Risk assessment of construction projects in China under traditional and industrial production modes

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Abstract

Purpose – High risk is one of the most prominent characteristics of the Chinese construction industry, and it poses a significant threat to construction projects. Owing to initiatives aimed at achieving high efficiency, low carbon emissions, etc., industrialization of the construction industry has become an inevitable trend in China. However, it remains to be discussed whether industrialization of construction can reduce the risks entailed in construction projects compared with traditional construction. The paper aims to discuss these issues.

Design/methodology/approach – Based on the theory of risk life cycle, this paper proposes a practical risk assessment technique to assess the risk life cycle, including the risk occurrence time and potential financial losses. This technique is then applied to assess the differences between the risks involved in an engineering, procurement and construction (EPC) project executed via traditional and industrial production modes.

Findings – The results show that the total duration of risks in the industrial construction project is half of that in the traditional project. In addition, the expected financial loss entailed in the industrial construction project is 29 percent lower than that in the traditional construction project. Therefore, industrial construction has the potential to optimize risk performance.

Originality/value – There is no significant difference between the traditional and industrial construction models in terms of probability of risk. The maximum total loss might occur in the procurement stage in the case of industrial production, and in the construction stage in the case of traditional production. Moreover, the total expected loss from risk in the EPC project in the industrial production mode is only half of that in the traditional production route. This study is expected to provide a new risk evaluation technique and promote an understanding of the life cycle of risk management in the construction industry.

Keywords Construction, Management, Methodology, Simulation, Approach

Paper type Research paper

1. Introduction

High risk is a defining characteristic and one of the most significant features of the construction industry. Arising from causes pertaining to human and non-human factors, risks in the construction industry can lead to substantial delays and financial losses. Therefore, effective risk assessment is critical to ensure the healthy development of the industry.

Previous studies have attempted to investigate risk assessment in the construction industry from macroscopic viewpoints such as economic (inflation, sudden changes in prices) (El-Sayegh, 2008), sociopolitical (Ling and Hoi, 2006), business (Wang *et al.*, 2008; Deng *et al.*, 2014), technical (English; Jin *et al.*, 2011) and occupational risks (Pinto *et al.*, 2011). These studies provide valuable insights into the macro-level risks in the industry. However, these studies fail to reflect the risk characteristics of the construction industry at the project level. A construction project is a complicated process comprising different stages and requiring different professional teams to ensure completion. Therefore, studies focusing on the different stages of construction projects are indispensable because of the distinct features of the risks present in each stage. In general, scholars have significantly explored the stages of design, bidding, logistics and construction. Particularly, the risk assessment of construction contracts (Kartam and Kartam, 2001; Zaghloul and Hartman, 2003; Haddad, 2007; Hameed and Woo, 2007), supplier-contractor collaboration (Bemelmans *et al.*, 2013; Rahman *et al.*, 2013) and approaches to determining the lower limit of the bid for a project

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(Chao and Liou, 2007) have been investigated extensively and thoroughly. In addition, some scholars have studied construction risk assessment from the perspectives of schedule (Nasir *et al.*, 2003; Huang and Wang, 2009; Luu *et al.*, 2009; Wang and Huang, 2009; Liu, 2011), quality (Ortega and Bisgaard, 2000; Andi and Minato, 2003) and safety (Hu *et al.*, 2011; Wu *et al.*, 2015; Zhou *et al.*, 2015). Although these studies entailed detailed discussions on risk assessment in the construction industry, investigation into risks from a life cycle perspective has been ignored.

Factually, risks are embodied in the entire construction project, and include time randomness, influence of relationships and associated cash flows (Ren, 1994). In summary, previous works have focused on risk assessment, ignoring the relationships between risks and time properties from a life cycle perspective. A complete evaluation of multi-target risks across all levels is a promising area of research (Jin, 2010) and is aimed at facilitating an understanding of risks at the project level.

Owing to the mature technologies of on-site construction and the low costs of labor and material, traditional production remains the dominant mode of construction in China (Shen and Yuanqi, 2015). Traditional production is the combination of on-site production and decentralized management, an example of which is the design–bid–build method. Traditional production is labor-, capital- and pollutant-intensive (Goh and Loosemore, 2017). Furthermore, coordination between different tasks is key to mitigate risks and losses. Industrial production is an integrative mode combining off-site production and unified management; an engineering, procurement and construction (EPC) project is an example (Sarja, 1998; Alinaitwe *et al.*, 2006; Girmscheid and Kapp, 2006). The industrial production mode has several advantages over traditional production in terms of labor productivity, energy conservation and low pollution (Xiahou *et al.*, 2018).

In China, high quality, high efficiency and sustainable development are attracting unprecedented attention. Therefore, a shift toward industrial production is an inevitable trend in the Chinese construction industry. Although the industrial production mode has the potential to improve labor and energy efficiencies and ensure sustainable development, it is uncertain whether it is more conducive to risk reduction than the traditional production model is. Based on a review of previous studies on the industrialization of construction, the existing literature can be categorized into the typical fields of traditional construction project management: cost overruns (Mao *et al.*, 2016; Hong *et al.*, 2018), scheduling delays (Arashpour *et al.*, 2016a, b, 2017) and quality and safety (Elrayes and Khalafallah, 2005; Mckay, 2010; Xin and Lam, 2013). A few studies focus on the risk assessment of construction industrialization. However, with advancements in construction industrialization, the limitations of these assessment methods have emerged.

Therefore, this paper aims to make the following contributions. To facilitate an understanding of risks in the construction industry, we propose an improved risk life cycle assessment technique at the project level. To clarify the issue of whether the industrial production mode of construction can mitigate risks better when compared with the traditional production mode, we conduct a case study to compare the risk life cycle characteristics of an EPC project executed via the two modes. Compared with the existing literature on risk assessment, this paper is expected to provide a new perspective to the understanding of risk life cycle, which can effectively facilitate risk management in the construction industry.

The rest of the paper is organized as follows. In Section 2, the methodology underpinning the risk life cycle assessment technique and the data source are presented. Section 3 provides a case study to compare the characteristics of the risk life cycles of traditional and industrial construction projects. Section 4 presents the empirical results. In Section 5, important findings are discussed further. Section 6 presents the policy implications of our findings. Section 7 provides the conclusions, limitations and future directions.

2. Risk life cycle theory and hypotheses

2.1 Risk life cycle and cash flow of loss from risks

Risks are common in most construction projects owing to their high sensitivity to the external environment. Construction risks typically exhibit randomness, which is mainly embodied in the following three aspects (Ren, 1994; Mo, 2007):

(1) the start time of risk is random;

(2) the duration of risk is random; and

(3) the financial loss arising from risk is random.

The "start time" of risk refers to the moment when the risk occurs, and the start times of the different risks obviously constitute a group of discrete points in time. The "duration" of risk represents the period from the start to the end of the risk. As shown in Figure 1, the risk life cycle is further divided into two stages: incubation and outbreak. The incubation stage is defined as the period from the initiation of the project to the start time of the risk. The outbreak stage refers to the period from the start to the end of the risk.

Throughout its "duration," the occurrence of risk follows a "first up, then down" pattern like an inverted-U distribution. The cash flow is the loss from risk embodied over the "duration," and arises from risky actions such as time delays, climate hazards, etc. For the purpose of convenience, this paper proposes a hypothesis that the distribution of cash flow loss is uniform, triangular or normal.

2.2 Evaluation of the relationships between risks

The start time, duration, probability and cash flow loss of the different risks interact inevitably and are influenced by environmental factors, thereby constituting a complicated risk network in construction projects. However, the relationships between risks can be classified into the following four basic categories:

(1) Independence

Independence indicates that there is no interconnection between the risks. As shown in Figure 2, risk A is independent of any other risks.

(2) Dependence

Dependence indicates that risk A occurs only if risk B occurs. Conversely, if risk B does not occur, risk A also does not occur.

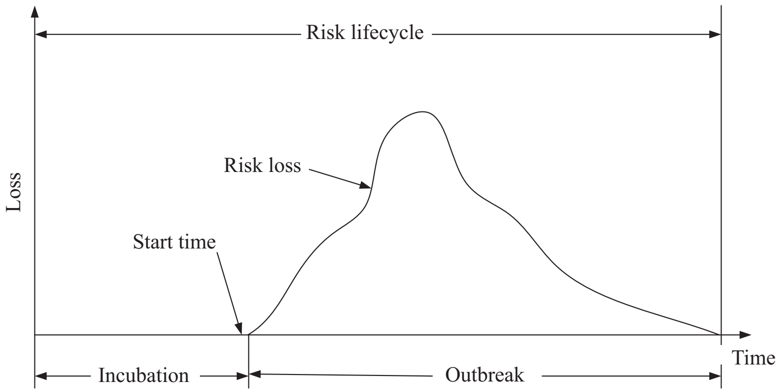

Figure 1.
The risk life cycle

(3) Parallel

In a parallel relationship, risk B probably occurs under the condition that one or more of risks A_1, A_2 ,…, A_n occur.

