

Prioritizing Operational Concerns of Crane Operator Training for Modular Integrated Construction

Qianru DU¹, Hung Lin CHI², Xiao LI³, and Geoffrey Q.P. SHEN⁴

¹ Ph.D. Student, Department of Building and Real Estate, Department of Building and Real Estate, Hong Kong Polytechnic Univ., Hung Hom, Kowloon, Hong Kong SAR. E-mail: 18042807r@connect.polyu.hk

² Research Assistant Professor, Department of Building and Real Estate, Department of Building and Real Estate, Hong Kong Polytechnic Univ., ZS706, Hung Hom, Kowloon, Hong Kong SAR. E-mail: hung-lin.chi@polyu.edu.hk

³ Ph.D., Department of Building and Real Estate, Department of Building and Real Estate, Hong Kong Polytechnic Univ., ZN1004, Hung Hom, Kowloon, Hong Kong SAR. E-mail: shell.x.li@connect.polyu.hk

⁴ Chair Professor, Department of Building and Real Estate, Department of Building and Real Estate, Hong Kong Polytechnic Univ., ZS732, Hung Hom, Kowloon, Hong Kong SAR. E-mail: geoffrey.shen@polyu.edu.hk

ABSTRACT

Due to the increasing adoption of prefabricated structures/components in the construction industry, the significance of using construction cranes for on-site installations is gradually increasing. As a result of the large size and bulky shape of the prefabricated components, the proper lifting and installation with cranes require better skills and proficiency from crane operators, compared with those performed through traditional cast-in-situ methods. Hence special requirements are needed on the operator training scheme. This paper investigates the operational concerns which a skilled crane operator would take into consideration in the Modular

Integrated Construction (MiC) environment. Semi-structured interviews were conducted to verify and rank the concerns with experts, including both operators and training tutors. The outcome reveals that "Overhead" is the top concern during the operating stage, followed by "High Payload," "Blinding Lifting," "Change of Direction," and "Short Path." By addressing these operational concerns in training, trainees can be better prepared to avoid the related problems in the lifting of complicated module units. In addition, discrepancies were found in the interview feedback between the tutors' group and the operators' group. The findings of this research will contribute to not only the existing MiC crane training scheme but also the future crane operators workmanship considering constraints incurred by the modules while implementing this advanced construction method in Hong Kong industry.

INTRODUCTION

Design for Manufacturing and Assembly (DfMA), a concept traced back in the 1970s, is a practice of designing products with manufacturing issues considered at the early stage to shorten product development time and ensure a smooth transition from design to manufacture (Bayoumi 2000). Building Construction Authority (BCA) in Singapore quoted the concept to be a construction practice. It refers to the construction that is designed and detailed for a substantial portion of work to be done off-site in a controlled manufacturing environment by dividing the structural elements into different components, fabricating them and then transporting to the site for the installation (BCA 2017). This concept has been implemented in the Hong Kong construction projects through the use of prefabricated components, such as precast façade, staircase, ground floor water tank,

panel wall, semi-precast slab, and volumetric precast bathroom. The Modular Integrated Construction (MiC) system is introduced as well, as the ultimate form of the concept of DfMA (Housing Authority 2019; Pan and Hon 2018). These modular units often impose more substantial loadings to the cranes than traditional construction materials or prefabricated components. It can even reach 15 to 20 tons for a steel module while 20 to 35 tons for a reinforced concrete one (BCA 2017). The heavy load, together with the large size and bulky shape of the modular units, raises many challenges for the corresponding lifting work to be performed accurately and timely.

Comparing with other industries, the construction industry still performs unsatisfactorily in safety aspect around the globe. In the UK, construction has caused 30 workers' fatal injuries between 2018 and 2019, ranked second place in terms of fatality and injury numbers among all industries (HSE 2019). Hong Kong has a similar safety risk in construction, given that the city is well-known for the compact living space and congested construction site. According to the statistics published by the Transport and Housing Bureau (THB), the average living space per public housing tenant is 13.3 m² in 2018 (THB 2018). Due to the congested space, injuries and fatalities in construction ranked number one among all industries in Hong Kong (Labour Department 2018). Three fatalities were identified related to the crane operation as shown in Table 1. These unsatisfactory working conditions and safety performance would increase the difficulty to hoist the large and bulky MiC modules.

