turn influences the planning for the off-site manufacturer. For the manufacturer, the solution is to produce more standard components for the contractor. However, as the assembly process is not controlled by the manufacturer, this solution has only a very limited effect.

Where the component is too heavy (IR8) and causes difficulties in the transportation and assembly, CT4 explained, '*The off-site component is heavier than traditional materials and is harder to transport and assemble. The irregular shapes increase the difficulty of transportation and assembly. Sometimes we choose to design smaller components to reduce this risk*.' However, CT1 has an opposite opinion, '*If we* *transport smaller components on-site, it means that more grout sleeve processing is needed and this will increase the on-site assembly time and influence the whole project process.*’ Thus the off-site component should be designed in an appropriate size. The current solution for IR8 in this company follows the component requirements from the consultant and this risk is incorporated as an OSC project feature.

PROJECT MANAGEMENT					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
IR3	C, D	Proper planning of projects taking into consideration emergencies (weather, government policy, etc.) to ensure the most appropriate conditions are provided for on-site period.	The contractor should pay extra costs if the period is adjusted or changed.		
IR4	C, D	Encouraging all participants to have good collaborations to ensure a common good is pursued for the project.			
IR5	Q, C, D	Cooperate with academia and industry to develop new risk management methods for OSC projects.			
IR10	Q, C, D			Construction manager should be given regular training to enable them to have current knowledge of practices in the industry.	

The on-site construction period adjustment or change (IR3) may influence the time schedule for the manufacturer, but has little influence on the cost. CT1 said, ‘*We could ask the contractor to follow the project planning, but we also have a contract with the contractor. If they do not follow the plan, we can ask them to pay the extra cost, at the very least they should follow the payment schedule.’* In this case, this company could receive their income on schedule even in the event of an IR3 situation.

For the OSC project, a lack of cooperation (IR4) seems to be a very serious problem. OSC projects require more cooperation than traditional construction projects, as CT3 explained, ‘*During my purchasing process, there are a few times when we have very good cooperation. Most of the time we always argue with the supplier as they want us to pay more money, sometimes even when we have some trouble, they choose to increase the material prices rather than to have cooperation.*’ The company tried to build a long-term and stable relationship with other participants to reduce the IR4 problem, and it seems that the contractor had a good relationship with the manufacturer during the researcher’s period of observation.

The lack of a suitable risk management method (IR5) has been recognised by the company. CT2 stated, ‘*We think that the risk exists, like the possibility of chaos in the production process. Right now, we are treating the symptoms but not the root cause. There is a problematic exposure and we solve the problem. Even worse, sometimes we solve the people who propose this problem.*’ The proposed response for IR5, namely greater cooperation with academia and industry to develop new risk management methods, is refused by CT2. ‘*It seems like a good method for risk management, but it is very hard to deploy. For industry, the competitive relationship arises because we do not want to share our technology with other companies.*’ However, the company is willing to cooperate with academia, although they prefer to have more communication with universities.

In this company, hard to deploy new management methods (IR10) that do not appear that important, as new management methods are only at a theoretical stage in this company. However, the company considers that IR10 will happen in the future, and thus it is necessary to prepare a solution for it. Regular training for the construction manager is a practical method.

TIME					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
IR9	D		Assemble the component in the	Regular training for on-site workers should	

			manufactory to reduce on-site joint assembly process.	be given for on-site assembly process.	

As mentioned in IR6, the complexity of joint assembly (IR9) is an on-site assembly limitation issue. The manufacturer has only limited influence on this risk.

OWNER					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
PR3	C, D	Project planning at the initial stage of projects should be done. The plan needs to be strictly implemented.	The owner should pay extra costs if demands are changed.	Establish EPC company, reduce the information exchange lag during demand change.	
PR4	C, D	An advanced announcement for the demand should be published. Communication for the owner and other participants should have a regular execution.			

According to CT2, '*It is very normal that owners change demands in traditional construction projects, but in OSC projects, any change in demand will cause us to change a lot of processes. Sometime the owner even changes the participants during the project process and we have to communicate with the new participant.*' Although owner-driven changes in demand (PR3) could greatly influence the OSC project, the manufacturer considers retaining the current *status quo* as CT2 informed, '*They give us the money, we have to listen to them.*'

As with PR3, 'demand not suitable for off-site project' (PR4), this also has a potentially negative influence on the off-site manufactory. As CT2 said, '*We had a project that asked us to build a curved concrete component and only needed one part. We have to ask the supplier to build a curved component model. It took a lot of effort to produce this component. However, after we delivered this component, they said they did not need it anymore, and the owner changed the demand again.*' It seems that the off-site manufactory only has limited influence on the owner's decision. Although the type of construction method has since changed, some owners still consider the project in the same way as a traditional construction project.

CONSULTANT					
CODE	QCD	RESPONSE			
		Avoidance	Transfer	Reduction	Retention
PR1	C, D			Designer should be given OSC training before designing.	
PR2	C, D			Designer should go on-site and conduct field trips to understand the process of on-site construction.	
PR7	Q, C, D			The construction drawing review process should be done before being implemented by all participants.	
PR8	Q, C, D	The consultants should establish cooperation and a common design mechanism.			

CT3 thought that the consultant lacked all manner of experience, and not only a lack of off-site experience (PR1), as CT3 related, '*The consultant's lack of experience arises because they do not want to go on-site, not only the construction site, but also the manufactory. They do not know the process for the manufacturer or the contractor, and they can only follow their design standards.*' As the consultant lacks experience, the manufacturer is willing to invite the consultant to visit the manufactory. However, only a few consultants have the time to visit the manufactory.

In CT3 view, the consultant's lack of on-site experience (PR2) mirrors PR1 (as mentioned above). The manufacturer suggested that the contractor invite the consultant to the construction site to understand the process for off-site component assembly.

During the data collection process, the design drawing was presented by CT2. Several design errors (PR7) were pointed out by CT2. 'As *you can see, in this design drawing, we can find at least three errors. In traditional construction projects, these are not a problem, but in OSC project, these will become a barrier for us or the contractor to build a better project.*' As a manufacturer, the consultant cannot be controlled, which means that the manufacturer can only find the design error after the design drawing has been completed. CT2 said, '*It is a time waste if there is any design error. We have to tell them there is an error, and wait them to make changes, and then it still has some error.*'

The consultant's lack of standardisation (PR8) is disagreed by CT3. '*The consultant does not lack of standardisation - they have too many standardisations. As they only follow the standardisation, they do not consider whether the standardisation is suitable for OSC.*' This view suggests that consultant standardisation is unsuitable for OSC and, as a result, the design is unsuitable for OSC. Nevertheless, as the manufacturer is not the consultant's standardisation rule maker, the only solution is waiting for the government or the consultants' association to develop the OSC standardisation.

MANUFACTURERS					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
PR9	Q, C, D			Ensuring manufacturing team is given the required training. Hire experienced workers.	

The manufacturer agreed that a lack of experience (PR9) is a risk. As CT2 indicated, '*Previously I was in another off-site manufactory. They bought a production line from Germany. It worked well until 3 months later. The production line suddenly stopped and nobody knows the reason. After the German expert came, the reason was found: the plastic film for the pipe outlet should be removed.'* In the manufactory, a lack of manufactory experience resulted in this problem, which necessitates more experienced workers for the manufactory. PR9 happened quite often during the observation process and should thus be considered a major risk for the off-site manufacturer.

CONTRACTORS					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
PR5	Q, C, D	Cooperate with colleges, encourage the colleges to train more experienced employees.		Ensuring on-site workers are given required training.	
PR6	Q, C, D			Ensuring on-site workers are given	

CODE	QCD	Avoidance	Transfer	Reduction	Retention
					required training.
PR10	Q, C, D			The contractors should cooperate and establish a common on-site assembly mechanism.	

CT2 mentioned the contractors' lack of experienced employees (PR5), not only in terms of a lack of on-site workers, but also of on-site managers, '*Then the contractor complained about the lack of experienced employees and they do not know where to find them. All OSC companies lack experience and we need to find the experience by ourselves.*' In response to PR5, CT2 said, '*Many contractors give training to all employees, however, the price is very expensive.*' In order to train the employees, the contractors have to pay extra costs.

The contractors' lack of experience (PR6) drew the same response as for PR5. CT2 said, '*We think that PR6 causes PR5. To solve this problem, the only thing we can do is to give the workers regular training.*' Regular training is the only method for the manufactory to respond effectively to PR6.

CT2 stated that IR6, IR9 and a lack of on-site assembly standardisation (PR10) are the same kinds of risk, as all of them are on-site assembly problems. The main reason comes from PR10, andCT2 said, '*Our components have few problems, but when we perform the on-site assembly, the migrant workers have no responsibility for their jobs and that causes a lot of problem for the components. It always causes us to take the responsibility for the migrant workers' faults, as the owner can only find us, not the workers.*' In this company, PR10 should be the responsibility of the contractor, although the manufacturer takes on a responsibility that shouldn't have been accepted. As for IR6 and IR9, the manufacturer has only a limited method of response.

GOVERNMENT POLICY					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
ER2	C			Pre-evaluate the cancellation of government subsidies to reduce the impact of cancellation of policy support.	
ER6	Q, C			Follow the lowest prefabricated rate requirements for unsuitable construction project.	

ER8	C, D	Due diligence and careful negotiations should be required before establishing the project in a new province.

Over recent years, the Chinese government has provided many policies to promote the OSC industry. However, a general lack of subsidy and support (ER2) is still mentioned by CT2. '*The government subsidy is for the clients. For example, if the building reaches the requirements of an OSC project, the clients could get a lot of subsidy and tax reductions from the project. For us, we could get tax reductions during the manufactory building process, and it would be better if we could get more support from the government.*' ER2 has become a barrier for off-site manufacturers in establishing manufactories. As the subsidy and support will be erased in future, any current manufacturer should consider future development. As CT2said, '*In the future, most OSC companies will go bankrupt and the companies which can survive without government support could win this race.*'

Rigid prefabricated rate requirements (ER6) cause the owner to choose low quality components. As CT2 explained, '*Some buildings are unsuitable for OSC, but the government policy results in the building having to follow the 20% prefabricated rate requirement. Some owners choose the lowest quality components to achieve these lowest prefabricated rate requirements. These low-quality components have a negative impact on the OSC industry's reputation.*' ER6 risk causes the owner to choose to save on cost and time rather than to ensure the quality of the building. The manufactory advised the government to give more flexible prefabricated rate requirements. However, for the current situation, the only method is to follow the owners' requirements.

This company is located in Guangdong province, designated as a first tier OSC development area. Local government policy standard differentiation (ER8) has only a small effect on this manufactory. As a private company, future development should be considered. CT2 related, '*Our headquarters want to build some new manufactories in other areas, as some provinces do not have any experience in OSC, which means that* *they have insufficient supporting facilities, such as suppliers, road conditions, government support, etc. That is why we should choose a province with enough support.*' For the manufactory, the location itself should be considered, as different provinces have different policies, and this an investigation of the policy and supporting facilities for the province is necessary.

RESOURCES					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
ER3	Q, C, D			Ensure that only trusted suppliers are engaged in the supply of materials and component models.	

From CT3 view, the component models' lack of standardisation (ER3) is a source of IR2. As CT3 explained, '*In Hong Kong, there are only a few types of component allowed, which results in component models being of certain types. These component models can be combined or split, which gives the manufacturer more flexibility. In mainland China, different owners have different requirements, which causes us to have to produce different type of component, and this forces the supplier to have to produce different component models.'* There are two reasons for risk in ER3. The first is that the component model is based on components and, if the component lacks standardisation, then the associated component model cannot be standardised. The second is that different suppliers provide different types of component models, and it is therefore impossible to combine models from different suppliers. To reduce this risk, this manufacturer chooses a certain supplier to produce metal models for general components. If there are any special component requirements, then timber models are designed and produced by the manufacturer.

SOCIETY					
CODE	**QCD**	**RESPONSE**			
		Avoidance	**Transfer**	**Reduction**	**Retention**
ER1	Q, C, D				Accept as a feature of Chinese society.
ER7	C			Project planning should be made well in advance. Sufficient cash flow should be maintained.	

ER4	C, D	High quality off-site projects should be completed to reduce bias.	
ER5	C, D		The problem of inconsistent quality demand is outside of control. It can only be changed by improving the inherent impression of OSC projects.

From CT1 perspective, contract bidding problems (ER1) is the highest risk for the OSC industry. As CT1 mentioned, '*You get what you pay for, but the owners do not understand this. They always choose the component with the lowest price and get the lowest quality components. If we lower our price, we will lose our money, and if we do not lower our price, we cannot get the project, which is even worse.*' Although the manufactory understands that ER1 results in low quality for off-site components, when combined with ER6, the owners are unwilling to pay the costs for the components and it is hard to change the owners' requirements.

An unstable economic situation (ER7) influences this manufactory's financial situation. From CT2 view, the COVID-19 pandemic of 2020 has had a negative influence, '*In the first half of this year, our workers could not come to the manufactory and we had to pause our project.*' Although COVID-19 is not an economic problem, it brings with it ER7 risk. CT2 has few options to respond to ER7, although advanced project planning to maintain sufficient cash flow was agreed upon by CT2.

Public prejudices against off-site building (ER4) seem to have less impact on the manufactory. AsCT1 said, '*We only need to produce the components, and the component always has a demand.*' However, CT1 also mentioned, '*If we talked with other people about OSC, the first thing they mentioned is whether the house is safe if the OSC project is constructed at such speed.*' It shows that the public still lacks understanding of OSC. For the manufacturer, the solution is in producing high quality components to reduce bias against OSC projects.

Inconsistent demand in terms of quality for OSC projects (ER5) is mentioned byCT2, ‘*When the regulatory authority comes to check our component, they always worry about the pockmarks on the component. All concrete components, not only OSC, but also those of traditional construction, will have pockmarks. People from regulatory authorities do not understand this and think it is a problem.*’ As with ER4, a lack of public understanding of OSC is the main cause of ER5. To respond to this risk, CT2 suggests that more people who have OSC knowledge should educate the public as to the merits of OSC. However, this solution cannot be controlled by the off-site manufacturer.

8.7.3 Risk response method - Case Two

Based on the interviewees’ feedback, site visits and document checks, the identification of each risk and the response to it are presented in Table 8.16 for the second case study.

Table 8.16: Summary for Case Study Two

CODE	QCD	RESPONSE METHOD
IR1	C	**Retention:** Consider as an unavoidable capital cost.
IR2	C	**Retention:** Consider as an unavoidable capital cost.
IR7	C	**Avoidance:** Put in place a backup plan to avoid negative effects of delayed payments.
IR6	C, D	**Reduction:** Produce standardised components to reduce on-site assembly process.
IR8	D	**Retention:** Contain this as a feature of OSC method.
IR3	D	**Transfer:** The contractor should pay extra costs if the period is adjusted or changed.
IR4	C, D	**Avoidance:** Encourage all participants to have good collaborations to ensure that common good is pursued for projects.
IR5	Q, C, D	**Avoidance:** Cooperate with academia to develop new risk management methods for OSC projects.
IR10	Q, C, D	**Reduction:** Construction manager should be given regular training to enable them to have current knowledge of best practices in the industry.
IR9	C, D	**Reduction:** Produce standardised components to reduce on-site assembly process.
PR3	C, D	**Retention:** Retain the problem as the owner is the source of funding.
PR4	C, D	**Retention:** Retain the problem as the owner is the source of funding.
PR1	C, D	**Reduction:** Invite the designer to visit off-site manufactory and learn the process of component production.

PR2	C, D	**Reduction:** Invite the designer to visit OSC site and learn the process of on-site assembly.
PR7	Q, C, D	**Reduction:** Perform construction drawing review and report the design problem.
PR8	Q, C, D	**Retention:** Accept the lack of off-site design standardisation.
PR9	Q, C, D	**Reduction:** Ensure manufacturer team is given the required training. Hire experienced workers.
PR5	Q, C, D	**Reduction:** Ensuring on-site workers are given the required training.
PR6	Q, C, D	**Reduction:** Ensuring on-site workers are given the required training.
PR10	Q, C, D	**Reduction:** Produce standardised components to reduce on-site assembly process.
ER2	C	**Reduction:** Pre-evaluate the cancellation of government subsidies to reduce the impact of cancellation of policy support.
ER6	Q, C	**Reduction:** Follow the lowest prefabricated rate requirement for unsuitable construction projects.
ER8	C, D	**Reduction:** Due diligence and careful negotiations should be required before establishing the project in a new province.
ER3	Q, C, D	**Reduction:** Ensure only trusted suppliers are engaged in the supply of materials and component models.
ER1	Q, C, D	**Retention:** Accept as a feature of Chinese society.
ER7	C	**Reduction:** Project planning should be made well in advance. Sufficient cash flow should be maintained.
ER4	C, D	**Reduction:** High quality off-site projects should be completed to reduce bias.
ER5	C, D	**Retention:** The problem of inconsistent quality demand is outside of control. It can only be changed by improving the inherent impression of OSC projects.

8.8 Reference table improvement

From these two case studies, it is possible to present the appropriate response methods for such organisations based on the scale of the organisation and the objectives of the project. The result of each risk and its appropriate response method for each of the two case studies are presented in Table 8.17.

Table 8.17: Summary of case study research

CODE	CASE ONE		CASE TWO	
	QCD	**RESPONSE METHOD**	**QCD**	**RESPONSE METHOD**
IR1	C	**Transfer:** Share the manufactory cost by becoming an EPC company.	C	**Retention:** Consider as an unavoidable capital cost.
IR2	C	**Transfer:** Share the manufactory cost by becoming an EPC company.	C	**Retention:** Consider as an unavoidable capital cost.
IR7	C, D	**Reduction:** Ensuring that issues of payment are well documented at the start of projects. Ensuring that payment arrangements made are executed according to plan. Receive payments in instalments.	C	**Avoidance:** Put a backup plan in place to avoid negative effects of delayed payments.
IR6	Q, C, D	**Avoidance:** Regular assessment of the working conditions and limitations should be considered.	C, D	**Reduction:** Produce standardised components to reduce on-site assembly process.
IR8	D	**Reduction:** Discuss with other participants designing a suitable component.	D	**Retention:** Contain this as a feature of OSC method.
IR3	C, D	**Reduction:** Urging the contractor to follow the construction plan.	D	**Transfer:** The contractor should pay extra costs if the period is adjusted or changed.
IR4	C, D	**Reduction:** Have regular meetings for all participants.	C, D	**Avoidance:** Encouraging all participants to have good collaborations to ensure a common good is pursued for the project.
IR5	Q, C, D	**Avoidance:** Cooperate with academia and industry to develop new risk management method for OSC project.	Q, C, D	**Avoidance:** Cooperate with academia to develop new risk management methods for OSC projects.
IR10	Q, C, D	**Reduction:** Construction manager is given regular training to enable them to have current knowledge of practices in the industry. Visiting other manufactories to learn more experience.	Q, C, D	**Reduction:** Construction manager should be given regular training to enable them to have current knowledge of best practices in the industry.
IR9	D	**Reduction:** A regular training for on-site worker should be given for the on-site assembly process.	C, D	**Reduction:** Produce standardised components to reduce on-site assembly process.

PR3	C, D	**Avoidance:** Project planning at the initial stage of projects should be done. The plan needs to be strictly implemented.	C, D	**Retention:** Retain the problem as the owner is the source of funding.
PR4	C, D	**Avoidance:** Communication with the owner and other participants should have a regular execution.	C, D	**Retention:** Retain the problem as the owner is the source of funding.
PR1	C, D	**Reduction:** Designer should be given OSC training before designing.	C, D	**Reduction:** Invite the designer to visit off-site manufactory and learn the process of component production.
PR2	C, D	**Reduction:** Designer should go on-site and conduct field trips to understand the process of on-site construction.	C, D	**Reduction:** Invite the designer to visit OSC site and learn the process of on-site assembly.
PR7	Q, C, D	**Reduction:** The construction drawing review process should be performed before being implemented by all participants. Designers should have regular training for OSC projects.	Q, C, D	**Reduction:** Doing construction drawing reviews and reporting design problems.
PR8	Q, C, D	**Avoidance:** The consultants should cooperate and establish a common design mechanism.	Q, C, D	**Retention:** Accept the lack of off-site design standardisation.
PR9	Q, C, D	**Reduction:** Ensuring manufacturing team is given the required training. Hire experienced workers.	Q, C, D	**Reduction:** Ensuring manufacturing team is given the required training. Hire experienced workers.
PR5	Q, C, D	**Reduction:** Ensuring on-site workers are given the required training.	Q, C, D	**Reduction:** Ensuring on-site workers are given the required training.
PR6	Q, C, D	**Reduction:** Ensuring on-site workers are given the required training.	Q, C, D	**Reduction:** Ensuring on-site workers are given the required training.
PR10	Q, C, D	**Reduction:** Monitor the on-site assembly process and give regular training to on-site workers.	Q, C, D	**Reduction:** Produce standardised components to reduce on-site assembly process.
ER2	C	**Reduction:** Pre-evaluate the cancellation of government subsidies to reduce the impact of cancellation of policy support.	C	**Reduction:** Pre-evaluate the cancellation of government subsidies to reduce the impact of cancellation of policy support.
ER6	Q, C	**Reduction:** Follow the lowest prefabricated rate requirements for unsuitable construction projects.	Q, C	**Reduction:** Follow the lowest prefabricated rate requirement for unsuitable construction projects.
ER8	C, D	**Reduction:** Due diligence and careful negotiations should	C, D	**Reduction:** Due diligence and careful negotiations

		be required before establishing the project in a new province.		should be required before establishing a project in a new province.
ER3	Q, C, D	**Reduction:** Ensure only trusted suppliers are engaged in the supply of materials and component models.	Q, C, D	**Reduction:** Ensure only trusted suppliers are engaged in the supply of materials and component models.
ER1	Q, C, D	**Reduction:** Establish EPC company to obtain internal contract.	Q, C, D	**Retention:** Accept as a feature of Chinese society.
ER7	C	**Reduction:** Project planning should be made well in advance. Sufficient cash flow should be maintained.	C	**Reduction:** Project planning should be made well in advance. Sufficient cash flow should be maintained.
ER4	C, D	**Reduction:** High quality off-site projects should be completed to reduce bias.	C, D	**Reduction:** High quality off-site projects should be completed to reduce bias.
ER5	C, D	**Reduction:** High quality off-site projects should be completed to reduce bias.	C, D	**Retention:** The problem of inconsistent quality demand is outside of control. This can only be changed by improving the inherent impression of OSC projects.

From the interview discussion, site visiting and document analysing, the OSM risk is concluded and reconstructed.

Table 8.18: Improved risk factors for OSM process

CODE	RISK FACTOR	IMPROVED RISK FACTOR	RISK GROUP
IR1	High off-site manufactory building costs	High initial cost	Cost
IR2	High component model and material fees		
IR6	On-site assembly limitations	High component assembly complexity	Contractor
IR9	Complexity of joint assembly		
PR10	Lack of on-site assembly standardisation		
PR5	Contractor lacks experienced employees	Contractor lacks experience	Contractor
PR6	Contractor lacks experience		
ER4	Public prejudice against off-site building	Public prejudice against off-site building	Society
ER5	Inconsistent quality demand for OSC projects		
PR1	Consultant lacks off-site experience	Consultant lacks experience	Consultant
PR2	Consultant lacks on-site experience		
PR7	Design error		

Combining Table 8.17 and Table 8.18, the OSM risk management process for managing those significant risk factors affecting OSC projects is presented in Table 8.19. Table 8.19 could help project managers to mitigate or eliminate the negative influences arising from these risk factors in OSC projects.