(4) Series

In a series relationship, risk B probably occurs only when all the risks A_1, A_2 , …, A_n occur.

Feedback: alongside the black solid arrows representing the risk relationships from the former to the latter, there are red dashed arrows representing the feedback effects from the latter to the former. In risk relationships, preceding events do not account for their impact on subsequent events, and this is precisely what generates risk. If the feedback effects from the latter to the former can be considered, the probabilities of, and losses arising from, risks could be decreased significantly. However, it is difficult to measure and quantify the impact of feedback from the latter to the former on the risk probability and loss, and this merits more sophisticated empirical studies and further discussions. In this paper, the feedback effect form the latter to the former is not considered.

The four basic types of risk relationships are shown in Figure 2.

2.3 Hypotheses for Monte Carlo simulations

The start time, duration, cash flow of loss and probability of risk are random variables that follow specific distributions. In this paper, we form three hypotheses (Ren, 1994):

H1. The start time and duration of EPC projects obey the triangular distribution.

H2. The cash flow obeys the triangular and uniform distributions.

H3. The risk probability obeys the normal distribution.

First, we prepare a list of risks in an EPC project executed via the traditional and industrial construction modes. Second, the relationships among the risks are determined by decomposing the structures of the traditional and industrial construction modes of the EPC project. Finally, Monte Carlo simulations for the start time, duration, probability and cash flow are carried out using Crystal Ball 11.0 Software.

3. Methodology and data sources

3.1 Framework of risk assessment

A conceptual framework for the risk life cycle assessment of a construction project is presented in Figure 3.

From Figure 3, it can be seen that the method of risk life cycle assessment comprises four major steps. First, the risk occurrences in the construction project are identified and a list of risks is created. Second, the relationships between the risks are evaluated based on logical relational factors. It is noteworthy that, in this paper, the logical relation depends on the organizational structure of the construction project. Next, the probability and its distribution, and the ranges of time and loss are defined. Finally, simulation and statistical analysis of the results are carried out.

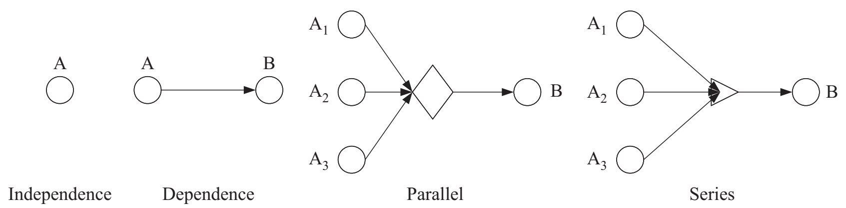

Figure 2.
The relationship between risks

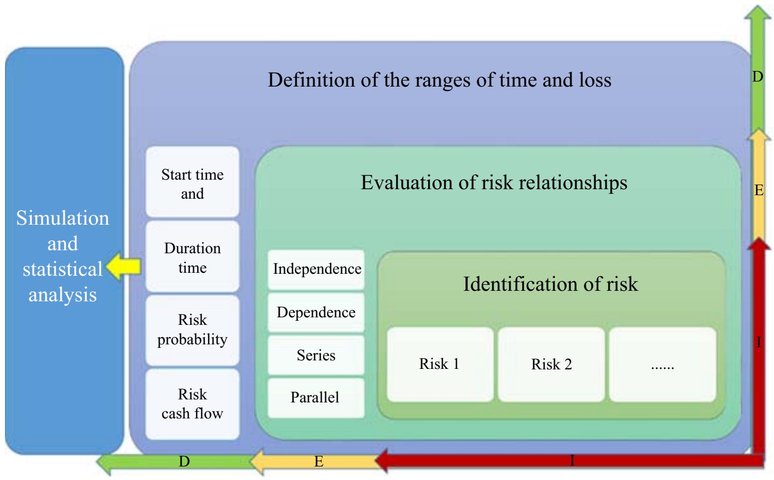

Figure 3.
The framework of risk life cycle assessment

To facilitate a clear understanding of the methodology framework, the relevant concepts have been clarified in Section 2. Section 2.1 provides the concepts of risk life cycle and cash flow. Section 2.2 illustrates the different types of risk relationships. Finally, the method of simulation employed in this paper is described in Section 2.3.

3.2 Identification of risks and their relationships

3.2.1 Risks and their relationships in traditional construction mode. The organizational structure of an EPC project in the traditional construction mode is shown in Figure 4.

From Figure 4, it can be seen that the structure of an EPC project in the traditional production mode can be decomposed into EPC (Haggag, 2006). The first stage is engineering, which includes all the pre-project works, such as planning, feasibility research

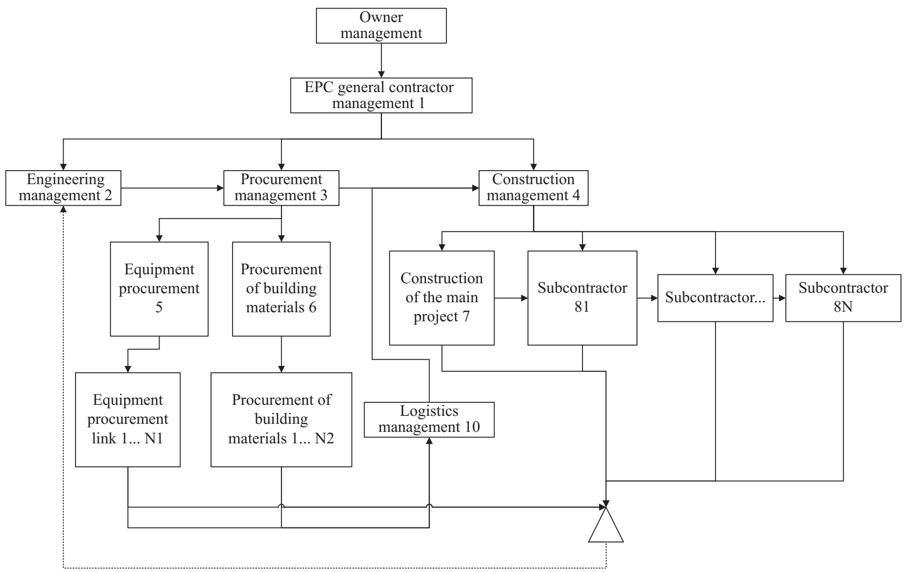

Figure 4.
The organization structure of traditional construction projects in EPC

and design. After the engineering works, the procurement of equipment and building materials begins in accordance with the pre-works. The next stage is construction, which progresses after the necessary equipment and building materials have been acquired. In fact, the activities of equipment and building material procurement partially overlap with those of the construction stage. For the purpose of convenience, this paper simplifies the relationship between procurement and construction, as shown in Figure 3. In addition, the main body of construction work and some professional sub-works are undertaken by the main contractor and some specialty subcontractors (Manu *et al.*, 2015). The main contractor and subcontractors not only influence the risk characteristics but also have significant impact on each other (Rahman *et al.*, 2013). In addition, management of logistics is required to coordinate the supply of equipment and construction materials for construction to progress. The risk relationships in an EPC project executed in the traditional construction model are detailed in Figure 5.

In Figure 5, the red dashed arrows represent the feedback effects from the latter to the former. It is difficult to quantify the impact of feedback from the latter to the former on the risk probability and loss. Therefore, it is not considered in this paper.

3.2.2 Risks and their relationships in industrial construction mode. The organizational structure of an EPC project in the industrial construction mode is shown in Figure 6.