Table 1. Fatalities of Crane Operation in Hong Kong in 2017

Date	Crane Type	Detail
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Dec 2017	Tower Crane	Due to the uneven center of gravity, the component fell off the hook after lifting. The deceased was working under the lifting area. (hk01.com 2017)
Nov 2017	Tower Crane	The cable was broken, and the component suddenly fell from height. (on.cc 2017a)
Jan 2017	Mobile Crane	The jib suddenly fell down. (on.cc 2017b)

Facing many fatalities in the local construction industry including the ones related to crane operation, the Construction Industry Council (CIC) established the Hong Kong Institute of Construction (HKIC) in 2017 to provide the complete personnel education and construction site practice training. The training aims to promote a culture of industrial safety awareness as well as to increase workers' professional skills. Training crane operators with profound skills to deal with the increasingly sophisticated component lifting is one of the key tasks for CIC to achieve in mitigating the safety incidents into the minimum. In this connection, facing the safety hazards in crane operation, particularly for MiC projects, it would be highly important to identify operational concerns when operating cranes with large lifting components and address those concerns in the further training scheme. The objectives of this research are to (1) consolidate and identify the concerns that crane operators often take into consideration; (2) verify the concerns by expert interviews; and (3) prioritize the concerns to facilitate the training of operators' decision making when encountering complex lifting problems in practice.

REVIEW OF CONCERNS IN CRANE OPERATION

According to the Cambridge dictionary (Cambridge University 2019), "concern" reflects "a worried or nervous feeling about something" in linguistics. It indicates a subjective view of the potential risk according to personal judgment. Therefore, to consolidate comprehensive potential concerns to the crane operator, this paper conducts a literature review on both the research domain and the regulations/guidelines in the local industry to enhance the practicality. Expert group interviews were conducted to further verify the summary.

The review is based on a broad search on the articles, books, theses that are related to the keywords "crane operation concerns" , "crane operation risks" and "crane fatalities". Among the results, Shapiros (2000) categorized the potential risks in crane operation into 9 macro levels. These risks include all construction parties from the designer to the frontline operators. MacCollum (2005) narrowed down the potential risks to the operation level by identifying 23 risks associated with most cranes. These risks can be categorized into four aspects: machinery issues, preparation works, inspection, and operational risks. Seven risks fell into the operational risks aspect including a) blind lifts; b) dropping of removable weights; c) lack of control; d) pinch point; e) swinging objectives; f) two-blocking; and g) upset due to overloading.

As for the practical regulation and guideline review, a consolidation about the searching results from the statutory departments including Labors Department (LD), Buildings Department (BD), as well as the expert advice was adopted. Compulsory regulations must be followed throughout the crane operations in Hong Kong. Legislation Cap 59I, Construction Sites (Safety) Regulations (Department of Justice 2006a), mandates the safe use of the crane (hoist) and the securing of the

loads on it through Part II to V. Legislation Cap 59J, the Factories and Industrial Undertakings (Lifting Appliances and Lifting Gear) Regulations (Department of Justice 2006b), regulates the application of the appliances, chains, ropes, gears in using cranes in Hong Kong. Another two compulsory regulations in Hong Kong are related to the operation side and named "Code of Practice for Safe Use of Tower Cranes" (COPTC) and "Code of Practice for Safe Use of Mobile Cranes" (COPMC). The CIC also published a recommendatory "Guidelines on Safety of Tower Crane" to provide an additional reference on good practices to enhance construction tower crane safety in terms of appliance checking, site supervision, and operational personnel's qualification. In Legislation Cap 59J and 59I, essential requirements for the lifting appliance, chains, ropes, and gears are specified. Riding on the essential requirements, the COPTC and COPMC further describe the safe working loading and operation conditions to be complied with during on-site operations. Since the Cap 59J and 59I focus on the setting up and general descriptions, the mandatory operational requirements should be consolidated from the COPTC and COPMC. Together with the requirement details abstracted from the COPs, several concern aspects were further summarized and listed in Table 2 (COPTC 2011; COPMC 2017).

