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Multi-Objective Optimization of Tower Crane Layout Planning in Modular Integrated Construction Considering Efficiency, Cost, and Lifting Safety

Fangzheng LI[1], Hung-Lin CHI[1], Rongyan LI[1], Roy Dong Wang[1], Tarek Zayed[1], and Bo Xiao[2]
[1] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong, SAR.
[2] Department of Civil, Environmental, and Geospatial Engineering, Michigan Technological University, USA.
fangzheng.li@connect.polyu.hk, hung-lin.chi@polyu.edu.hk, rongyan.li@connect.polyu.hk, dongcq.wang@connect.polyu.hk, tarek.zayed@polyu.edu.hk, boxiao@mtu.edu

Abstract

With the increase of modular integrated construction (MiC) projects, the planning of tower crane layout (TCLP) becomes vitally essential to achieve a balance among multiple goals, such as efficiency, economy, and safety. However, existing TCLP studies are usually formed as single-objective optimization based on total lifting time for conventional construction sites. There should be trade-offs among multiple goals, especially safety. In addition, the heavier components of MiC, requiring cranes with larger lifting capacity, pose a challenge in terms of cost. Therefore, it is necessary to propose a more general and reasonable model to assist managers in making better decisions for TCLP. This study aims to develop a multi-objective optimization model with efficiency, cost, and lifting safety considerations for MiC projects. Firstly, based on literature research and accident statistics, the total transportation time, total cost of tower cranes, and total lifting moment are chosen as the three optimization objectives. Then, the improved three-objective optimization model, considering module positioning time and separate movement features of tower cranes, is proposed. To solve the proposed multi-objective problem, the evolutionary algorithm NSGA-III is used for solutions. The proposed model can provide a series of trade-off solutions for efficiency, cost, and safety, representing different combinations of crane location, supply point location, and orientation. A MiC project in Hong Kong is studied as a case to verify the feasibility and effectiveness of the proposed model. The results show that the proposed model can

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determine the optimized layout plan with minimum time, cost, and lifting moment by locating the tower crane point, supply point, and supply point orientation. Disregarding the orientation of the supply point would result in an additional 18.2% transportation time, leading to increased costs. Compared to the original layout scheme, the developed model can save up to 41.7% in transportation time and improve safety by 27.4%.

1 Introduction

In Sep 2022, a fatal work accident occurred at a construction site in Hong Kong. A tower crane collapsed and struck a nearby office, resulting in the death of three employees and injuries to six employees (Labour Department Hong Kong 2022). The seriousness and danger of tower crane accidents are highlighted. Tower cranes, as one of the main vertical transportation equipment on construction sites, play a vital role in building construction, especially high-rise ones. However, it is estimated that tower crane-related accidents have occurred regularly in Hong Kong in the last 10 years, and more than 100 accidents occur globally each year. Construction crane safety has become one major concern of the Labour Department of HKSAR (Chen et al. 2022; Tam and Fung 2011). Accidents involving tower cranes not only threaten the lives of construction workers but also bring significant economic losses and schedule delays to construction projects. Therefore, strengthening the safety management of tower cranes and preventing and reducing accidents have become important remedies for the construction industry.

Modular integrated construction (MiC) has emerged as a cutting-edge and transformative technology in the construction industry in recent years (Darko et al. 2020). This innovative approach offers several distinct advantages over traditional construction methods. Firstly, MiC has the potential to reduce construction time by up to 30% (Tsz Wai et al. 2023). Secondly, the controlled factory environment and standardized manufacturing processes inherent in MiC ensure enhanced construction quality and precision. Thirdly, MiC greatly improves the working conditions and safety of construction sites. Furthermore, MiC aligns with the principles of sustainable development by promoting energy efficiency and reducing emissions.