Similar to that in the traditional construction mode, the structure of an EPC project in the industrial production mode can be decomposed into the stages of engineering, procurement, logistics and construction. However, the most significant difference between the traditional and industrial construction modes is that the process of construction is transformed from on-site construction in the former to distributed prefabrication and on-site assembly in the latter (Yang, 2011). In traditional production, the stage of construction takes place on-site and is completed by the general contractor and subcontractors. In industrial production, the construction stage entails assembly on the field of the prefabricated units manufactured in factories (Wang and Ji, 2011). Therefore, in the construction stage, only the assembly contractor is required to complete the construction

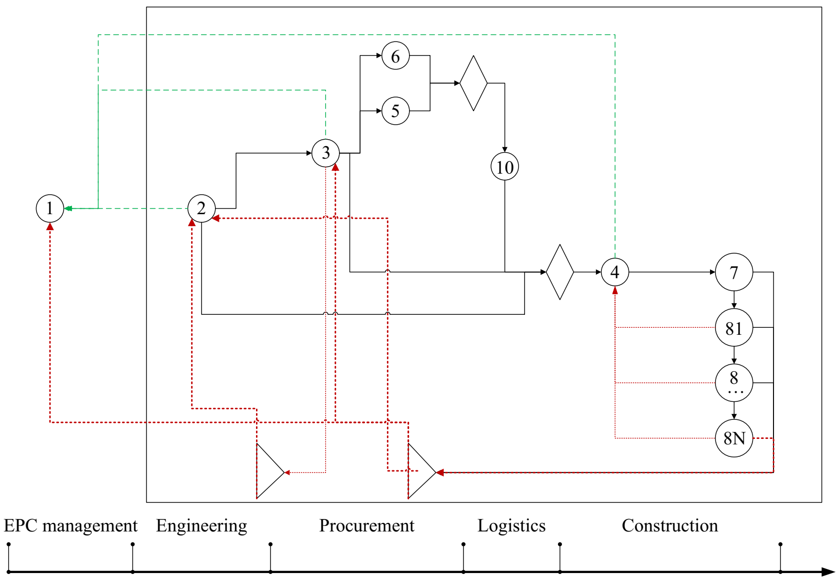

Figure 5.
The risk relationships of construction project in traditional production mode

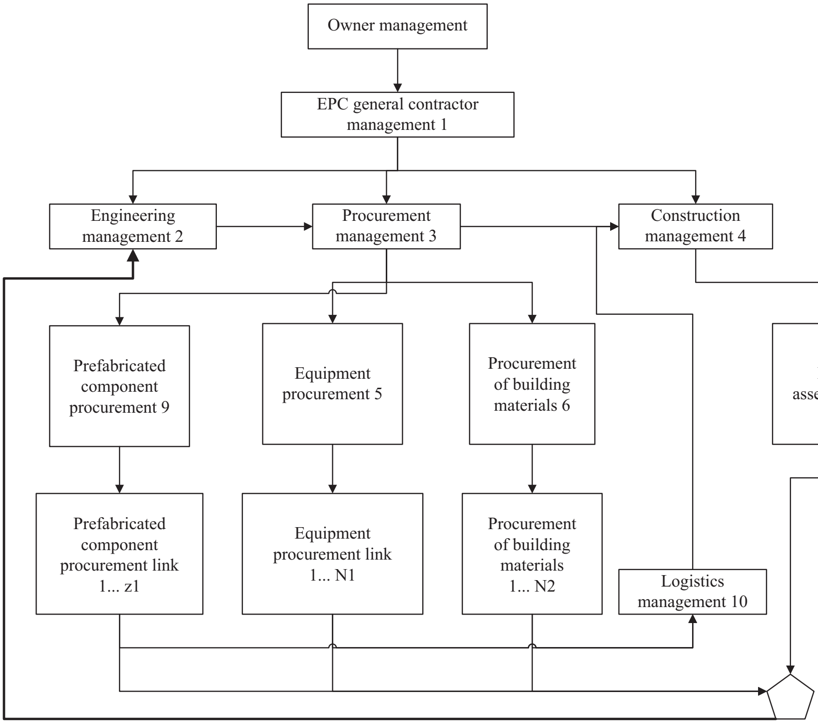

Figure 6. The organization structure of industrial construction projects in EPC

tasks and replaces the several subcontractors involved in the traditional production model. In this model, the prefabricated components and assembly technologies have realized standardized and batch production in factories (Arashpour *et al.*, 2016a, b, 2017; Goh and Loosemore, 2017). Furthermore, in addition to equipment and material procurement, the procurement of prefabricated components is an essential component of the procurement stage in the industrial production mode. Meanwhile, the management of logistics is critical to complete the construction project successively. The risk relationships in the industrial production model are detailed in Figure 7.

3.3 Data sources and processing

The raw data used in this paper were obtained by conducting a survey on the international project. In accordance with the risk life cycle theory, the data on risk probability, cash flow, start time and duration time formed the basis for the design of the questionnaire. A total of 155 professional practitioners and 38 managers working on the international project for more than five years participated in the survey. Brief introductions to the risk life cycle theory and the international project were attached to the questionnaire to ensure that all the respondents had a clear understanding of the questions. Since the survey was carried out on a specific project and the questionnaires were distributed in person, all the questionnaires were duly completed and returned. The detailed information is listed in Sections 3.3.1, 3.3.2, and 3.3.3.

3.3.1 Start time and duration. As shown in Figures 3–6, the relationships among, and start times of, the risks in the EPC project are assessed based on the organizational structure in the traditional and industrial construction modes. The detailed information is listed in Table I.

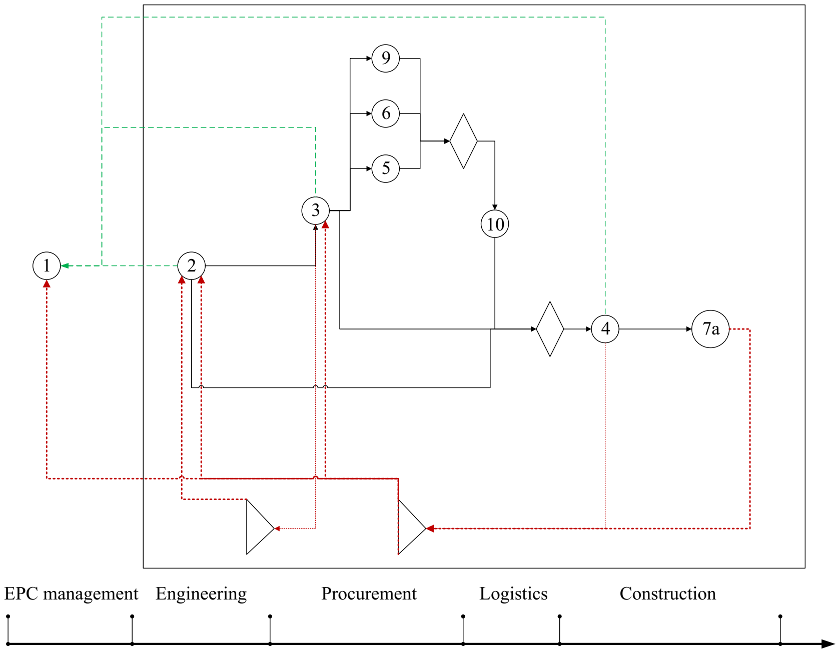

Figure 7.
The risk relationships of construction project in industrial production mode

Table I.
The original data and relation for RS_i, RD_i and RF_i in the pattern of traditional production

Number of risks	Antecedents	Distribution	Proceedings
R2		T	$RF_2 = RS_2 + RD_2$
R3	2	T	$RS'_3 = RF_2 + RS_3,\ RF_3 = RS'_3 + RD_3$
R4	2, 3, 10	T	$RS'_4 = \mathrm{MAX}(RF_3 + RS_4, RF_2 + RS_4, RF_{10} + RS_4)$ $RF_4 = RS'_4 + RD_4$
R5	3	T	$RS'_5 = RF_3 + RS_5,\ RF_5 = RS'_5 + RD_5$
R6	3	T	$RS'_6 = RF_3 + RS_6,\ RF_6 = RS'_6 + RD_6$
R7	4	T	$RS'_7 = RF_4 + RS_7,\ RF_7 = RS'_7 + RD_7$
R10	5, 6	T	$RS'_{10} = \mathrm{MAX}(RF_5 + RS_{10}, RF_6 + RS_{10})$ $RF_{10} = RS'_{10} + RD_{10}$
R81	4, 7	T	$RS'_{81} = RF_7 + RS_{81},\ RF_{81} = RS'_{81} + RD_{81}$
R82	81	T	$RS'_{82} = RF_{81} + RS_{82},\ RF_{82} = RS'_{82} + RD_{82}$
R83	82	T	$RS'_{83} = RF_{82} + RS_{83},\ RF_{83} = RS'_{83} + RD_{83}$
R84	83	T	$RS'_{84} = RF_{83} + RS_{84},\ RF_{84} = RS'_{84} + RD_{84}$
R85	84	T	$RS'_{85} = RF_{84} + RS_{85},\ RF_{85} = RS'_{85} + RD_{85}$

The estimation method of Project Evaluation and Review Techniques was employed to assess the start times and durations, as shown in Equation (1).

$$\text{Most likely results} = \frac{\text{Pessimistic estimate} + \text{Optimistic estimate} + 4 \times \text{Most likely estimate}}{6}, \tag{1}$$

$$\text{Standard deviation} = \frac{\text{Pessimistic estimate} - \text{Optimistic estimate}}{6}. \tag{2}$$

The pessimistic, optimistic and most likely estimates of start time and duration were obtained according to the Delphi method. RS_i, RD_i and RF_i are the most likely estimates of the start time, duration and finish time, respectively, of risk i. It is worth noting that RS_i is the time interval starting from RF_{i-1} rather than from the initiation of the entire project. The start time of risk i from the initiation of the entire project is denoted by RS'_i. The relationships between RS_i, RD_i and RS'_i can be demonstrated as follows.

$$RF_i = RS_i + RD_i, \tag{3}$$

$$RS'_{i+1} = RF_i + RS_{i+1}. \tag{4}$$

The Monte Carlo simulation is carried out for RS_i and RD_i in the traditional and industrial construction models. RS_i and RD_i are random variables subjected to triangular distribution based on the pessimistic, optimistic and most likely estimates. The simulation time is set as 3,000. Based on the suggestions of experts, engineers, technicians and on-site staff and managers, the original data of the start times and durations of all the risks in the traditional and industrial production models were set in this paper (see Table I). To eliminate interference from irrelevant factors, the original data of start time and duration used for the Monte Carlo simulations are consistent for both the traditional and industrial production models. All the detailed information is shown in Tables I and II.