Table 2. Operational Regulative Requirements and Corresponding Concerns

COPTC Requirements	COPMC Requirements	Summarized Concerns
Mode of operation and control	Mode of operation and control	Clear view and control stability
Safe working loads	Safe working loads	Safe working loads
-	Near maximum working loads	Safe working loads
Handling of loads near persons	-	Crossover and overhead
-	Traveling with suspended loads	Suspended loading
Carrying of persons by crane	Carrying of persons by crane	Carrying of persons by crane
Communication system	Communication system	Communication system
Weather conditions	Weather conditions	Weather conditions

After consolidating the potential concerns from both academic research works and the industry regulations, five concerns of the operational risks are selected according to the repeated appearance from different works of literature shown in Table 3. Among the concerns consolidated, weather conditions are not included in this study since the crane operation should be suspended if Typhoon

Signals or other extreme weather notifications are effective (Labour Department 2019).

Table 3. Crane Operational Concerns in Hong Kong

Category	Operational Concerns	Description
Safety	Blind Lifting	Preference not to perform rigging within the region of the construction site where cannot be visually monitored
	High Payload	Preference not to operate rigging activities across the zones with high loading capacity required (high rigging moment)
	Overhead and Crossover	Preference not to move across over the surrounding buildings, workers, construction equipment, etc.
Productivity	Short-Path	Preference to move the lifting object along with the lifting trajectory with minimized distance to the destination
Effectiveness	Change Direction	Preference not to change the direction of rigging too many time (frequently)

METHODOLOGY

The research is designed into four phases as shown in Figure 1.

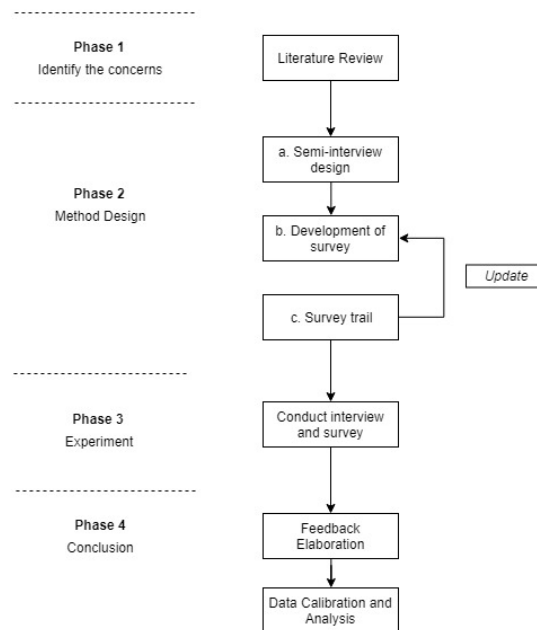


Figure 1. The Flow of the Research Development

The main purpose of this research is to verify and prioritize the usually subjective operational concerns into a categorized concern list for easy reference in the future operation training process. To achieve this, a semi-structured interview with two expert groups (the experienced operators and crane training tutors) is designed to verify the concerns on the list. Furthermore, during the correspondence with the experts in the semi-structured interview, other concerns which may not be revealed in literature can be supplemented in a qualitative way (Galletta 2013). The interview is divided into three parts: (a) the background investigation of the experts; (b) verification and sequence of the concerns; (c) investigation on other concerns and their essentials, which are not included in concern list used by the interview. Inspired by the NASA-Task Load Index, the concerns are compared in pairs to show

relative importance due to the subjectivity of the task (Hart and Staveland 1988). The survey, in comparison format, was conducted via a computer program with 15 "one or the other" choices to minimize the answers' randomness as well as the interviewee's effort to answer.

