Research on Optimization of Tower Crane Position in High rise Buildings Based on Neural Networks

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Abstract:
In order to improve efficiency, the tower crane scheme for high-rise buildings should consider the reach distance of the crane, which directly affects the capacity of the crane and is directly related to the operating cost of the crane. This article proposes a neural network-based method for optimizing the position of high-rise building tower cranes to improve operational efficiency. The case study results indicate that this method can accurately estimate the capacity of the tower crane, automatically perform the result comparison process, improve the efficiency of the tower crane position optimization process, and reduce operating costs. This optimization model can be used to consider the operation plan of tower cranes or to design building layout planning when changing the trailer position during on-site construction.
Keywords: high-rise building tower crane；Location optimization；neural network

1. INTRODUCTION

In recent years, the rise of high-rise buildings has posed new challenges to the study of the position of tower cranes. Reasonable tower crane positions in high-rise building construction can not only improve construction efficiency, but also ensure construction safety and avoid safety accidents caused by tower crane overturning. Therefore, domestic scholars have made many beneficial explorations and improvements in the study of tower crane positions. The widespread use of numerical analysis programs for dynamic analysis and optimization research of tower cranes in engineering structures has become a hot topic [3]. In addition to numerical simulation methods, some scholars have explored the study of tower crane positions in high-rise buildings using methods such as fuzzy mathematics theory, multi-attribute decision analysis, and genetic algorithms, and have achieved certain research results [4]. With the continuous development and progress of computer technology, these methods will be increasingly valued and widely used, providing more research ideas and methods for the selection of tower crane positions in high-rise buildings [5]. This article uses artificial neural networks to establish a numerical model related to the cost and efficiency of tower cranes in high-rise buildings, and optimizes the position of tower cranes to improve operational efficiency. The research content is as follows.

2. RESEARCH METHOD

2.1 DATA SELECTION FOR TOWER CRANE POSITION OPTIMIZATION

Firstly, set the workspace to a grid. As shown in Figure 2, 0.5 m is set as the basic unit（x，y） for the width and height of the coordinates. After identifying input data and variables, perform tower crane data processing and trailer position selection. To estimate the capacity of the tower crane, two distances are calculated using the variables of tower crane, trailer, and unit position: (1) the distance from the trailer to the tower crane, and (2) the distance from the unit to the tower crane. Considering the positional variables, the maximum distance that the tower crane should reach for lifting was obtained. In order to minimize this distance, the genetic algorithm in step 1 of the model framework was used for optimization. The optimization object that reduces the maximum distance is defined as:

$$P = \min\left[\max\{r,\rho\},\ \max\left\{r,\ Units\right\}\right] \qquad (1)$$

In the formula，r is Tower crane position . ρ is the only dimension for optimizing tower crane position Trailer position. m;;:　$Units$ is the feasible unit for tower crane position, m.

To minimize the cost function, variables represented by coordinates, such as tower crane position, feasible unit position, and trailer position, are transformed into weighted product factors. Figure 4 shows the definition of the product factor structure. The factor length (P) is defined as the sum of the number of coordinate positions (Pc) that the tower crane can locate and the number of coordinate positions (Pt) that the trailer can locate. This gene is defined as the number of tower cranes located on coordinates. For example, when the tower crane is located at the feasible unit position (Px), the weight is represented as "1"; Otherwise, the weight is represented as "0". The representation of trailer positioning weight is the same as that of tower crane positioning weight. In this study, it is assumed that a tower crane and trailer can be located, so the sum of gene values is 2. Based on the installation location of the unit, these weights are used as variables to obtain the optimal parking position for the tower crane and trailer. By interactively combining the position of tower cranes and trailers, the optimization effect can be improved, and increasing the number of iterations can achieve better results.

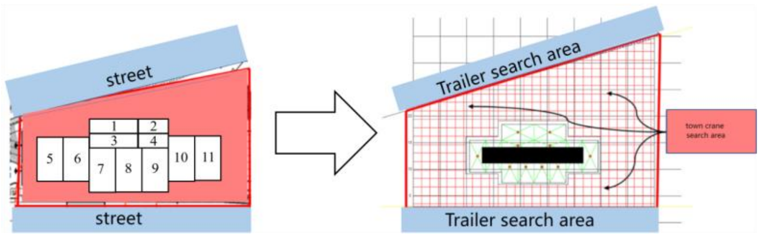

Figure 1: Setting up search areas for tower cranes and trailers based on the initial construction plan

After optimizing the distance between the tower crane position and the trailer position, the maximum distance and maximum weight of each feasible unit can be used to estimate the capacity of the tower crane. Then, from the maximum top load database calculated based on distance, self powered height, and rent, obtain the tower crane models and specifications that meet the lifting capacity. In the recommended tower cranes, tower cranes with a self height greater than the building height are shown in step 2 of the model framework. Generally speaking, if there are no tower cranes that meet the conditions or if the unit weight changes, it is necessary to go back to the first step, select a new tower crane that needs to change the input data such as on-site conditions, and enter more tower cranes in the database. Then, the model results provide the location of the tower crane and trailer, as well as the specifications of the tower crane, such as capacity, self powered height, and rent. In addition, if it is recommended to use multiple tower cranes, the tower cranes should be ranked based on rent to determine the on-site work plan.