Table 8.19: Adjusted risk management reference table for OSM process

RISK TYPE	RISK GROUP	RISK FACTOR	QCD	RESPONSE METHOD
Internal risk	Cost	High initial cost	C	**Reduction** Establish EPC company and share the cost with other participants. **Retention** Accept this risk as an unavoidable capital cost.
		Components paid for after delivery	C	**Reduction**: Ensuring issues of payment are well documented at the start of projects. Ensuring payment arrangements made are executed according to plan. Obtain payment in instalments. **Avoidance:** Place a backup plan or sufficient cash flow to avoid negative effects of delayed payments.
	Off-site feature	Component is too heavy	D	**Reduction**: Discuss with other participants the design of a suitable component to reduce the size of component. **Retention:** Contain this risk as a feature of OSC method.
	Project management	On-site construction period adjustment or change	C, D	**Reduction**: Urging the contractor to follow the construction plan. **Transfer**: Sign contract with contractor. If the period is adjusted or changed, the contractor should pay extra costs.
		Lack of cooperation	Q, C, D	**Reduction**: Have regular meetings for all participants. Encouraging all participants to have good collaborations to ensure a common good is pursued for the project.
		Lack of risk management method	Q, C, D	**Avoidance**: Cooperate with academia and industry to develop new risk management method for OSC projects.
		Hard to deploy new management method	Q, C, D	**Reduction**: Construction manager should be given regular training to enable them to have current knowledge of practices in the industry. Visiting other manufactories to gain more experience.
Participant risk	Owner	Owner changes demands	C, D	**Avoidance**: Project planning at the initial stage should be done. The plan needs to be strictly implemented. **Retention**: Retain the problem as the owner is the source of funding.
		Demand not suitable for	C, D	**Avoid**: Communication with the owner and other participants should

		off-site project		be conducted regularly. **Retention**: Retain the problem as the owner is the source of funding.
	Consultant	Consultant lack of experience	C, D	**Reduction**: Designer should be given OSC training before designing and conduct field trips on-site to better understand the on-site construction process.
		Design error	Q, C, D	**Reduction**: The construction drawing review process should be completed before being implemented by all participants. Designer should have regular training in OSC projects.
		Consultant lack of standardization	Q, C, D	**Avoidance**: The consultants should cooperate and establish a common design mechanism. **Retention**: Accept the lack of off-site design standardisation.
	Manufacturer	Manufacturer lack of experience	Q, C, D	**Reduction**: Ensuring manufacturer team is given the required training. Hire experienced workers.
	Contractor	Contractor lack of experience	Q, C, D	**Reduction**: Ensuring on-site workers are given the required training.
		Lack of on-site assembly standardization	Q, C, D	**Reduction**: Monitor the on-site assembly process and give regular training to on-site workers. **Avoidance:** Regular assessment of the working conditions and limitations should be considered. **Reduction**: Regular training should be given to on-site workers for on-site assembly process. Produce standardised components to reduce on-site assembly process.
External risk	Government policy	Lack of subsidy and support	C	**Reduction**: Pre-evaluate the cancellation of government subsidies to reduce the impact of cancellation of policy support.
		Rigid prefabricated rate requirement	Q, C	**Reduction**: Follow the lowest prefabricated rate requirement for unsuitable construction projects.
		Differentiation in local government policy standards	C, D	**Reduction**: Due diligence and careful negotiations should be required before establishing a project in a new province.

	Resource	Component model lacks standardisation	Q, C, D	**Reduction**: Ensure only trusted suppliers are engaged in the supply of materials and component models.
	Society	Contract bidding problem	Q, C, D	**Reduction**: Establish EPC company to obtain internal contracts. **Retention**: Accept as a feature of Chinese society.
		Unstable economic situation	C	**Reduction**: Project planning should be made well in advance. Sufficient cash flow should be maintained.
		Public prejudice against off-site building	C, D	**Reduction**: High quality off-site projects should be completed to reduce bias. **Retention**: The problem of inconsistent quality demand is outside of control. It can only be changed by improving the inherent impression of OSC projects.

8.9 OSM Framework improvement

After the case study, the details of the OSM risk management process can be defined. An OSM risk management integration framework is presented in Figure 8.7. Compared with the original framework, the integrating framework adds the key points for each step in the risk management process.

1. Risk identification: For the Chinese OSM risk management process, the scope of the risk factor is the phenomenon that has a negative effect on the OSM process's aims and objectives, including the internal and external environments. By focusing on the scope of the OSM risk factor, the significant risk factor can be identified in this process.
2. Risk assessment: OSM risk factors can be divided into 3 risk types and 10 risk groups. The 3 risk types include internal risk, participant risk, and external risk. The 10 risk groups include cost, off-site feature, project management, the owner, consultant, manufacturer, contractor, government policy, resource, and society.
3. Risk analysis: In an OSM risk management process, how the risk factors influence the QCD of an OSC project should be considered. An appropriate analysis method can be qualitative, quantitative or a combination of the two. For example, an interview or questionnaire can be used for risk analysis.
4. Risk response: For OSM risk management, depending on the types of OSC manufactory, the appropriate response method can be chosen from avoidance, transfer, reduction, and reduction.
5. Risk management reference table: In order to give the OSM risk manager an example and support for the OSM risk management process, the risk management reference table is recommended for the risk manager. The risk manager can use the reference table to check the common risk factors associated with the OSM process and find the appropriate response method based on different types of OSM companies.

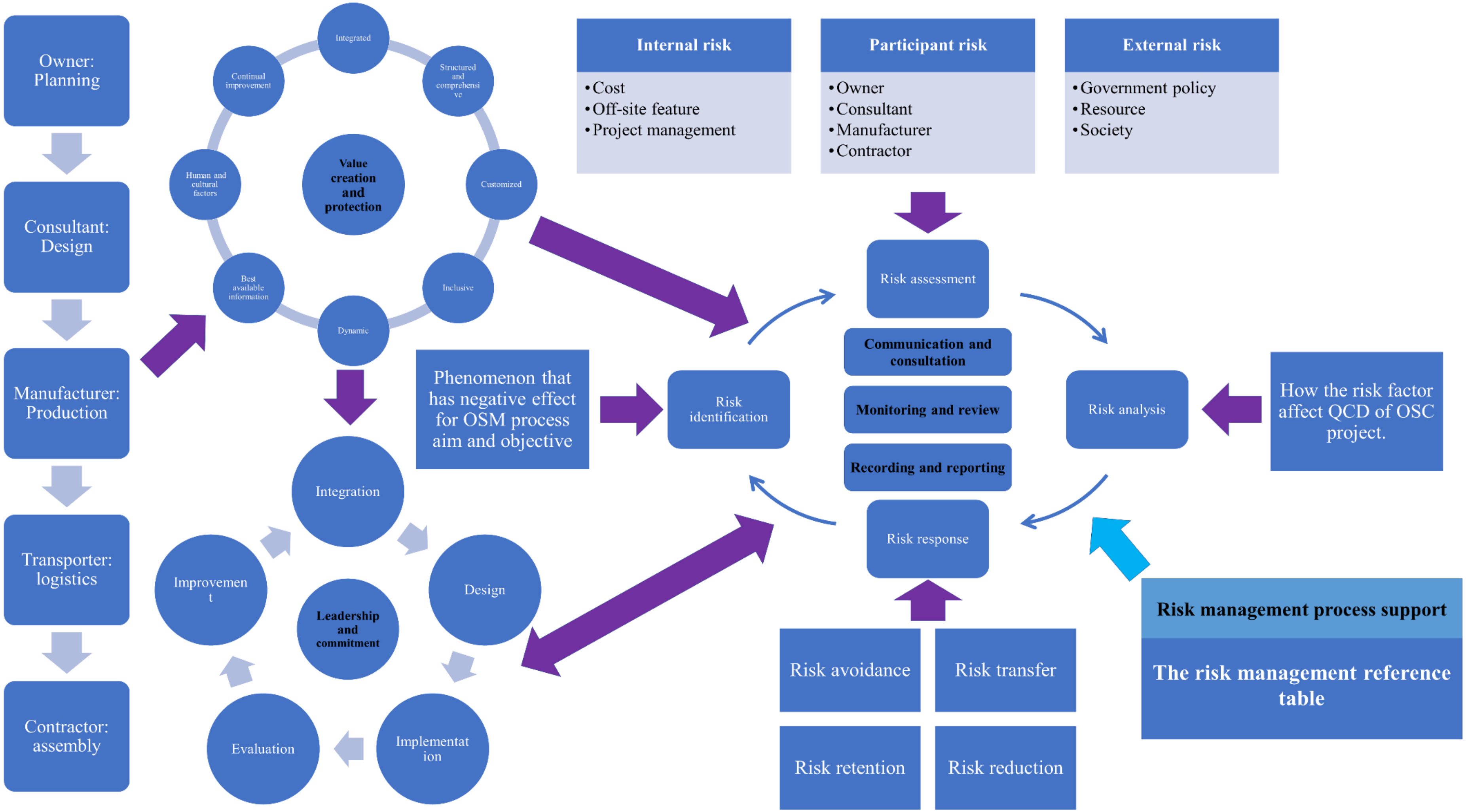


Figure 8.7: OSM risk management integrating framework

Based on the case study process, it is found that Figure 8.6 lacks detail on risk management process, which causes it is hard for manufactory to deploy the risk management in the OSC project. Figure 8.7 added the detail of the OSM risk management process.

Figure 8.7 presents the improved OSM risk management framework. In order to implement the framework, the process to propose the framework for the OSC project is presented below.

1. The process consists of four main stages: risk identification, risk assessment, risk analysis, and risk response.
2. Risk could emerge at any step of the OSC project. In that case, all risk factor should be managed through the same process, starting from risk identification.
3. Stage one: risk identification includes the process of identifying OSM risk factor and filtering them from uncertainty or hazards. The feature of OSM risk factor is the phenomenon that has a negative effect on the OSM process aims and objectives. A risk register should be created and maintained during the OSM project process. Regular meeting or discussion can be used in this stage.
4. Stage two: risk assessment includes the process of dividing all risk factor into certain risk group and risk type. This stage could define which risk factor can be solved by the manufactory, and which risk cannot. Interview, brainstorming, or checklist can be used in this stage.
5. Stage three: risk analysis includes the process of analysing probability and impact of each risk factor, and finding out the significant risk factor. This is conducted using the probability-impact matrix. The score of the probability-impact matrix base on how the risk factors affect QCD for OSM process. This stage quantifies each risk factor and prioritizes the risks accordingly.
6. Stage four: risk response includes the process of identifying how to respond to the significant risk factors. According to the feature of project, types of company, or QCD influence of project, Risk need to be responded in four

methods: risk avoidance, risk transfer, risk reduction, and risk reduction. Risks are also assigned to a specific owner, who will be responsible for the risk factor. There is a need to identify options to reduce probability and impact and to determine the potential benefits.

7. There are various tools and techniques to be used in the risk management process. however, the decision for risk factor is based on judgement and human behaviour. In order to help the OSC project manager with insufficient experience in risk management, it is possible to check the risk management reference table to find out the common OSM risk factors and how to respond to them.

The framework presented the risk management process for OSM risk. Previous Chinese articles also considered the OSC risk and developed the OSC risk management framework. For example, Yao (2021) analysed the OSC onsite assembly process by using the AHP method, and divided risk group into people, material, machine, method, and environment. He (2021) developed a risk management framework for construction project, by considering audit, resource allocation, financial management, team building, and material procurement. The strategy of risk management framework requires cooperation from whole constriction practitioners. Ding et al. (2019) combined Integrated Product Development (IPD) with the OSC project to develop a collaborative management framework. Five areas should be considered during the framework development: trust, coordination, motivation, cooperation, and communication. Zhang et al. (2018) combined BIM and OSC to reduce risk in OSC project, and determined that BIM can reduce the risk factor in on-site assembly process, which could become a useful tool in the OSC risk management process.

However, previous Chinese articles only focus on one method to develop the framework, or only consider one step of the risk management process. Compared with methods and framework from Chinese articles, this research focuses on the OSM process, and extends risk management not only risk analyse and risk response, but also risk identification and risk assessment. The framework in this research presents several different risk management methods for OSM risk factor. In that case, this framework could help the OSM risk manager to manage the risk factor more effectively.

8.10 Chapter summary

This chapter presents the findings of this research. In order to achieve the aims and objectives of this research, a mixed methodology was used in the form of interview and questionnaire data which were collected and analysed. No fewer than 77 risk factors were identified from the interview analysis process, and 28 risk factors were identified as being significant risk factors from the analysis of the questionnaire. The significant risks were divided into 3 subtypes and 11 groups, and the most significant risk factor for each risk type was identified. Based on these significant risk factors, a framework was defined based on the interviews and the literature review. Each risk factor was presented together with at least one response to either avoid, transfer, reduce or otherwise retain risk.

This chapter also presents the validation of the OSM risk framework in China. By using case studies, interviewees from the two case studies were invited to share their views. In order to identify the appropriate risk responses for each case, documentary observations, site observations and interviews were proposed. The case studies were used to validate the OSM risk framework and establish how the risk factors affect QCD for OSC projects. The results from the case studies indicate that the findings in the research are valid and can be generalised across OSM projects in China.

CHAPTER 9 - CONCLUSION AND FUTURE WORK

9.1 Introduction

This chapter presents the conclusions of the thesis. The purpose of this research was to understand the risks arising in the OSM process and better understand how to manage them to reduce costs, time overruns and quality issues. In order to accomplish this goal, the general concepts of risk and OSC were first defined. This research also indicated the risks inherent within the Chinese OSM process and how these risks influence Chinese OSC projects. The significant risks for the Chinese OSM process were identified and the appropriate risk response methods were analysed. The findings of the research were developed to produce a risk management framework for the wider OSM process in China. The conclusions of this research are discussed next.

9.2 Key Research Findings

The aim of this research was to identify and assess the risks inherent within the OSM process and to develop a suitable framework that provides a suitable risk management method for OSC projects. By developing such a risk management framework, this research found that a risk management process can help the off-site manufacturer to reduce the negative influences of QCD in OSC projects. Thus, it was necessary to adopt a suitable risk management method for OSM. Also, it was important to define the types of OSC projects involved as the risk management method must be changed for different projects and, as a result, the risk response method can be better aligned with the project.

By using the risk framework, the risk manager of the OSC project could follow the process and use the framework to reduce the risks arising in the OSM process. This process combined the empirical-based framework to ensure that the risk is managed systematically. Additionally, the risk manager also can adjust the framework in different project environments to provide a basis for OSM process risk management.

In order to implement a successful process all participants in an OSC project must cooperate during the project life cycle.

9.3 Research Objectives Revisited

Chapter 1 introduced a general overview of OSC. In China, a large number of building construction projects have established OSC methods. However, as it is a new construction methodology, OSC projects still require further development as the projects always suffer from time delays, cost overruns, and low quality. Compared with traditional construction methods, the OSC process includes a manufacturing process which is considered to be the main feature of an OSC methodology. The risks inherent in the OSM process result in a QCD problem for the off-site components. In China, the risks for the OSM process arise frequently, and OSC risk management still needs more development. One of the reasons is lack of a suitable risk management framework for OSC projects. Therefore, this research has tried to establish a general risk framework for OSC projects and presents risk responses that mitigate issues of unforeseen costs, time overruns, and low quality. In order to achieve the aim, five objectives were identified and explained below:

1. To evaluate existing risk and risk management processes

Chapter 2 assessed the general understanding of risk and risk management from a literature review. Risk history and backgrounds, basic concepts, definitions, and types were identified. In order to understand the main features of risk, the concepts of opportunity, hazard, uncertainty and risk were compared and evaluated. Subsequently, the potential risks arising in the OSC industry were categorised. The advantages of risk management in the construction industry were presented to identify the importance of risk management in OSC projects. By examining different risk management processes, general risk management methods were identified and classified into 4 steps.

To present the process of risk management, Chapter 3 explains the risk management process and divides the methodology into qualitative and quantitative approaches. The definition of each process was further explained and the appropriate methodological approach was recognised by means of a literature review. This chapter presented a list of methods used in risk identification, assessment, analysis, and response.

By identifying the risk and risk management through literature review in Chapter 2 and Chapter 3, the objective 'To evaluate existing risk and risk management processes' has been achieved.

2. To explore the features of OSC and OSM

To identify the features of OSC and OSM, Chapter 4 presented the definition of OSC. By comparing the differences arising between traditional construction and OSC, the features of OSC can be identified. The literature shows that the OSM process is a significant step in an OSC project. However, there are few instances of OSM risk management research in the current literature. Hence, a construction risk management framework is presented which was used in this research for the OSM process.

By identifying OSC and OSM through literature review in Chapter 4, the objective 'To explore the features of OSC and OSM' has been achieved.

3. To investigate the risks inherent within each phase of the OSM process in China

Chapter 5 reviewed the various methodological options from literature and identified the most appropriate approach to achieve the aims of this research. The qualitative method was found to be the most suitable approach to investigate the risks associated with each phase of the OSM process, and a quantitative study was used to identify key risk factors affecting the OSM process in China.

Consequently, by interviewing 25 experts across the OSC industry, Chapter 6 identified 77 risk factors implicated in the OSM process. An influence diagram was designed to present these risk factors and they were subsequently classified into 3 types, namely project process risk, project member risk, and external risk. Thirteen risk groups were identified, specifically cost, features of project, project management, time, owner, consultant, manufacturer, transporter, contractor, environment, political, resources and society. By developing the influence diagram, the risk factors arising within the OSM process are presented and connected to QCD for OSC projects.

Chapter 6 presented an interview as the qualitative method to identify the risk factor for the OSM process, the objective 'To investigate the risks inherent within each phase of the OSM process in China' has been achieved in this chapter.

4. To assess the significant risks of the OSM process in China

Based on the 77 risk factors delineated in Chapter 6, Chapter 7 identified the significant risks for OSM by means of a quantitative methodology. In order to determine the most significant risk factors affecting the OSM process in China, a questionnaire was also used to collect the views of owners, consultants, manufacturers, transporters, and contractors. Based on a five-point Likert scale questionnaire, the participants were asked to evaluate the probability and likely impact of those risk factors identified within the OSM process. Risk factors which were probability higher than 3.30 and that had an impact higher than 3.34 were defined as significant risk factors. After that, some 28 risk factors were identified as being significant risks for the OSM process in China.

Questionnaire was used as the quantitative method to identify the significant OSM risk factors Chapter 7, which achieved the objective 'To assess the significant risks of the OSM process in China'.

5. To develop and validate a suitable framework for implementing risk influence analysis

Chapter 8 presented a risk management framework based on interviews and a questionnaire to support risk management in the OSM process within China. This framework was developed based on four processes, namely risk factor identification, risk factor explanation and assessment, risk factor response method, and the construction of a suitable risk framework model. To validate the framework, two case studies were deployed in two different types of OSC companies. To validate these risk factors and establish how the significant risk factors affect QCD in OSC projects, case studies were used as a validation method. By conducting interviews, documentary observations and site observations during the case studies process, the framework was validated by the cases. The results presented suggest that the proposed framework is valid for the Chinese OSM process risk management process and the outcomes further suggest that such a risk framework should be generalised across OSC projects in China.

Combined interview and questionnaire result, two Case study was used in Chapter 8 to design and validate the risk framework. In that case, the objective ‘To develop and validate a suitable framework for implementing risk influence analysis’ has been achieved.

9.4 Contribution to Knowledge

This research has made several key contributions to the existing body of knowledge and understanding. These contributions to our knowledge of OSM risk management are summarised below.

From the literature review, time overrun, extra costs, and low quality are still pervasive within Chinese OSC projects. Only a few Chinese OSC projects consider risk factors and how risk influences these projects before they are implemented. Thus, this research identifies those risks inherent in the OSM process which may cause the OSC projects to overrun, suffer extra cost, or produce low quality based on the interview process. This research could help to solve these problems in Chinese OSC projects. By developing an influence diagram, these risk factors and their conditional interrelationships with QCD within the Chinese OSM process are presented.

Another contribution was the significant risk factors defined for the OSM process. The definition of significant risk factors is based on the knowledge and experience accrued by OSC experts, which could prove useful for refining the OSM process. By defining these significant risk factors, the risks were classified and grouped into project risk, participant risk, or external risk.

The appropriate response method for each risk is presented to mitigate the negative effects of those risks. As the type of company may result in different response methods, four types of risk response methods were presented to the manufacturer, namely risk avoidance, risk transfer, risk reduction, and risk retention. The risk response method could serve to reduce the risk effects for the OSC project and improve the capacity of the off-site manufacturer to handle the project life cycle.

From the literature review, there is no research focus on the risk factors identified for the Chinese OSM process. In this case, the risk management framework which was developed from this research could help off-site manufacturers in China to improve the performance of their OSC projects and reduce the QCD problems caused by the risks identified. This risk management framework has thus proved that it can successfully present the significant risk factors which affect OSC projects and how best to respond to them within the Chinese construction environment.

The previous risk management standards or frameworks such as ISO 31000 and PAS7000 are only be used as best practices or guidance for the project. These frameworks do not explain how to manage risk in the OSC environment. Additionally, these frameworks do not present the process of how OSM risk should be managed. This research developed an OSM risk management framework for the Chinese OSC project. The framework considered the feature of both the Chinese environment and OSC environment, and presented the detail of OSM risk management process. This framework presents a basis for internal controls and management for OSM risk factor, Chinese OSC manufactories could develop their risk management practices by using this framework as guidance or support. In addition, a risk management reference table is presented to help the inexperienced OSM risk manager to manage the common OSM risk in an easier way.

9.5 Research limitations

Although this research includes construction organisations in northern China (Beijing), central China (Hubei) and southern China (Guangdong), the top tier areas of the OSC industry in the nation, the research findings may be similar for other parts of China.

However, other Chinese provinces are not the top tier areas of the OSC industry, may have different weights for the risk factors and so the results of this research may not be suitable for them. In that case, further expansion of the datasets to cover more industry practitioners from different areas is necessary, which could provide further insights for OSM risk management. Similarly, although the risk factors may be similar across Chinese OSC organisations, it is still necessary to conduct additional research if the framework is to be deployed in other countries.

To reduce the bias arising this research used a mixed methodology, including interviews, a questionnaire, and two case studies. However, some participants chose not to share all their information, which may reduce the accuracy of the research outcome. For example, participants tend to hide shortages and exaggerate risks within other organisations.

Another limitation is the case study process itself. The framework was only validated for two construction projects of two OSC companies in the same province. This may mean that the findings are only applicable to parts of China.

This research was conducted and analysed by only one researcher and may still consists of a minor degree of subjectivity. In that case, other researchers may explain the data in a different way.

9.6 Recommendations

Based on the research, the recommendations for the Chinese OSC industry relate to four areas:

1. The risk management framework developed in this research should be adopted and implemented by Chinese OSC manufacturers. Putting this framework into practice will help OSC organisations systematically identify and analyse those OSM risk factors affecting OSC projects. Dividing by risk types, OSC organisations should focus primarily on project risk factors and participant risk factors, while the Chinese government should focus on external factors. This will help to better understand the significant risk factors associated with OSC

projects and to plan effective risk response methods to reduce the negative effects of these risk factors. It also recommends the OSC manufacturers record the framework implementation data, and analyse the data for the framework improvement. The OSC project manager can add the new risk factors from the project, and analyse the new risk factors through the framework.