The adoption of MiC in Hong Kong has been on the rise, with its application extending to various projects such as public housing, schools, and dormitories. Despite its growing popularity, MiC technology is still in its nascent stages, presenting much room for further improvement and refinement. The cornerstone of on-site operations in MiC projects, particularly in high-rise buildings, lies in the installation of heavy-duty modules using tower cranes. Consequently, meticulous planning and optimization of tower cranes are paramount to ensure the smooth execution and success of MiC projects.

Tower crane layout planning (TCLP) is a key issue in construction site layout planning, aiming at determining the optimal tower crane layout scheme based on specific objectives and constraints in a complex construction environment. Optimal tower crane layout planning is of utmost importance for both conventional and modular construction projects. However, the inherent characteristics of MiC projects necessitate the development of a more general and reasonable model. The unique requirements of MiC, such as the need for precise module installation, the handling of heavy-duty components, and crane movement patterns, demand a tailored approach to tower crane planning. Specific challenges posed by modular construction should be taken into account, ensuring that the tower crane layouts are optimized to maximize efficiency, minimize costs, and guarantee the safe execution of the project.

Zhang et al. (1999) established the hook travel model for tower cranes, which laid the foundation for evaluating the travel time of tower cranes. Genetic algorithm and mixed-integer linear programming (MILP) were used to optimize the tower crane location in most later studies (Huang et al. 2011; Huang and Wong 2018; Tam et al. 2001). Zhang and Pan (2021) established the criteria considering high-rise MiC features and developed a two-step framework using a fuzzy-AHP-TOPSIS approach to optimize the tower crane layout. Unlike most studies that adopt the optimization-based approach, agent-based simulation (Younes and Marzouk 2018) was used to minimize operation time considering conflicts. BIM and VR-prototyping were used for planning interaction, avoiding clashes, and facilitating the decision-making process (Wang et al. 2015; Zhang and Pan 2021). The emergence of the GAN-based deep learning method using image-to-image translation greatly simplifies the decision-making process of TCLP (Li et al. 2023). However, existing TCLP studies are mostly about single-objective optimization based on total lifting time for conventional construction sites. Improving the existing models to meet the demand of MiC should be considered. The heavier components of the MiC require cranes with larger lifting capacity, safety, and cost should be put more emphasis on in addition to efficiency.

To fill the gaps in the current research and to address the realities in MiC, this paper develops a multi-objective optimization model with proper safety considerations for MiC projects and assists managers in making better decisions for TCLP. This study aims to provide the main contractors of MiC projects with a range of alternative tower crane layout plans. These plans offer multiple solutions that address the trade-offs among efficiency, cost, and safety. By presenting a variety of options, project managers can make informed decisions and select the optimal layout plan based on their specific project requirements and priorities.

2 Method

List of symbols	
N	Total number of modules to be lifted
I	Total number of potential tower crane locations
J	Total number of potential supply points
K	Total number of demand points
n	ID of module $n \in N$
i	ID of tower crane locations $n \in N$
j	ID of potential supply points $j \in J$
k	ID of demand points $k \in K$
α	Coordination degree of trolleying and jib slewing
β	Coordination degree of hook movements in vertical and horizontal planes
γ	Safety factor to ensure a safety redundancy (e.g., 0.9)
w_n	Weight of *n*th module (t)
(X_{Ci}, Y_{Ci}, Z_{Ci})	Coordinate of *i*th tower crane location
(X_{Sj}, Y_{Sj}, Z_{Sj})	Coordinate of *j*th supply point
(X_{Dk}, Y_{Dk}, Z_{Dk})	Coordinate of *k*th demand point
V_h	Hoisting velocity of hook (m/min)
V_ω	Slewing velocity of jib (rad/min)
V_r	Radial velocity of trolley (m/min)
V_{ro}	Rotation velocity of hook for positioning a module (rad/min)
$T^i_{\omega(j,k)}$	Time for tangential movement of jib
$T^i_{r(j,k)}$	Time for radial movement of trolley

