Risks Identification and Allocation in the Supply Chain of Modular Integrated Construction (MiC)

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ABSTRACT
Modular integrated construction (MiC) is an offsite construction technique which can improve construction quality, the certainty of the project cost, provide value for money and reduce construction time, waste generation, and carbon emissions. However, MiC is associated with a unique business model, engineering, supply chain, and stakeholder composition, resulting in bespoke uncertainties and risks. Prominent among them is the uncertainties and risk events in its linked supply chain segments. However, risks identification and allocation in the MiC supply chain segments is not well-established. This research identified and assessed 28 risk events (REs) across the manufacturing, logistics and on-site assembly segments of the MiC supply chain. A principal component analysis generated 10, 6 and 12 REs within the modular manufacturing, logistics, and on-site assembly segments, respectively. A fuzzy synthetic evaluation (FSE) modeling revealed that the on-site assembly REs are the most critical set of risk events with a criticality index of 5.58, followed by the modular manufacturing risk events (5.28) and logistics risk events (5.08). These rankings and criticality assessment have profound implications for the practice and praxis MiC risks management. It is a source of relevant information to stakeholders and practitioners in understanding the MiC supply chain risk events and may prioritize the riskiest events to improve the performance of MiC projects. Again, the assessed REs contributes to the checklists of MiC risk events and may form the basis for future studies on the risk of MiC. Future studies may examine the assessed risk events in different countries using larger samples.

KEYWORDS
Risk events; Modular integrated construction; Supply chain; Schedule delays; Uncertainties

INTRODUCTION
Modular integrated construction (MiC) refers to a construction system where independent building elements, usually completed with finishes, fixtures, and fittings are produced in an offsite factory and then transported to a construction site for final assembly and installation (Hong Kong Buildings Department, 2018). MiC is a typical offsite construction (OSC) technique where 80-90% of a whole building can be completed in a factory environment (Smith, 2016). Like OSC, MiC reduces construction time, solid waste generation and water footprint (Jaillon and Poon, 2008). The approach also improves productivity, continuity of workflow and safety of construction workers (Pan et al., 2008). However, the business model of MiC is associated with a unique engineering, supply chain, stakeholder composition and management requirements different from those of the conventional construction (CC) approach. As such, MiC is associated with bespoke risks events and uncertainties. Prominent among them is the risk events associated with the MiC supply chain. For instance, dimensional and geometric intolerances of the modular components are recipes for reworks and poor quality (Shahtaheri et al., 2017). Also, the dominant design information gap between designers and manufacturers could trigger scope changes

resulting in schedule delays (Li et al., 2017). Moreover, cranes malfunction and weather disruptions may generate significant schedule delays (Li et al., 2018). Given the distinct supply chain profiles between MiC and the CC, risk management strategies of the latter are not directly applicable to the former (Li et al., 2013). Also, the impact of risk events on the performance of MiC projects is more pronounced due to its shorter schedules, difficulty in rectifying errors, inflexibility to design changes during construction, and the higher cost of reworks (Shahtaheri et al., 2017).

As a result, there is a growing body of bespoke research on the risks of MiC. For example, Li et al. (2013) identified and assessed risk factors that affect the cost and schedule performance of MiC. Li et al. (2016, 2017, 2018) examined schedule delays and risks of MiC projects in Hong Kong and Shahtaheri et al. (2017) investigated MiC risk management strategies. Previous risks studies on the MiC supply chain revolve around these mainstream risk aspects. However, risk events identification and allocation in the MiC supply chain is not well-established. Such research is crucial because the segments of the MiC supply chain are complex and fragmented but interdependent (Li et al., 2018, 2017) such that disruptions and disturbances in upstream supply chain segments may compromise the continuity of downstream segments. For example, too early delivery of modular elements to a site requires storage space whereas delays in the delivery of modular elements could halt the entire installation process (Li et al., 2018). Therefore, MiC risk management practice and praxis could be enhanced if there is a broadened understanding of the major risk events in its supply chain. As such, this research identified and allocated risk events across the manufacturing, logistics and the on-site assembly segments of the MiC supply chain, drawing on the opinions of international MiC experts.