2. More risk management training should be provided by Chinese OSC organisations. More risk management seminars, workshops or training sessions should be applied for the off-site manufactory practitioner. The course of training should include, but not be limited to the risk management process, OSC company identification, QCD analysis, and OSC organisational communication methods. The training also should invite staff from other types of organisation and government agents to enhance the communications arising between the organisations of OSC industry and government.
3. It is necessary to develop a complete OSC project plan at the outset of OSC projects. The plan should be developed by all organisations which would include the participant OSC project, and there should be agreed by all organisations to follow the plan before the project execution. This could reduce the possibility of disputes arising and variations in output during the construction stage. The project planning process could help the organisations to understand the project goals and reduce the time wasted in future. Risk management could help the OSC practitioners have a better understanding of the feasibility of the project.
4. When recruiting project managers in OSC organisations, it is first necessary to hire a project manager knowledgeable in risk management and the ability to adopt the method of OSC projects. The project manager should have both project management experience and OSC project experience, which could help to understand the risk of OSC project clearer. Further, both general and specific training should be provided by the project managers. If such an expert

is hard to find in the OSC industry, alternative approaches such as training abroad or cooperating with universities should be considered.

9.7 Future areas of research

This research has contributed to the existing knowledge of OSC practices in China. The OSM risk management framework presents a solution for off-site manufactories to respond to OSC risk. However, the researcher has identified the need for further research. Five avenues of future research could be considered:

1. Based on the literature review from 503 articles, there have been suggestions to improve the OSC risk management method, which requires reforming traditional construction risk management method to OSC risk method. It requires more coordination of the work and schedules of the project from inception to completion. Further research could focus on how to improve cooperation between OSC organisations, including the computation method for the OSC organisation, the contracting and the responsibilities of each OSC organisation, and so forth.
2. Based on the research, it shows that the design phase causes the most significant risk factor in OSC project, it is necessary to conduct research into how to design and implement the construction plan for a given OSC project, which could significantly reduce the risk in OSC project. Further research could focus on the gap in the traditional project and OSC project design processes, which serve to explain the phenomenon of Chinese consultants within the traditional project design experience who might otherwise lack OSC project design experience.
3. This gap in the area of risk assessment shows that the understanding of OSC risk should not be limited by past experience. Although this research focused on OSM risk identification and analysis, other OSC risk organisations including the owner, consultant, and contractor have not yet been analysed. Therefore, more work could be done in these areas by future research. This

could help to define the risk of the entire OSC project life cycle, and enable us to understand the internal relationship arising between the risk factors from different OSC organisations.

4. In practical terms, OSC organisations in China should provide more integrated training programmes for OSC practitioners, especially risk management course should be included. This means how to provide the training should be considered. It is suggested that the researcher should explore the level of each risk management training course by developing OSC risk training guidance for OSC organisations.
5. The goal of additional research is to glean further insight into how risk management is deployed across OSC projects. The mechanism of OSC organisational behaviour should then be considered to see if there is a connection. The decision making process by an OSC organisation should be observed and concluded to understand the internal logic of the OSC organisation in deploying certain risk management methods.

REFERENCES

Abujnah, M. S. (2010). *Towards a risk management framework for Libyan house-building projects.* (PhD), University of Salford, Salford. Retrieved from: https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.521541

Aburas, H. (2011). "Off-site construction in Saudi Arabia: the way forward". *Journal of Architectural Engineering,* 17 (4), p. 122-124.

Acharya, A. S., Prakash, A., Saxena, P., & Nigam, A. (2013). "Sampling: Why and how of it". *Indian Journal of Medical Specialties,* 4 (2), p. 330-333.

Agogino, A. M., & Rege, A. (1987). "IDES: Influence diagram based expert system". *Mathematical modelling,* 8 p. 227-233.

Ahn, S., Crouch, L., Kim, T. W., & Rameezdeen, R. (2020). "Comparison of Worker Safety Risks between Onsite and Offsite Construction Methods: A Site Management Perspective". *Journal of Construction Engineering and Management,* 146 (9), p. 05020010.

Akossou, A., & Palm, R. (2013). "Impact of data structure on the estimators R-square and adjusted R-square in linear regression". *Int. J. Math. Comput,* 20 (3), p. 84-93.

Alaghbari, W. e., Kadir, M. R. A., & Salim, A. (2007). "The significant factors causing delay of building construction projects in Malaysia". *Engineering, Construction and Architectural Management,* 14 (2), p. 192-206.

Aleshin, A. (2001). "Risk management of international projects in Russia". *International Journal of Project Management,* 19 (4), p. 207-222.

Alvanchi, A., Azimi, R., Lee, S., AbouRizk, S. M., & Zubick, P. (2011). "Off-site construction planning using discrete event simulation". *Journal of Architectural Engineering,* 18 (2), p. 114-122.

Alvik, A., Haldorsen, T., & Lindemann, R. (2005). "Consistency of reported alcohol use by pregnant women: anonymous versus confidential questionnaires with item nonresponse differences". *Alcoholism: Clinical and Experimental Research,* 29 (8), p. 1444-1449.

Amaratunga, D., Baldry, D., Sarshar, M., & Newton, R. (2002). "Quantitative and qualitative research in the built environment: application of "mixed" research approach". *Work study,* 51 (1), p. 17-31.

Andersen, A., & Dennison, J. (2018). "An Introduction to Quantile-Quantile Plots for the Experimental Physicist". *AJP,* 87 (5), p. 1-4.

Andretta, M. (2014). "Some considerations on the definition of risk based on concepts of systems theory and probability". *Risk Analysis,* 34 (7), p. 1184-1195.

Arabiat, A. (2013). *Modelling construction client risk performance using organisation behaviour parameters.* (PhD), Loughborough University, Loughborough. Retrieved from: http://pstorage-loughborough-53465.s3.amazonaws.com/17079971/Thesis2013Arabiat.pdf

Arafat, S., Chowdhury, H. R., Qusar, M., & Hafez, M. (2016). "Cross cultural adaptation & psychometric validation of research instruments: A methodological review". *Journal of Behavioral Health,* 5 (3), p. 129-136.
Arana, I., Ederra, J. M., Atarés, P. A., Garin, S. A., López, J. R. A., & Ceballos, M. d. C. J. (2010). "Evaluation of risk factors in fatal accidents in agriculture". *Spanish Journal of agricultural research,* (3), p. 592-598.
Arashpour, M., Abbasi, B., Arashpour, M., Hosseini, M. R., & Yang, R. (2017). "Integrated management of on-site, coordination and off-site uncertainty: Theorizing risk analysis within a hybrid project setting". *International Journal of Project Management,* 35 (4), p. 647-655.
Arashpour, M., Wakefield, R., Abbasi, B., Arashpour, M., & Hosseini, R. (2018). "Optimal process integration architectures in off-site construction: Theorizing the use of multi-skilled resources". *Architectural Engineering and Design Management,* 14 (1-2), p. 46-59.
Arashpour, M., Wakefield, R., Abbasi, B., Lee, E., & Minas, J. (2016). "Off-site construction optimization: Sequencing multiple job classes with time constraints". *Automation in Construction,* 71 p. 262-270.
Arashpour, M., Wakefield, R., Blismas, N., & Maqsood, T. (2015). "Autonomous production tracking for augmenting output in off-site construction". *Automation in Construction,* 53 p. 13-21.
Arayici, Y., Egbu, C., & Coates, S. (2012). "Building information modelling (BIM) implementation and remote construction projects: issues, challenges, and critiques". *Journal of Information Technology in Construction,* 17 p. 75-92.
Arieff, A. (2002). *Prefab* (1st ed.). Layton: Gibbs Smith Publishers.
Arif, M. (2009). "Editorial–Special issue on offsite manufacturing". *Construction innovation,* 9 (1), p. 5-6.
Arif, M., & Egbu, C. (2010). "Making a case for offsite construction in China". *Engineering, Construction and Architectural Management,* 17 (6), p. 536-548.
Arifin, W. N., & Zahiruddin, W. M. (2017). "Sample size calculation in animal studies using resource equation approach". *The Malaysian journal of medical sciences: MJMS,* 24 (5), p. 101.
Aris, N. A. M., Fathi, M. S., Harun, A. N., & Mohamed, Z. (2019). "Towards A Sustainable Supply of Affordable Housing with Prefabrication Technology: An Overview". *Journal of Advanced Research in Business and Management Studies,* 15 (1), p. 1-13.
Asante-Duah, K. (2017). *Public health risk assessment for human exposure to chemicals* (1st ed. Vol. 27). London: Springer.
Ashley, D. B., & Bonner, J. J. (1987). "Political risks in international construction". *Journal of Construction Engineering and Management,* 113 (3), p. 447-467.
Ashton, A. H., & Ashton, R. H. (1985). "Aggregating subjective forecasts: Some empirical results". *Management science,* 31 (12), p. 1499-1508.

Atkinson, R. (1999). "Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria". *International Journal of Project Management,* 17 (6), p. 337-342.

Aven, T. (2016). "Risk assessment and risk management: Review of recent advances on their foundation". *European Journal of Operational Research,* 253 (1), p. 1-13.

Aven, T., Ben-Haim, Y., Andersen, H. B., & Cox, T. (2015). Society for Risk Analysis Glossary. Accesss date: 21/06/2018. Retrieved from:https://www.sra.org/wp-content/uploads/2020/04/SRA-Glossary-FINAL.pdf

Ayyub, B. M. (2014). *Risk analysis in engineering and economics* (2nd ed.). London: Crc Press.

Azhar, S. (2011). "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry". *Leadership and management in engineering,* 11 (3), p. 241-252.

Azman, M., Ahamad, M., & Hussin, W. (2012). "Comparative study on prefabrication construction process". *International surveying research journal,* 2 (1), p. 45-58.

Azman, M., Ahamad, M., Majid, T., & Hanafi, M. (2010a). "The common approach in off-site construction industry". *Australian Journal of Basic and Applied Sciences,* 4 (9), p. 4478-4482.

Azman, M., Ahamad, M., Majid, T., & Hanafi, M. (2010b). *Perspective of Malaysian industrialized building system on the modern method of construction In 11th Asia Pacific Industrial Engineering and Management Systems Conference, Melaka, Malaysia* Published:

Baig, A. A., Ruzli, R., & Buang, A. B. (2013). "Reliability analysis using fault tree analysis: a review". *International Journal of Chemical Engineering and Applications,* 4 (3), p. 169.

Baker, S., Ponniah, D., & Smith, S. (1998). "Techniques for the analysis of risks in major projects". *Journal of the Operational Research Society,* 49 (6), p. 567-572.

Baker, S., Ponniah, D., & Smith, S. (1999a). "Risk response techniques employed currently for major projects". *Construction Management & Economics,* 17 (2), p. 205-213.

Baker, S., Ponniah, D., & Smith, S. (1999b). "Survey of risk management in major UK companies". *Journal of Professional Issues in Engineering Education and Practice,* 125 (3), p. 94-102.

Baloi, D., & Price, A. D. (2003). "Modelling global risk factors affecting construction cost performance". *International Journal of Project Management,* 21 (4), p. 261-269.

Banerjee, A., Chitnis, U., Jadhav, S., Bhawalkar, J., & Chaudhury, S. (2009). "Hypothesis testing, type I and type II errors". *Industrial psychiatry journal,* 18 (2), p. 127.

Barnes, M. (1983). "How to allocate risks in construction contracts". *International Journal of Project Management,* 1 (1), p. 24-28.

Baron, P. (2019). "Owning one's epistemology in religious studies research methodology". *Kybernetes,* 49 (8), p. 2057-2071.

Bartlett, J. (2004). *Project risk analysis and management guide* (2nd ed.). London: APM Publishing Limited.

Basto, M., & Pereira, J. M. (2012). "An SPSS R-menu for ordinal factor analysis". *Journal of statistical software,* 46 (4), p. 1-29.

Beck, U. (2014). *The brave new world of work* (1st ed.). Hoboken: John Wiley & Sons.

Bekefi, T., Epstein, M. J., & Yuthas, K. (2008). "Creating growth: Using opportunity risk management effectively". *Journal of Accountancy,* 205 (6), p. 72.

Belia, S., Fidler, F., Williams, J., & Cumming, G. (2005). "Researchers misunderstand confidence intervals and standard error bars". *Psychological methods,* 10 (4), p. 389.

Ben, M. G., & Yohai, V. J. (2004). "Quantile–quantile plot for deviance residuals in the generalized linear model". *Journal of Computational and Graphical Statistics,* 13 (1), p. 36-47.

Benesty, J., Chen, J., Huang, Y., & Cohen, I. (2009). Pearson correlation coefficient. In *Noise reduction in speech processing* (pp. 1-4): Springer.

Bi, K., Huang, P., & Ye, H. (2015). "Risk identification, evaluation and response of low-carbon technological innovation under the global value chain: A case of the Chinese manufacturing industry". *Technological Forecasting and Social Change,* 100 p. 238-248.

Biddle, C., & Schafft, K. A. (2015). "Axiology and anomaly in the practice of mixed methods work: Pragmatism, valuation, and the transformative paradigm". *Journal of Mixed Methods Research,* 9 (4), p. 320-334.

Blismas, N., Pasquire, C., & Gibb, A. (2006). "Benefit evaluation for off-site production in construction". *Construction Management and Economics,* 24 (2), p. 121-130.

Blismas, N. G., Pendlebury, M., Gibb, A., & Pasquire, C. (2005). "Constraints to the use of off-site production on construction projects". *Architectural Engineering and Design Management,* 1 (3), p. 153-162.

Boehm, B. (2014). Software Project Risk and Opportunity Management. In *Software Project Management in a Changing World* (pp. 107-121): Springer.

Boyd, N., Khalfan, M. M., & Maqsood, T. (2013). "Off-site construction of apartment buildings". *Journal of architectural engineering,* 19 (1), p. 51-57.

Boyd, R. (2011). *Fatal risk: A cautionary tale of AIG's corporate suicide* (1st ed.). Hoboken: John Wiley & Sons.

Bozdağ, C. E., Kahraman, C., & Ruan, D. (2003). "Fuzzy group decision making for selection among computer integrated manufacturing systems". *Computers in Industry,* 51 (1), p. 13-29.

Brinkmann, S., & Kvale, S. (2018). *Doing interviews* (1st ed. Vol. 2). Thousand Oaks: Sage.

Brown, B. J., & Baker, S. (2007). *Philosophies of research into higher education* (4th ed. Vol. 14). London: Bloomsbury Publishing.

Brown, J. D. (2000). "What issues affect Likert-scale questionnaire formats". *Shiken: JALT Testing & Evaluation SIG Newsletter,* 4 (1), p. 27-33.

Brown, T. A. (2015). *Confirmatory factor analysis for applied research* (2nd ed.). New York: Guilford publications.

Bryman, A. (2016). *Social research methods* (4th ed.). Oxford: Oxford university press.

BSI. (2008). *31100 (2008) Risk management–Code of practice*. London: British Standards InstituteRetrieved from: https://shop.bsigroup.com/ProductDetail/?pid=000000000030191339

Buchan, D. H. (1994). "Risk analysis-some practical suggestions". *Cost Engineering,* 36 (1), p. 29.

Bunge, M. (1977). *Treatise on basic philosophy: Ontology I: the furniture of the world* (1st ed. Vol. 3). Berlin: Springer Science & Business Media.

Burns, O. M., Turnipseed, D., & Riggs, W. E. (1991). "Critical success factors in manufacturing resource planning implementation". *International Journal of Operations & Production Management,* 11 (4), p. 5-19.

Busby, J. S., & Zhang, H. (2008). "The pathogen construct in risk analysis". *Project management journal,* 39 (3), p. 86-96.

Camfield, L., & Ruta, D. (2007). "'Translation is not enough': using the Global Person Generated Index (GPGI) to assess individual quality of life in Bangladesh, Thailand, and Ethiopia". *Quality of Life Research,* 16 (6), p. 1039-1051.

Card, A. J., Ward, J. R., & Clarkson, P. J. (2012). "Beyond FMEA: The structured what-if technique (SWIFT)". *Journal of Healthcare Risk Management,* 31 (4), p. 23-29.

Carifio, J., & Perla, R. (2008). "Resolving the 50-year debate around using and misusing Likert scales". *Medical education,* 42 (12), p. 1150-1152.

Carpenter, N., & Bausman, D. C. (2016). "Project delivery method performance for public school construction: Design-bid-build versus CM at risk". *Journal of Construction Engineering and Management,* 142 (10), p. 05016009.

Castro, F. G., Kellison, J. G., Boyd, S. J., & Kopak, A. (2010). "A Methodology for Conducting Integrative Mixed Methods Research and Data Analyses". *Journal of Mixed Methods Research,* 4 (4), p. 342-360.

Catchpole, K., Neyens, D. M., Abernathy, J., Allison, D., Joseph, A., & Reeves, S. T. (2017). "Framework for direct observation of performance and safety in healthcare". *BMJ quality & safety,* 26 (12), p. 1015-1021.

CCIA. (2021). Statistical analysis of construction industry development in 2020. Accesss date: 17/07/2021. Retrieved from:https://mp.weixin.qq.com/s/EAO_iMuFO_rJ7ii6MQO1kg

Cervone, H. F. (2006). "Project risk management". *OCLC Systems & Services: International digital library perspectives,* 22 (4), p. 256-262.

Chapman, C., & Ward, S. (2000). "Estimation and evaluation of uncertainty: a minimalist first pass approach". *International Journal of Project Management,* 18 (6), p. 369-383.

Chapman, C., & Ward, S. (2011). *How to manage project opportunity and risk* (3rd ed.). Hoboken: John Wiley & Sons.

Chapman, R. J. (1999). "The likelihood and impact of changes of key project personnel on the design process". *Construction Management & Economics,* 17 (1), p. 99-106.

Chapman, R. J. (2001). "The controlling influences on effective risk identification and assessment for construction design management". *International Journal of Project Management,* 19 (3), p. 147-160.

Cheadle, C., Vawter, M. P., Freed, W. J., & Becker, K. G. (2003). "Analysis of microarray data using Z score transformation". *The Journal of molecular diagnostics,* 5 (2), p. 73-81.

Chen, G.-X., Shan, M., Chan, A. P., Liu, X., & Zhao, Y.-Q. (2019). "Investigating the causes of delay in grain bin construction projects: the case of China". *International Journal of Construction Management,* 19 (1), p. 1-14.

Chermack, T. J. (2004). "Improving decision-making with scenario planning". *Futures,* 36 (3), p. 295-309.

Chileshe, N., Rameezdeen, R., & Hosseini, M. R. (2016). "Drivers for adopting reverse logistics in the construction industry: a qualitative study". *Engineering, Construction and Architectural Management,* 23 (2), p. 134-157.

Chinbat, U. (2009). "Using simulation for reducing risk of a mining optimization project". *International Journal of Simulation Modelling (IJSIMM),* 8 (3), p. 166-177.

Choi, H.-H., Cho, H.-N., & Seo, J. (2004). "Risk assessment methodology for underground construction projects". *Journal of Construction Engineering and Management,* 130 (2), p. 258-272.

Chryssolouris, G. (2013). *Manufacturing systems: theory and practice* (2rd ed.). Berlin: Springer Science & Business Media.

Clark, R., Pledger, M., & Needler, H. (1990). "Risk analysis in the evaluation of non-aerospace projects". *International Journal of Project Management,* 8 (1), p. 17-24.

Cleden, D. (2017). *Managing project uncertainty* (1st ed.). Milton Park: Routledge.

Cohen, S., & Roussel, J. (2005). *Strategic supply chain management: the five disciplines for top performance* (2nd ed.). New York: McGraw-Hill.

Cooper, D. (2004). "The australian and new zealand standard on risk management, as/nzs 4360: 2004". *Tutorial Notes: Broadleaf Capital International Pty Ltd,* p. 128-151.

Corotis, R., Harris, J., & Fox, R. (1981). "Delphi methods: theory and design load application". *Journal of the Structural Division,* 107(6) p. 1095-1105.

Creedy, G. D., Skitmore, M., & Wong, J. K. (2010). "Evaluation of risk factors leading to cost overrun in delivery of highway construction projects". *Journal of Construction Engineering and Management,* 136 (5), p. 528-537.

Dağsuyu, C., Göçmen, E., Narlı, M., & Kokangül, A. (2016). "Classical and fuzzy FMEA risk analysis in a sterilization unit". *Computers & Industrial Engineering,* 101 p. 286-294.

Dalton, T., Wakefield, R., & Horne, R. (2011). "Australian suburban house building: industry organisation, practices and constraints". *Australian Housing and Urban Research Institute Positioning Paper Series,* p. 1-56.

Davies, C. (2005). *The prefabricated home* (1st ed.). London: Reaktion books.

Dawes, J. (2008). "Do data characteristics change according to the number of scale points used? An experiment using 5-point, 7-point and 10-point scales". *International journal of market research,* 50 (1), p. 61-104.

Delvosalle, C., Fievez, C., Pipart, A., & Debray, B. (2006). "ARAMIS project: a comprehensive methodology for the identification of reference accident scenarios in process industries". *Journal of Hazardous Materials,* 130 (3), p. 200-219.

Dickey, J. W., & Watts, T. M. (1978). *Analytic techniques in urban and regional planning: with applications in public administration and affairs* (1st ed.). New York: McGraw-Hill Science, Engineering & Mathematics.

Diebel, J., & Thrun, S. (2005). "An application of Markov random fields to range sensing". In *Proceedings of the 18th International Conference on Neural Information Processing Systems, Vancouver, British Columbia, Canada*. Retrieved from: http://www.cse.psu.edu/~rtc12/CSE586Spring2010/papers/mrfdiebel_thrun_nips.pdf

Dikmen, I., Birgonul, M. T., & Han, S. (2007). "Using fuzzy risk assessment to rate cost overrun risk in international construction projects". *International Journal of Project Management,* 25 (5), p. 494-505.

Dionne, G. (2013). "Risk management: History, definition, and critique". *Risk Management and Insurance Review,* 16 (2), p. 147-166.

Dionne, G., & Eeckhoudt, L. (1985). "Self-insurance, self-protection and increased risk aversion". *Economics Letters,* 17 (1-2), p. 39-42.

DOD, & NASA. (1962). *PERT/COST System Design*. NASARetrieved from: https://catalog.hathitrust.org/Record/001621597

Doran, D., & Giannakis, M. (2011). "An examination of a modular supply chain: a construction sector perspective". *Supply Chain Management: An International Journal*, 16 (4), p. 260-270.
Du, Q., Shao, L., Zhou, J., Huang, N., Bao, T., & Hao, C. (2019). "Dynamics and scenarios of carbon emissions in China's construction industry". *Sustainable Cities and Society,* 48 p. 101556.
Dziadosz, A., & Rejment, M. (2015). "Risk Analysis in Construction Project-Chosen Methods". *Procedia Engineering,* 122 p. 258-265.
Easterby-Smith, M., Thorpe, R., & Jackson, P. R. (2012). *Management research* (1st ed.). Thousand Oaks: Sage.
Edwards, P., & Bowen, P. (2013). *Risk management in project organisations* (1st ed.). Milton Park: Routledge.
Edwards, P. J., & Bowen, P. A. (1998). "Risk and risk management in construction: a review and future directions for research". *Engineering, Construction and Architectural Management*, 5 (4), p. 339-349.
El-Sayegh, S. M. (2008). "Risk assessment and allocation in the UAE construction industry". *International Journal of Project Management*, 26 (4), p. 431-438.
El-Sayegh, S. M., Manjikian, S., Ibrahim, A., Abouelyousr, A., & Jabbour, R. (2018). "Risk identification and assessment in sustainable construction projects in the UAE". *International Journal of Construction Management,* p. 1-10.
Eldabi, T., Irani, Z., Paul, R. J., & Love, P. E. D. (2001). *Simulation Modelling: Bridging the Gap between Positivism and Interpretivism In Information Science Innovations ISI'2001* Published:
Everett, J., & Watson, J. (1998). "Small business failure and external risk factors". *Small Business Economics,* 11 (4), p. 371-390.
Ezell, B. C., Bennett, S. P., Von Winterfeldt, D., Sokolowski, J., & Collins, A. J. (2010). "Probabilistic risk analysis and terrorism risk". *Risk Analysis: An International Journal*, 30 (4), p. 575-589.
Falconer, D. J., & Mackay, D. R. (1999). "The key to the mixed method dilemma". In *Proceedings of the 10th Australasian Conference on Information Systems*. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.5.148&rep=rep1&type=pdf
Fan, M., Lin, N.-P., & Sheu, C. (2008). "Choosing a project risk-handling strategy: An analytical model". *International Journal of Production Economics,* 112 (2), p. 700-713.
Fayol, H. (1949). *General and industrial management* (1st ed.). Eastford: Martino Fine Books.
Ferdous, R., Khan, F., Sadiq, R., Amyotte, P., & Veitch, B. (2011). "Fault and event tree analyses for process systems risk analysis: uncertainty handling formulations". *Risk Analysis,* 31 (1), p. 86-107.