$T^{i}_{h(j,k)}$	Total horizontal movement time
$T_{v(j,k)}$	Total vertical movement time
$T^{i}_{ro(j,k)}$	Time for positioning a module
$T_{j,k,i}$	Total hook travel time

2.1 Problem Statement and Assumptions

The TCLP problem is formulated as a multi-objective problem with the aim to maximize efficiency, minimize costs, and maximize lifting safety. For information on a given construction site, the site is first simplified into a drawing with pre-determined demand, supply, and candidate tower crane locations. The data provided will be input into the optimization model developed. The model is then solved using a genetic algorithm.

In the model, the type of tower crane is given, with known crane configurations such as load charts and velocities. Available locations to set up the tower crane and areas for storing modules were pre-determined, and information on module requests, such as positions and weights, was provided. The model was proposed based on the following assumptions:

(1) The module is provided in one supply location, and the orientation of the supply location represents that of the module.

(2) The available areas for the module supply point and tower crane are pre-defined based on site conditions.

(3) Only one tower crane is considered, which can be assigned to any of the available tower crane locations.

2.2 Proposed mathematical model

Time and cost are the single objectives selected for optimization in most of the current literature, so they are selected in this paper as the first two optimization objectives. The total cost of a tower crane is assumed to be the sum of the fixed and operation costs for that crane model. In addition, the lifting moment is adopted as an indicator of safety based on literature research, accident reports, and expert interviews. The establishment of each goal will be discussed specifically below:

(1) Total transportation time and total cost

Transportation time has been consistently adopted as a primary optimization objective in crane layout optimization studies. This metric represents the total operation time required to complete all element transportation tasks from supply point(s) to demand point(s), indicating crane transport productivity. Zhang's model for calculating hook travel time has been extensively utilized. This model takes into consideration the tower crane's three degree-of-freedom motion pattern (radial, horizontal, and vertical), as shown in Figure 1.

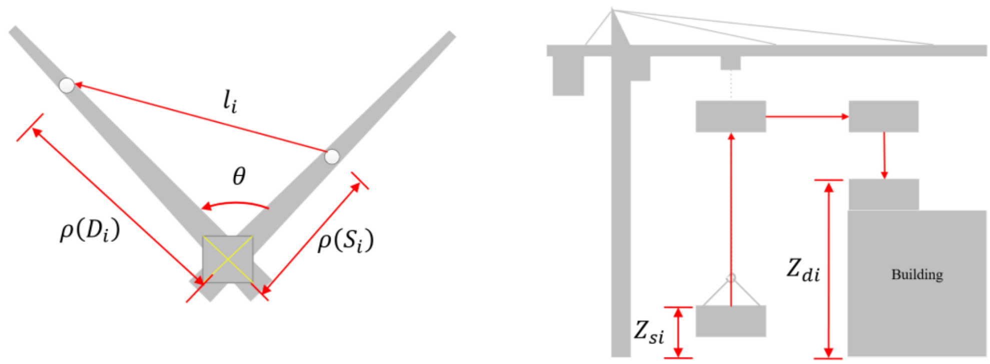

Figure 1: Mathematical model of tower crane radial, horizontal, and vertical movements

For modular construction, since the modules need to be transported precisely to their final location and installed, the orientation of the modules needs to be rotationally aligned before the final lift-off, as shown in Figure 2. The final positioning angle of the module can be obtained from the orientation of the supply point, the angle of the module at the demand point, and the horizontal rotation angle of the tower crane, as shown in Eq. (6). TCLP should fully simulate the features of MiC, such as crane movement pattern (move the trolley first and then rotate the jib (or vice versa)) and rotation for the module positioning.