RESEARCH METHODS AND DATA SOURCES

The paper adopted a quantitative methodological framework to identify and allocate risks in the MiC supply chain. Following a comprehensive literature review, a checklist of 40 risk events (REs) associated with the supply chain of MiC was developed. However, following structured interviews with experts, the number was reduced to 28 REs.

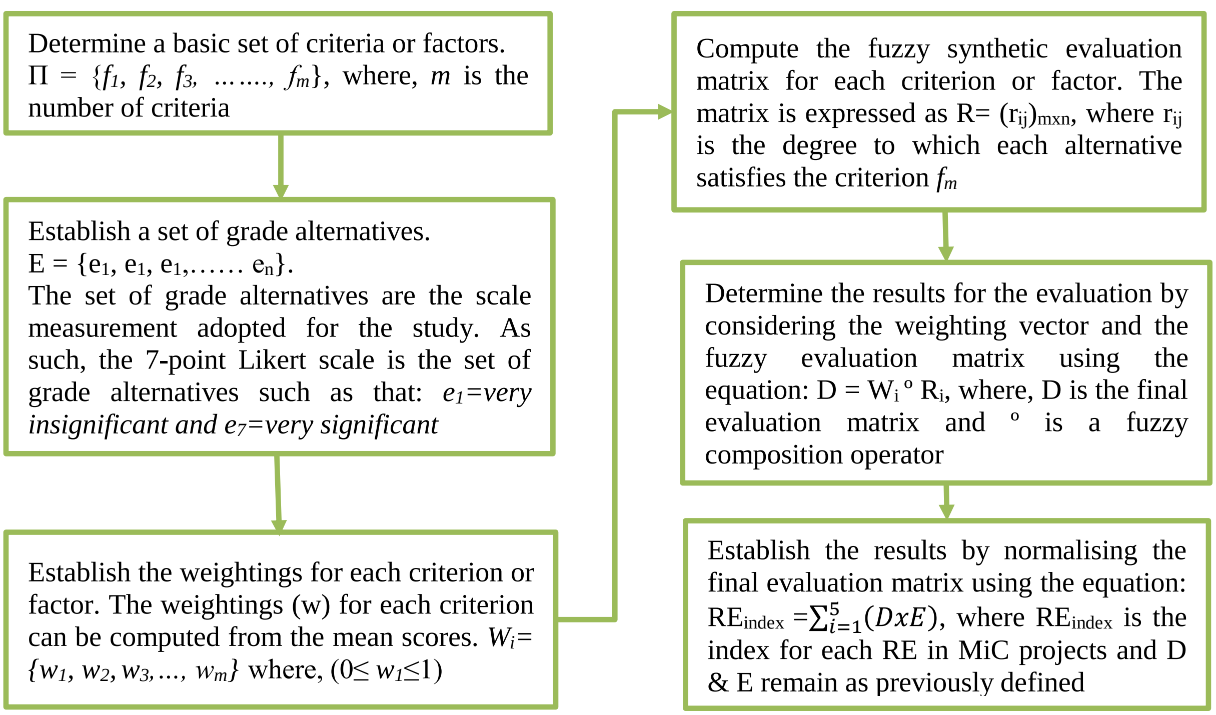

Figure 1. Flowchart of the FSE modeling procedure

A constructive questionnaire scoring system was developed to collect data on the varying criticality of the risk events. The questionnaire was an online survey using survey monkey, LinkedIn messaging and emails. It was distributed to 200 researchers in 15 countries. The experts were requested to indicate the level of criticality of a risk event within the MiC supply chain on a 7-point Likert scale where 1=very insignificant, 2=moderately insignificant, 3=slightly insignificant, 4=neutral, 5=slightly significant, 6=moderately significant, 7=very significant. Following several reminders, 37 valid responses were received from Malaysia (7), Australia (5), China (10), UK (5), U.S. (4), Singapore (1), and Hong Kong (5). Although it constituted a small response rate of 18.5%, previous international surveys even recorded lower response rates such as 14% (Osei-Kyei et al., 2017). A principal component analysis was conducted to cluster the risk events and a fuzzy synthetic evaluation (FSE) analysis facilitated modeling of the risk events. Prior to the factor analysis and FSE modeling, the sample size and data were examined against their suitability for factor analysis. The data were analyzed using IBM SPSS Statistics v.25. Figure 1 shows the FSE modeling procedure, adapted from Ameyaw and Chan (2015). FSE is a component of fuzzy set theory (Zadeh, 1965), which uses membership functions to evaluate linguistic variables such as *very low, low, moderate* etc. These subjective expressions are inherent in the responses of experts regarding the criticality of the risk events. Thus, the paper adopted the FSE because it can conduct an objective assessment of these subjective opinions of the experts (Sadiq and Rodriguez, 2004).