Flage, R., & Aven, T. (2015). "Emerging risk–Conceptual definition and a relation to black swan type of events". *Reliability Engineering & System Safety,* 144 p. 61-67.

Flanagan, R., & Norman, G. (1993). *Risk analysis for construction* (1st ed.). Hoboken: Blackwell Science.

Forum, H. (2002). *Homing in on excellence: A commentary on the use of off-site fabrication methods for the UK housebuilding industry*. London: The Housing Forum LondonRetrieved from:

Frank, M. (1999). "Treatment of uncertainties in space nuclear risk assessment with examples from Cassini mission applications". *Reliability Engineering & System Safety,* 66 (3), p. 203-221.

Frosdick, S. (1997). "The techniques of risk analysis are insufficient in themselves". *Disaster Prevention and Management: An International Journal,* 6 (3), p. 165-177.

Fulford, R., & Standing, C. (2014). "Construction industry productivity and the potential for collaborative practice". *International Journal of Project Management,* 32 (2), p. 315-326.

Gallager, R. (1970). *Information theory and reliable communication* (Vol. 30). New York: Wiley: International Centre for Mechanical Sciences

Gan, X., Zuo, J., Ye, K., Skitmore, M., & Xiong, B. (2015). "Why sustainable construction? Why not? An owner's perspective". *Habitat international,* 47 p. 61-68.

Gann, D. M. (1996). "Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan". *Construction Management & Economics,* 14 (5), p. 437-450.

Genovese, C. R., Lazar, N. A., & Nichols, T. (2002). "Thresholding of statistical maps in functional neuroimaging using the false discovery rate". *Neuroimage,* 15 (4), p. 870-878.

Gentner, D., & Smith, L. (2012). "Analogical reasoning". *Encyclopedia of human behavior,* 2 p. 130-136.

Gibb, A., & Isack, F. (2003). "Re-engineering through pre-assembly: client expectations and drivers". *Building Research & Information,* 31 (2), p. 146-160.

Gibb, A. G. (1999). *Off-site fabrication: prefabrication, pre-assembly and modularisation* (1st ed.). Hoboken: John Wiley & Sons.

Gibb, A. G. (2001). "Standardization and pre-assembly-distinguishing myth from reality using case study research". *Construction Management & Economics,* 19 (3), p. 307-315.

Gillham, B. (2008). *Developing a questionnaire* (2nd ed.). London: A&C Black.

Glen., S. (2020). Sample Size in Statistics (How to Find it): Excel, Cochran's Formula, General Tips. Accesss date: 09/09/2020. Retrieved

from:https://www.statisticshowto.com/probability-and-statistics/find-sample-size/
Gliem, J. A., & Gliem, R. R. (2003). "Calculating, interpreting, and reporting Cronbach's alpha reliability coefficient for Likert-type scales". In *Midwest Research-to-Practice Conference in Adult, Continuing, and Community*. Retrieved from: http://scholarworks.iupui.edu/handle/1805/344
Glover, J., White, D. O., & Langrish, T. A. (2002). "Wood versus concrete and steel in house construction: A life cycle assessment". *Journal of Forestry,* 100 (8), p. 34-41.
Goldratt, E. (1997). *Critical Chain* (1st ed.). Great Barrington: The North River Press Publishing Corporation.
Goldratt, E. M. (1990). *Theory of constraints* (1st ed.). New York: North River Croton-on-Hudson.
Gong, P., Teng, Y., Li, X., & Luo, L. (2019). "Modeling constraints for the on-site assembly process of prefabrication housing production: a social network analysis". *Sustainability,* 11 (5), p. 1387.
Goodier, C., & Gibb, A. (2005). "The value of the UK market for offsite". *London: Buildoffsite. Retrieved May,* 10 p. 2012.
Goodier, C., & Gibb, A. (2007). "Future opportunities for offsite in the UK". *Construction Management and Economics,* 25 (6), p. 585-595.
Goulding, J. S., Pour Rahimian, F., Arif, M., & Sharp, M. (2015). "New offsite production and business models in construction: priorities for the future research agenda". *Architectural Engineering and Design Management,* 11 (3), p. 163-184.
Goyal, S. K., & Deshmukh, S. (1992). "A critique of the literature on just-in-time manufacturing". *International Journal of Operations & Production Management,* 12 (1), p. 18-28.
Green, J., & Thorogood, N. (2018). *Qualitative methods for health research* (1st ed.). Thousand Oaks: sage.
Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). "Toward a conceptual framework for mixed-method evaluation designs". *Educational evaluation and policy analysis,* 11 (3), p. 255-274.
Greenland, S., Senn, S. J., Rothman, K. J., Carlin, J. B., Poole, C., Goodman, S. N., & Altman, D. G. (2016). "Statistical tests, P values, confidence intervals, and power: a guide to misinterpretations". *European journal of epidemiology,* 31 (4), p. 337-350.
Griffith, A., & Headley, J. (1998). "Management of small building works". *Construction Management & Economics,* 16 (6), p. 703-709.
Grote, G. (2015). "Promoting safety by increasing uncertainty–Implications for risk management". *Safety science,* 71 p. 71-79.

Groth, K. M., & Swiler, L. P. (2013). "Bridging the gap between HRA research and HRA practice: A Bayesian network version of SPAR-H". *Reliability Engineering & System Safety,* 115 p. 33-42.

Grove, S. K., Burns, N., & Gray, J. (2012). *The practice of nursing research: Appraisal, synthesis, and generation of evidence* (7th ed.). Amsterdam: Elsevier Health Sciences.

Guo, Q., Xu, Z., Zhang, G., & Tu, T. (2010). "Comparative analysis between the EPC contract mode and the traditional mode based on the transaction cost theory". In *2010 IEEE 17th International Conference on Industrial Engineering and Engineering Management*. Retrieved from: https://ieeexplore.ieee.org/abstract/document/5646643/

Gupta, S., & Bhattacharya, J. (2007). "Reliability analysis of a conveyor system using hybrid data". *Quality and Reliability Engineering International,* 23 (7), p. 867-882.

Hagan, F. E. (1997). *Research methods in criminal justice and criminology* (1st ed.). Boston: Allyn and Bacon Boston.

Haimes, Y. Y. (2009). "On the complex definition of risk: A systems-based approach". *Risk Analysis: An International Journal,* 29 (12), p. 1647-1654.

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (1998). *Multivariate data analysis* (1st ed. Vol. 5). Upper Saddle River: Prentice Hall.

Haller, M., Lu, W., Stehn, L., & Jansson, G. (2015). "An indicator for superfluous iteration in offsite building design processes". *Architectural Engineering and Design Management,* 11 (5), p. 360-375.

Hallikas, J., Karvonen, I., Pulkkinen, U., Virolainen, V.-M., & Tuominen, M. (2004). "Risk management processes in supplier networks". *International Journal of Production Economics,* 90 (1), p. 47-58.

Hamati-Ataya, & Inanna. (2014). "Transcending objectivism, subjectivism, and the knowledge in-between: the subject in/of 'strong reflexivity'". *Review of International Studies,* 40 (01), p. 153-175.

Han, S. H., Yun, S., Kim, H., Kwak, Y. H., Park, H. K., & Lee, S. H. (2009). "Analyzing schedule delay of mega project: Lessons learned from Korea train express". *IEEE transactions on engineering management,* 56 (2), p. 243-256.

Han, Y., & Wang, L. (2018). "Identifying barriers to off-site construction using grey DEMATEL approach: case of China". *Journal of Civil Engineering and Management,* 24 (5), p. 364-377.

Handcock, M. S., & Gile, K. J. (2011). "Comment: On the concept of snowball sampling". *Sociological Methodology,* 41 (1), p. 367-371.

Harms-Ringdahl, L. (2003). *Safety analysis: principles and practice in occupational safety* (2nd ed.). Boca Raton: CRC Press.

Harpe, S. E. (2015). "How to analyze Likert and other rating scale data". *Currents in Pharmacy Teaching and Learning,* 7 (6), p. 836-850.

Harriman, D. (2010). *The logical leap: Induction in physics* (1st ed.). New York: Berkley.

Harrington, S., & Niehaus, G. (2003). "United grain growers: enterprise risk management and weather risk". *Risk Management and Insurance Review,* 6 (2), p. 193-208.

Harwell, M. R., & Gatti, G. G. (2001). "Rescaling ordinal data to interval data in educational research". *Review of Educational Research,* 71 (1), p. 105-131.

Hashemi, A. (2015). "Offsite Manufacturing: A Survey on the Current Status and Risks of Offsite Construction in Iran". *Journal of Civil Engineering and Architecture,* 9 p. 141-152.

Hassan, M. R., & Nath, B. (2006). "Stock market forecasting using hidden Markov model: a new approach". *IEEE International Conference on Systems,* 2 p. 1073-1078.

Hastak, M., & Shaked, A. (2000). "ICRAM-1: Model for international construction risk assessment". *Journal of Management in Engineering,* 16 (1), p. 59-69.

Hatmoko, J. U. D., & Scott, S. (2010). "Simulating the impact of supply chain management practice on the performance of medium-sized building projects". *Construction Management and Economics,* 28 (1), p. 35-49.

Heale, R., & Twycross, A. (2015). "Validity and reliability in quantitative studies". *Evidence-based nursing,* 18 (3), p. 66-67.

Health, E. P. o. P., Jeger, M., Bragard, C., Caffier, D., Candresse, T., Chatzivassiliou, E., . . . MacLeod, A. (2018). "Guidance on quantitative pest risk assessment". *EFSA Journal,* 16 (8), p. e05350.

Heckmann, I., Comes, T., & Nickel, S. (2015). "A critical review on supply chain risk–Definition, measure and modeling". *Omega,* 52 p. 119-132.

Heidegger, M. (2008). *Ontology—The hermeneutics of facticity* (1st ed.). Bloomington: Indiana University Press.

Herbert, G., & Herbert, G. (1978). *Pioneers of prefabrication: the British contribution in the nineteenth century* (1st ed. Vol. 19). Baltimore: Johns Hopkins University Press

Hertz, D. B. (1964). "Risk analysis in capital investment". *Harvard Business Review,* 42 p. 95-106.

Hill, N. (2005). "On the origins of crucks: an innocent notion". *Vernacular architecture,* 36 (1), p. 1-14.

Hillson, D. (1999). *Developing effective risk responses In Proceedings of the 30th Annual Project Management Institute Seminars & Symposium* 10-16 Published:

Hillson, D. (2002). "Extending the risk process to manage opportunities". *International Journal of Project Management,* 20 (3), p. 235-240.

Hillson, D. (2003). *Effective opportunity management for projects: Exploiting positive risk* (1st ed.). Boca Raton: CRC Press.

Hillson, D. (2004). Analysing Assumptions & Constraints: IF-THEN. Accesss date: 28/06/2018. Retrieved from:https://risk-doctor.com/wp-content/uploads/2020/06/08-Assumptions-and-Constraints.pdf

Hofer, B. K. (2001). "Personal epistemology research: Implications for learning and teaching". *Educational psychology review,* 13 (4), p. 353-383.

Hong, J., Shen, G. Q., Li, Z., Zhang, B., & Zhang, W. (2018). "Barriers to promoting prefabricated construction in China: A cost–benefit analysis". *Journal of Cleaner Production,* 172 p. 649-660.

Houston, S. (2014). "Meta-theoretical paradigms underpinning risk in child welfare: Towards a position of methodological pragmatism". *Children and Youth Services Review,* 47 p. 55-60.

Hovorka, D. S., & Lee, A. S. (2010). "Reframing interpretivism and positivism as understanding and explanation: Consequences for information systems research". Retrieved from: https://aisel.aisnet.org/icis2010_submissions/188/

Howell, D., Windahl, C., & Seidel, R. (2010). "A project contingency framework based on uncertainty and its consequences". *International Journal of Project Management,* 28 (3), p. 256-264.

Hsu, P.-Y., Aurisicchio, M., & Angeloudis, P. (2017). "Investigating schedule deviation in construction projects through root cause analysis". *Procedia computer science,* 121 p. 732-739.

Hughes, W., & Murdoch, J. R. (2001). *Roles in construction projects: analysis and terminology* (1st ed.). Reading: Construction Industry Publications.

Hulett, D. T. (2014). Use Decision Trees to Make Important Project Decisions. *Cost Engineering.* Accesss date: 06/05/2020. Retrieved from:http://projectrisk.com/white_papers/Use_Decision_Trees_to_Make_Important_Project_Decisions.pdf

Hwang, B.-G., Thomas, S. R., Haas, C. T., & Caldas, C. H. (2009). "Measuring the impact of rework on construction cost performance". *Journal of Construction Engineering and Management,* 135 (3), p. 187-198.

Hwang, B.-G., Zhao, X., & Toh, L. P. (2014). "Risk management in small construction projects in Singapore: status, barriers and impact". *International Journal of Project Management,* 32 (1), p. 116-124.

Iloiu, M., & Csiminga, D. (2009). "Project Risk Evaluation Methods-Sensitivity Analysis". *Annals of the University of Petroşani,* 9 (2), p. 29-32.

IMF. (2019). *Download entire World Economic Outlook database*. Retrieved from: https://www.imf.org/external/pubs/ft/weo/2019/02/weodata/download.aspx

IRGC. (2005). White Paper on Risk Governance: Towards an Integrative Framework. Accesss date: 15/05/2018. Retrieved from:https://link.springer.com/chapter/10.1007/978-1-4020-6799-0_1

Ishii, N., Takano, Y., & Muraki, M. (2014). "An order acceptance strategy under limited engineering man-hours for cost estimation in Engineering–

Procurement–Construction projects". *International Journal of Project Management,* 32 (3), p. 519-528.
ISO. (2009a). 31000: 2009 Risk Management—Principles and Guidelines. In. Geneva: International Organization for Standardization.
ISO. (2009b). 31010: Risk management–Risk assessment techniques. In (Vol. 552). London: International Organization for Standardization.
ISO. (2018a). ISO 31000 - Risk management. In. London: International Organization for Standardization.
Israel, G. D. (1992). Determining sample size. Accesss date: 11/04/2020. Retrieved from:https://www.researchgate.net/profile/Subhash-Basu-3/post/how_could_i_determine_sample_size_for_my_study/attachment/5ebaa4924f9a520001e613b6/AS%3A890361492811785%401589290130539/download/samplesize1.pdf
Itakura, K. (2020). "Evaluating the impact of the US–China trade war". *Asian Economic Policy Review,* 15 (1), p. 77-93.
Iveta, K., & Ivankova, K. (2010). "Constraint management system–optimized production technology (OPT)". *scientific journal on transport and logistics „LOGI,* 2 (1), p. 35-39.
Jaafari, A. (2001). "Management of risks, uncertainties and opportunities on projects: time for a fundamental shift". *International Journal of Project Management,* 19 (2), p. 89-101.
Jablonowski, M. (2006). *Precautionary Risk Management Dealing with Catastrophic Loss Potentials in Business, The Community and Society*: Palgrave Macmillan UK.
Jaillon, L., Poon, C.-S., & Chiang, Y. (2009). "Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong". *Waste Management,* 29 (1), p. 309-320.
Jaillon, L., & Poon, C. (2014). "Life cycle design and prefabrication in buildings: A review and case studies in Hong Kong". *Automation in Construction,* 39 p. 195-202.
Jamieson, S. (2004). "Likert scales: How to (ab) use them?". *Medical education,* 38 (12), p. 1217-1218.
Jauch, L. R., & Kraft, K. L. (1986). "Strategic management of uncertainty". *Academy of management review,* 11 (4), p. 777-790.
Jergeas, G. F., & Ruwanpura, J. (2010). "Why cost and schedule overruns on mega oil sands projects?". *Practice Periodical on Structural Design and Construction,* 15 (1), p. 40-43.
Jiang, R., Mao, C., Hou, L., Wu, C., & Tan, J. (2017). "A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation". *Journal of Cleaner Production,* 172 p. 649-660.

Jiang, R., Mao, C., Hou, L., Wu, C., & Tan, J. (2018). "A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation". *Journal of Cleaner Production,* 173 p. 225-234.

Jiang, W., & Han, J. (2009). "The methods of improving the manufacturing resource planning (MRP II) in ERP". In *2009 International Conference on Computer Engineering and Technology*. Retrieved from: https://ieeexplore.ieee.org/abstract/document/4769493/

John, G., Clements-Croome, D., Fairey, V., & Loy, H. (2005). "Contextual prerequisites for the application of ILS principles to the building services industry". *Engineering, Construction and Architectural Management,* 12 (4), p. 307-328.

Johnson, B., & Turner, L. A. (2003). "Data collection strategies in mixed methods research". *Handbook of mixed methods in social and behavioral research,* p. 297-319.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). "Toward a definition of mixed methods research". *Journal of Mixed Methods Research,* 1 (2), p. 112-133.

Kadam, P., & Bhalerao, S. (2010). "Sample size calculation". *International journal of Ayurveda research,* 1 (1), p. 55.

Kahraman, C., Beskese, A., & Ruan, D. (2004). "Measuring flexibility of computer integrated manufacturing systems using fuzzy cash flow analysis". *Information Sciences,* 168 (1-4), p. 77-94.

Kamar, A. M., Abd Hamid, Z., & Azman, N. A. (2011). "Industrialized building system (IBS): Revisiting issues of definition and classification". *International journal of emerging sciences,* 1 (2), p. 120.

Kanter, S. L. (2009). "Ethical approval for studies involving human participants: academic medicine's new policy". *Academic Medicine,* 84 (2), p. 149.

Kaplinski, O. (2013). "Risk management of construction works by means of the utility theory: a case study". *Procedia Engineering,* 57 p. 533-539.

Karakas, K., Dikmen, I., & Birgonul, M. T. (2013). "Multiagent System to Simulate Risk-Allocation and Cost-Sharing Processes in Construction Projects". *Journal of Computing in Civil Engineering,* 27 (3), p. 307-319.

Kasa, K., & Lei, X. (2018). "Risk, uncertainty, and the dynamics of inequality". *Journal of Monetary Economics,* 94 p. 60-78.

Kassem, M. A., Khoiry, M. A., & Hamzah, N. (2019). "Using probability impact matrix (PIM) in analyzing risk factors affecting the success of oil and gas construction projects in Yemen". *International Journal of Energy Sector Management,* 14 (3), p. 527-546.

Kavisankar, L., & Chellappan, C. (2011). "A Mitigation model for TCP SYN flooding with IP Spoofing". In *2011 International Conference on Recent Trends in Information Technology (ICRTIT)*. Retrieved from: https://ieeexplore.ieee.org/abstract/document/5972435

Keeney, B. P. (2017). *Aesthetics of change* (1st ed.). New York: Guilford Publications.
Kekolahti, P. (2011). "Using Bayesian belief networks for modeling of communication service provider businesses". In *8th Bayesian Modelling Applications Workshop*. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.232.3602&rep=rep1&type=pdf#page=62
Kendrick, T. (2015). "Project opportunity risk sink or risk source?". In *PMI® Global Congress 2015, North America, Orlando, FL*. Retrieved from: https://pmisv.org/downloads-files/special-folder/programs/pmis/2015/1154-project-opportunity-risk-sink-or-risk-source/file
Kennedy, R., Xiang, X., Madey, G., & Cosimano, T. (2005). "Verification and validation of scientific and economic models". In *Proc. Agent*. Retrieved from: https://www3.nd.edu/~nom/Papers/agent2005_revised.pdf
Khasha, R., Sepehri, M. M., & Khatibi, T. (2013). "A fuzzy FMEA approach to prioritizing surgical cancellation factors". *International Journal of Hospital Research*, 2 (1), p. 17-24.
Kim, S.-Y., Van Tuan, N., & Ogunlana, S. O. (2009). "Quantifying schedule risk in construction projects using Bayesian belief networks". *International Journal of Project Management*, 27 (1), p. 39-50.
Klemetti, A. (2006a). "Risk management in construction project networks". p.
Klibi, W., & Martel, A. (2012). "Scenario-based supply chain network risk modeling". *European Journal of Operational Research*, 223 (3), p. 644-658.
Kliem, R. L., & Ludin, I. S. (1997). *Reducing project risk* (1st ed.). Aldershot: Gower Publishing, Ltd.
Kline, P. (2000). *A psychometrics primer* (1st ed.). London: Free Association Books.
Knapp, T. R. (1990). "Treating ordinal scales as interval scales: an attempt to resolve the controversy". *Nursing research*, 39 (2), p. 121-123.
Knight, F. H. (2012). *Risk, uncertainty and profit* (4th ed.). North Chelmsford: Courier Corporation.
Knowledge, P. M. (2018). Risk Data Quality Assessment. Accesss date: 29/06/2018. Retrieved from:https://project-management-knowledge.com/definitions/r/risk-data-quality-assessment/
Kong, L., Li, H., Luo, H., Ding, L., Luo, X., & Skitmore, M. (2017). "Optimal single-machine batch scheduling for the manufacture, transportation and JIT assembly of precast construction with changeover costs within due dates". *Automation in Construction*, 81 p. 34-43.
Kwak, Y.-H. (2005). *A brief history of project management* (1st ed.). Westport: Greenwood Publishing Group.
Kwan, T. W., & Leung, H. K. N. (2011). "A Risk Management Methodology for Project Risk Dependencies". *IEEE Transactions on Software Engineering*, 37 (5), p. 635 - 648.

Lam, E. W., Chan, A. P., & Chan, D. W. (2010). "Qualitative survey on managing building maintenance projects". *World Academy of Science, Engineering and Technology*, 65 p. 232-236.

Lang, A., Glass, J., & Goodier, C. I. (2016). "Are housebuilders' production strategies a barrier to offsite construction uptake in the UK?". In *The 32nd Annual ARCOM Conference (ARCOM 2016), Manchester, UK*. Retrieved from: https://repository.lboro.ac.uk/articles/Are_housebuilders_production_strategies_a_barrier_to_offsite_construction_uptake_in_the_UK_/9432158/1

Lanigan, M. (1992). *Engineers in business: The principles of management and product design* (1st ed.). Boston: Addison-Wesley Publishing Company

Laryea, S. (2008). "Risk pricing practices in finance, insurance and construction". In *The construction and building research conference of the Royal Institution of Chartered Surveyors, Dublin Institute of Technology*. Retrieved from: http://centaur.reading.ac.uk/16292/

Latham, S. M. (1994). *Constructing the team*: HM Stationery Office London.

Lee, E., Park, Y., & Shin, J. G. (2009). "Large engineering project risk management using a Bayesian belief network". *Expert Systems with Applications*, 36 (3), p. 5880-5887.

Lee, S. M., & Ebrahimpour, M. (1984). "Just-in-time production system: some requirements for implementation". *International Journal of Operations & Production Management*, 4 (4), p. 3-15.

Lee, W.-S., Grosh, D. L., Tillman, F. A., & Lie, C. H. (1985). "Fault Tree Analysis, Methods, and Applications A Review". *IEEE transactions on reliability*, 34 (3), p. 194-203.