3.3.2 Probability of risk. As shown in Figures 4 and 6, the organizational structure of an EPC project is a typically complicated network of series and parallel relationships. Accordingly, the probabilities of risks can be calculated by the following basic pattern:

$$P(\mathrm{A}_1 \cap \mathrm{A}_2 \cap \cdots \cap \mathrm{A}_n) = P(\mathrm{A}_1)P(\mathrm{A}_2)\ldots P(\mathrm{A}_n), \tag{5}$$

$$P(\mathrm{A}_1 \cup \mathrm{A}_2 \cup \cdots \cup \mathrm{A}_n) = 1 - \overline{P(\mathrm{A}_1)} \times \overline{P(\mathrm{A}_2)} \times \cdots \times \overline{P(\mathrm{A}_n)}, \tag{6}$$

$$\mathrm{P}(\mathrm{B}_i|\mathrm{A}) = \frac{P(\mathrm{AB}_i)}{P(\mathrm{A})} = \frac{P(\mathrm{B}_i) \cdot P(\mathrm{A}|\mathrm{B}_i)}{\sum_i P(\mathrm{B}_i) \cdot P(\mathrm{A}|\mathrm{B}_i)}. \tag{7}$$

The probabilities of all the risks in the traditional and industrial production models of the EPC project are listed in Tables III and IV, respectively. The raw data employed for the Monte Carlo simulations of the traditional and industrial production models are consistent. All the detailed information is shown in Tables III and IV.

Number of risks	Antecedents	Distribution	Proceedings
R2		T	$RF_2 = RS_2 + RD_2$
R3	2	T	$RS'_3 = RF_2 + RS_3,\ RF_3 = RS'_3 + RD_3$
R4	2, 3, 10	T	$RS'_4 = \mathrm{MAX}(RF_3 + RS_4, RF_2 + RS_4, RF_{10} + RS_4)$ $RF_4 = RS'_4 + RD_4$
R5	3	T	$RS'_5 = RF_3 + RS_5,\ RF_5 = RS'_5 + RD_5$
R6	3	T	$RS'_6 = RF_3 + RS_6,\ RF_6 = RS'_6 + RD_6$
R7a	4	T	$RS'_{7a} = RF_4 + RS_{7a},\ RF_{7a} = RS'_{7a} + RD_{7a}$
R10	5, 6, 9	T	$RS'_{10} = \mathrm{MAX}(RF_5 + RS_{10}, RF_6 + RS_{10}, RF_9 + RS_{10})$ $RF_{10} = RS'_{10} + RD_{10}$
R9	3	T	$RS'_9 = RF_3 + RS_9,\ RF_9 = RS'_9 + RD_9$

Table II.
The original data and relation for RS_i, RD_i and RF_i in the pattern of industrial production

Risk	Antecedents	P_i (total probability of Ri)
R2		$P_2 = P_{i2}$
R3	R1, R2	$P_3 = P_{i3} \times (1 - P_2) + P_{32} \times P_2$
R4	R1, R2, R3, R10	$P_4 = P_{i4} \times (1-P_2)(1-P_3)(1-P_{10})$ $+P_{4,2} \times P_2(1-P_3)(1-P_{10})$ $+P_{4,3} \times P_3(1-P_2)(1-P_{10})$ $+P_{4,10} \times P_2(1-P_3)(1-P_2)$ $+P_{4,23} \times P_2 \times P_3(1-P_{10})$ $+P_{4,210} \times P_2 \times P_{10}(1-P_3)$ $+P_{4,310} \times P_3 \times P_{10}(1-P_2)$ $+P_{4,2310} \times P_2 \times P_3 \times P_{10}$
R5	R3	$P_5 = P_{i5} \times (1-P_3) + P_{5,3} \times P_3$
R6	R3	$P_6 = P_{i6} \times (1-P_3) + P_{6,3} \times P_3$
R7	R4	$P_7 = P_{i7} \times (1-P_4) + P_{7,4} \times P_4$
R10	R5, R6	$P_{10} = P_{i10} \times (1-P_5)(1-P_6)$ $+P_{10,5} \times (1-P_6) \times P_5$ $+P_{10,6} \times P_6 \times (1-P_5)$ $+P_{10,56} \times P_5 \times P_6$
R81	R7	$P_{81} = P_{i81} \times (1-P_7) + P_{81,7} \times P_7$
R82	R81	$P_{82} = P_{i82} \times (1-P_{81}) + P_{82,81} \times P_{81}$
R83	R82	$P_{83} = P_{i83} \times (1-P_{82}) + P_{83,82} \times P_{82}$
R84	R83	$P_{82} = P_{i84} \times (1-P_{83}) + P_{84,83} \times P_{83}$
R85	R84	$P_{82} = P_{i85} \times (1-P_{84}) + P_{85,84} \times P_{84}$

Table III.
The risk probability of traditional production

Risk i	Antecedents	Total probability of Ri
R2		$P_2 = P_{i2}$
R3	R1, R2	$P_3 = P_{i3} \times (1 - P_2) + P_{32} \times P_2$
R4	R1, R2, R3, R10	$P_4 = P_{i4} \times (1-P_2)(1-P_3)(1-P_{10})$ $+P_{4,2} \times P_2(1-P_3)(1-P_{10})$ $+P_{4,3} \times P_3(1-P_2)(1-P_{10})$ $+P_{4,10} \times P_2(1-P_3)(1-P_2)$ $+P_{4,23} \times P_2 \times P_3(1-P_{10})$ $+P_{4,210} \times P_2 \times P_{10}(1-P_3)$ $+P_{4,310} \times P_3 \times P_{10}(1-P_2)$ $+P_{4,2310} \times P_2 \times P_3 \times P_{10}$
R5	R3	$P_5 = P_{i5} \times (1-P_3) + P_{5,3} \times P_3$
R6	R3	$P_6 = P_{i6} \times (1-P_3) + P_{6,3} \times P_3$
R7a	R4	$P_7 = P_{i7} \times (1-P_4) + P_{7,4} \times P_4$
R10	R5, R6	$P_{10} = P_{i10} \times (1-P_5)(1-P_6)(1-P_9)$ $+P_{10,5} \times P_5(1-P_6)(1-P_9)$ $+P_{10,6} \times P_6(1-P_5)(1-P_9)$ $+P_{10,9} \times P_9(1-P_5)(1-P_6)$ $+P_{10,56} \times P_5 \times P_6(1-P_9)$ $+P_{10,59} \times P_5 \times P_9(1-P_6)$ $+P_{10,69} \times P_6 \times P_9(1-P_5)$ $+P_{10,569} \times P_5 \times P_6 \times P_9$
R9	R7	$P_9 = P_{i9} \times (1-P_3) + P_{9,3} \times P_3$

Table IV.
The risk probability of industrial production

3.3.3 Cash flow of loss from risk. For the purpose of convenience, the losses pertaining to all risk occurrences are translated into monetary values. The cash flow of loss from risk may comprise a series of discrete points, continuous lines, successive stages, etc. Changes in cash flows may be sudden and sharp in the short run or moderate in the long term. As mentioned in Section 2.1, the cash flow of loss from risk is embodied throughout the duration because of risky actions, natural hazards and other environmental factors. Therefore, the distribution of cash flow is varied and complicated, and is influenced by internal and external environment factors. To adhere to the focus of this paper and reflect on objective facts, the distributions of cash flow were determined following consultations with professionals and experts. In this study, the Monte Carlo simulations were conducted based on the detailed information provided in Tables V and VI, respectively, for the traditional and industrial production models.

4. Results

4.1 Simulation results of start time and duration

The results of simulation of start time and duration are listed in Table VII. It can be seen that the expected value of the finish time (*RF*) of the last sub-work in the traditional production pattern is 214.60 weeks, while that in the industrial production pattern is 103.97 weeks. This indicates that the total EPC project duration in the traditional production mode is twice that in the industrial production mode. It is noteworthy that the difference between the two modes in terms of the expected value of total duration lies in the construction stage. The duration of the construction stage decreases sharply in the industrial production mode, wherein the construction stage mainly comprises off-site manufacture and on-site assembly. Although laborers with greater expertise and skills are required to support production activities in this mode, there is a concurrent reduction in both the duration of risk occurrences and resultant financial losses.