RESULTS ANALYSIS

General Information

The interview covered two groups of industry experts, namely experienced operators and the crane training tutors in the HKIC. Totally eight experts were invited to interviews regarding the concerns of crane operation. The experts' background information is shown in Table 4. All operators and tutors are working in the frontline of the construction crane operation in Hong Kong . The interviewees are all male for both the operators and the tutors.

Table. 4 Experts' Background Consolidation

	3-5 Years	5-10 Years	> 10 Years
Number of Experienced Operators	1	1	3
Number of Crane Training Tutors	/	/	3

The interviews are designed for the operators and the tutors separately. All

interviewees were invited to express their views on how the concerns may affect the MiC lifting procedure. In the skilled operator group, all interviewees expressed their opinions on the concerns listed. Four experts shared that the selected concerns are of high importance in the daily operation process. One opined that the list could cover the concerns related to the hoisting period. Apart from the concerns provided in the interview, the skilled operators supplemented the loading swing problems, the loading and the crane types as additional important concerns that should be taken into consideration.

On the other hand, in the training tutor group, it was mentioned that the operation angles would be a critical concern during the hoisting period. It was further suggested that crane operators are recommended to foster a good practice to stand by to brake the crane during the operation in order to swiftly stop the crane from suffering from potential hazards. In addition, communication with other workers and the signaler also plays an important role in safe crane operation.

Data Analysis

To mitigate the accidental deviation and the individual factors, the quantitative interview data obtained were firstly checked by two-side Grubbs' test to see if there are outliers in the feedbacks (Grubbs 1950). The Grubbs' test starts with the calculation of:

$$G = \frac{|Y_i - \underline{Y}|}{s} \quad (1)$$

where \underline{Y} denotes the sample mean, and s denotes the standard deviation.

Then, check:

$$G > \frac{(N-1)}{\sqrt{N}} \sqrt{\frac{t_{\alpha}^2}{2N} \frac{N-2}{N-2 + t_{\alpha}^2}} \quad (2)$$

where t denotes the upper critical value of the t-distribution. If the condition listed above is valid, outliers are considered to exist, and the testing dataset would be rejected. In such cases, data entries shall be removed and the remaining dataset to be tested again until the dataset that passes the test is derived. It thus can be considered as an outlier-free one.

After analyzing the interview feedbacks from the experts, no data shall be ticked out, which also confirms the consistency of the experts' opinions.

Findings

Figure 2 represents the weights on the major concerns for the crane operators to be considered on-site. Five major concerns are further divided into three groups as classified in Table 3. The "Blind Lifting", "Overhead", and "High Payload" are categorized as major ones influencing "Safety" while the "Short Path" concern affects the "Productivity". "Change Direction" concern would influence the operational "Effectiveness" during the operation. Figure 3 and 4 demonstrate the weights on the concerns obtained from the experienced operators and the crane training tutors, respectively.