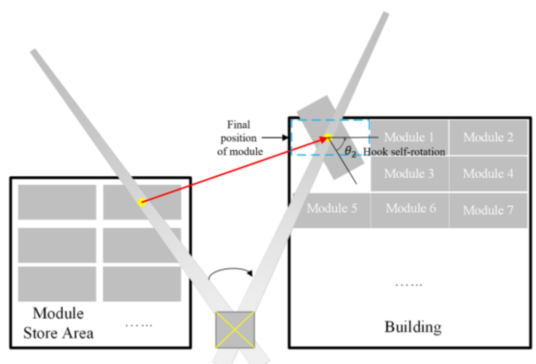

Figure 2: Tower crane module positioning for modular construction

In this study, the time consumed for the module positioning module is appended in Zhang's model to more accurately characterize lifting in MiC. When the lifting of a module starts, the operators often move the trolley first and then rotate the jib (or vice versa) in MiC. As a result, the coordination degree α and β equal to 1.0 for modular element lifting. The traveling time for a module can be obtained using Eq. (7).

$$T^i_{r(j,k)} = \frac{\left|l_{i,j} - l_{i,k}\right|}{V_r} \quad (1)$$

$$T^i_{\omega(j,k)} = \frac{1}{V_\omega}.\arccos\ \theta^i_{\omega(j,k)} \quad (2)$$
$$[0 \leq \arccos\,(\theta) \leq \pi]$$

$$T_{v(j,k)} = \frac{\left|Z_{Sj} - Z_{Dk}\right|}{V_v} \quad (3)$$

$$T^i_{h(j,k)} = max\left(T^i_{r(j,k)}, T^i_{\omega(j,k)}\right) + \alpha min\ (T^i_{r(j,k)}, T^i_{\omega(j,k)}) \quad (4)$$

$$T_{sd} = max\left(T^{i}_{h(j,k)}, T_{v(j,k)}\right) + \beta min\ (T^{i}_{h(j,k)}, T_{v(j,k)}) \tag{5}$$

$$T^{i}_{ro(j,k)} = \frac{1}{V_{hr}}.\left|\theta_{Dk} - \theta_{S} - \theta^{i}_{\omega(j,k)}\right| \tag{6}$$

$$T_{j,k,i} = T_{sd} + T_{ro} \tag{7}$$

Thus, the objective function of minimizing total transportation time is shown in Eq. (8).

$$min\, TT = min \sum_{j}^{J} T_{j,k,i} \tag{8}$$

After obtaining the total transportation time, the cost can be calculated. For a given type of tower crane, the cost can be simplified into two parts: operation costs and fixed costs. The operation cost equals the total transportation time *TT* multiplied by unit time cost *C*. The fixed cost C_f incorporates the delivery, assembly, maintenance, and disassembly fee of the tower crane. Thus, the objective function of minimizing total cost is shown in Eq. (9).

$$min\, TC = min \sum_{j}^{J} T_{j,k,i}\, .\, C + C_f \tag{9}$$

(2) Total lifting moment

The lifting moment of a crane is an essential safety consideration for enhanced operation safety (others include working conditions and crane stability). Project managers often choose the lifting moment and the lifting capacity to select the tower crane configurations. This ensures the safety of using the tower crane while controlling the rental costs. However, the lifting moment can either raise or lower the support reaction of the tower crane base, so it is inseparably linked to the safety of tower crane operation.

The high weight and size of the modular components impose higher requirements on the safety of the tower crane for module lifting. This is to prevent the tower crane from overturning and to ensure the safety of module lifting. The lifting moment equals the product of the module weight and the tower crane's working radius. It induces the force of rotation around the axis of a tower crane. Structural failure and collapse may occur if the selected crane capacity does not satisfy the maximum lifting moment. Hebiba et al. (2022) used total lifting moments and total hook travel time as two optimization objectives to select an optimal crane location and supply locations, and the effectiveness of the proposed methodology is validated by a case study. As a result, the lifting moment *LM* is chosen to represent safety in this study. The lifting moment *LM* is calculated by Eq. (10), based on a single crane location associated with supply and demand locations. The lifting supply moments and lifting demand moments can be obtained from Eq. (11). Thus, the objective function of minimizing the total lifting moment is shown in Eq. (12).