Risk *i*	Min.	Risk loss ml	Max.	Distribution
2	7,500	9,045	110,940	*T*
3	2,000	3,500	45,00	*U*
4	5,020	6,500	8,000	*T*
5	1,020	1,900	2,500	*U*
6	1,109	2,022	3,011	*U*
7	6,000	7,000	9,000	*T*
10	5,000	6,000	7,500	*U*
81	5,000	5,500	6,500	*T*
82	4,500	4,900	5,500	*T*
83	4,500	5,020	5,900	*T*
84	5,000	5,500	6,500	*T*
85	6,000	6,500	7,000	*T*

Table V. The risk loss in the pattern of traditional production (Unit: US$)

Risk *i*	Min.	Risk loss ml	Max.	Distribution
2	7,500	9,045	110,940	*T*
3	2,000	3,500	4,500	*U*
4	5,020	6,500	8,000	*T*
5	1,020	1,900	2,500	*U*
6	1,109	2,022	3,011	*U*
7a	6,000	7,000	9,000	*T*
10	5,000	6,000	7,500	*U*
9	5,000	5,500	6,500	*T*

Table VI. The risk loss in the pattern of industrial production (Unit: US$)

Risk i	Traditional production EV(RS)	EV(RD)	EV(RF)	Industrial production EV(RS)	EV(RD)	EV(RF)
R2	3.66	6.97	10.63	3.68	6.97	10.66
R3	25.92	5.66	31.58	26.11	5.65	31.76
R4	87.70	6.000	93.70	77.65	6.000	83.65
R5	46.86	5.97	52.83	47.11	6.000	53.11
R6	46.18	4.66	50.84	46.42	4.72	51.13
R7	107.66	6.24	113.90			
R7a				97.63	6.34	103.97
R10	68.48	5.97	74.46	36.76	5.00	64.41
R81	129.60	5.03	134.63			
R82	149.56	5.66	155.22			
R83	169.26	5.63	174.89			
R84	188.45	5.31	193.75			
R85	208.64	5.96	214.60			
R9				59.41	5.00	41.76

Table VII.
The simulation results of start time and duration (Unit: week)

4.2 Simulation results of probability

Based on the raw data and methods listed in Tables III and IV, we conducted Monte Carlo simulations for the probabilities of all risks in the traditional and industrial production modes, respectively. The results are shown in Table VIII.

From Table VIII, it can be seen that there is no significant difference between the expected values of the probabilities of risks of the construction project in traditional and industrial production modes. However, the number of risk events and their relationships are remarkably different. The construction project in the industrial production mode does not have the risks R81, R82, R83, R84, and R85, which represent the risks of subcontractors, but entails the risk R9.

4.3 Simulation results of loss from risk

The values of loss from risk in the construction project in traditional and industrial production modes are listed in Table IX.

As can be seen in Table IX, the total expected value of loss from risk is \$98,550.79 in the traditional production pattern and \$75,415.91 in the industrial production pattern, which is 23.5 percent lower.

Risk i	Probability-traditional EV	SD	Probability-industrial EV	SD
R2	0.498	0.201	0.502	0.199
R3	0.575	0.129	0.572	0.128
R4	0.565	0.062	0.566	0.061
R5	0.406	0.092	0.406	0.093
R6	0.827	0.106	0.827	0.103
R7	0.474	0.133		
R7a			0.474	0.128
R10	0.556	0.095	0.557	0.096
R81	0.743	0.137		
R82	0.716	0.089		
R83	0.540	0.092		
R84	0.553	0.139		
R85	0.710	0.095		
R9			0.504	0.059

Table VIII.
The simulation results of risk events probability

Risk i	Loss-industrial	Loss-traditional
R2	42,629.43	43,422.39
R3	3,244.21	3,239.23
R4	6,494.21	6,523.79
R5	1,760.96	1,768.07
R6	2,052.87	2,057.78
R7		7,327.03
R7a	7,332.62	
R10	5,654.88	6,272.35
R81		5,675.69
R82		4,968.84
R83		5,136.48
R84		5,660.57
R85		6,498.57
R9	6,246.73	
Total	75,415.91	98,550.79

Table IX. The simulation results of risk loss (Unit: US$)

4.4 Expected loss in traditional and industrial projects

The expected loss from, and probabilities of, all risks in the traditional and industrial productions modes of the EPC project are detailed in Table X. The maximum expected loss arises from the risk R2 in both the traditional and industrial production modes. However, the total loss from risk in industrial production is only half of that in traditional production with the values being $39,117.84 and 54845.61, respectively. Therefore, it can be concluded that loss from risk is remarkably lower in the industrial production mode than in the traditional production mode.

From Table X, the pronounced decrease in total loss from risk in the industrial production mode is because the on-site construction in traditional production has been replaced with field assembly in industrial production. Traditional on-site construction processes are complicated and require different professional subcontractors for execution. The risks of traditional on-site construction are influenced by the technologies and management of, and coordination among, all the subcontractors. However, the industrial construction process requires only a qualified assembly contractor to complete the task of assembly. The number of, and losses arising from, risks in the construction stage are

	Industrial			Traditional		
Risk	Loss (US$)	Probability	Expected loss (US$)	Loss (US$)	Probability	Expected loss (US$)
R2	42,629.43	0.502	21,399.97	43,422.39	0.498	21,624.35
R3	3,244.21	0.572	1,855.69	3,239.23	0.575	1,862.557
R4	6,494.21	0.566	3,675.72	6,523.79	0.565	3,685.941
R5	1,760.96	0.406	714.95	1,768.07	0.406	717.8364
R6	2,052.87	0.827	1,697.72	2,057.78	0.827	1,701.784
R7			0.00	7,327.03	0.474	3,473.012
R7a	7,332.62	0.474	3,475.66			0
R10	5,654.88	0.557	3,149.77	6,272.35	0.556	3,487.427
R81			0.00	5,675.69	0.743	4,217.038
R82			0.00	4,968.84	0.716	3,557.689
R83			0.00	5,136.48	0.54	2,773.699
R84			0.00	5,660.57	0.553	3,130.295
R85			0.00	6,498.57	0.71	4,613.985
R9	6,246.73	0.504	3,148.35			0
Total	75,415.91		39,117.84	98,550.79		54,845.61

Table X. The total and expected loss in traditional and industrial production mode diminished significantly. Therefore, it is conducive to the risk management of a construction project to employ industrial production, especially in China, which lags behind developed countries in terms of industrialization of construction.

5. Discussion

5.1 Cash flow of loss from risk

The cash flow of loss from risks in the construction project in traditional and industrial production modes are shown in Figures 8 and 9, respectively.

As shown in Figure 8, the cash flow of loss from risk in the EPC project in traditional production mode mostly begins in week 3.66 and ends in week 214.60. It is noteworthy that both the maximum total loss and longest risk duration are in the construction stage. However, from the perspective of loss intensive, the loss per week from risk might peak in the engineering stage.

Figure 9 illustrates the cash flow of loss from risks in the industrial production mode. The first cash flow of loss from risk might occur in week 3.68 and end in about week 104. In contrast with the traditional production mode, most of the total loss from risk might occur in the procurement stage rather than in the construction stage. However, in terms of the loss intensive, the maximum loss per week from risk is mostly in the engineering stage. In addition, both the total loss from risk and risk duration in the industrial production mode are much lower than those in the traditional production mode.

5.2 Comparative analysis of risk life cycles in traditional and industrial projects

The losses from risks in the construction project in traditional (T–loss) and industrial production (I–loss) modes are shown in Figure 10.