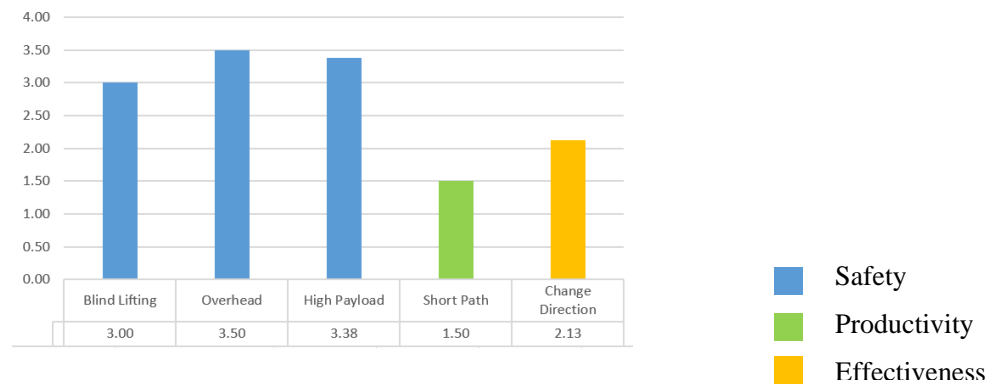


Figure 2. Concerns Weighting Results from Overall Interviews

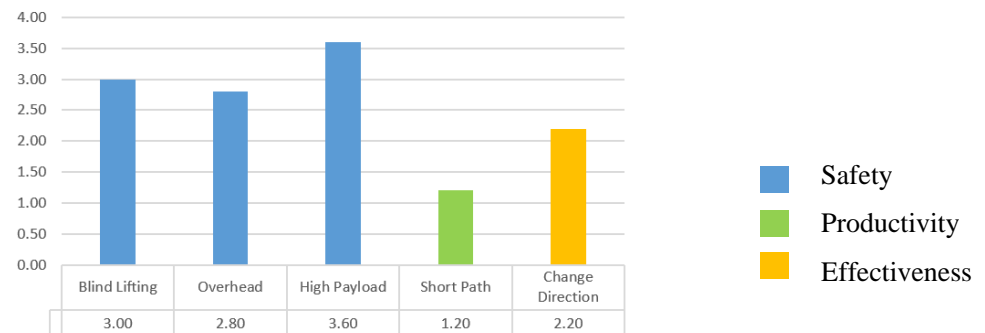


Figure 3. Concerns Weighting Results from Experienced Operators

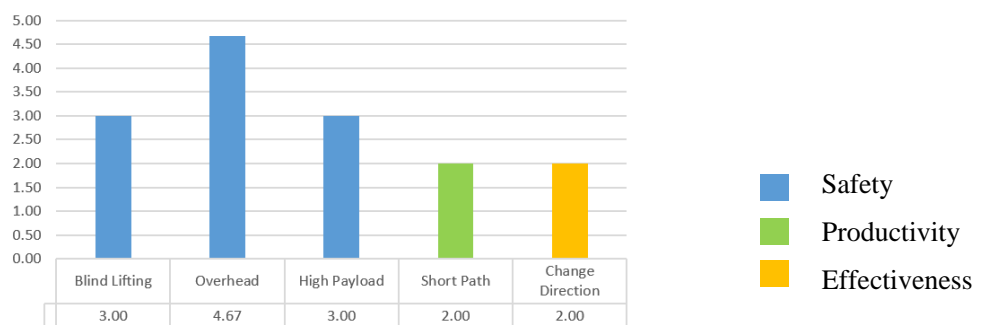


Figure 4. Concerns Weighting Results from Crane Training Tutors

Four major findings can be summarized from the overall verification as follows:

1. In general, the "Safety" category ranks the top among the three categories with an average weight of 3.29. Both the experienced operators and crane training

tutors deemed it to be the first priority to be considered when operating cranes on-site. The category "Productivity" earns relatively less weight, ranking at the last place. This is because the efficiency for MiC module lifting is already higher than the traditional construction methods, thus productivity would be relatively less considered. On the contrary, MiC modules sometimes can reach 3.1m (width) times 8.75m (length) in size and 20 to 30 tons in weight (Buildings Department 2019; BCA 2017), hence the safety control of the MiC modules during lifting would be more of a concern.