$$LM_{j,k,i} = \sqrt{M^{2}_{n(i,j)} + M^{2}_{n(i,k)}} \tag{10}$$

$$\begin{aligned} M_{n(i,k)} &= w_n.\, l_{i,k} = w_n.\sqrt{(X_{Dk} - X_{\mathrm{Ci}})^2 + (Y_{Dk} - Y_{Ci})^2} \\ M_{n(i,j)} &= w_n.\, l_{i,j} = w_n.\sqrt{(X_{Sj} - X_{\mathrm{Ci}})^2 + (Y_{Sj} - Y_{Ci})^2} \end{aligned} \tag{11}$$

$$\min TLM = \min \sum_{j}^{J} LM_{j,k,i} \tag{12}$$

(3) Constraints

1. Given a tower crane location, the supply point and demand point of the module should be within the coverage of the tower crane.

$$R_{Cmin} \leq l_{i,j} = \sqrt{(X_{Sj} - X_{Ci})^2 + (Y_{Sj} - Y_{Ci})^2} \leq R_{Cmax} \tag{13}$$

$$R_{Cmin} \le l_{i,k} = \sqrt{(X_{Dk} - X_{Ci})^2 + (Y_{Dk} - Y_{Ci})^2} \le R_{Cmax} \tag{14}$$

2. For each module, the weight at the supply point and demand point should be within the loading capacity of the tower crane.

$$\begin{aligned} w_n &\le \gamma . LC(\sqrt{(X_{Sj} - X_{Ci})^2 + (Y_{Sj} - Y_{Ci})^2}) \\ w_n &\le \gamma . LC(\sqrt{(X_{Dk} - X_{Ci})^2 + (Y_{Dk} - Y_{Ci})^2}) \end{aligned} \tag{15}$$

$$LC(x) = \frac{a}{x} - b \tag{16}$$

3. For each module, the lifting moment at the supply point and demand point should be within the maximum lifting moment of the tower crane. The safety factor γ (0.9 here) is introduced to ensure a safety redundancy.

$$\begin{aligned} M_{n(i,j)} &= w_n . \sqrt{(X_{Sj} - X_{Ci})^2 + (Y_{Sj} - Y_{Ci})^2} \le \gamma . M_{max} \\ M_{n(i,k)} &= w_n . \sqrt{(X_{Dk} - X_{Ci})^2 + (Y_{Dk} - Y_{Ci})^2} \le \gamma . M_{max} \end{aligned} \tag{17}$$

2.3 Muti-objective optimization evolutionary algorithms

Since the study in this paper can be regarded as a combinatorial optimization problem, evolutionary algorithms NSGA-III (Deb 2011; Deb and Jain 2014) are utilized to solve the three-objectives problem. The NSGA-III algorithm (as shown in Figure 3) is a relatively mature branch of the genetic algorithm and has great advantages in solving multi-objective combinatorial optimization problems. Compared with the exact solution method, NSGA-III can save computational cost. As the complexity of the project increases, the time taken for the exact solution will show a significant increase while the solution time of the evolutionary algorithm is still within acceptable limits. The basic operations of NSGA-III include Select, Crossover, Mutation, and Elitist Strategy, simulating the natural evolutionary process. NSGA-III is simple and efficient in achieving the Pareto front. With the introduction of a reference point mechanism, the selection process is guided to maintain the diversity of solutions when solving three or more optimization objective problems.