Leedy, P. D., & Ormrod, J. E. (2014). *Practical research: Planning and design* (12th ed.). London: Pearson Education.

Leeuw, J. D., Shankman, D., Wu, G., de Boer, W. F., Burnham, J., He, Q., . . . Xiao, J. (2010). "Strategic assessment of the magnitude and impacts of sand mining in Poyang Lake, China". *Regional Environmental Change*, 10 (2), p. 95-102.

Lehtiranta, L. (2014). "Risk perceptions and approaches in multi-organizations: A research review 2000–2012". *International Journal of Project Management*, 32 (4), p. 640-653.

Lewis, W. G., Pun, K. F., & Lalla, T. (2006). "Exploring soft versus hard factors for TQM implementation in small and medium-sized enterprises". *International Journal of productivity and performance management*, 55 (7), p. 539-554.

Li, C. Z., Xue, F., Li, X., Hong, J., & Shen, G. Q. (2018). "An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction". *Automation in Construction*, 89 p. 146-161.

Li, H., Guo, H., Skitmore, M., Huang, T., Chan, K., & Chan, G. (2011). "Rethinking prefabricated construction management using the VP-based IKEA model in Hong Kong". *Construction Management and Economics*, 29 (3), p. 233-245.

Li, H. X., Al-Hussein, M., Lei, Z., & Ajweh, Z. (2013). "Risk identification and assessment of modular construction utilizing fuzzy analytic hierarchy process (AHP) and simulation". *Canadian Journal of Civil Engineering,* 40 (12), p. 1184-1195.

Li, X., Li, Z., & Wu, G. (2017). "Modular and offsite construction of piping: Current barriers and route". *Applied Sciences,* 7 (6), p. 547.

Li, Z., Hong, J., Xue, F., Shen, G. Q., Xu, X., & Mok, M. K. (2016). "Schedule risks in prefabrication housing production in Hong Kong: a social network analysis". *Journal of Cleaner Production,* 134 p. 482-494.

Li, Z., Shen, G. Q., & Xue, X. (2014). "Critical review of the research on the management of prefabricated construction". *Habitat international,* 43 p. 240-249.

Li, Z., Wu, Z., He, Y., & Fulei, C. (2005). "Hidden Markov model-based fault diagnostics method in speed-up and speed-down process for rotating machinery". *Mechanical Systems and Signal Processing,* 19 (2), p. 329-339.

Lichtenberg, S. (2000). *Proactive management of uncertainty using the successive principle: a practical way to manage opportunities and risks* (1st ed.). Press: Polyteknisk Press.

Lieberman, M. D., & Cunningham, W. A. (2009). "Type I and Type II error concerns in fMRI research: re-balancing the scale". *Social cognitive and affective neuroscience,* 4 (4), p. 423-428.

Lin, Y.-H., Lin, C.-C., & Tyan, Y.-Y. (2011). "An integrated quantitative risk analysis method for major construction accidents using Fuzzy Concepts and Influence Diagram". *Journal of Marine Science and Technology,* 19 (4), p. 383-391.

Linstone, H. A., & Turoff, M. (1975). *The Delphi Method* (1st ed.). Reading, MA: Addison-Wesley.

Lipol, L. S., & Haq, J. (2011). "Risk analysis method: FMEA/FMECA in the organizations". *International Journal of Basic & Applied Sciences,* 11 (05), p. 74 - 82.

Liu, H., Skibniewski, M. J., & Wang, M. (2016). "Identification and hierarchical structure of critical success factors for innovation in construction projects: Chinese perspective". *Journal of civil engineering and management,* 22 (3), p. 401-416.

Liu, S.-S., & Wang, C.-J. (2012). "Optimizing linear project scheduling with multi-skilled crews". *Automation in Construction,* 24 p. 16-23.

Locke, E. A. (2007). "The case for inductive theory building". *Journal of Management,* 33 (6), p. 867-890.

Lofstedt, R. E. (2011). "Risk versus Hazard–How to Regulate in the 21 st Century". *European Journal of Risk Regulation,* 2 (2), p. 149-168.

Lopes, R. A., Dias, R. C., Queiroz, B. Z. d., Rosa, N. M. d. B., Pereira, L. d. S. M., Dias, J. M. D., & Magalhães, L. d. C. (2015). "Psychometric properties of the

Brazilian version of the Pain Catastrophizing Scale for acute low back pain". *Arquivos de Neuro-psiquiatria,* 73 (5), p. 436-445.

Love, P. E., Davis, P. R., Chevis, R., & Edwards, D. J. (2011). "Risk/reward compensation model for civil engineering infrastructure alliance projects". *Journal of Construction Engineering and Management,* 137 (2), p. 127-136.

Lowrance, W. W. (1976). *Of acceptable risk: Science and the determination of safety* (1st ed.). Burlington: William Kaufmann.

Lu, N. (2007). "Investigation of Designers' and General Contractors' Perceptions of Offsite Construction Techniques in the United States Construction Industry". *All Dissertations,* 81 (3), p. 177-188.

Lu, N. (2009). "The current use of offsite construction techniques in the United States construction industry". In *Construction Research Congress 2009: Building a Sustainable Future*. Retrieved from: https://ascelibrary.org/doi/abs/10.1061/41020(339)96

Lu, N., & Liska, R. W. (2008). "Designers' and general contractors' perceptions of offsite construction techniques in the United State construction industry". *International journal of construction education and research,* 4 (3), p. 177-188.

Lu, W., & Yuan, H. (2013). "Investigating waste reduction potential in the upstream processes of offshore prefabrication construction". *Renewable and Sustainable Energy Reviews,* 28 p. 804-811.

Lucko, G., & Rojas, E. M. (2010). "Research validation: Challenges and opportunities in the construction domain". *Journal of Construction Engineering and Management,* 136 (1), p. 127-135.

Lune, H., & Berg, B. L. (2017). *Qualitative research methods for the social sciences* (8th ed.). London: Pearson.

Lyu, H.-M., Sun, W.-J., Shen, S.-L., & Zhou, A.-N. (2020). "Risk assessment using a new consulting process in fuzzy AHP". *Journal of Construction Engineering and Management,* 146 (3), p. 04019112.

MacCallum, R. C., Widaman, K. F., Zhang, S., & Hong, S. (1999). "Sample size in factor analysis". *Psychological methods,* 4 (1), p. 84.

MacIntyre, A. (2013). "Relativism, power, and philosophy". *The American Philosophical Association Centennial Series,* p. 313-333.

Mao, C., Shen, Q., Pan, W., & Ye, K. (2015). "Major Barriers to Off-Site Construction: The Developer's Perspective in China". *Journal of Management in Engineering,* 31 (3), p. 223-245.

Markowski, A. S., Mannan, M. S., & Bigoszewska, A. (2009). "Fuzzy logic for process safety analysis". *Journal of Loss Prevention in the Process Industries,* 22 (6), p. 695-702.

Marshall, D., Worthing, D., Heath, R., & Dann, N. (2013). *Understanding housing defects* (4th ed.). Milton Park: Taylor & Francis.

Maruna, S. (2010). Mixed Method Research in Criminology: Why Not Go Both Ways? In A. R. Piquero & D. Weisburd (Eds.), *Handbook of Quantitative Criminology* (pp. 123-140). New York: Springer.

Maylor, H., Blackmon, K., & Huemann, M. (2016). *Researching business and management* (1st ed.). London: Macmillan International Higher Education.

McCarney, M., & Gibb, A. (2012). "Interface management from an offsite construction perspective". *Management*, 775 p. 784.

McGeorge, D., & Zou, P. X. (2012). *Construction management: new directions* (1st ed.). Hoboken: John Wiley & Sons.

McKay, L. J. (2010). *The effect of offsite construction on occupational health and safety*. (PhD), Loughborough University, Loughborough. Retrieved from: https://repository.lboro.ac.uk/articles/thesis/The_effect_of_offsite_construction_on_occupational_health_and_safety/9454415

Mecklin, C. J., & Mundfrom, D. J. (2005). "A Monte Carlo comparison of the Type I and Type II error rates of tests of multivariate normality". *Journal of Statistical Computation and Simulation*, 75 (2), p. 93-107.

Mehdizadeh, R. (2012). *Dynamic and multi-perspective risk management of construction projects using tailor-made Risk Breakdown Structures*. (PhD), Université Paris-Est Marne la Vallée, Retrieved from: https://www.researchgate.net/profile/Rasool-Mehdizadeh/publication/230608866_Dynamic_and_multi-perspective_risk_management_of_construction_projects_using_tailor-made_Risk_Breakdown_Structures/links/0912f50213bf3ae750000000/Dynamic-and-multi-perspective-risk-management-of-construction-projects-using-tailor-made-Risk-Breakdown-Structures.pdf

Mehr, R. I., & Hedges, B. A. (1963). *Risk management in the business enterprise* (1st ed.). Wakefield RD Irwin.

Meiling, J. (2010). *Continuous improvement and experience feedback in off-site construction: timber-framed module prefabrication*. (PhD), Luleå tekniska universitet, Sweden. Retrieved from: https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A991185&dswid=3036

Meiling, J., Backlund, F., & Johnsson, H. (2012). "Managing for continuous improvement in off-site construction". *Engineering, Construction and Architectural Management*, p.

Menzel, S., Nordström, E.-M., Buchecker, M., Marques, A., Saarikoski, H., & Kangas, A. (2012). "Decision support systems in forest management: requirements from a participatory planning perspective". *European Journal of Forest Research*, 131 (5), p. 1367-1379.

Mietzner, D., & Reger, G. (2005). "Advantages and disadvantages of scenario approaches for strategic foresight". *International Journal of Technology Intelligence and Planning*, 1 (2), p. 220-239.

Miller, R., & Lessard, D. (2001). "Understanding and managing risks in large engineering projects". *International Journal of Project Management,* 19 (8), p. 437-443.

Mills, A. (2001). "A systematic approach to risk management for construction". *Structural survey,* 19 (5), p. 245-252.

MOHURD. (2017). "13th Five-Year" Prefabricated Building Action Plan. Accesss date: June 8, /2019. . Retrieved from:http://www.mohurd.gov.cn/wjfb/201703/W020170329100632.doc

Morgan, M. G., Henrion, M., & Small, M. (1990). *Uncertainty: a guide to dealing with uncertainty in quantitative risk and policy analysis* (1st ed.). Cambridge: Cambridge university press.

Mornement, A., & Holloway, S. (2007). *Corrugated iron: building on the frontier* (1st ed.). New York: WW Norton & Company.

Morris, P. W. (2013). *Reconstructing project management* (2nd ed.). Hoboken: John Wiley & Sons.

Morse, J. M. (2016). *Mixed method design: Principles and procedures* (3rd ed.). Walnut Creek: Left Coast Press.

Mortazavi, F., Mousavi, S. A., Chaman, R., Khosravi, A., & Janke, J. R. (2015). "Cross cultural adaptation, validity, and reliability of the farsi breastfeeding attrition prediction tools in Iranian pregnant women". *Iranian Red Crescent Medical Journal,* 17 (3), p. e26354.

Mostafa, S., Chileshe, N., & Abdelhamid, T. (2016). "Lean and agile integration within offsite construction using discrete event simulation: A systematic literature review". *Construction innovation,* 16 (4), p. 483-525.

Motaleb, H. O., & Kishk, M. (2014). "Assessing risk response maturity: A framework for construction projects success in the United Arab Emirates". *International Journal of Managing Projects in Business,* 7 (2), p. 247-262.

Mulholland, B., & Christian, J. (1999). "Risk assessment in construction schedules". *Journal of Construction Engineering and Management,* 125 (1), p. 8-15.

Mustafa, M. A., & Al-Bahar, J. F. (1991). "Project risk assessment using the analytic hierarchy process". *IEEE transactions on engineering management,* 38 (1), p. 46-52.

Myers, M. D. (2019). *Qualitative research in business and management* (3rd ed.). Thousand Oaks: Sage.

Naderifar, M., Goli, H., & Ghaljaie, F. (2017). "Snowball sampling: A purposeful method of sampling in qualitative research". *Strides in Development of Medical Education,* 14 (3), p. 1-6.

Nadim, W., & Goulding, J. S. (2009). "Offsite production in the UK: The construction industry and academia". *Architectural Engineering and Design Management,* 5 (3), p. 136-152.

Nadim, W., & Goulding, J. S. (2011). "Offsite production: a model for building down barriers: A European construction industry perspective". *Engineering, Construction and Architectural Management,* 18 (1), p. 82-101.

Nakamura, M., Sakakibara, S., & Schroeder, R. (1998). "Adoption of just-in-time manufacturing methods at US-and Japanese-owned plants: some empirical evidence". *IEEE transactions on engineering management,* 45 (3), p. 230-240.

Nasirian, A., Arashpour, M., & Abbasi, B. (2018). "Multiskilled Human Resource Problem in Off-Site Construction". In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*. Retrieved from: https://www.researchgate.net/profile/Mehrdad-Arashpour/publication/328372562_Multiskilled_Human_Resource_Problem_in_Off-Site_Construction/links/5e53a6e6458515072db7abc6/Multiskilled-Human-Resource-Problem-in-Off-Site-Construction.pdf

Nawi, M., Osman, W. N., & Che-Ani, A. I. (2014). "Key factors for integrated project team delivery: A proposed study in IBS Malaysian construction projects". *Advances in Environmental Biology,* p. 1868-1873.

NBS. (2021). National Data. Accesss date: 08/07/2021. Retrieved from:https://data.stats.gov.cn/english/easyquery.htm?cn=E0102

NicholasTaleb, N. (2015). "The black swan: The impact of the highly improbable". *Victoria,* 250 (2), p. 595-7955.

Noguchi, M. (2005). "'Cost-Performance'Marketing Strategy for the Delivery of Solar Photovoltaic Homes". In *Proceedings of the ISES 2005 Solar World Congress*. Retrieved from: http://radar.gsa.ac.uk/1260/

Norman, G. (2010). "Likert scales, levels of measurement and the "laws" of statistics". *Advances in Health Sciences Education,* 15 (5), p. 625-632.

Nowotny, H., Scott, P., Gibbons, M., & Scott, P. B. (2001). *Re-thinking science: Knowledge and the public in an age of uncertainty* (1st ed.). Argentina: SciELO Argentina.

NRC. (1983). *Committee on the institutional means for assessment of risks to public health*. Retrieved from: https://www.ncbi.nlm.nih.gov/books/NBK216627/

O'Cathain, A., & Thomas, K. J. (2004). "" Any other comments?" Open questions on questionnaires–a bane or a bonus to research?". *BMC medical research methodology,* 4 (1), p. 1-7.

Odimabo, O. (2016). *Risk management system to guide building construction projects' in developing countries: a case study of Nigeria.* (PhD), University of Wolverhampton, Wolverhampton. Retrieved from: https://wlv.openrepository.com/handle/2436/618537

Olsson, R. (2007). "In search of opportunity management: Is the risk management process enough?". *International Journal of Project Management,* 25 (8), p. 745-752.

Osborn, A. F. (1963). *Applied imagination; principles and procedures of creative problem-solving: principles and procedures of creative problem-solving* (3rd ed.). New York: Scribner.

Oxford-Dictionary. (2017). *Oxford Dictionary* (3rd ed.). Oxford: Oxford.

Pan, W. (2006). *A decision support tool for optimising the use of offsite technologies in housebuilding.* (PhD), Loughborough University, Loughborough. Retrieved from: https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.432272

Pan, W., & Arif, M. (2011). "Manufactured Construction: Revisiting the construction-manufacturing relations". In *Proceedings of the 27th Annual ARCOM Conference*. Retrieved from: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1058.6538&rep=rep1&type=pdf

Pan, W., Gibb, A. G., & Dainty, A. R. (2007). "Perspectives of UK housebuilders on the use of offsite modern methods of construction". *Construction Management and Economics*, 25 (2), p. 183-194.

Pan, W., Gibb, A. G., & Dainty, A. R. (2008). "Leading UK housebuilders' utilization of offsite construction methods". *Building Research & Information,* 36 (1), p. 56-67.

Pan, W., Gibb, A. G., & Dainty, A. R. (2012). "Strategies for integrating the use of off-site production technologies in house building". *Journal of Construction Engineering and Management,* 138 (11), p. 1331-1340.

Pan, W., & Goodier, C. (2011). "House-building business models and off-site construction take-up". *Journal of Architectural Engineering,* 18 (2), p. 84-93.

Pan, W., & Sidwell, R. (2011). "Demystifying the cost barriers to offsite construction in the UK". *Construction Management and Economics*, 29 (11), p. 1081-1099.

Park, M., Ingawale-Verma, Y., Kim, W., & Ham, Y. (2011). "Construction policymaking: With an example of Singaporean government's policy to diffuse prefabrication to private sector". *KSCE Journal of Civil Engineering,* 15 (5), p. 771-779.

Parsian, N., & Dunning, T. (2009). "Developing and validating a questionnaire to measure spirituality: A psychometric process". *Global journal of health science*, 1 (1), p. 2-11.

Pathirage, C., Haigh, R., Amaratunga, D., & Baldry, D. (2008). "Knowledge management practices in facilities organisations: a case study". *Journal of Facilities Management*, 6 (1), p. 5-22.

Payne, S. L. (2009). *The institutional capacity of the UK speculative housebuilding industry–responding to the brownfield development policy agenda.* (PhD), University of Glasgow, Glasgow. Retrieved from: http://theses.gla.ac.uk/853/

Peng, W., & Sui Pheng, L. (2011). "Managing the embodied carbon of precast concrete columns". *Journal of Materials in Civil Engineering,* 23 (8), p. 1192-1199.

Pereira, J., Fragoso, M., & Todorov, M. (2016). "Risk assessment using Bayesian belief networks and analytic hierarchy process applicable to jet engine high pressure turbine assembly". *IFAC-PapersOnLine,* 49 (12), p. 133-138.

Perminova, O., Gustafsson, M., & Wikström, K. (2008). "Defining uncertainty in projects–a new perspective". *International Journal of Project Management*, 26 (1), p. 73-79.

Perry, J. G. (1985). "Risk and its management in construction projects". *Proceedings of the Institution of Civil Engineers,* 78 p. 499-521.

Peterson, C. E. (1965). "Prefabs in the California gold rush, 1849". *The Journal of the Society of Architectural Historians,* 24 (4), p. 318-324.

Pimentel, J. L. (2019). "Some biases in Likert scaling usage and its correction". *International Journal of Science: Basic and Applied Research (IJSBAR),* 45 (1), p. 183-191.

PIRI. (2019). Market analysis of Chinese off-site construction industry in 2018. Accesss date: 10/09/2020. Retrieved from:https://bg.qianzhan.com/trends/detail/506/190417-73006431.html

PMI. (2017). *A guide to the project management body of knowledge* (5th ed. Vol. 44). Philadelphia: Project Management Institute.

Polit, D., & Hungler, B. (1994). "Essentials of nursing research: Methods, appraisal, asid utilization". 10 (3), p. 175-158.

Ponniah, D., & Smith, S. (1998). "Techniques for the analysis of risks in major projects AU - Baker, S". *Journal of the Operational Research Society,* 49 (6), p. 567-572.

Prix, R. (2010). "The F-statistic and its implementation in ComputeFStatistic v2". In *Technical Report LIGO Scientific Collaboration*. Retrieved from: https://dcc-lho.ligo.org/public/0001/T0900149/003/CFSv2-LIGO-T0900149-v3.pdf

Promsawad, P., Tan, C. C., Kantabutra, S., & Nakeeree, P. (2014). "Operative factors influencing customer loyalty for electrical applicances retail stores in Chiang rai, Thailand". In *Afbe conference papers*. Retrieved from: https://repository.bbg.ac.id/bitstream/391/1/AFBE-2014.pdf#page=392

Psomas, E., Vouzas, F., & Kafetzopoulos, D. (2014). "Quality management benefits through the “soft” and “hard” aspect of TQM in food companies". *The TQM Journal,* 26 (5), p. 431-444.

Purdy, G. (2010). "ISO 31000: 2009—setting a new standard for risk management". *Risk Analysis: An International Journal*, 30 (6), p. 881-886.

Pyster, A., Olwell, D. H., Hutchison, N., Enck, S., Anthony Jr, J. F., & Henry, D. (2012). *Guide to the systems engineering body of knowledge* (2nd ed.). Cranfield BKCASE Editorial Board.

Rahman, M. M. (2014). "Barriers of implementing modern methods of construction". *Journal of Management in Engineering,* 30 (1), p. 69-77.

Rao, A., & Scheraga, D. (1988). "Moving From Manufacturing Resource Planning To Just-In-Time". *Production and inventory management Journal,* 29 (1), p. 44.

Rashed, A. (2005). "The application of risk management in infrastructure construction projects". *Cost Engineering,* 47 (8), p. 20.

Rashki, M., Miri, M., & Moghaddam, M. A. (2014). "A simulation-based method for reliability based design optimization problems with highly nonlinear constraints". *Automation in Construction,* 47 p. 24-36.

Rattray, J., & Jones, M. C. (2007). "Essential elements of questionnaire design and development". *Journal of clinical nursing,* 16 (2), p. 234-243.

Rausch, C., Nahangi, M., Haas, C., & Liang, W. (2019). "Monte Carlo simulation for tolerance analysis in prefabrication and offsite construction". *Automation in Construction,* 103 p. 300-314.

Rausch, C., Nahangi, M., Perreault, M., Haas, C. T., & West, J. (2017). "Optimum assembly planning for modular construction components". *Journal of Computing in Civil Engineering,* 31 (1), p. 04016039.

Raz, T., & Michael, E. (2001). "Use and benefits of tools for project risk management". *International Journal of Project Management,* 19 (1), p. 9-17.

Rechenthin, D. (2004). "Project safety as a sustainable competitive advantage". *Journal of safety research,* 35 (3), p. 297-308.

Renault, B. Y., Agumba, J. N., & Balogun, O. (2016). "Drivers for and Obstacles to Enterprise Risk Management in Construction Firms: A Literature Review". *Procedia Engineering,* 164 (2c), p. 402-408.

Renn, O. (2008). White paper on risk governance: Toward an integrative framework. In *Global risk governance* (pp. 3-73): Springer.

Rezakhani, P. (2012). "Classifying key risk factors in construction projects". *Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura,* 58 (2), p. 27.

Ringen, K., Dong, X. S., Goldenhar, L. M., & Cain, C. T. (2018). "Construction safety and health in the USA: Lessons from a decade of turmoil". *Annals of work exposures and health,* 62 (1), p. S25-S33.

Ringland, G., & Schwartz, P. P. (1998). *Scenario planning: managing for the future* (1st ed.). Hoboken: John Wiley & Sons.

Ritchie, B., & Marshall, D. V. (1993). *Business risk management*: Chapman & Hall.

Ritchie, J., Lewis, J., & Elam, R. G. (2013). *Qualitative research practice: A guide for social science students and researchers* (2nd ed. Vol. 111). Thousand Oaks: Sage.

Rivas, J. (2010). Realism. For real this time: scientific realism is not a compromise between positivism and interpretivism. In *Scientific Realism and International Relations* (pp. 203-227): Springer.

Rivza, S., & Pilvere, I. (2012). "Historical and Theoretical Aspects of the Term "Risk"". In *Economic Science for Rural Development Conference Proceedings*. Retrieved from: http://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=16913078&AN=77424821&h=2gCqDoB3by%2Fz

ZHW%2BcS8sWOpvewTNUbTesPAg5u15laEInj8U1SROZIiGiWxcMBqFc30aceOGv4kzyXSo%2FRNgXA%3D%3D&crl=c

Robinson, A., & Swindells, T. (2012). "Customized Container Architecture". In *ACSA Fall Conference*. Retrieved from: https://www.acsa-arch.org/proceedings/Fall%20Conference%20Proceedings/ACSA.FALL.12/ACSA.FALL.12.12.pdf

Robinson John, B. L. (1991). "Delphi Methodology for Economic Impact Assessment". *Journal of Transportation Engineering*, 117 (3), p. 335-349.