2. Among all individual concerns, "Overhead" concern should be paid the most attention, with weight as high as 3.5. "High Payload," rating at 3.375, ranks the second place among all concerns though experts further commented that the existing cranes have a payload monitoring system to aware the operators if the loading has been exceeded. "Blind Lifting" gets the third place but still has a weight of 3, which is far beyond the "Change Direction" (weighted 2.125) and "Short Path" (weighted 1.5). The priority sequence of all concerns can be concluded as follows:

$$\begin{aligned} & \textit{Overhead} > \textit{High Payload} > \textit{Blind Lifting} > \textit{Change Direction} \\ & > \textit{Short Path} \end{aligned}$$

In the hoisting of the MiC modules, though it is less likely for the workers to work directly under the lifting path, the modules will still fly over plenty of riggers responsible for configuring the modules' direction and position. Moreover, since the size and shadow area of the modules would be larger than conventional construction materials, the falling hazards shall be more severe to the underneath

which incurred that “Overhead” became the most important concern. "High payload" should also be a great concern to the MiC hoisting due to the heavy loading of the module itself.

3. From the interview results by different groups, it is worth mentioning that the rankings are slightly different between the experienced operator group and the crane training tutor group.

Experienced operators showed great concerns on "High Payload" and followed by "Blind Lifting". "Overhead" scored the third place by 0.2 points less than the "Blind Lifting." The overall ranking of the experienced operator group could be seen below:

$$\begin{aligned} & \textit{High Payload} > \textit{Blind Lifting} > \textit{Overhead} > \textit{Change Direction} \\ & > \textit{Short Path} \end{aligned}$$

On the other hand, "Overhead" was assessed to be the highest-ranked concern with a weight of 4.67 by crane training tutors. "Blind Lifting" and "High Payload" had the same rating of 3.5, while "Change Direction" scored the same as "Short Path" as 2. The ranking from the crane training tutors was summarized as follows:

$$\begin{aligned} & \textit{Overhead} > \textit{High Payload} = \textit{Blind Lifting} > \textit{Change Direction} \\ & = \textit{Short Path} \end{aligned}$$

4. Apparent deviations between the experienced operators and the crane

training tutors on the concerns weighting is seen from the interview feedbacks. In addition, the average weight of all five concerns obtained from experienced operators is 2.56, less than 2.93 averaged from the crane training tutors. This reveals that the concern awareness of the operators on-site is lower than the tutors who trained the potential labor in the institute. The deviations maybe because of the focus variation between teaching and practicing in the real construction site. On one hand, the tutors may intentionally pay more attention to safety to form a better habit for the trainees, while the practitioners intentionally focus more on practical matters, for instance, to take as much payload as the crane could to pursue profit. On the other hand, such differences may be unintentional: either because the tutors failed to catch up with the recent development on techniques and demands of the industry, or the practitioners, with years of experience, became sloppy on safety-related matters.

CONCLUSION

This paper identified five essential concerns in daily crane operations by comprehensively reviewing literature both from the research papers and practical guidelines in the Hong Kong construction industry. The concerns were verified and rated through interviews, subsequently ordered as (1) Overhead; (2) High Payload; (3) Blind Lifting; (4) Change Direction and (5) Short Path. It is revealed that concerns related to "Safety" are of high priority in a sophisticated working environment. For other categories, "Effectiveness" has a stronger influence on the crane operator's action than those affected by "Productivity."

Also, deviations were found in the interview results between the experienced operators and crane training tutors, which may be caused by (i) the

tutors pay more attention to the safety aspects to foster the safety awareness of the practitioners; (ii) discrepancies do exist between the training school and on-site practice which may require the knowledge catch-up of the tutors or the safety awareness increase from the practitioners. Regarding the finding of the deviation between training and practice, it is worth exploring the roots that lead to such cognitive difference between the tutors and workers in future works to upgrade the existing crane operator training, in particular in lifting MiC modules.

In summary, this paper identified the essential concerns during on-site crane operation into three categories and further prioritizes the individual concerns as well as the categories via experts' interviews. The findings can help the training tutors as well as the apprenticeship to quickly identify and cope with problems encountered in the lifting of complicated module units. By considering these findings, the crane operators can be better prepared, which can potentially shorten the decision-making time, and improve the crane operation accuracy. The findings not only provide an essential and critical reference to the design of training framework but also stipulate incisive starting points to develop the intelligent crane system in delivering and hoisting the MiC modules, which needs complex crane operation related decision making from time to time.

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