RESULTS AND DATA ANALYSIS

Preliminary analyses were conducted to ascertain the suitability of the data and sample size for the factor analysis and FSE modeling. Table 1 shows the mean scores and factor weightings of the risk events (REs). Albeit the 1:1 factor to sample size ratio fell short of the 1:5 prerequisite (Lingard and Rowlinson, 2006), other statistical assessments proved the data sufficient for factor analysis and FSE modeling. A Cronbach's Alpha of 0.824 highlighted the high internal consistency and reliability of the scale of the survey instrument. The high Alpha value was expected because the respondents were all experts and understood the Likert scale scoring system. A correlation matrix of the 28 risk events (REs) showed a good association coefficient of at least 0.4 among all events, which is above the threshold of 0.3 (Lingard and Rowlinson, 2006). The anti-image correlation matrix suggested the removal of RE1-0.480, which was lower than the threshold of 0.5 (ibid) but the event was included because of its higher coefficient in the correlation matrix. As a measure of sampling adequacy, the Kaiser-Meyer-Olkin (KMO) Test of the 28 variables resulted in a high value of 0.725, which is within an acceptable range and as such, the data is suitable for factor analysis. The Bartlett Test of Sphericity showed a χ^2 value of 148.560 at a significant p-value of 0.000, indicating that the correlation matrix of the sample was not an identity matrix and hence, the null hypothesis should be rejected.

Following these statistical assessments, the factor analysis (principal component analysis) was conducted. The Varimax rotation with Kaiser Normalization converged in 8 iterations at three-factor groupings. A parallel analysis using the Eigenvalue Monte Carlo Simulation syntax of SPSS (O'Connor, 2000), reaffirmed the three-factor groupings. Table 2 shows the factor extractions and their loadings. The weightings of the risk events (REs) were computed based on the formula suggested in Yeung et al. (2007)

$$W_i = \frac{M_i}{\sum M_{\ddot{\mu}}} \qquad (1)$$

Where W_i denotes the weighting of each RE or REG; M_i denotes the mean score value of each RE or REG; and $\sum M_{\ddot{\mu}}$ denotes the sum of mean scores of all REs or REGs.

It was then useful to ascertain the most critical risk event groupings (REGs) based on their membership functions. The membership functions of the REGs are determined from the membership functions of each RE using the percentage responses for the grades in the Likert scale for each risk event. For instance, the summary statistics showed that 21.1% of experts graded "design information gap between designer and manufacturer (RE9)" as moderately significant, 50.8% as significant and 28.1% as very significant. As such, its membership function (MF) is computed as:

$$\text{MF}_{(RE9)} = \frac{0.000}{VI(1)} + \frac{0.000}{I(2)} + \frac{0.000}{MI(3)} + \frac{0.000}{N(4)} + \frac{0.211}{S\,(5)} + \frac{0.508}{MS\,(6)} + \frac{0.281}{VS(7)} \quad (2)$$

This can also be expressed as MF $_{(RE9)}$ = (0.00, 0.00, 0.00, 0.00, 0.21, 0.51, 0.28).