Rosenberg, M. (2015). *Society and the adolescent self-image* (1st ed.). Princeton: Princeton university press.

Ross, A., & Willson, V. L. (2017). One-sample T-test. In *Basic and advanced statistical tests* (pp. 9-12): Brill Sense.

Rossman, G. B., & Wilson, B. L. (1994). "Numbers and words revisited: Being “shamelessly eclectic”". *Quality and Quantity*, 28 (3), p. 315-327.

Rwelamila, P., & Hall, K. (1995). "Total systems intervention: an integrated approach to time, cost and quality management". *Construction Management and Economics*, 13 (3), p. 235-241.

Safeopedia. (2018). Checklist Analysis (CLA). Accesss date: 22/06/20108. Retrieved from:https://www.safeopedia.com/definition/5005/checklist-analysis-cla

Salama, T., Salah, A., & Moselhi, O. (2017). "Integration of offsite and onsite schedules in modular construction". In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*. Retrieved from: https://www.researchgate.net/profile/Tarek-Salama-4/publication/318084667_Integration_of_Offsite_and_Onsite_Schedules_in_Modular_Construction/links/5957e1ef458515ea4c604208/Integration-of-Offsite-and-Onsite-Schedules-in-Modular-Construction.pdf

Saleh, R. A., Sweis, R. J., & Saleh, F. I. M. (2018). "Investigating the impact of hard total quality management practices on operational performance in manufacturing organizations". *Benchmarking: An International Journal*, 25 (7), p. 2040-2064.

Samson, D., & Terziovski, M. (1999). "The relationship between total quality management practices and operational performance". *Journal of operations management*, 17 (4), p. 393-409.

Santos, J. J. A. d., Costa, T. A. d., Guilherme, J. H., Silva, W. C. d., Abentroth, L. R. L., Krebs, J. A., & Sotoriva, P. (2015). "Adaptation and cross-cultural validation of the Brazilian version of the Warwick-Edinburgh mental well-being scale". *Revista da Associação Médica Brasileira*, 61 (3), p. 209-214.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students* (7t'h ed.). London: Pearson education.

Saygin, C., & Kilic, S. (1999). "Integrating flexible process plans with scheduling in flexible manufacturing systems". *The International Journal of Advanced Manufacturing Technology*, 15 (4), p. 268-280.

SCGO. (2016). *Opinions from the General Office of the State Council on development of off-site buildings;国务院办公厅关于大力发展装配式建筑的指导意见*. Retrieved from: http://www.gov.cn/zhengce/content/2016-09/30/content_5114118.htm

Schaede, U. (1989). "Forwards and futures in tokugawa-period Japan: A new perspective on the Dōjima rice market". *Journal of Banking & Finance*, 13 (4-5), p. 487-513.

Schatteman, D., Herroelen, W., Van de Vonder, S., & Boone, A. (2008). "Methodology for integrated risk management and proactive scheduling of construction projects". *Journal of Construction Engineering and Management*, 134 (11), p. 885-893.

Schieg, M. (2006). "Risk management in construction project management". *Journal of Business Economics and Management*, 7 (2), p. 77-83.

Serpella, A. F., Ferrada, X., Howard, R., & Rubio, L. (2014). "Risk management in construction projects: a knowledge-based approach". *Procedia-Social and Behavioral Sciences*, 119 p. 653-662.

Shachter, R. D. (1986). "Evaluating influence diagrams". *Operations research*, 34 (6), p. 871-882.

Shahzad, W. M., & Mbachu, J. (2013). "Prefabrication as an onsite productivity enhancer: analysis of impact levels of the underlying constraints and improvement measures in New Zealand construction industry". *International Journal of Project Organisation and Management*, 5 (4), p. 334-354.

Shang, G., & Sui Pheng, L. (2013). "Understanding the application of Kaizen methods in construction firms in China". *Journal of Technology Management in China*, 8 (1), p. 18-33.

Sharma, S., Sawhney, A., & Arif, M. (2017). "Parametric modelling for designing offsite construction". *Procedia Engineering*, 196 p. 1114-1121.

Singh, N. (1993). "Design of cellular manufacturing systems: an invited review". *European Journal of Operational Research*, 69 (3), p. 284-291.

Sjöberg, L. (1980). "The risks of risk analysis". *Acta Psychologica*, 45 (1), p. 301-321.

Skorupka, D. (2008). "Identification and initial risk assessment of construction projects in Poland". *Journal of Management in Engineering*, 24 (3), p. 120-127.

Slaughter, E. S. (2000). "Implementation of construction innovations". *Building Research & Information*, 28 (1), p. 2-17.

Smajdor, A., Sydes, M. R., Gelling, L., & Wilkinson, M. (2009). "Applying for ethical approval for research in the United Kingdom". *Bmj*, 339 (4), p. b4013.

Smith, N. J., Merna, T., & Jobling, P. (2009). *Managing risk: in construction projects* (1st ed.). Hoboken: John Wiley & Sons.

Smith, R. E. (2009). "History of prefabrication: a cultural survey". In *Third International Congress on Construction History*. Retrieved from:

https://structurae.net/de/fachliteratur/tagungsbeitrag/history-of-prefabrication-a-cultural-survey
Snape, D., & Spencer, L. (2003). *Qualitative Research Practice: A Guide for Social Science Students and Researchers* (1st ed.). London: Sage.
Snider, H. (1956). "Reaching professional status: A program for risk management". *Corporate Risk Management: Current Problems and Perspectives,* 112 p. 30-35.
Soin, S. S. (1992). *Total quality control essentials: Key elements, methodologies, and managing for success* (1st ed.). New York: McGraw-Hill Companies.
Song, Y.-Y., & Ying, L. (2015). "Decision tree methods: applications for classification and prediction". *Shanghai archives of psychiatry,* 27 (2), p. 130.
Sotille, M. (2016). Expert judgment. Accesss date: 29/06/2018. Retrieved from:https://www.projectmanagement.com/wikis/344587/Expert-judgment#_note1
Sousa, V., Almeida, N. M., & Dias, L. A. (2014). "Risk-based management of occupational safety and health in the construction industry–Part 1: Background knowledge". *Safety science,* 66 p. 75-86.
Sowa, J. F. (2001). Building, sharing, and merging ontologies. Accesss date: 2020/14/04. Retrieved from:http://www.jfsowa.com/ontology/ontoshar.htm
Spielmann, H., Grune, B., Liebsch, M., Seiler, A., & Vogel, R. (2008). "Successful validation of in vitro methods in toxicology by ZEBET, the National Centre for Alternatives in Germany at the BfR (Federal Institute for Risk Assessment)". *Experimental and Toxicologic Pathology,* 60 (2-3), p. 225-233.
Striegel-Moore, R. H., & Bulik, C. M. (2007). "Risk factors for eating disorders". *American psychologist,* 62 (3), p. 181.
Sullivan, G. M., & Artino Jr, A. R. (2013). "Analyzing and interpreting data from Likert-type scales". *Journal of graduate medical education,* 5 (4), p. 541-542.
Sumner, M. (2009). "Information security threats: a comparative analysis of impact, probability, and preparedness". *Information Systems Management,* 26 (1), p. 2-12.
Suri, R. (1985). "An overview of evaluative models for flexible manufacturing systems". *Annals of Operations Research,* 3 (1), p. 13-21.
Sutrisna, M., Cooper-Cooke, B., Goulding, J., & Ezcan, V. (2019). "Investigating the cost of offsite construction housing in Western Australia". *International Journal of Housing Markets and Analysis,* 12 (1), p. 15-24.
Sutrisna, M., & Goulding, J. (2019). "Managing information flow and design processes to reduce design risks in offsite construction projects". *Engineering, construction and architectural management,* 26 (2), p. 267-284.
Swider, S. (2015). "Building China: precarious employment among migrant construction workers". *Work, employment and society,* 29 (1), p. 41-59.
Sykes, W. (1990). "Validity and reliability in qualitative market research: A review of the literature". *Journal of the Market Research Society,* 32 (3), p. 289-328.

Tabachnick, B. G., & Fidell, L. S. (2007). *Experimental designs using ANOVA* (1st ed.). Cole: Thomson Brooks.

Tah, J., & Carr, V. (2000). "A proposal for construction project risk assessment using fuzzy logic". *Construction Management & Economics,* 18 (4), p. 491-500.

Tam, V. W., Tam, C. M., Zeng, S., & Ng, W. C. (2007). "Towards adoption of prefabrication in construction". *Building and environment,* 42 (10), p. 3642-3654.

Tamimi, S., Dickman, J., & Bauman, R. (1990). "Risk analysis using influence diagrams". In *Uncertainty Modeling and Analysis, 1990. Proceedings., First International Symposium on*. Retrieved from: https://ieeexplore.ieee.org/abstract/document/151277/

Taroun, A. (2014). "Towards a better modelling and assessment of construction risk: Insights from a literature review". *International Journal of Project Management,* 32 (1), p. 101-115.

Tastan, M., & Yilmaz, K. (2008). "Organizational citizenship and organizational justice scales' adaptation to Turkish". *Egitim ve Bilim,* 33 (150), p. 87.

Taylor, I., & Bassler, J. (1997). "Application of ANSI Standard to Space Station Resources". *Proceedings INOSE International*, 5 (1), p. 22-26.

Taylor, J. R. (2015). "The China dream is an urban dream: Assessing the CPC's national new-type urbanization plan". *Journal of Chinese Political Science,* 20 (2), p. 107-120.

Taylor, M. D. (2010). "A definition and valuation of the UK offsite construction sector". *Construction Management and Economics,* 28 (8), p. 885-896.

Taylor, S. J., Bogdan, R., & DeVault, M. (2015). *Introduction to qualitative research methods: A guidebook and resource* (4th ed.). Hoboken: John Wiley & Sons.

Tayur, S., Ganeshan, R., & Magazine, M. (2012). *Quantitative models for supply chain management* (3rd ed. Vol. 17). Berlin: Springer Science & Business Media.

Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences* (1st ed.). Los Angeles: Sage.

Theoharidou, M., Kotzanikolaou, P., & Gritzalis, D. (2009). "Risk-based criticality analysis". In *International Conference on Critical Infrastructure Protection*. Retrieved from: https://link.springer.com/chapter/10.1007/978-3-642-04798-5_3

Thomala, L. L. (2019). Number of construction employees in China 2008-2018. Accesss date: 10/09/2020. Retrieved from:https://www.statista.com/statistics/279243/number-of-construction-employees-in-china/#:~:text=In%202018%2C%20Chinese%20construction%20enterprises%20employed%20approximately%2055.6%20million%20people.

Tixier, J., Dusserre, G., Salvi, O., & Gaston, D. (2002). "Review of 62 risk analysis methodologies of industrial plants". *Journal of Loss Prevention in the Process Industries*, 15 (4), p. 291-303.

Torretta, V., Rada, E. C., Schiavon, M., & Viotti, P. (2017). "Decision support systems for assessing risks involved in transporting hazardous materials: A review". *Safety science*, 92 p. 1-9.

TPC. (2017). *General Office of Beijing Municipal Government Implementation opinions on accelerating the development of prefabricated buildings;北京市政府办公厅关于加快发展装配式建筑的实施意见*. Retrieved from: http://zjw.beijing.gov.cn/bjjs/xxgk/kjzc/tztg/413796/index.shtml

Trochim, W., & Donnelly, J. P. (2008). *The research methods knowledge base* (3rd ed.). Mason: Atomic Dog Publishing In.

Trousselard, M., Steiler, D., Raphel, C., Cian, C., Duymedjian, R., Claverie, D., & Canini, F. (2010). "Validation of a French version of the Freiburg Mindfulness Inventory-short version: relationships between mindfulness and stress in an adult population". *BioPsychoSocial medicine*, 4 (1), p. 8.

Tummala, R., & Schoenherr, T. (2011). "Assessing and managing risks using the Supply Chain Risk Management Process (SCRMP)". *Supply Chain Management: An International Journal*, 16 (6), p. 474-483.

Turner III, D. W. (2010). "Qualitative interview design: A practical guide for novice investigators". *The qualitative report*, 15 (3), p. 754.

Tweeds, C. (1996). *Laxton's Guide to Risk Analysis and Management*: Butterworth-Heinemann.

UN. (2004). *Living with Risk—A Global Review of Disaster Reduction Initiatives* New York: United NationsRetrieved from: https://www.unisdr.org/files/657_lwr1.pdf

Valer, D. B., Aires, M., Fengler, F. L., & Paskulin, L. M. G. (2015). "Adaptation and validation of the Caregiver Burden Inventory for use with caregivers of elderly individuals". *Revista Latino-Americana de Enfermagem*, 23 (1), p. 130-138.

Van der Heijden, K. (2011). *Scenarios: the art of strategic conversation* (1st ed.). Hoboken: John Wiley & Sons.

Van Laerhoven, H., van der Zaag-Loonen, H. J., & Derkx, B. H. (2004). "A comparison of Likert scale and visual analogue scales as response options in children's questionnaires". *Acta paediatrica*, 93 (6), p. 830-835.

Vanhoucke, M. (2011). "On the dynamic use of project performance and schedule risk information during projecttracking". *Omega*, 39 (4), p. 416-426.

Varis, O., Kettunen, J., & Sirviö, H. (1990). "Bayesian influence diagram approach to complex environmental management including observational design". *Computational Statistics & Data Analysis*, 9 (1), p. 77-91.

Venables, T., Barlow, J., & Gann, D. (2004). "Manufacturing Excellence". In *UK Capacity in Offsite Manufacturing, London*. Retrieved from: https://www.researchgate.net/profile/James-Barlow-

2/publication/259557894_Manufacturing_excellence_UK_capacity_in_offsite_manufacturing/links/0deec52c71f9d4ea03000000/Manufacturing-excellence-UK-capacity-in-offsite-manufacturing.pdf

Vernikos, V. K., Goodier, C. I., Broyd, T. W., Robery, P. C., & Gibb, A. G. (2014). "Building information modelling and its effect on off-site construction in UK civil engineering". *Proceedings of the Institution of Civil Engineers-Management, Procurement and Law*, 167 (3), p. 152-159.

Vernikos, V. K., Goodier, C. I., Gibb, A. G., Robery, P., & Broyd, T. (2012). *Realising offsite construction and standardisation within a leading UK infrastructure consultancy*. (PhD), Loughborough University, Loughborough. Retrieved from: https://repository.lboro.ac.uk/articles/conference_contribution/Realising_offsite_construction_and_standardisation_within_a_leading_UK_infrastructure_consultancy/9437231/1

Vernikos, V. K., Goodier, C. I., Nelson, R., & Robery, P. (2013). "Implementing an offsite construction strategy: a UK contracting organisation case study". In *29th Annual ARCOM Conference, Reading*. Retrieved from: https://www.researchgate.net/profile/Chris-Goodier/publication/269704441_Implementing_an_Offsite_Construction_Strategy_A_UK_Contracting_Organisation_Case_Study/links/552558f40cf24b822b3fe86b/Implementing-an-Offsite-Construction-Strategy-A-UK-Contracting-Organisation-Case-Study.pdf

Veryzer Jr, R. W. (1998). "Discontinuous innovation and the new product development process". *Journal of Product Innovation Management: an international publication of the product development & management association*, 15 (4), p. 304-321.

VijayaKumar, A. (2013a). Expert Judgment. Accesss date: 29/06/2018. Retrieved from:http://getpmpcertified.blogspot.com/2013/01/expert-judgment.html

VijayaKumar, A. (2013b). Risk Data Quality Assessment. Accesss date: 29/06/2018. Retrieved from:http://getpmpcertified.blogspot.com/2013/01/risk-data-quality-assessment.html

VijayaKumar, A. (2013c). Risk Urgency Assessment. Accesss date: 29/06/2018. Retrieved from:http://getpmpcertified.blogspot.com/2013/01/risk-urgency-assessment.html

Virtanen, K., Raivio, T., & Hamalainen, R. (1998). "Modeling pilot decision making by an influence diagram". In *AIAA Modeling and Simulation Technologies Conference and Exhibit*. Retrieved from: https://arc.aiaa.org/doi/pdf/10.2514/6.1998-4537

Visser, K., & Joubert, P. (2008). "Risk assessment modelling for the South African construction industry". In *PICMET'08-2008 Portland International Conference on Management of Engineering & Technology, Cape Town*. Retrieved from: https://ieeexplore.ieee.org/abstract/document/4599749/

Vose, D. (2008). *Risk analysis: a quantitative guide* (1st ed.). Hoboken: John Wiley & Sons.

Waern, R. (2008). "Scandinavia: Prefabrication as a model of society". *Home delivery: Fabricating the modern dwelling,* 16 (10), p. 27-31.

Wakeham, J. (2015). "Uncertainty: History of the Concept". *International Encyclopedia of the Social & Behavioral Sciences,* 24 (2), p. 716-721.

Wall, D. M. (1997). "Distributions and correlations in Monte Carlo simulation". *Construction Management and Economics,* 15 (3), p. 241-258.

Walton, D. (2014). *Abductive reasoning* (1st ed.). Tuscaloosa: University of Alabama Press.

Wang, H., Alidaee, B., Glover, F., & Kochenberger, G. (2006). "Solving group technology problems via clique partitioning". *International Journal of Flexible Manufacturing Systems,* 18 (2), p. 77-97.

Wang, K., & Liu, Y. (2014). "Can Beijing fight with haze? Lessons can be learned from London and Los Angeles". *Natural hazards,* 72 (2), p. 1265-1274.

Wang, M.-T., & Chou, H.-Y. (2003). "Risk allocation and risk handling of highway projects in Taiwan". *Journal of Management in Engineering,* 19 (2), p. 60-68.

Wang, T., Gao, S., Li, X., & Ning, X. (2018). "A meta-network-based risk evaluation and control method for industrialized building construction projects". *Journal of Cleaner Production,* 205 p. 552-564.

Wang, X., Chen, Y., Liu, B., Shen, Y., & Sun, H. (2013). "A total factor productivity measure for the construction industry and analysis of its spatial difference: A case study in China". *Construction Management and Economics,* 31 (10), p. 1059-1071.

Wang, Y., Li, H., & Wu, Z. (2019). "Attitude of the Chinese public toward off-site construction: A text mining study". *Journal of Cleaner Production,* 238 (4), p. 117926.

Ward, S., & Chapman, C. (2003). "Transforming project risk management into project uncertainty management". *International Journal of Project Management,* 21 (2), p. 97-105.

Ward, S. C. (1999). "Assessing and managing important risks". *International Journal of Project Management,* 17 (6), p. 331-336.

Warner, F. (1992). Risk: Analysis, perception and management. Accesss date: 07/08/2020. Retrieved from:https://royalsociety.org/topics-policy/publications/1992/risk/

Watkins, M. W. (2018). "Exploratory factor analysis: A guide to best practice". *Journal of Black Psychology,* 44 (3), p. 219-246.

Weber, R. (2004). "Editor's comments: the rhetoric of positivism versus interpretivism: a personal view". *MIS quarterly,* 28 (1), p. iii-xii.

Wheelen, T. L., Hunger, J. D., Hoffman, A. N., & Bamford, C. E. (2017). *Strategic management and business policy* (1st ed.). London: Pearson.

Winch, G. (1998). "Zephyrs of creative destruction: understanding the management of innovation in construction". *Building Research & Information,* 26 (5), p. 268-279.

Winch, G. M. (2010). *Managing construction projects* (3rd ed.). Hoboken: John Wiley & Sons.

Wind, Y., & Saaty, T. L. (1980). "Marketing applications of the analytic hierarchy process". *Management science*, 26 (7), p. 641-658.

Wong, L. (2008). "Data analysis in qualitative research: A brief guide to using NVivo". *Malaysian family physician: the official journal of the Academy of Family Physicians of Malaysia,* 3 (1), p. 14.

Woolson, R. F., Bean, J. A., & Rojas, P. B. (1986). "Sample size for case-control studies using Cochran's statistic". *Biometrics,* p. 927-932.

Woon, K. C. (2000). "Assessment of TQM implementation: Benchmarking Singapore's productivity leaders". *Business Process Management Journal,* 6 (4), p. 314-330.

Wu, H., & Leung, S.-O. (2017). "Can Likert Scales be Treated as Interval Scales?—A Simulation Study". *Journal of Social Service Research,* 43 (4), p. 527-532.

Wu, H., Mao, C., & Liu, G. (2015). "Market Expectations of Government's Measures to Promote Off-site Construction in Mainland China: Developers' Perspective". In *Proceedings of the 19th International Symposium on Advancement of Construction Management and Real Estate, Berlin*. Retrieved from: https://link.springer.com/chapter/10.1007/978-3-662-46994-1_86

Wu, Z., Nisar, T., Kapletia, D., & Prabhakar, G. (2017). "Risk factors for project success in the Chinese construction industry". *Journal of manufacturing technology management,* 28 (7), p. 855-860.

Wuni, I. Y., & Shen, G. Q. (2019). "Risks identification and allocation in the supply chain of Modular Integrated Construction (MiC)". *Modular and Offsite Construction (MOC) Summit Proceedings,* 8 (5), p. 189-197.

Wuni, I. Y., Shen, G. Q., & Mahmud, A. T. (2019). "Critical risk factors in the application of modular integrated construction: a systematic review". *International Journal of Construction Management,* 16 (3), p. 1-15.

Xiong, W., Yang, J., Wang, Z., Hu, H., Xu, F., & Zhang, J. (2018). *Improving supply chain communications for off-site construction using Process Specification Language In ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* 1-9 Published: IAARC Publications

Xue, H., Zhang, S., Su, Y., Wu, Z., & Yang, R. J. (2018b). "Effect of stakeholder collaborative management on off-site construction cost performance". *Journal of Cleaner Production,* 184 p. 490-502.

Yahya, M. A., & Shafie, M. N. S. (2012). "Level of acceptance towards industrialised building system (IBS) In Malaysia". *International Journal of Sustainable Construction Engineering and Technology,* 3 (1), p. 96-103.

Yang, Z., Ma, Z., & Wu, S. (2016). "Optimized flowshop scheduling of multiple production lines for precast production". *Automation in Construction*, 72 p. 321-329.

Yu, T., Man, Q., Wang, Y., Shen, G. Q., Hong, J., Zhang, J., & Zhong, J. (2019). "Evaluating different stakeholder impacts on the occurrence of quality defects in offsite construction projects: A Bayesian-network-based model". *Journal of Cleaner Production*, 241 (1), p. 118390.

Zavadskas, E. K., Turskis, Z., & Tamošaitiene, J. (2010). "Risk assessment of construction projects". *Journal of civil engineering and management*, 16 (1), p. 33-46.

Zayed, T., Amer, M., & Pan, J. (2008). "Assessing risk and uncertainty inherent in Chinese highway projects using AHP". *International Journal of Project Management*, 26 (4), p. 408-419.

Zeng, J., An, M., & Smith, N. J. (2007). "Application of a fuzzy based decision making methodology to construction project risk assessment". *International Journal of Project Management*, 25 (6), p. 589-600.

Zhai, X., Reed, R., & Mills, A. (2013). "Increasing the level of sustainability via off-site production: a study of the residential construction sector in China". In *PRRES 2013: Proceedings of the 19th Annual Conference of the Pacific Rim Real Estate Society, Melbourne*. Retrieved from: https://dro.deakin.edu.au/view/DU:30055239

Zhang, G., & Zou, P. X. (2007). "Fuzzy analytical hierarchy process risk assessment approach for joint venture construction projects in China". *Journal of Construction Engineering and Management*, 133 (10), p. 771-779.