As shown in Figure 10, there are some significant differences between the risk life cycle characteristics of the construction project in traditional and industrial production modes. First, the start time and cash flow of engineering (R2) in industrial production are earlier than those in traditional production. Second, the total risk duration of the industrial

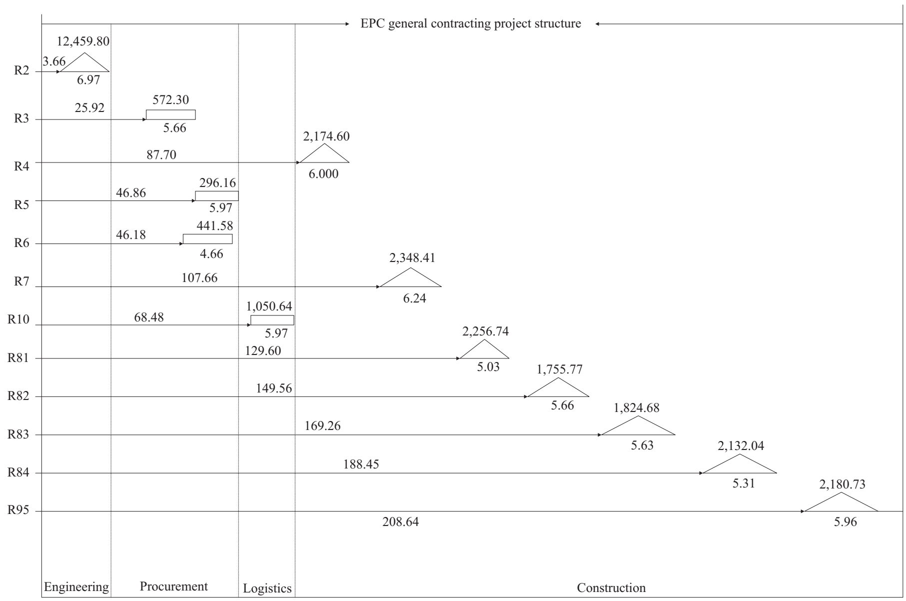

Figure 8.
The cash flow of risk loss in traditional production

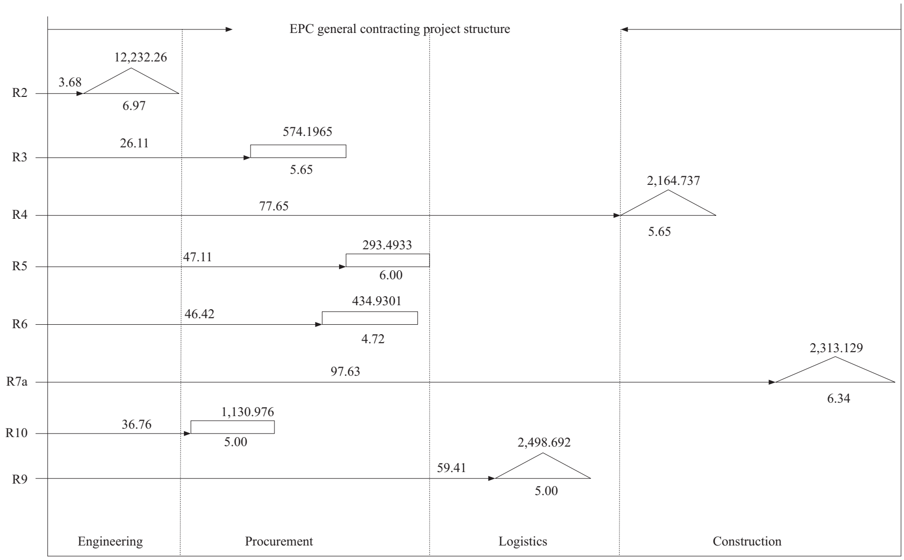

Figure 9.
The cash flow in industrial production

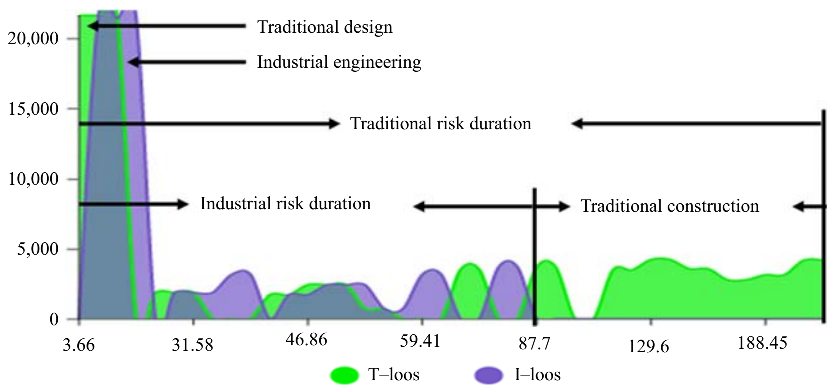

Figure 10.
The risk loss in the construction projects in traditional (T–loss) and industrial production (I–loss)

construction project is 87.7 weeks, which is only half of that of the traditional construction project. From Figure 10, it can be seen that the additional time from week 87.7 to week 214.6 is spent in the construction stage of the project in the traditional production mode. Thus, the application of industrial production in projects can greatly reduce the duration of the construction stage. Finally, significant loss from risk occurs predominantly in the engineering and construction stages in the traditional construction project, but in the engineering stage in the industrial construction mode. Therefore, the application of industrial production in projects can greatly reduce the loss from risks in the construction stage. The cash flows of the construction project in traditional and industrial production modes are shown in Figure 11.

In Figure 11, the cash flow of loss from risks in traditional production consists of two major parts, of which one is in the engineering stage and the other is in the construction stage. Conversely, the cash flow of loss from risks in industrial production consists of one major part that is in the engineering stage.

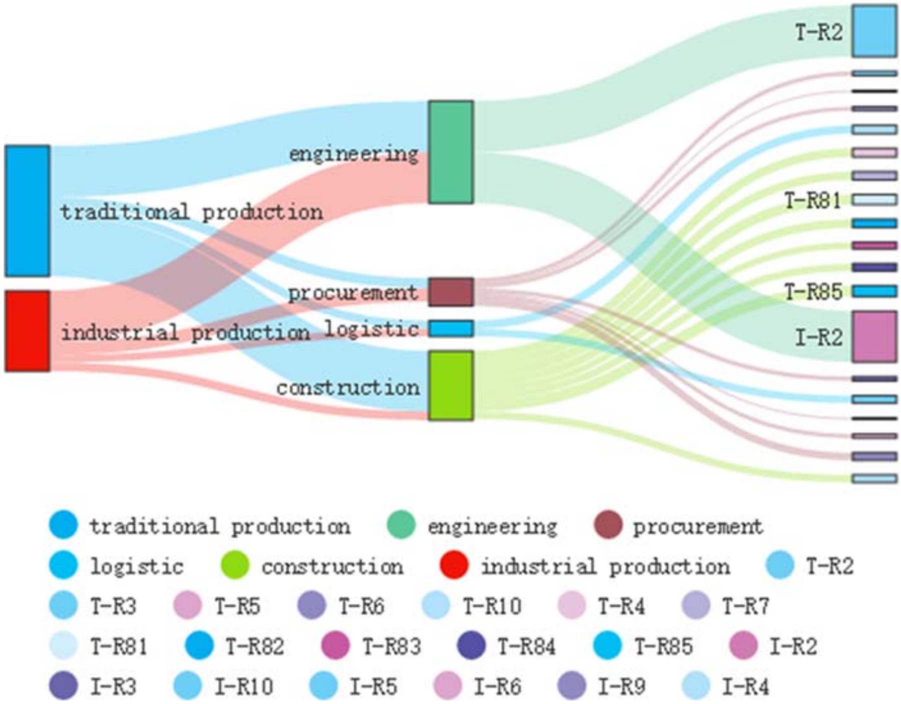

Figure 11.
The cash flow of construction projects in traditional and industrial production mode

5.3 Impacts of different levels of industrialization on risk life cycle characteristics

This paper employs the risk life cycle theory and Monte Carlo simulations to study the risk life cycle characteristics of an EPC project executed in traditional and industrial production modes but does not consider the project whose production mode lies between the two. Industrialization of the construction industry is a gradual process of transition from the traditional production mode to a completely industrial production mode. Especially in China, with the exception of Beijing and Shanghai, the level of industrialization of the construction industry is about 5–10 percent. Therefore, it is imperative to study the risk life cycle characteristics of construction projects under different levels of industrialization.

As the level of industrialization helps shape the structure and on-site production mode of the EPC project, it has significant influences on its risk life cycle characteristics. On the one hand, the risk relationships would change significantly on account of changes to the structure (Li *et al.*, 2017). On the other hand, the number of contractors and probabilities of risks in the construction stage would be substantially different owing to upgrades to the on-site production mode (Teng *et al.*, 2017). Most importantly, industrialization would facilitate the application of big data, Internet of things, cloud computing and other advanced technologies in construction projects. Thus, decision making throughout the organization will be supported heavily by evidence from big data fragments (Acharya *et al.*, 2018). However, the impact of industrialization level on risk probability is complicated and uncertain, and an understanding of this requires immense practical experience and statistical analysis. This paper focuses on how risk life cycle characteristics change in response to structural changes in a construction project under different levels of industrialization. Therefore, a brief discussion on the structural changes of an EPC project under different levels of industrialization follows.

The organizational structure of an EPC project executed according to a model that lies between traditional and industrial production is shown in Figure 12.

From the perspective of work contents, the most obvious changes take place in the engineering and construction stages. However, from a structural perspective, most changes take place in the procurement and construction stages. As shown in Figure 9, besides equipment and material procurement, the procurement of prefabricated components is considered the critical issue in the procurement and construction stage. In addition, the focus in the construction stage is shifted from on-site construction to on-site assembly. As the level of industrialization increases, the proportion of on-site construction decreases while that of on-site assembly increases. Therefore, the structure of the construction project undergoes substantial changes. Meanwhile, the probabilities of, and losses from, risks also change significantly. To clarify these issues, more practical experience and statistical analysis of data are needed.