Table 1. Mean scores and factor weightings of the MiC supply chain risk events

No.	Risk Events	Mean Score of REs	Weightings for each RE	Total MS for each REG	Weightings for each REG
RE1	Changes in the operation rate of modular factory	6.19	0.108		
RE2	Vertical & horizontal errors in fabricating modular elements	6.16	0.108		
RE3	Lack of lifting equipment at manufacturing plant	5.74	0.100		
RE4	Delays in modular materials procurement	5.26	0.092		
RE5	Mechanical malfunction of modular production equipment	5.11	0.089		
RE6	Misplacement of modules on storage site	5.86	0.102		
RE7	Poorly produced modules	6.18	0.108		
RE8	Geometric conflicts between components during manufacturing	6.09	0.106		
RE9	Design information gap between designer and manufacturer	6.07	0.106		
RE10	Shortage of modular Production materials	4.58	0.080		
REG1	**Modular manufacturing risk events**			**57.24**	**0.372**
RE11	Distance between the site and the module production factory	6.04	0.186		
RE12	Extreme weather disruptions	5.33	0.164		
RE13	Excessive approval procedures	5.65	0.174		
RE14	Logistic information inaccuracy	4.47	0.138		
RE15	Traffic, Congestion, transportation vehicle and road damage	4.39	0.135		
RE16	Delay in the delivery of modules	6.54	0.202		
REG2	**Logistics risk events**			**32.42**	**0.211**
RE17	Production schedules not reflecting site conditions	3.91	0.061		
RE18	Improper lifting equipment selection on the construction site	6.07	0.095		
RE19	Errors in modular connection on the site	6.33	0.099		
RE20	Rework due to discrepancy or interruptions between drawings	6.37	0.099		
RE21	Dimensional and geometric variability	5.81	0.091		
RE22	Change of project design or scope	5.77	0.090		
RE23	Modular elements installation error	5.61	0.087		
RE24	Tower crane breakdown or malfunction	5.60	0.087		
RE25	Slow quality inspection process	5.61	0.087		
RE26	Obscurity in identifying proper modular elements	5.09	0.079		
RE27	Inadequate planning and scheduling	5.37	0.084		
RE28	Inefficient verification of modules	2.63	0.041		
REG3	**On-site assembly risk events**			**64.17**	**0.417**
	Total Risk Events Grouping (REG)			**153.83**	

Following the same approach, the membership function for each RE was computed as shown in column four of Table 3. To compute the MFs of the REGs, the formula in step 5 of Figure 1 was used.

$$\mathrm{D_i} = W_i \circ R_i \quad (3)$$

Where D denotes the final evaluation matrix, W_i is the weightings for all REs under each REG and R_i denotes the membership function matrix for each REG.

Table 2. Risk events factor extractions and their loadings

No.	Risk Events	Factor Loadings	Eigenvalue	% of variance explained	Cumulative % of variance explained
	Modular manufacturing risk events		**11.146**	**39.807**	**39.807**
RE4	Delays in modular materials procurement	0.860			
RE5	Mechanical malfunction of modular production equipment	0.848			
RE10	Shortage of modular Production materials	0.815			
RE9	Design information gap between designer and manufacturer	0.771			
RE7	Poorly produced modules	0.728			
RE8	Geometric conflicts between components during manufacturing	0.682			
RE6	Misplacement of modules on storage site	0.611			
RE2	Vertical & horizontal errors in fabricating modular elements	0.597			
RE3	Lack of lifting equipment at the manufacturing plant	0.524			
RE1	Changes in the operation rate of modular factory	0.480			
	Logistics risk events		**3.151**	**11.255**	**51.062**
RE16	Delay in the delivery of modules	0.844			
RE15	Traffic, Congestion, transportation vehicle and road damage	0.825			
RE14	Logistic information inaccuracy	0.766			
RE11	Distance between the site and the module production factory	0.653			
RE13	Excessive approval procedures	0.646			
RE12	Extreme weather disruptions	0.587			
	On-site assembly risk events		**2.413**	**8.617**	**59.679**
RE27	Inadequate planning and scheduling	0.899			
RE28	Inefficient verification of modules	0.889			
RE17	Production schedules not reflecting site conditions	0.829			
RE24	Tower crane breakdown or malfunction	0.829			
RE26	Obscurity in identifying proper modular elements	0.800			
RE25	Slow quality inspection process	0.796			
RE22	Change of project design or scope	0.752			
RE21	Dimensional and geometric variability	0.718			
RE23	Modular elements installation error	0.664			
RE20	Rework due to discrepancy or interruptions between drawings	0.612			
RE18	Improper lifting equipment selection on the construction site	0.521			
RE19	Errors in modular connection on the site	0.521			

Note-Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser Normalization. Rotation converged in 8 iterations.