2.4 Case study using a MiC project

The selected project is a 28-storey subsidized sale house in Hong Kong, of which 25 floors are modular buildings, as shown in Figure 4. The house provides 300 room units in total using over 1200 concrete modules, ranging from 2.8 tons to 21.7 tons. Each floor was constructed using 49 modules around in-situ components. The modules required for the building are serviced by one tower crane. Detailed modular information is provided in Table 1. Therefore, an independent tower crane, POTAIN MCT805, is assigned, which has a maximum lifting weight of 25 t and coverage of 35 m. After a site investigation, the possible supply area and tower crane area were determined, and 11 potential tower crane locations and 34 supply points were selected, as shown in Figure 4. The locations of the demand points are the 49 locations where modules need to be installed. The goal is to determine the optimal supply point location, supply point orientation, and tower crane location for trade-offs among efficiency, cost, and safety.

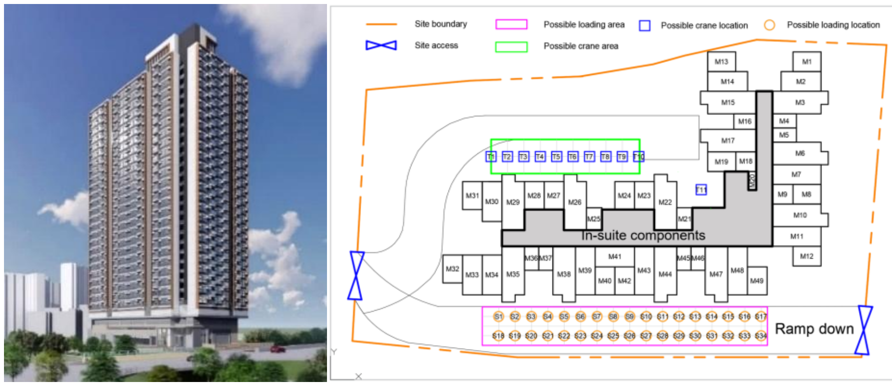

Figure 3: The exterior view of the construction site and site layout scheme

Module IDs	Length (mm)	Width (mm)	Height (mm)	Weight (t)	Module position		
					x	y	Degree (rad)
M1	3410	2400	3000	9.8	58071	38787	0
M2	4860	2400	3000	15.57	57346	36387	0
M3	6800	2750	3000	21.7	57256	33812	0
…		…		…		…	…
M48	5920	2400	3000	18.33	49607	13317	1.57
M49	3410	2400	3000	9.8	52007	12062	1.57

Table 1: Module information

3 Results and discussions

After the multi-objective optimization process, three non-dominated solutions to the Pareto frontier exist. This shows that the three solutions strictly outperform all other solutions in all three objective functions. In order to demonstrate the diversity of the Pareto frontiers and the selectivity of the results, we added the solution set of the second frontier as well, and the final results are shown in Figure 5. A total of 20 solution points were obtained. The three solutions to the Pareto frontier (P1, P2, and P3) and P4, P5, P6 from the other frontier are shown in Table 1 for comparison. Also, the original project's layout is listed. It is noted that a set of solutions are on the Pareto frontier that seeks an optimal balance between multiple goals. Afterwards, multiple criteria decision analysis (MCDA) methods such as weighted sum model (WSM), technique for order preference by similarity to ideal solution (TOPSIS), and analytic hierarchy process (AHP) can be used for weighting the three objectives based on specific project requirements and designer priorities.

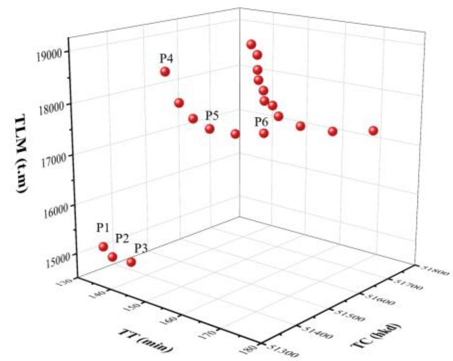

Figure 4: The obtained Pareto fronts

The original layout scheme is shown in Figure 6, where T8 and S3 are selected as the tower crane location and supply location, and the default setting of supply point orientation is 0 degrees. All three solutions to the Pareto frontier choose T11 for locating the tower crane. The optimal layout calculated from our model is shown in Figures 7 and 8. Figure 7 shows the layout with minimum time and cost, where T11 and S11 are selected as the tower crane location and supply location, and the supply point orientation is 40 degrees. As for the layout with minimum lifting moment, T11, S13, and 40 degrees are determined.