It is noteworthy that logistics management is critical for the success of construction projects at different levels of industrialization. Accurate scheduling of the procurement of equipment, materials, and prefabricated components, and their timely delivery are extremely essential for construction projects (Li *et al.*, 2016). Owing to data constraints, this paper does not discuss this further. The risk relationships in construction projects with different levels of industrialization are shown in Figure 13.

6. Policy implications

6.1 Promotion of industrial production in the Chinese construction industry

The industrialization of construction is considered an inevitable trend in China owing to its advantages in building quality improvement, energy conservation and mitigation of pollution. Additional advantages such as increase in labor productivity, reduction in project duration, and decrease in loss from risks have been confirmed in this paper. Industrialization is the most suitable way to facilitate sustainable development in the Chinese construction industry, where the present level of industrialization is very low. The traditional production mode of construction has its own advantages, such as mature

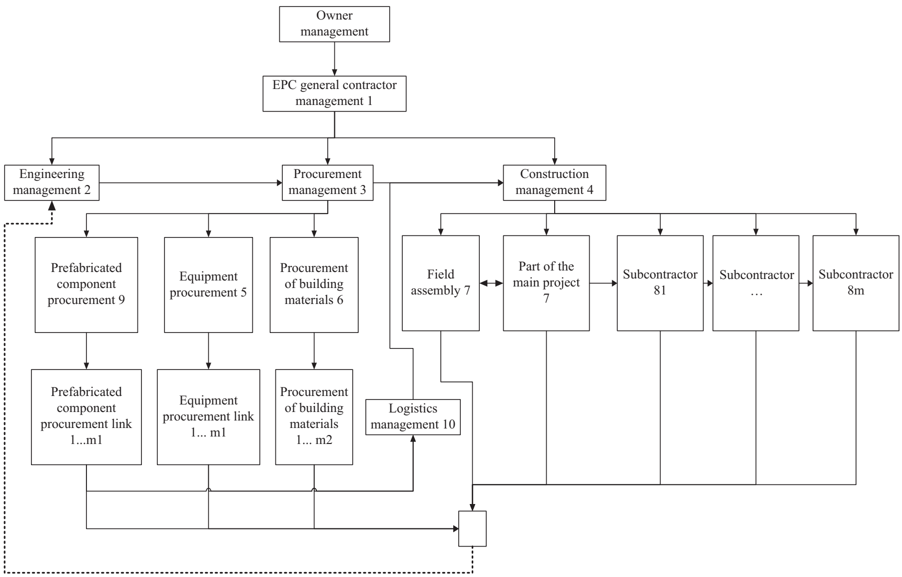

Figure 12. The organization structure of construction project falling in between traditional and industrial production mode in EPC

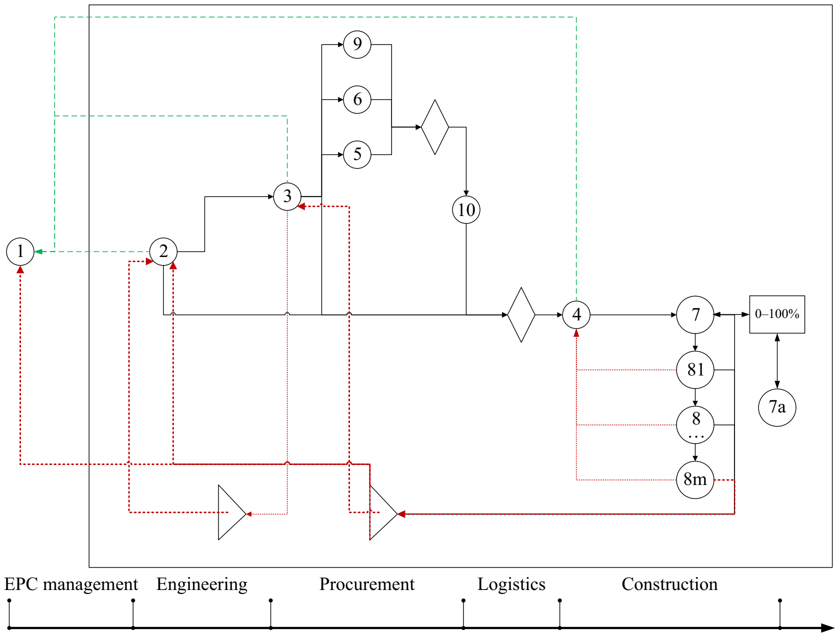

Figure 13.
The risk relationships of conduction projects with different industrial level

traditional technologies and low labor cost. Moreover, the initial stage of transformation from the traditional to industrial production mode is required to ease the industry's dependence on the former, and this would entail significant resources and costs. However, the benefits of construction industrialization cannot be seen in the short term. The adoption and implementation of such practices is driven by pressure from stakeholders, corporate practices that are environmentally ethical and market demand (Latan *et al.*, 2018). Therefore, national policies should focus on providing a more favorable environment, especially in the fields of economy and technology, to prompt the industrialization of construction in China. Taxation, subsidies and credit are the main tools of implementation of economic policies, which should conform to market regulations. From the technology perspective, the standardization of systems for building prefabricated components lies at the core of the obstacles to be overcome in improving the level of industrialization in the construction industry of China.

6.2 "Early access" in industrial construction in EPC project for risk reduction

The integration of industrial technologies with environmentally sustainable manufacturing decisions would be implemented via improvement projects, thereby requiring effective project teams to be organized (Jabbour *et al.*, 2018). The EPC project has the advantage of integration management, which comprises the EPC stages. It provides the opportunity for professional staff members engaged in the procurement and construction stages to play an important role in the engineering stage. In this paper, we label this opportunity as "early access" for procurement and construction professionals. Their level of participation in the engineering phase has a significant influence on risk reduction. The advantage of integrated management in an EPC project becomes more prominent in the industrial production mode. It facilitates cooperation among professional staff members in the EPC stages. The risk management of the entire project is rendered convenient and efficient.

7. Conclusion

Industrialization of the construction industry has become an inevitable trend in China owing to its benefits of low energy consumption and high efficiency. However, further discussions are required to determine whether the industrial production mode can reduce the risks involved compared with the traditional construction mode. Based on the theory of risk life cycle, this paper proposes a practical risk management technique to assess the risk characteristics. Based on the results, the following conclusions are drawn:

(1) The relationships among and number of risk occurrences in traditional and industrial construction projects are remarkably different. Risks arising from subcontractors in the traditional mode are transformed into risks from manufacturers in the industrial mode. The probabilities of, and cash flow of losses from, risks are significantly lower in the latter.

(2) The finish time of the last sub-work in the traditional production mode (214.60 weeks) is more than twice that in the industrial production mode (103.97 weeks). Moreover, the total expected value of loss from risk is 23.5 percent lower in industrial production than in traditional production.

(3) In the traditional production mode, most of the loss from risk might occur in the construction stage while the maximum loss per week might be incurred in the engineering stage. By contrast, in industrial production, the majority of loss from risk might occur in the procurement stage rather than in the construction stage. Similar to traditional production, the maximum loss per week might be incurred in the engineering stage.

(4) The total loss from risk is significantly lower in industrial production than in traditional production because the on-site construction stage in the latter is replaced with field assembly in the former. Traditional on-site construction process are complicated and require different professional subcontractors for execution. However, the industrial construction process requires only a qualified assembly contractor to complete the task of assembly. The number of, and losses pertaining to, risks in the construction stage are diminished significantly. Therefore, it is favorable for construction projects, from a risk management perspective, to employ industrial production, especially in China, which lags far behind developed countries in terms of the level of industrialization of construction.

It is noteworthy that the level of construction industrialization has significant influences on the risk life cycle characteristics. The relationships among risks, number of subcontractors and risk probabilities would change substantially based on the production mode. This paper focuses on how the risk life cycle characteristics change because of structural variations in construction projects in both traditional and industrial production modes. However, determining the influence of the level of industrialization on the characteristics of the risk life cycle is complicated and uncertain, and calls for immense practical experience and statistical analysis.

References

Acharya, A., Singh, S.K. *et al.* (2018), "Big data, knowledge co-creation and decision making in fashion industry", *International Journal of Information Management*, Vol. 42, pp. 90-101.

Alinaitwe, H.M., Mwakali, J. *et al.* (2006), "Assessing the degree of industrialisation in construction – a case of Uganda", *Journal of Civil Engineering and Management*, Vol. 12 No. 3, pp. 221-229.

Andi and Minato, T. (2003), "Design documents quality in the Japanese construction industry: factors influencing and impacts on construction process", *International Journal of Project Management*, Vol. 21 No. 7, pp. 537-546.