Table 3. Membership functions of Res and REGs

Code	Risk Events groupings (REG)	Weighting for REs	Membership Functions of Level 2 (REs)	Membership function of Level 1 (REGs)
	Modular manufacturing risk events (REG1)			(0.02 0.05 0.08 0.08 0.18 0.36 0.22)
RE4	Delays in modular materials procurement	0.092	(0.05 0.25 0.25 0.33 0.08 0.04 0.00)	
RE5	Mechanical malfunction of modular production equipment	0.089	(0.09 0.25 0.40 0.19 0.07 0.00 0.00)	
RE10	Shortage of modular Production materials	0.080	(0.05 0.09 0.28 0.23 0.19 0.14 0.02)	
RE9	Design information gap between designer and manufacturer	0.106	(0.00 0.00 0.00 0.00 0.21 0.51 0.28)	
RE7	Poorly produced modules	0.108	(0.00 0.00 0.00 0.00 0.19 0.44 0.37)	
RE8	Geometric conflicts between components during manufacturing	0.106	(0.00 0.00 0.00 0.04 0.14 0.53 0.29)	
RE6	Misplacement of modules on storage site	0.102	(0.00 0.00 0.00 0.02 0.32 0.46 0.21)	
RE2	Vertical & horizontal errors in fabricating modular elements	0.108	(0.00 0.00 0.00 0.00 0.21 0.42 0.37)	
RE3	Lack of lifting equipment at manufacturing plant	0.100	(0.00 0.00 0.00 0.09 0.32 0.37 0.22)	
RE1	Changes in the operation rate of modular factory	0.108	(0.00 0.00 0.00 0.02 0.09 0.58 0.31)	
	Logistics risk events (REG2)			(0.00 0.03 0.07 0.26 0.25 0.28 0.12)
RE16	Delay in the delivery of modules	0.202	(0.00 0.04 0.09 0.16 0.32 0.33 0.07)	
RE15	Traffic, Congestion, transportation vehicle and road damage	0.135	(0.02 0.04 0.14 0.42 0.18 0.16 0.05)	
RE14	Logistic information inaccuracy	0.138	(0.00 0.04 0.14 0.42 0.16 0.21 0.04)	
RE11	Distance between the site and the module production factory	0.186	(0.00 0.00 0.00 0.02 0.25 0.42 0.32)	
RE13	Excessive approval procedures	0.174	(0.00 0.02 0.07 0.47 0.23 0.11 0.11)	
RE12	Extreme weather disruptions	0.164	(0.00 0.02 0.02 0.16 0.32 0.40 0.09)	
	On-site assembly risk events (REG3)			(0.01 0.03 0.05 0.07 0.22 0.36 0.26)
RE27	Inadequate planning and scheduling	0.084	(0.00 0.02 0.09 0.07 0.37 0.25 0.21)	
RE28	Inefficient verification of modules	0.041	(0.21 0.25 0.37 0.07 0.09 0.02 0.00)	
RE17	Production schedules not reflecting site conditions	0.061	(0.05 0.09 0.28 0.23 0.19 0.14 0.02)	
RE24	Tower crane breakdown or malfunction	0.087	(0.00 0.02 0.04 0.12 0.21 0.37 0.23)	
RE26	Obscurity in identifying proper modular elements	0.079	(0.04 0.05 0.05 0.18 0.23 0.25 0.21)	
RE25	Slow quality inspection process	0.087	(0.00 0.00 0.04 0.11 0.30 0.33 0.23)	
RE22	Change of project design or scope	0.090	(0.00 0.02 0.00 0.04 0.33 0.37 0.25)	
RE21	Dimensional and geometric variability	0.091	(0.00 0.02 0.00 0.05 0.25 0.46 0.22)	
RE23	Modular elements installation error	0.087	(0.00 0.02 0.00 0.11 0.32 0.35 0.21)	
RE20	Rework due to discrepancy or interruptions between drawings	0.099	(0.00 0.00 0.00 0.00 0.07 0.49 0.44)	
RE18	Improper lifting equipment selection on the construction site	0.095	(0.00 0.00 0.00 0.00 0.14 0.51 0.35)	
RE19	Errors in modular connection on the site	0.099	(0.00 0.00 0.00 0.00 0.11 0.46 0.43)	