Points	Tower crane location	Supply point	Supply point orientation	*TT* (min)	*TC* (HKD)	*TLM* (t.m)
P1	T11	S11	40°	148.4	51,484	15,130
P2	T11	S12	30°	151.2	51,512	14,899
P3	T11	S13	40°	155.4	51,554	14,792
P4	T9	S4	50°	143.0	51,433	18,575
P5	T10	S10	60°	157.2	51,572	17,329
P6	T10	S8	60°	162.0	51,628	17,443
The original scheme	T8	S6	0°	210.3	52,103	18,854

Table 2: Solutions from Pareto fronts and original project scheme

Figure 5: The original site layout scheme ($\theta_S = 0°$)

Figure 6: Layout with minimum time & cost ($\theta_S = 40°$)

Figure 7: Layout with minimum lifting moment ($\theta_S = 40°$)

The time consumed by the positioning of the module is considered in the model, and the orientation of the module is thus optimized to minimize the time. Under the case P1, the total transportation time is 148.4 mins when the orientation is 40°. However, the total transportation time would be 181 mins if the orientation of the module is not considered, an 18.2% increase over the former. This means that it is essential to properly plan the orientation of the module to minimize total operation time and cost. It is worth noting that the time taken to position a module depends on the velocity of rotation. Faster rotation velocity will reduce the time and increase the risk of operations such as dropping modules (the rotation velocity is 0.5 rad/min in this paper). In terms of lifting safety, the total lifting moment of the original arrangement is 18,854 t.m, while the minimum total lifting moment of the P3 case is 14,792 t.m, a reduction of 27.4%, and the operating safety of the tower crane is further improved. Compared to the original layout scheme, the developed model can save up to 41.7% in transportation time and improve safety by 27.4%.

4 Conclusions

This study proposes a three-objective optimization model considering efficiency, cost, and lifting safety, which is applicable to MiC and traditional site conditions. The features and crane movement pattern of MiC are considered in the efficiency objective function, including the module rotation positioning and separate operation of tower crane motion. Besides, the lifting moment is selected as one of the objectives, representing the safety of the tower crane operation. The genetic algorithm NSGA-III is adopted to solve the proposed multi-objective problem. A case study using a MiC project in Hong Kong is conducted to verify the proposed model. Planners can choose from the solutions in the Pareto frontier based on the project needs and preferences for better decision-making. Based on the case study results, our model can determine the optimized layout plan with minimum time, cost, and lifting moment by locating the tower crane point, supply point, and supply point orientation. Disregarding the orientation of the supply point would result in an additional 18.2% transportation time, leading to increased costs. Compared to the original layout scheme, the developed model can save up to 41.7% in transportation time and improve safety by 27.4%.

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References

Chen, J., H.-L. Chi, Q. Du, and P. Wu. 2022. "Investigation of Operational Concerns of Construction Crane Operators: An Approach Integrating Factor Clustering and Prioritization." J. Manage. Eng., 38 (4): 04022020. https://doi.org/10.1061/(ASCE)ME.1943-5479.0001044.

Darko, A., A. P. C. Chan, Y. Yang, and M. O. Tetteh. 2020. "Building information modeling (BIM)-based modular integrated construction risk management – Critical survey and future needs." Computers in Industry, 123: 103327. https://doi.org/10.1016/j.compind.2020.103327.

Deb, K. 2011. "Multi-objective Optimisation Using Evolutionary Algorithms: An Introduction." Multi-objective Evolutionary Optimisation for Product Design and Manufacturing, L. Wang, A. H. C. Ng, and K. Deb, eds., 3–34. London: Springer London.