Zhang, J., Long, Y., Lv, S., & Xiang, Y. (2016). "BIM-enabled Modular and Industrialized Construction in China". *Procedia Engineering*, 145 (1), p. 1456-1461.

Zhang, L., & Agapiou, A. (2020). "Influence Diagrams for Off-Site Construction Manufacturing Risk Assessment". *Proceedings of the Institution of Civil Engineers-Management, Procurement and Law*, 0 (0), p. 1-15.

Zhang, L., Rahimian, F. P., Agapiou, A., & Goulding, J. (2017). "Offsite construction: An opportunity for improving risk management". In *International research conference 2017: shaping tomorrow's built environment*, *Salford*. Retrieved from: https://www.researchgate.net/profile/Ruchini-Jayasinghe-3/publication/329362701_A_Systematic_Literature_Review_On_Sustainable_Management_Of_The_Post-End-Of-Life_PEoL_Of_Buildings/links/5c04a245299bf1a3c15e42d1/A-Systematic-Literature-Review-On-Sustainable-Management-Of-The-Post-End-Of-Life-PEoL-Of-Buildings.pdf#page=909

Zhang, Y., & Sun, K.-f. (2011). "Top 225 international contractors in 2011 ENR report". *J. Eng. Manage*, 25 (5), p. 584-590.

Zhi, H. (1995). "Risk management for overseas construction projects". *International Journal of Project Management*, 13 (4), p. 231-237.

Zhi, Z., & Xue-jin, F. (2010). "Application study on fuzzy influence diagram in highway tunnel construction safety risk assessment". In *2010 International Conference on Management Science & Engineering 17th Annual Conference Proceedings, Melbourne*. Retrieved from: https://ieeexplore.ieee.org/abstract/document/5719816

Zio, E. (2018). "The future of risk assessment". *Reliability Engineering & System Safety*, 177 (1), p. 176-190.

BIBLIOGRAPHY

Abduh, M., Wirahadikusumah, R. D., & Messah, Y. (2018). *Framework development methodology for sustainable procurement of construction works in Indonesia In MATEC Web of Conferences* 02014 Published: EDP Sciences

ACE. (2020). The architectural profession in europe 2020. Accesss date: 22/01/2022. Retrieved from:https://www.ace-cae.eu/fileadmin/user_upload/2020ACESECTORSTUDY.pdf

AIA. (2020). Best Practices. Accesss date: 22/01/2022. Retrieved from:https://www.aia.org/best-practices

AIPM. (2021). AIPM PROFESSIONAL COMPETENCY STANDARDS FOR PROJECT MANAGEMENT. Accesss date: 21/01/2022. Retrieved from:https://www.aipm.com.au/documents/aipm-key-documents/aipm_project_practitioner_professional_competency_.aspx

Akintoye, A. S., & MacLeod, M. J. (1997). "Risk analysis and management in construction". *International Journal of Project Management*, 15 (1), p. 31-38.

APM. (2018). APM Body of Knowledge 7th edition. Accesss date: 21/01/2022. Retrieved from:https://www.apm.org.uk/book-shop/apm-body-of-knowledge-7th-edition/

Arif, M., Blismas, N., & Wakefield, R. (2009). "Drivers, constraints and the future of offsite manufacture in Australia". *Construction innovation*, 9 (1), p. 72-83.

ASSP. (2011). ANSI/ASSP Z690.1-2011 Vocabulary for Risk Management. Accesss date: 21/01/2022. Retrieved from:https://store.assp.org/PersonifyEbusiness/Store/Product-Details/productId/4906

Bao, Z., Laovisutthichai, V., Tan, T., Wang, Q., & Lu, W. (2021). "Design for manufacture and assembly (DfMA) enablers for offsite interior design and construction". *Building Research & Information*, p. 1-14.

BSI. (2014). Supply chain risk management. . Accesss date: 21/01/2022. Retrieved from:https://shop.bsigroup.com/products/supply-chain-risk-management-supplier-prequalification/standard

BSI. (2018). BS ISO 31000: 2018. Accesss date: 30/07/2021. Retrieved from:https://shop.bsigroup.com/ProductDetail?pid=000000000030315447

Cagliano, A. C., Grimaldi, S., & Rafele, C. (2015). "Choosing project risk management techniques. A theoretical framework". *Journal of risk research*, 18 (2), p. 232-248.
Carter, B., Hancock, T., Morin, J., & Robin, N. (1994). *Introducing RISKMAN: the European project risk management methodology*: NCC Blackwell London.
Chan, D. W., Olawumi, T. O., & Ho, A. M. (2019). "Perceived benefits of and barriers to Building Information Modelling (BIM) implementation in construction: The case of Hong Kong". *Journal of Building Engineering*, 25 p. 100764.
Chapman, C., & Ward, S. (2003). *Project risk management: processes, techniques, and insights*: Wiley.
Chen, X., Chen, Q., Zhang, Z., Cheng, Y., & Qi, Z. (2018). *BIM+ Robot Creates a New Era of Building Construction In Journal of Physics: Conference Series* 012142 Published: IOP Publishing
Chen, Y., Du, X., & Wang, Y. (2017). "OSC risk assessment system establishment and analysis 装配式建筑风险评估体系的建立和方法研究". *价值工程*, 36 (28), p. 4.
Chia, E. S. (2006). *Risk assessment framework for project management In Engineering Management Conference, 2006 IEEE International* 376-379 Published: IEEE
Collis, J., & Hussey, R. (2013). *Business research: A practical guide for undergraduate and postgraduate students* (4th ed.). London: Macmillan International Higher Education.
Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches* (6th ed.). Thousand Oaks: Sage publications.
CSA. (2009a). CAN/CSA-Q850-97 (R2009): Risk Management: Guideline for Decision Makers. Accesss date: 21/01/2022. Retrieved from:https://www.csagroup.org/store/product/2700327/#:~:text=This%20Guideline%20describes%20a%20process,is%20necessary%20for%20decision%2Dmaking.&text=This%20Guideline%20provides%20a%20description,step%2Dby%2Dstep%20process.
CSA. (2009b). CSA-Q850-97 (R2009) Risk management: guideline for decision makers. Accesss date: 30/07/2021. Retrieved from:https://www.scc.ca/en/standardsdb/standards/6777
Ding, X., Chang, X., & Liu, M. (2019). "OSC management framework in IPD mode IPD 模式在装配式建筑中的管理框架". *北方建筑*, 4 (04), p. 73-76.
Egbu, A. U., Olomolaiye, P., & Gameson, R. (2007). "A quantitative model for assessing the impact of land use planning on urban housing development in Nigeria". *International Development Planning Review*, 29 (2), p. 215.
Ghasemi, F., Sari, M. H. M., Yousefi, V., Falsafi, R., & Tamošaitienė, J. (2018). "Project Portfolio Risk Identification and Analysis, Considering Project Risk Interactions and Using Bayesian Networks". *Sustainability*, 10 (5), p. 1609.

Gunduz, M., & Elsherbeny, H. A. (2020). "Operational framework for managing construction-contract administration practitioners' perspective through modified Delphi method". *Journal of Construction Engineering and Management*, 146 (3), p. 04019110.

Guo, Z., & Liang, T. (2017). "A brief research for OSC developing 浅谈装配式建筑的发展". *价值工程*, 36 (2), p. 3.

He, J. (2021). "Risk management framework for Internal control of construction industry 基于风险管理框架下的建筑业内部控制探究". *今日财富*, (19), p. 46-48.

He, M., & Gao, L. (2021). "OSC Supply Chain risk control research 基于供应链的装配式建筑风险控制研究". *山西建筑*, 47 (24), p. 2.

He, R., Li, M., Gan, V. J., & Ma, J. (2021). "BIM-enabled computerized design and digital fabrication of industrialized buildings: A case study". *Journal of Cleaner Production*, 278 p. 123505.

Huang, D., You, J., & Du, B. (2007). "Construction project management method analysis based on profit-risk model 基于收益-风险的建筑项目管理模式分析". *同济大学学报：自然科学版*, 35 (12), p. 6.

ICE. (2020). Design Risk Management. Accesss date: 21/01/2022. Retrieved from:https://www.ice.org.uk/knowledge-and-resources/best-practice/design-risk-management

Imai, M. (2007). "Gemba Kaizen. A commonsense, low-cost approach to management". *International Journal of Physical Distribution & Logistics Management,*, 36 (10), p. 7-15.

ISO. (2018b). ISO 31000: risk managment. Accesss date: 30/07/2021. Retrieved from:https://www.iso.org/iso-31000-risk-management.html

ISO. (2019). ISO 14971:2019(en), Medical devices. Accesss date: 21/01/2022. Retrieved from:https://www.iso.org/standard/72704.html

Issa, U. H., Mosaad, S. A., & Hassan, M. S. (2020). *Evaluation and selection of construction projects based on risk analysis In Structures* 361-370 Published: Elsevier

Jannadi, O. A., & Almishari, S. (2003). "Risk assessment in construction". *Journal of Construction Engineering and Management*, 129 (5), p. 492-500.

Ji, C., Su, X., Qin, Z., & Nawaz, A. (2022). "Probability analysis of construction risk based on noisy-or gate bayesian networks". *Reliability Engineering & System Safety*, 217 p. 107974.

Ji, Y., Zhu, F., Li, H. X., & Al-Hussein, M. (2017). "Construction industrialization in China: Current profile and the prediction". *Applied Sciences*, 7 (2), p. 180.

Johnsson, H., & Meiling, J. H. (2009). "Defects in offsite construction: timber module prefabrication". *Construction Management and Economics*, 27 (7), p. 667-681.

JSA. (2001). JIS Q 2001:2001 Guidelines for development and implementation of risk management system. Accesss date: 30/07/2021. Retrieved from:https://www.normadoc.com/english/jis-q-2001-2001-2313491.html

Kamali, M., & Hewage, K. (2016). "Life cycle performance of modular buildings: A critical review". *Renewable and Sustainable Energy Reviews,* 62 p. 1171-1183.

Kannan, V. R., & Choon Tan, K. (2006). "Buyer-supplier relationships". *International Journal of Physical Distribution & Logistics Management,* 36 (10), p. 755-775.

Klemetti, A. (2006b). "Risk management in construction project networks". 22 (3), p. 115.

Kobo-Greenhut, A., Reuveni, H., Ben Shlomo, I., & Megnezi, R. (2019). "Unstructured brainstorming is not enough: structured brainstorming based on four verification and validation questions yields better hazard identification in healthcare". *International Journal for Quality in Health Care,* 31 (7), p. 16-21.

Krause, D. R., Vachon, S., & Klassen, R. D. (2009). "Special topic forum on sustainable supply chain management: introduction and reflections on the role of purchasing management". *Journal of Supply Chain Management,* 45 (4), p. 18-25.

Kumar, K. S., & Narayanan, R. (2021). "Review on construction risk and development of risk management procedural index–A case study from Chennai construction sector". *Materials Today: Proceedings,* 43 p. 1141-1146.

Larkin, P., Gracie, R., Shafiei, A., Dusseault, M., Sarkarfarshi, M., Aspinall, W., & Krewski, D. (2019). "Risk management in carbon capture and geological storage: insights from a structured expert elicitation". *International Journal of Risk Assessment and Management,* 22 (3-4), p. 404-428.

Lee, M., Cheah, W., Lau, S., Lee, X., Abdullahi, A., & Wong, S. (2020). *Evaluation of practicality of virtual design and construction (VDC) with 5D building information modelling (BIM) through a case study In IOP Conference Series: Materials Science and Engineering* 012058 Published: IOP Publishing

Li, L., Geng, B., QI, B., & Lei, Y. (2013). "Cost comparison between OSC project and traditional construction project 装配式建筑工程与现浇建筑工程成本对比与实证研究". *建筑经济,* (9), p. 4.

Li, W., He, M., Sun, Y., & Cao, Q. (2019). "A proactive operational risk identification and analysis framework based on the integration of ACAT and FRAM". *Reliability Engineering & System Safety,* 186 p. 101-109.

Li, Y. (2013). "Supplier risk management of construction enterprises 基于低风险的建筑企业供应商管理". *科教导刊,* p. 5.

Luko, S. N. (2013). "Risk management principles and guidelines". *Quality Engineering,* 25 (4), p. 451-454.

Mao, C., Xie, F., Hou, L., Wu, P., Wang, J., & Wang, X. (2016). "Cost analysis for sustainable off-site construction based on a multiple-case study in China". *Habitat International,* 57 p. 215-222.

McMeekin, N., Wu, O., Germeni, E., & Briggs, A. (2020). "How methodological frameworks are being developed: evidence from a scoping review". *BMC medical research methodology,* 20 (1), p. 173.

Monzer, N., Fayek, A. R., Lourenzutti, R., & Siraj, N. B. (2019). "Aggregation-based framework for construction risk assessment with heterogeneous groups of experts". *Journal of Construction Engineering and Management*, 145 (3), p. 04019003.

Nieto-Morote, A., & Ruz-Vila, F. (2011). "A fuzzy approach to construction project risk assessment". *International Journal of Project Management*, 29 (2), p. 220-231.

NZS. (2004). AS/NZS 4360: 2004 Risk management. Accesss date: 30/07/2021. Retrieved from:https://www.standards.org.au/standards-catalogue/sa-snz/publicsafety/ob-007/as-slash-nzs--4360-2004

Parritz, R. H., & Troy, M. F. (2013). *Disorders of childhood: Development and psychopathology* (3rd ed.). Boston: Cengage learning.

Perry, J., & Hayes, R. (1985). "Risk and its management in construction projects". *Proceedings of the Institution of Civil Engineers*, 78 (3), p. 499-521.

Pessoa, S., Guimarães, A., Lucas, S., & Simões, N. (2021). "3D printing in the construction industry-A systematic review of the thermal performance in buildings". *Renewable and Sustainable Energy Reviews*, 141 p. 110794.

PMI. (2009). practice standard for project risk management. Accesss date: 21/01/2022. Retrieved from:https://www.pmi.org/-/media/pmi/documents/public/pdf/certifications/practice-standard-project-risk-management.pdf?v=1e0b5985-74af-4c57-963c-b91a9af6fecb

PMRC. (2002). Chinese project management body of knowledge guidelines Accesss date: 21/01/2022. Retrieved from:https://www.worldcat.org/title/chinese-project-management-body-of-knowledge-guidelines-cpmbok-guidelines/oclc/50958381

RIBA. (2020). RIBA Plan of Work. Accesss date: 22/01/2022. Retrieved from:https://www.architecture.com/knowledge-and-resources/resources-landing-page/riba-plan-of-work#available-resources

Rodgers, M., Thomas, S., Harden, M., Parker, G., Street, A., & Eastwood, A. (2016). "P30 Developing a methodological framework for organisational case studies: A rapid review and consensus development process". *J Epidemiol Community Health*, 70 (Suppl 1), p. A67-A67.

Ruoheng, Z., J, Z. A. S., Saeed, T., & Jennifer, W. (2019). "Long-standing themes and new developments in offsite construction: the case of UK housing". *Proceedings of the Institution of Civil Engineers - Civil Engineering*, 172 (6), p. 29-35.

SAC. (2013). GB/T 23694-2013 (GBT 23694-2013). Accesss date: 21/01/2022. Retrieved from:https://www.chinesestandard.net/PDF/English.aspx/GBT23694-2013

Sepasgozar, S., & Davis, S. (2018). "Construction technology adoption cube: An investigation on process, factors, barriers, drivers and decision makers using NVivo and AHP analysis". *Buildings*, 8 (6), p. 74.

Shibani, A., Agha, A., Hassan, D., Al-Hadeethi, Y., & Choudhury, M. (2021). "Effectiveness of the Modern Methods of Construction in Terms of Cost and Time: A Case Study of the United Kingdom". *Journal of Civil Engineering Research,* 11 (1), p. 19-28.

Sousa, V., Almeida, N. D., & Dias, L. A. (2012). "Risk management framework for the construction industry according to the ISO 31000: 2009 standard". *Journal of Risk Analysis and Crisis Response,* 2 (4), p. 261-274.

Steyerberg, E. W., & Harrell Jr, F. E. (2016). "Prediction models need appropriate internal, internal-external, and external validation". *Journal of clinical epidemiology,* 69 p. 245.

Suharyanto, A., & Simanjuntak, M. R. A. (2020). *Risk identification of Design And Build at school building construction project in central Jakarta In IOP Conference Series: Materials Science and Engineering* 012090 Published: IOP Publishing

Tchankova, L. (2002). "Risk identification–basic stage in risk management". *Environmental Management and Health,* 13 (3), p. 290-297.

Tserng, H. P., Yin, S. Y. L., Dzeng, R. J., Wou, B., Tsai, M. D., & Chen, W. Y. (2009). "A study of ontology-based risk management framework of construction projects through project life cycle". *Automation in Construction,* 18 (7), p. 994-1008.

Unver, S., & Ergenc, I. (2021). "Safety risk identification and prioritize of forest logging activities using analytic hierarchy process (AHP)". *Alexandria Engineering Journal,* 60 (1), p. 1591-1599.

Walker, S., Liberti, L., & McAuslane, N. (2011). "Refining the Benefit–Risk Framework for the Assessment of Medicines: Valuing and Weighting Benefit and Risk Parameters: CMR International Institute for Regulatory Science Forum on Benefit–Risk Weighting 17–18 June 2010 Washington, DC". *Clinical Pharmacology & Therapeutics,* 89 (2), p. 179-182.

Wang, S., Zhou, Q., & Tian, D. (2017). "The application of BIM Technology in OSC project in EPC environment 工程总承包背景下 BIM 技术在装配式建筑工程中的应用研究". *工程管理学报,* 31 (6), p. 6.

Williamson, G. R. (2006). "Introduction to Social Research Quantitative and Qualitative Approaches, 2nd edn". *Journal of Advanced Nursing,* 54 (5), p. 639-639.

Wu, P., Xu, Y., Jin, R., Lu, Q., Madgwick, D., & Hancock, C. M. (2019). "Perceptions towards risks involved in off-site construction in the integrated design & construction project delivery". *Journal of Cleaner Production,* 213 p. 899-914.

Xue, H., Zhang, S., Su, Y., Wu, Z., & Yang, R. J. (2018a). "Effect of stakeholder collaborative management on off-site construction cost performance". *Journal of Cleaner Production,* 184 (1), p. 490-502.

Yang, Q. (2021). "OSC risk factors analyse and control 装配式建筑在施工管理中的风险因素与控制". *建筑技术研究*, 4 (5), p. 17-19.
Yao, N. (2021). "Quality risk analysis of OSC project based on AHP method 基于层次分析法的装配式建筑施工阶段质量风险分析". *安徽建筑*, 28 (12), p. 182-183.
Zhafri, Z., Effendi, M., & Rosli, M. F. (2018). *Optimization of assembly process and environmental impact using DFMA and sustainable design analysis: Case study of drone In AIP Conference Proceedings* 020074 Published: AIP Publishing LLC
Zhai, X., Reed, R., & Mills, A. (2014). "Factors impeding the offsite production of housing construction in China: an investigation of current practice". *Construction Management and Economics*, 32 (1-2), p. 40-52.
Zhang, L., & Xu, S. (2018). "Risk management of OSC based on BIM Technology 基于 BIM 技术的装配式建筑风险管理研究". *安徽建筑*, 24 (3), p. 2.
Zhang, X., & Mohandes, S. R. (2020). "Occupational Health and Safety in green building construction projects: A holistic Z-numbers-based risk management framework". *Journal of Cleaner Production*, 275 p. 122788.
Zheng, Z. (2021). "Application of information technology in risk management of OSC 信息化技术在装配式建筑风险管理中的应用". *设备管理与维修*, (20), p. 2.
Zou, P. X., Zhang, G., & Wang, J. (2007). "Understanding the key risks in construction projects in China". *International Journal of Project Management*, 25 (6), p. 601-614.

Appendix 1: Consent Form

Consent Form

Name of department: Architecture

Title of the study: Offsite construction manufacture process risk and risk management interview

- I confirm that I have read and understood the Participant Information Sheet for the above project and the researcher has answered any queries to my satisfaction.
- I confirm that I have read and understood the Privacy Notice for Participants in Research Projects and understand how my personal information will be used and what will happen to it (i.e., how it will be stored and for how long).
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, up to the point of completion, without having to give a reason and without any consequences.
- I understand that I can request the withdrawal from the study of some personal information and that whenever possible researchers will comply with my request. This includes the following personal data:
    - Audio recordings of interviews that identify me;
    - My personal information from transcripts.
- I understand that anonymised data (i.e., data that do not identify me personally) cannot be withdrawn once they have been included in the study.
- I understand that any information recorded in the research will remain confidential and no information that identifies me will be made publicly available.
- I consent to being a participant in the project.
- I consent to being audio and/or video recorded as part of the project.

(PRINT NAME)	
Signature of Participant:	Date:

Appendix 2: Participant Information Sheet

Participant Information Sheet

[FOR USE WITH STANDARD PRIVACY NOTICE FOR RESEARCH PARTICIPANTS]

Name of department: Architecture

Title of the study: Offsite construction manufacture process risk and risk management interview

Introduction

My name is Lin Zhang, I am an architecture PhD student in the University of Strathclyde.

What is the purpose of this research?

The aim of this research is to understand offsite construction manufacture process risk and risk management method and develop software to manage the risk during this process.

Many articles agree offsite construction could reduce construction risk. As offsite construction is not widely used as construction method, offsite construction still needs promotion. In order to promote offsite construction, risk in offsite construction needs to be solved.

The main different process between traditional construction and offsite construction is manufacture process, as most new risks in offsite construction come from manufacture process, the new risk management method for these risks is needed. Further development includes software support for construction risk manager.

Do you have to take part?

This participation is voluntary. Participants have a right to withdraw from the research without detriment.

What will you do in the project?

During this project, participants will be asked several semi-structured interview questions. Each interview will take approximately one hour. All interview will be taking in Vanke manufactory through face-to-face.

Why have you been invited to take part?

In order to understand risk and risk management in offsite construction manufacture process, four types of construction roles have been invited: construction manager, dispatch manager, quality assurance manager, and goods in manager.

As questionnaire will be developed after interview, five roles are excluded: crane operator, welding fabricator, steel fixer, concrete finisher, and stonemason. These roles will be asked through questionnaire.

What information is being collected in the project?

The role of participant will be collected. As different roles have different view angel for risk, it is necessary to divided them clearly.

The answer for Simi-question will be collected. For example, “how to solve client demand change in offsite construction”, this question will be answered by construction manager.

Who will have access to the information?

Information will only be accessed by investigator and chief Investigator.

Where will the information be stored and how long will it be kept for?

Data will be stored in investigator’s computer for two years and will be stored in University of Strathclyde cloud indefinitely.

What happens next?

If participant has any further question, please ask the investigator.

Participant will be informed after investigator’s thesis is published.

Researcher contact details:

Name: Lin Zhang

Status: Doctoral student

Telephone (UK): +44 (0)752 349 8698

Telephone (China): +8613972152279

Email: lin.zhang.100@strath.ac.uk

Chief Investigator details:

Name: Dr Andrew Agapiou

Status: Senior Lecturer

Department: Architecture

Telephone: +44 (0)141 548 3067

E-mail: andrew.agapiou@strath.ac.uk

Appendix 3: Interview process: pilot study

Offsite construction manufacture process risk and risk management interview questions

Lin Zhang (PhD Candidate), Architecture, University of Strathclyde

Pre-section: introduction of interviewee

1) What is your position in current company?
2) How long have you been involved in the construction industry?

Section 1: identify the main building elements for analysis.

1) Could you please give an overview of your company?

Section 2: verify activities associated with the methods of each offsite manufacture phase.