Arashpour, M., Wakefield, R. *et al.* (2016a), "Off-site construction optimization: sequencing multiple job classes with time constraints", *Automation in Construction*, Vol. 71, pp. 262-270.

Arashpour, M., Wakefield, R., Blismas, N. and Abbasi, B. (2016b), "Quantitative analysis of rate-driven and due date–driven construction: production efficiency, supervision, and controllability in residential projects", *Journal of Construction Engineering & Management*, Vol. 142 No. 1.

Arashpour, M., Wakefield, R. *et al.* (2017), "Optimal process integration architectures in off-site construction: theorizing the use of multi-skilled resources", *Architectural Engineering & Design Management*, pp. 1-14.

Bemelmans, J., Voordijk, H. *et al.* (2013), "Supplier-contractor collaboration in the construction industry", *Engineering Construction & Architectural Management*, Vol. 19 No. 4, pp. 342-368.

Chao, L.C. and Liou, C.N. (2007), "Risk-minimizing approach to bid-cutting limit determination", *Construction Management & Economics*, Vol. 25 No. 8, pp. 835-843.

Deng, X., Pheng, L.S. *et al.* (2014), "Project system vulnerability to political risks in international construction projects: the case of Chinese contractors", *Project Management Journal*, Vol. 45 No. 2, pp. 20-33.

Elrayes, K. and Khalafallah, A. (2005), "Trade-off between safety and cost in planning construction site layouts", *Journal of Construction Engineering & Management*, Vol. 131 No. 11, pp. 1186-1195.

El-Sayegh, S.M. (2008), "Risk assessment and allocation in the UAE construction industry", *International Journal of Project Management*, Vol. 26 No. 4, pp. 431-438.

English, W., "CPWR Technical Report: Risk of Isocyanate Exposure in the Construction Industry".

Girmscheid, G. and Kapp, M. (2006), "Industrialization processes in Swiss SMEs", Adaptable Structures.

Goh, E. and Loosemore, M. (2017), "The impacts of industrialization on construction subcontractors: a resource based view", *Construction Management & Economics*, Vol. 35 No. 5, pp. 1-17.

Haddad, B. (2007), "Risk management in the contractual language in the construction industry – the effect of exculpatory clauses on contractor bid price", dissertations & theses – Gradworks 58.

Haggag, T. (2006), "Tracking and controlling of engineering deliverables for EPC projects", *Building Civil & Environmental Engineering*.

Hameed, A. and Woo, S. (2007), "Risk importance and allocation in the Pakistan construction industry: a contractors' perspective", *Ksce Journal of Civil Engineering*, Vol. 11 No. 2, pp. 73-80.

Hong, X., Zhang, S., Su, Y., Wu, Z. and Yang, R.J. (2018), "Effect of stakeholder collaborative management on off-site construction cost performance", *Journal of Cleaner Production*, Vol. 184, May, pp. 490-502.

Hu, K., Rahmandad, H. *et al.* (2011), "Factors influencing the risk of falls in the construction industry: a review of the evidence", *Construction Management & Economics*, Vol. 29 No. 4, pp. 397-416.

Huang, J.W. and Wang, X.X. (2009), "Risk analysis of construction schedule based on PERT and MC Simulation", Vol. 2, pp. 150-153.

Jabbour, A.B.L.D., Jabbour, C.J.C., Foropon, C. and Filho, M.G. (2018), "When titans meet – can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors", *Technological Forecasting & Social Change*, Vol. 132, July, pp. 18-25.

Jin, C.H. (2010), "The lifecycle comprehensive risk evaluation for real estate projects – principle", *IEEE International Conference on Advanced Management Science (IEEE ICAMS)*.

Jin, X., Zuo, J. *et al.* (2011), "Major quantitative techniques for risk analysis in the construction industry: a comparative analysis".

Kartam, N.A. and Kartam, S.A. (2001), "Risk and its management in the Kuwaiti construction industry: a contractors' perspective", *International Journal of Project Management*, Vol. 19 No. 6, pp. 325-335.

Latan, H., Jabbour, C.J.C. *et al.* (2018), "Effects of environmental strategy, environmental uncertainty and top management's commitment on corporate environmental performance: The role of environmental management accounting", *Journal of Cleaner Production*, Vol. 180, pp. 297-306.

Li, C.Z., Hong, J. *et al.* (2016), "Schedule risks in prefabrication housing production in Hong Kong: a social network analysis", *Journal of Cleaner Production*, Vol. 134, pp. 482-494.

Li, C.Z., Zhong, R.Y., Xue, F., Xu, G., Chen, K., Huang, G.G. and Shen, G.Q. (2017), "Integrating RFID and BIM technologies for mitigating risks and improving schedule performance of prefabricated house construction", *Journal of Cleaner Production*, Vol. 165, November, pp. 1048-1062.

Ling, F.Y.Y. and Hoi, L. (2006), "Risks faced by Singapore firms when undertaking construction projects in India", *International Journal of Project Management*, Vol. 24 No. 3, pp. 261-270.

Liu, H.B. (2011), "Schedule risk management method of construction project based on critical chain", *International Conference on Electric Technology and Civil Engineering*.

Luu, V.T., Kim, S.Y. *et al.* (2009), "Quantifying schedule risk in construction projects using Bayesian belief networks", *International Journal of Project Management*, Vol. 27 No. 1, pp. 39-50.

Mckay, L.J. (2010), "The effect of offsite construction on occupational health and safety", Loughborough University.

Manu, E., Ankrah, N. *et al.* (2015), "Trust influencing factors in main contractor and subcontractor relationships during projects", *International Journal of Project Management*, Vol. 33 No. 7, pp. 1495-1508.

Mao, C., Xie, F. *et al.* (2016), "Cost analysis for sustainable off-site construction based on a multiple-case study in China", *Habitat International*, Vol. 57, pp. 215-222.

Mo, J.W. (2007), "Model for construction project scheduling and updating considering the dependent randomness of activities", *International Conference on Wireless Communications, Networking and Mobile Computing*.

Nasir, D., Mccabe, B. *et al.* (2003), "Evaluating risk in construction–schedule model (ERIC–S): construction schedule risk model", *Journal of Construction Engineering & Management*, Vol. 129 No. 5, pp. 518-527.

Ortega, I. and Bisgaard, S. (2000), "Quality improvement in the construction industry: three systematic approaches", *Total Quality Management*, Vol. 11 Nos 4-6, pp. 383-392.

Pinto, A., Nunes, I.L. *et al.* (2011), "Occupational risk assessment in construction industry – Overview and reflection", *Safety Science*, Vol. 49 No. 5, pp. 616-624.

Rahman, S.H.A., Endut, I.R. *et al.* (2013), "Current challenges towards successful relationship between main contractor and subcontractor", *Business Engineering and Industrial Applications Colloquium*.

Ren, H. (1994), "Risk lifecycle and risk relationships on construction projects", *International Journal of Project Management*, Vol. 12 No. 2, pp. 68-74.

Sarja, A. (1998), "Open and industrialised building".

Shen, Z. and Yuanqi, L.I. (2015), "Essence and connotation for construction in building industrialization in China", *Progress in Steel Building Structures*.

Teng, Y., Mao, C. *et al.* (2017), "Analysis of stakeholder relationships in the industry chain of industrialized building in China", *Journal of Cleaner Production*, Vol. 152, pp. 387-398.

Wang, N. and Ji, Y. (2011), "Analysis on key factors to affect construction industrialization development in China", *International Conference on Information Management, Innovation Management and Industrial Engineering*.

Wang, X.X. and Huang, J.W. (2009), "Risk Analysis of Construction Schedule Based on Monte Carlo Simulation", *International Symposium on Computer Network and Multimedia Technology*.

Wang, Y., Yongjian, K.E. *et al.* (2008), "Changes and Trends of Political Risks in China PPP Projects", *Construction Economy*.

Wu, X., Liu, Q. *et al.* (2015), "Prospective safety performance evaluation on construction sites", *Accident Analysis & Prevention*, Vol. 78, pp. 58-72.

Xiahou, X., Yuan, J. *et al.* (2018), "Exploring the driving factors of construction industrialization development in China", *International Journal of Environmental Research and Public Health*, Vol. 15 No. 3.

Xin, N. and Lam, K.C. (2013), "Cost–safety trade-off in unequal-area construction site layout planning", *Automation in Construction*, Vol. 32 No. 4, pp. 96-103.

Yang, S. (2011), "Discussion on problem of construction industrialization", *Construction Technology*.

Zaghloul, R. and Hartman, F. (2003), "Construction contracts: the cost of mistrust", *International Journal of Project Management*, Vol. 21 No. 6, pp. 419-424.

Zhou, Z., Yang, M.G. *et al.* (2015), "Overview and analysis of safety management studies in the construction industry", *Safety Science*, Vol. 72, pp. 337-350.

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