Deb, K., and H. Jain. 2014. "An Evolutionary Many-Objective Optimization Algorithm Using Reference-Point-Based Nondominated Sorting Approach, Part I: Solving Problems With Box Constraints." IEEE Trans. Evol. Computat., 18 (4): 577–601. https://doi.org/10.1109/TEVC.2013.2281535.

Hebiba, A. M., A. Bouferguene, S. Moon, and S. Han. 2022. "Wind-Wise Automated Stability Analysis for Selection of Tower Crane and Location." J. Constr. Eng. Manage., 148 (11): 04022127. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002377.

Huang, C., and C. K. Wong. 2018. "Optimization of crane setup location and servicing schedule for urgent material requests with non-homogeneous and non-fixed material supply." Automation in Construction, 89: 183–198. https://doi.org/10.1016/j.autcon.2018.01.015.

Huang, C., C. K. Wong, and C. M. Tam. 2011. "Optimization of tower crane and material supply locations in a high-rise building site by mixed-integer linear programming." Automation in Construction, 20 (5): 571–580. https://doi.org/10.1016/j.autcon.2010.11.023.

Labour Department Hong Kong. (2022). Retrieved from Labour Department Hong Kong website: https://www.labour.gov.hk/common/osh/pdf/wsa/WSA-Collapse_of_a_Tower_Crane_ENG.pdf

Li, R., H.-L. Chi, Z. Peng, X. Li, and A. P. C. Chan. 2023. "Automatic tower crane layout planning system for high-rise building construction using generative adversarial network." Advanced Engineering Informatics, 58: 102202. https://doi.org/10.1016/j.aei.2023.102202.

Tam, C. M., T. K. L. Tong, and W. K. W. Chan. 2001. "Genetic Algorithm for Optimizing Supply Locations around Tower Crane." J. Constr. Eng. Manage., 127 (4): 315–321. https://doi.org/10.1061/(ASCE)0733-9364(2001)127:4(315).

Tam, V. W. Y., and I. W. H. Fung. 2011. "Tower crane safety in the construction industry: A Hong Kong study." Safety Science, 49 (2): 208–215. https://doi.org/10.1016/j.ssci.2010.08.001.

Tsz Wai, C., P. Wai Yi, O. Ibrahim Olanrewaju, S. Abdelmageed, M. Hussein, S. Tariq, and T. Zayed. 2023. "A critical analysis of benefits and challenges of implementing modular integrated construction." International Journal of Construction Management, 23 (4): 656–668. https://doi.org/10.1080/15623599.2021.1907525.

Wang, J., X. Zhang, W. Shou, X. Wang, B. Xu, M. J. Kim, and P. Wu. 2015. "A BIM-based approach for automated tower crane layout planning." Automation in Construction, 59: 168–178. https://doi.org/10.1016/j.autcon.2015.05.006.

Younes, A., and M. Marzouk. 2018. "Tower cranes layout planning using agent-based simulation considering activity conflicts." Automation in Construction, 93: 348–360. Elsevier.

Zhang, P., F. C. Harris, P. O. Olomolaiye, and G. D. Holt. 1999. "Location Optimization for a Group of Tower Cranes." J. Constr. Eng. Manage., 125 (2): 115–122. https://doi.org/10.1061/(ASCE)0733-9364(1999)125:2(115).

Zhang, Z., and W. Pan. 2021. "Multi-criteria decision analysis for tower crane layout planning in high-rise modular integrated construction." Automation in Construction, 127: 103709. https://doi.org/10.1016/j.autcon.2021.103709.

Zhang, Z., and W. Pan. 2021. "Virtual reality supported interactive tower crane layout planning for high-rise modular integrated construction." Automation in Construction, 130: 103854. https://doi.org/10.1016/j.autcon.2021.103854.