For instance, considering REG2- Logistics risk events (Table 1), the weightings for all the REs under this principal component (i.e. RE11, RE12, RE13, RE14, RE15, and RE16) can be expressed as:

$$W_2 = (0.186, 0.164, 0.174, 0.138, 0.135, 0.202) \text{ and } R=\begin{bmatrix} 0.00 & 0.00 & 0.00 & 0.02 & 0.25 & 0.42 & 0.32 \\ 0.00 & 0.02 & 0.02 & 0.16 & 0.32 & 0.40 & 0.09 \\ 0.00 & 0.02 & 0.07 & 0.47 & 0.23 & 0.11 & 0.11 \\ 0.00 & 0.04 & 0.14 & 0.42 & 0.16 & 0.21 & 0.04 \\ 0.02 & 0.04 & 0.14 & 0.42 & 0.18 & 0.16 & 0.05 \\ 0.00 & 0.04 & 0.09 & 0.16 & 0.32 & 0.33 & 0.07 \end{bmatrix}$$

Therefore, the membership function for REG2 is computed as:

$$D_2 = (0.186, 0.164, 0.174, 0.138, 0.135, 0.202) \times \begin{bmatrix} 0.00 & 0.00 & 0.00 & 0.02 & 0.25 & 0.42 & 0.32 \\ 0.00 & 0.02 & 0.02 & 0.16 & 0.32 & 0.40 & 0.09 \\ 0.00 & 0.02 & 0.07 & 0.47 & 0.23 & 0.11 & 0.11 \\ 0.00 & 0.04 & 0.14 & 0.42 & 0.16 & 0.21 & 0.04 \\ 0.02 & 0.04 & 0.14 & 0.42 & 0.18 & 0.16 & 0.05 \\ 0.00 & 0.04 & 0.09 & 0.16 & 0.32 & 0.33 & 0.07 \end{bmatrix}$$

D_2 = (0.00 0.03 0.07 0.26 0.25 0.28 0.12)

Using the same approach, the membership functions of the remaining REGs are computed and shown in column 5 of table 3. Given the membership functions for each REG, the criticality index (table 4) for each principal component was computed using the following equation:

$$\text{REG}_{\text{index}} = \sum_{i=1}^{5}(D * E) \quad (4)$$

Where, $\text{REG}_{\text{index}}$ is the index for each REG in the MiC supply chain, D & E remain as previously defined. The indices for all risk events groupings, their criticality level and ranking are shown in Table 4. The index for each REG is computed as follows:

REG1 = (0.02, 0.05, 0.08, 0.08, 0.18, 0.36, 0.22) x (1, 2, 3, 4, 5, 6, 7) = **5.28**
REG2 = (0.00, 0.03, 0.07, 0.26, 0.25, 0.28, 0.12) x (1, 2, 3, 4, 5, 6, 7) = **5.08**
REG3 = (0.01, 0.03, 0.05, 0.07, 0.22, 0.36, 0.26) x (1, 2, 3, 4, 5, 6, 7) = **5.58**

Table 4. Criticality Indices of the REGs in the MiC Supply Chain

No.	Factor groupings	Index	Criticality	Ranking
REG1	Modular manufacturing risk events	5.28	Very Critical	2
REG2	Logistics risk events	5.08	Critical	3
REG3	On-site assembly risk events	5.58	Very Critical	1

DISCUSSIONS OF THE RISK EVENTS GROUPINGS (REGs)

The fuzzy synthetic evaluation (FSE) generated 3 critical risk events groupings in the supply chain of MiC. From table 4, the on-site assembly risk events ranked first with a criticality index of 5.58, tailed by modular manufacturing risk events and then, logistics risk events with criticality indices of 5.28 and 5.08, respectively. These rankings offer relevant information to MiC practitioners and project managers on riskiest events within the MiC supply chain. This could assist them in prioritizing the group (s) of risk events which are deemed the most critical in the MiC supply chain.