1) Could you please define the process of offsite manufacture phase?
    a. Which process do you think is the most important? Why?
    b. How these process influence project?

Section 3: verify risks associated with each offsite manufacture phase.

1) Could you please define the risk for each process of offsite manufacture phase?
2) Is there a specific person on this project in charge of risk identification and/or management?
    a. If so, what do they do?
    b. If there is nobody, how is risk management tackled on the project?

Section 4: opinion/evidence for each risk

1) How these risks influence your project?
2) Could you please rank each risk through below variable?
    a. Probability
    b. Impact

Section 5: Identify current solution for offsite manufacture process risk.

1) How does your company solve these risks?
    a. Why your company choose these methods?

Section 6: Discuss about whether current solution could solve these risk.

1) Do these solutions have any influence for the project?
2) Do you have any suggestion for current risk management process?

Post-section: further discussion

1) Are there any other issues which you think ought to be addressed associated with risk management?

Appendix 4: Interview process: main study

Offsite construction manufacture process risk and risk management interview questions

Lin Zhang (PhD Candidate), Architecture, University of Strathclyde

Pre-section: introduction of interviewee

1) What is your position in current company?
2) How long have you been involved in the construction industry?

Section 1: identify the main building elements for analysis.

3) Could you please give an overview of your company?

   Tips: includes company type, customer feature, and company's product.

Section 2: verify activities associated with the methods of each offsite manufacture phase.

4) Could you please define the process of your company phase in offsite construction?

Tips: Current offsite construction process could be divided into five processes:

1. *Estimating, production planning & recruitment;*
2. *Structural engineering, detailing& project co-ordination;*
3. *Manufacture;*
4. *Logistics;*
5. *Assembly on-site;*

Please explain what your company is responsible for. For example, if your company focus on step 3, please explain the process of step 3.

c. How these process influence project?

d. Which process do you think is the most important? Why?

Section 3: verify risks associated with each offsite manufacture phase.

5) Could you please define the risk for each process of offsite manufacture phase?

   Tips: for example, risk could become from inside: employee mistake, machine misuse, extra cost for the machine; or outside: legal issues, lack of educational

6) Is there a specific person on this project in charge of risk management?

   Tips: please present people who have responsibility for risk and risk management.

   Tips: risk management could be divided into four steps:

   i. *Risk identification: identify risk in project.*
   ii. *Risk assessment: assess how risk could influence project.*
   iii. *Risk analysis: analyse risk through tools or method.*

iv. *Risk response: present method to solve the risk.*

c. If so, what do they do?

d. If nobody, how is risk management tackled on the project?

Section 4: opinion/evidence for each risk

7) How these risks influence your project?

Tips: for example, if policy change influences the project, please tell me the detail about the policy, and how this policy influence project.

8) Could you please rank each risk through below variable?

c. Probability

d. Impact

Tips: please rank it with number 1-5. Generally, risk could be defined as two aspects:

1. *Probability: how often could the risk happen?*

2. *Impact: how bad could it influence the project?*

Section 5: Identify current solution for offsite manufacture process risk.

9) How does your company solve these risks?

Tips: please include the detail of solution. For example, how to educate the employee to avoid risk "employee lack of experience"?

10) Why your company choose these methods?

Tips: for example, like employee lack of experience, the solution is educating them before employing them. Better solution could be employing the expert; however, the expert is too expensive (or no expert for offsite construction).

Section 6: Discuss whether current solution could solve these risks.

11) Do these solutions have any influence for the project?

Tips: negative influence like extra cost is also necessary.

12) Do you have any suggestion for current risk management process?

Tips: Any suggestions are welcome.

Post-section: further discussion

13) Are there any other issues that you think ought to be addressed associated with risk management?

Tips: any problem, issue, uncertain, or hazards that cause project delay or extra cost are welcome.

Appendix 5: Questionnaire: pilot study

Offsite Manufactory Risk Assessment Questionnaire

This questionnaire will be used for Chinese offsite manufactory risk and the influence of the risk and will only be used in my PhD thesis. Thank you for your participation.

1、How many years do you work in the construction industry?

○0~5 years

○5~10 years

○10~15 years

○> 15 years

2、How long has your company been established?

○0~5 years

○5~10 years

○10~15 years

○> 15 years

3、What is the size of your company?

○Large (Employees 1000)

○Medium (Employees 500~1000)

○Small (Employees < 500)

4、What is the core business of your company?

☐Owner

☐Consultant

☐Manufacturer

☐Transporter

☐Contractor

☐Other ___________

5、What the type of your company?

○State-owned company

○Private Company

○Foreign Company

○Joint Venture Company

○Other ___________

Please ranking the risk below, based on how it could influence the project of offsite manufactory?

6、Cost

	Very important	Important	Moderately Important	Slightly Important	Unimportant
High factory investment	○	○	○	○	○
Working	○	○	○	○	○

process increase					
Pay after delivery	○	○	○	○	○
Training fees increase	○	○	○	○	○
Type of worker increase	○	○	○	○	○
Regular employee increase	○	○	○	○	○
High component model fee	○	○	○	○	○
High raw material fee	○	○	○	○	○

7、Feature of offsite

	Very important	Important	Moderately Important	Slightly Important	Unimportant
Setting time of concrete is too long	○	○	○	○	○
Heavy component	○	○	○	○	○
Component support interference	○	○	○	○	○
On-site assembly limitation	○	○	○	○	○

8、Project management

	Very	Important	Moderately	Slightly	Unimportant

	important		Important	Important	
Lack of cooperation	○	○	○	○	○
On-site process changes	○	○	○	○	○
Lean construction limitation	○	○	○	○	○
EPC lack of cooperation	○	○	○	○	○
Lack of risk management method	○	○	○	○	○

9、Time

	Very important	Important	Moderately Important	Slightly Important	Unimportant
Grout sleeve time is long	○	○	○	○	○
Complexity of Joint assembly	○	○	○	○	○
Insufficient production time	○	○	○	○	○

10、Owner

	Very important	Important	Moderately Important	Slightly Important	Unimportant
Change demand	○	○	○	○	○
Demand not suitable for offsite construction	○	○	○	○	○

Change partner	○	○	○	○	○

11、Consultant

	Very important	Important	Moderately Important	Slightly Important	Unimportant
Conceptual design error	○	○	○	○	○
Design development error	○	○	○	○	○
Lack of offsite experience	○	○	○	○	○
Lack of on-site experience	○	○	○	○	○
Lack of responsibility	○	○	○	○	○
Lack of standardization	○	○	○	○	○
Lack of professional software	○	○	○	○	○

12、Manufacturer

	Very important	Important	Moderately Important	Slightly Important	Unimportant
Labour lack of experience	○	○	○	○	○
Manager lack of experience	○	○	○	○	○
Lack of manager	○	○	○	○	○
Lack of Labour	○	○	○	○	○
Lack of	○	○	○	○	○

responsibility					
Production error	○	○	○	○	○
Assembly line lack of control	○	○	○	○	○
Improper operation sequence	○	○	○	○	○
Lack of factory facilities	○	○	○	○	○
Multiple projects at the same time	○	○	○	○	○
Insufficient depot	○	○	○	○	○
Insufficient assembly line	○	○	○	○	○

13、Transporter

	Very important	Important	Moderately Important	Slightly Important	Unimportant
Driver lack of experience	○	○	○	○	○
Transport accident	○	○	○	○	○
Lack of responsibility	○	○	○	○	○
Wrong component storage order	○	○	○	○	○
Component binding is not solid	○	○	○	○	○
Bad road	○	○	○	○	○

condition					
Long transport distance	○	○	○	○	○
Road restrictions	○	○	○	○	○

14、Contractor

	Very important	Important	Moderately Important	Slightly Important	Unimportant
Lack of willingness to participate	○	○	○	○	○
Lack of experience	○	○	○	○	○
Lack of labour	○	○	○	○	○
Lack of responsibility	○	○	○	○	○
Lack of standardization	○	○	○	○	○
Multiple factories at the same time	○	○	○	○	○
Grout sleeve inspection is impossible	○	○	○	○	○

15、Environment

	Very important	Important	Moderately Important	Slightly Important	Unimportant
Geographical environment	○	○	○	○	○
Temperature of factory	○	○	○	○	○
Seasonal changes	○	○	○	○	○

Natural disaster	○	○	○	○	○

16、Political

	Very important	Important	Moderately Important	Slightly Important	Unimportant
Lack of standard	○	○	○	○	○
Local standard differentiation	○	○	○	○	○
Wrong prefabricated rate	○	○	○	○	○
Lack of subsidy	○	○	○	○	○
Lack of support	○	○	○	○	○

17、Resource

	Very important	Important	Moderately Important	Slightly Important	Unimportant
Wrong PC model design	○	○	○	○	○
Low material quality	○	○	○	○	○
Supplier delay	○	○	○	○	○
Lack of material	○	○	○	○	○
PC model lack standardization	○	○	○	○	○
The complexity of PC model	○	○	○	○	○
Equipment damage	○	○	○	○	○

18、Society

	Very important	Important	Moderately Important	Slightly Important	Unimportant

Contact bidding problem	○	○	○	○	○
Unstable economic situation	○	○	○	○	○
Prejudice for offsite	○	○	○	○	○
Inconsistent quality demand	○	○	○	○	○

19、Do you have any more risk that can influence offsite manufactory?

1 ____________________

2 ____________________

3 ____________________

20、If so, please ranking the risk above.

	Very important	Important	Moderately Important	Slightly Important	Unimportant
1	○	○	○	○	○
2	○	○	○	○	○
3	○	○	○	○	○

Appendix 6: Questionnaire: main study

Offsite Manufactory Risk Assessment Questionnaire

Hello, you are invited to participate in a research study titled [offsite manufactory risk assessment questionnaire]. This study is being done by Lin Zhang from Architecture at the University of Strathclyde. This project aims to find out the risk in offsite manufactory process, and help Chinese offsite manufactory have a more efficient working process and reduce cost and time for the project. Participant will be asked to finish a questionnaire; most questions are multiple choice. It will take around 10-15 minute to finish it. Further details, including information about data protection, are available by please email me at [lin.zhang.100@strath.ac.uk], or call me at [13972152279]

1、How many years do you work in the construction industry?

○0~5 years

○5~10 years

○10~15 years

○>15years

2、How many years do you work for offsite construction?

○0~5 years

○5~10 years

○10~15 years

○>15years

3、How many off-site projects did you completed?

○0 project

○1-3 projects

○4-6 projects

○7-9 projects

○10 projects

4、What is the core business of your company?

☐Owner

☐Consultant

☐Manufacturer

☐Transporter

☐Contractor

☐Other ____________

5、What the type of off-site component does your company use or produce?

☐Off-site precast concrete

☐Off-site steel frame

☐Off-site timber frame

☐Other ____________

Please ranking the risk below, based on how it could influence the project of offsite manufactory? (1 is the minimum number, and 5 is the maximum number).

6、Cost

	Probability	Impact
High manufactory building investment		
Overall working process increase		
Component pay after delivery		
Training fee increase		
Type of worker increase		
Regular employee increase		
High component model and raw material fee		

7、Offsite feature

	Probability	Impact
The component is too heavy		
Interference from component support		
On-site assembly limitation		

8、Project management

	Probability	Impact
Lack of cooperation among all parties		
On-site period changes or adjustment		
Lack of risk management method		
Hard to deploy new management method		

9、Time

	Probability	Impact
The complexity installation of component joint		
Insufficient production time		

10、Owner

	Probability	Impact
Owner change demand		
Owner's demand not suitable for off-site construction		
Owner change project partner		

11、Consultant

	Probability	Impact
Design error		

Consultant lack of off-site construction experience		
Consultant lack of on-site process experience		
Consultant lack of responsibility		
Lack of off-site design standard		
Lack of off-site design software		

12、Manufacturer

	Probability	Impact
Manufacturer lack of experience		
Manufacturer lack of practitioners		
Manufacturer lack of responsibility		
component production error		
Assembly line lack of supervision		
Lack of manufactory facilities		
Producing different types of components at the same time		
Insufficient component depot		
Insufficient assembly line		

13、Transporter

	Probability	Impact
Transporter lack of experience		
Transporter lack of responsibility		
Mistake during the transfer process		
Transport road problems		
Transportation distance is too long		

14、Contractor

	Probability	Impact
Contractor lack of willingness to participate		
Contractor lack of experience		
Contractor lack of responsibility		
Contractor lack of practitioners		
Lack of on-site assembly standard		

15、Environment

	Probability	Impact

Manufactory geographical environment		
Manufacturing indoor environment		
Seasonal changes		
Natural disaster		

16、Government policy

	Probability	Impact
Lack of government standard		
Local government standard differentiation		
The rigid requirement of assembly rate		
Lack of subsidy and support		

17、Resource and material

	Probability	Impact
Low material quality		
Material supply delay		
Lack of material		
Component model lack of standardization		
Equipment damage		

18、Social context

	Probability	Impact
The problem of the lowest price wins the bid		
Unstable economic situation		
Prejudice for off-site construction project		
Inconsistent quality demand for off-site component		

19、what else risks can influence offsite manufactory?

1 ____________________

2 ____________________

3 ____________________

20、Please ranking the risk above.

	Probability	Impact
1		
2		
3		

Appendix 7: NVivo node structure

Name	Files	References	Created On
Project process	0	0	2019/9/2 18:56
Time	0	0	2019/9/3 21:47
Preparation time	7	8	2019/9/3 23:39
Onsite operation	5	6	2019/9/3 21:47
Project management	0	0	2019/8/31 0:19
Risk management method	3	3	2019/8/31 0:19
New management method	9	10	2019/9/2 19:06
Cooperation	6	8	2019/9/2 19:05
Feature of project	0	0	2019/9/2 23:33
Offsite feature	4	7	2019/9/2 23:28
Concrete feature	6	10	2019/9/3 22:00
Cost	0	0	2019/9/2 18:56
Resource cost	5	8	2019/9/4 0:03
Labor cost	4	6	2019/9/3 22:12
Initial cost	7	9	2019/9/2 18:56

Name	Files	References	Created On
Project member	0	0	2019/8/30 22:02
Transporter	0	0	2019/8/30 22:32
Transportation limitation	6	7	2019/8/30 22:32
Storage process	2	2	2019/9/3 21:11
Standardization	4	5	2019/9/2 23:13
Responsibility	2	3	2019/9/2 23:08
Experience	4	4	2019/9/4 0:05
Owner	0	0	2019/8/30 23:16
Partner	2	2	2019/9/3 23:31
Demand	6	7	2019/9/3 23:43
Manufacturer	0	0	2019/8/30 23:15
Size of manufactory	7	8	2019/9/3 23:16
Responsibility	5	6	2019/9/4 0:10
Project complexity	3	3	2019/9/2 19:07
Produce process	7	10	2019/9/3 22:55
Participant	5	5	2019/9/3 22:50
Panel quality	7	8	2019/9/2 23:23
Experience	10	12	2019/9/2 23:04
Contractor	0	0	2019/8/30 23:15
Technology	3	3	2019/9/3 21:57
Standardization	2	2	2019/9/2 18:50
Responsibility	6	6	2019/9/2 16:51
Participant	4	5	2019/9/2 23:54
Onsite complexity	3	3	2019/9/2 18:53
Expericence	5	5	2019/9/2 18:49
Consultant	0	0	2019/8/30 21:32
Technology	2	2	2019/9/3 23:12
Standardization	9	9	2019/9/2 18:48
Responsibility	3	3	2019/9/2 18:54
Experience	4	4	2019/8/30 23:56
Design error	19	25	2019/9/4 18:18

Name	Files	References	Created On
External	0	0	2019/8/30 22:10
Environment	0	0	2019/9/3 22:53
Factory environment	5	6	2019/9/4 1:47
Natural disaster	2	2	2019/9/4 0:54
Political	0	0	2019/8/31 0:00
Standard	7	9	2019/9/3 21:23
Support	2	2	2019/9/3 23:16
Resource	0	0	2019/8/30 22:10
Resource Quality	4	6	2019/9/4 0:34
Resource shortage	6	7	2019/9/2 23:53
Resource standardization	8	12	2019/8/30 22:33
Resource usability	4	4	2019/9/2 23:04
Society	0	0	2019/9/2 16:59
Prejudice for offsite	3	3	2019/9/2 16:59
Social convention	1	1	2019/9/2 23:24
Socioeconomic environment	2	2	2019/9/2 23:16

Name	Files	References
External	0	0
Environment	0	0
Factory environment	5	6
Example	1	1
Natural disaster	2	2
Example	1	1
Political	0	0
Standard	7	9
Example	1	1
Reason	1	1
solution	2	3
Support	2	2
Reason	1	1
Solution	2	2
Resource	0	0
Resource Quality	4	6
Resource shortage	6	7
Resource standardization	8	12
Resource usability	4	4
Society	0	0
Prejudice for offsite	3	3
Social convention	1	1
Socioeconomic environment	2	2
Project member	0	0
Project process	0	0

Drag selection here to code to a new node

[redacted] - § 1 reference coded [2.24% Coverage]

Reference 1 - 2.24% Coverage

而且南方气候比较热，很多工人跑了。（工人难以在炎热环境坚持）

[redacted] - § 1 reference coded [1.80% Coverage]

Reference 1 - 1.80% Coverage

A:毕竟人多的地方就需要管理。还有人员的波峰波谷，人员的数量的上升与下降，这个人员的增加压力很大。（工人的人员波动）

[redacted] - § 1 reference coded [4.54% Coverage]

Reference 1 - 4.54% Coverage

所以精益生产的投入和产出的比例不符合，这样我们的动力就不足，那么我们改善审批就做不了，投资回报就不足。这个仅仅是一方面。还有很多方面，比如一体的设计，我们的国内一体设计集中在几家公司，很多时候他们有几个方案，然后他们就用那几个方案去游说别人，别人其实是不懂的，他们游说别人去用这种方式。但是其实每个区域不同，产品的类型也就不一样的。（设计类型的在不同地区适应性不同）

[redacted] - § 2 references coded [7.69% Coverage]

Reference 1 - 3.14% Coverage

还有环境的影响，比如噪音，热，这种会影响工人的心情，这种工作效率就会下降。这个比传统的工地还是改善了很多，但是本身还是会有影响。（天气气候影响工人效率）

Reference 2 - 4.55% Coverage

还有业务的不连续性，照成持续性的波动。就是项目之间的衔接过长。比如国内上半

Appendix 8: Interview transcripts example

Q6:为什么会出现这些问题？

A6:及时性是因为甲方给的时间太短。我们国内都是先把合同拿下来，然后后面再考虑。（原材料无法及时到货的原因）

模具不匹配是因为我们的工艺不成熟，没有足够的时间去验证是否合理。很多时候我们只能边做边发现问题。我们如果有 2 个月时间，那么是够的，但是有时候只有 20 多天，30 多天，那时间就不够。（模具与生产流程不匹配的原因）

Q5:采购有什么问题么？

Q5:一般没什么问题，就在合同中设置的公司去采购。有时候会延迟发货。第一就是我们没用过的，需要去市场找。有时候是市场定制定做的，比如一些预埋件，需要时间来做。（供应商发货可能会延迟）

所以我们一般采用分批到货的方式。（延迟到货的解决方案）

Q: 那么预生产指的是哪些呢？

A:首先是制作，然后我们看设想工艺是否能达到质量标准。

Q:生产上有什么问题么？

A:主要还是人，我们现在自动化不是很高，也比较复杂，一般都是工人拿着图和尺去量，这时候就可能人看错了，或者量错了。（工人工作上产生误差）

所以我们就需要每条生产线上，请专人管理这个问题。如果达到了要求，我们就进行混凝土浇筑，达不到要求，我们就进行修改。（利用监督减少误差）

Q:关于运输部分有什么问题么？

A:运输主要是进行招标，或者和运输公司洽谈，签订合同。最大问题就是构件做好了，在运输过程中出现从车上滑落，或者有裂缝。（行车过程中存在风险）

甲方要求，到货的及时率，这些都是不可控的。（可能无法及时到货）

Q:构件有可能会存储在您的公司吧，这样会有什么问题么？

A:存储也不会存储多久。因为国内现在都是相当于量身定制一套模具，那么这个项目做完了，这个模具就没有作用了。（模具不能重复使用，产生浪费）

如果是通用的模具，我们拿到图纸就可以做，所以来自甲方的压力也会小很多。

Q:那么为什么不通用模具呢？

A:因为房子的层高，结构，户型，还有拆分方式不一样，都会导致无法通用。或者只有少部分的模具可以通用。这个项目做完后，工厂比较大，可能会有专门存储，工厂比较小，那么就放在外面堆场了。（模具无法通用的原因）

Q:您说有些模具可以通用，那么是哪些模具？

A:叠合楼板有单向楼板和双向楼板，楼板的高度都是一样的，不管是公建也好，住宅也好，楼板的厚度都不超过 70，包括楼板的出筋尺寸也是可以通用的。

那些套筒剪力墙，还有飘窗阳台，这些是很少能够通用。如果说能通用的话，这些东西的组装，拆分都是非常麻烦。可能在这个项目用完之后，这个模具的循环寿命就已经到了报废时间。（复杂的模板更难进行养护）

Q:堆场有什么问题么？

A:最主要的是多项目生产，划分区域应该怎么做。还有就是发货的时候，要把构件从堆场里面找出来，也就是可视化堆场吧。有些工厂有，有些工厂没有。（构件调用缺乏可视化操作）

有些项目会计划比如 5 月到 8 月做完，但是现场的天气等问题，导致迟迟没要货，一直在占用堆场，导致其他项目无法生产。（现场施工不及时，导致堆场停滞）

Q13:您还有什么需要补充的？

A13:还有比如原材料的上涨，比如最近国内砂石的上涨特别严重。我们一般是没有存储原材料的堆场的。（原材料价格上涨导致成本上升）

有时候可能就是砂石本身很紧张，导致我们拿着这个钱，都买不到合格的原材料。因为构件生产比传统的原材料要求更高。（原材料有时很难买到）

因为我所经历的项目，可能 17 年合同就签了，但是 18 年才开始供货。但是后面材料的上涨，导致我们实际生产过程中的成本远比我们签合同的时候高，但是调价的范围也在合同里面限制的很死。（原材料导致成本上涨的例子）

还有就是我们构件转运的过程中，有时候会磕碰的问题。就是转到堆场，或者运输会产生。（转运到堆场会产生磕碰）

可能是堆场人员操作不够熟练，或者可能是有时本来不需要动这个构件。但是由于时间堆积太久，我们需要生产新构件的时候，不得不把原来的构件挪到别处去，这时候转运的过程增加了，所以就增加了风险。（转运时会磕碰的原因）

所以说了这么多，其实都是因为计划赶不上变化。

Q:那么您认为 EPC 会改善计划么？

Risk	**From**	**To**	**Responsible person (or group)**	**Affected person (or group)**	**Why it happened**	**Example**	**How to solve**	**New risk from solution**
Production time is limit.	1	3	Owner	Manufacturer	Many owner only give too short time to produce the panel.	If the panel begin to produce 2 month ago, it would be okay for manufacturer. But most of them only have 1 month to produce the panel. The model design and produce need around 20 days.		
Development design suggestion drawing is not suitable for realistic.	2	3	Consultant	Manufacturer	Government suggestion drawing is too complex, and not suitable for Manufacturer.		Design another suggestion drawing for themselves.	
Owner demand change.	1	3	Owner	Manufacturer				
Worker and manager are not good at understand drawing.	3	3	Manufacturer	Manufacturer	Traditional manufactory products are similar, but offsite manufactory panels are different.		Worker should understand the drawing. Manager should have more responsibility.	
Tradition construction worker do not	3	3		Manufacturer	Worker do not like manufactory	In traditional construction, error or mistake is allowed,		