On-site Assembly Risk Events

This risk events grouping explains 8.62% of the total variance of the factor analysis and was ranked first with a criticality index of 5.58. It was considered very critical on the 7-point Likert scale. This principal component has 12 sub-risk events. Of these, inadequate planning and scheduling (RE27) had the highest factor loading of 0.899 and scored a mean of 5.37. Inefficient verification of modules (RE28) had the second highest factor loading of 0.889. Production schedules not reflecting site conditions (RE17) and tower crane breakdown or malfunction (RE24) both had the third highest factor loading of 0.829 but scored means of 2.63 and 5.60, respectively. These risk events result in excessive schedule delays, reworks, quality problems and poor stability (Shahtaheri et al., 2017). The remaining risk events within this group are recipes for loss of assembly time and time overrun (Li et al., 2016, 2017, 2018).

Modular Manufacturing Risk Events

This risk events grouping accounts for 39.81% of the total variance of the factor analysis and was ranked second with a criticality index of 5.28. It was considered very critical on the 7-point Likert scale. This principal component has 10 sub-risk events. Of these, delays in modular materials procurement (RE4), mechanical malfunction of modular production equipment (RE5), shortage of modular production materials (RE10), design information gap between designer and manufacturer (RE9) and poorly produced modules (RE7) had the top 5 highest factor loadings of 0.860, 0.848, 0.815, 0.771, and 0.728, respectively. The success and suitability of the modular elements largely depend on the quality of modular design and specification. However, it is still a common practice for the design team to produce drawings 'behind the wall' and expect the manufacturer to interpret the specifications 'over the wall'. This unhealthy practice has triggered quality concerns as it generates problems of discrepancies for manufacturers (Li et al., 2017). Again, modular fabrication depends on the availability of the requisite paraphernalia and materials such as modular production equipment, materials etc. Thus, delays in procuring some of these materials could compromise the production of modules, resulting in schedule delays (Li et al., 2018). The impact could be multiplied if 'Just-in-Time' delivery arrangement is made (Kong et al., 2018). Also, in conditions where there are no safety modular production equipment, mechanical breakdown or malfunction of equipment could result in lower production output. Such malfunction would result in the inability to produce the scheduled number of modules for the given time frame, leading to possible schedule delays (Li et al., 2018). The remaining risk events within this grouping had factor loadings less than 0.7 and may not be equally important.

Logistics Risk Events

This risk events grouping explains 11. 26% of the total variance of the factor analysis and was ranked third with a criticality index of 5.08. It was considered critical on the 7-point Likert scale. This component has 6 sub-risk events. Of these, delay in the delivery of modules (RE16) had the highest factor loading of 0.844 followed by 'traffic, congestion, transportation, vehicle, and road damage' (RE15) and Logistic information inaccuracy (RE14) having factor loadings of 0.825 and 0.766, respectively. The last three include distance between the site and the module production factory (0.653), excessive approval procedures (0.646) and extreme weather disruptions (0.587). For reasons such as extreme weather disruptions, unavailability of truck drivers, traffic congestion as well as transport vehicular and road damages, the delivery of modules could be delayed significantly. Such delays have triggered significant additional cost in the six-day cycle assembly of prefabricated public housing projects in Hong Kong (Li et al., 2018). Excessive approval procedures could lead to schedule delays and the logistics information inaccuracy may result in the delivery of inappropriate modules or to the wrong place (Li et al., 2018; Li et al., 2013).

CONCLUSION

The study investigated the risk events in the MiC supply chain. It identified and assessed the criticality of 28 risk events across the manufacturing, logistics and on-site assembly segments of the MiC supply chain. A principal component analysis generated 10, 6 and 12 risk events within the manufacturing, logistics and on-site assembly segments, respectively. An FSE modeling revealed that the on-site assembly risk events are the most critical set of risks events with a criticality index of 5.58, followed by the modular manufacturing risk events (5.28) and logistics risk events (5.08). These rankings and criticality assessment have profound implications for MiC practice. Practitioners may prioritize the riskiest events to improve the performance of MiC. Again, the paper contributes to the extant literature on the risk of MiC and may form the basis for future studies on the risk of MiC. However, a generalization of the results is constrained owing to the smaller sample size which may not reflect the global perspective. Notwithstanding, the results are reliable based on statistical assessments.

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