2.2 TRAINING MODEL BASED ON RBF NEURAL NETWORK

The relationship between the optimal solution of tower crane position and its cost function is a highly nonlinear and strongly coupled relationship. For the optimization objective of this study, the optimal solution of the tower crane position and the cost function can only be expressed through an implicit function. The strong non-linear mapping and decoupling capabilities of RBF neural networks make them very suitable for establishing models for solving cost functions. RBF neural network is currently the most widely used neural network model due to its global convergence ability. It has been theoretically proven that RBF networks with three or more layers can globally approximate any rational function. Therefore, this study uses a three-layer RBF network to establish a mapping relationship between tower crane position and its cost function, and uses this model to solve the cost function to obtain the optimal solution for tower crane position.

For a tower crane structural system with three design variables, the RBF network model has three neurons in the input layer, seven neurons in the hidden layer, and one neuron in the output layer to describe the optimal position of the tower crane. The activation function of a radial basis function is based on the distance between the input quantity and the weight quantity (note that the weight vector here is not the weight from the hidden layer to the output layer, please refer to the structure of the radial basis neural model below) as the independent variable. The general expression of the activation function of a radial basis network is as follows:

$$R(\|d\|) = \exp(-\|d\|)$$

The corresponding activation function is expressed as：

$$R(r-w)=\exp(-\frac{1}{2\sigma^2}\|r-w\|^2)$$

In the formula: where represents the input vector, represents the center of the Gaussian function with weights, is the variance of the Gaussian function, and can be used to adjust the influence radius; As the distance between the weight value and the input quantity decreases, the output of the network continuously increases. The closer the input vector is to the center of the radial basis function, the larger the output generated by the hidden layer nodes. That is to say, the radial basis function produces a local response to the input signal, which is then mapped to the final output layer through a layer of linear transformation, resulting in the output layer also approaching 0 and finally obtaining the optimal solution for the tower crane position. Using the neural network toolbox provided by MATLAB software for the design and training of neural networks, the program code for creating a BP network is as follows [5]:

Algorithm: Neural network-based optimization of tower crane position in high-rise buildings

Requirement: Initialize r, ρ, $Units$, $Epoch=0$, $Epochmax$, σ;

target: trained r;

while *Epoch* < *Epochmax* **do**

$r=(r-\min(r))/(r-\max(r))$;

end while

Epoch = *Epoch* +1

net= *newff*(minmax(*P*)，[7,1]，{‘tansig’，‘logsig’，‘trainlm’；

//**create** RBF **neural network**

net.trainParam.Epoch=1000； //**times**

net.trainParam.Goal=exp(-10)； //**target**

net=*init*(*net*)； // **initialization**

net=*train*(*net*，*r*，*P*);// **Training**

3. ANALYSIS OF CALCULATION RESULTS

This section introduces a case study on validating the tower crane and trailer site selection model in high-rise modular building engineering by comparing the maximum distance in the initial tower crane operation plan with the maximum distance in the optimization results. The selected project is a modular apartment building that has not yet been constructed, and the initial tower crane and trailer positions from the on-site work plan were used in the case study. Table 1 provides an overview of the case project. The case project is a seven story modular building consisting of 62 units of two types (3 meters) × 6 meters, 2 meters × Composed of 6 meters and used to elevate these units. To ensure the use of tower cranes, the number of floors in the building has been increased from 7 to 15 (45 meters, with each floor height of approximately 3 meters). In addition, in this study, in order to optimize the tower crane, only the physical conditions (layout of modular buildings, distance between roads and buildings) were maintained, while the lifting areas (installation location of tower cranes, location of trailers) were all usable areas, as shown in Table 1.

Table 1 Case Study Project Information

Content	Initial parameters	revision parameters
area	3070.50 m^2	
plan	Multipurpose buildings	
floor	7	15
height	27meters	45meters
units	62	
maximum payload	12tons	

Use the coordinates of the weight center of the module unit as a reference point to estimate the distance from the crane. After inputting the weight, use a neural network model to select the position of the tower crane. Based on estimated values such as weight and position, obtain the tower crane position that meets the lifting conditions in the feasible area. Determine the tower crane model by comparing the self force height of the tower crane with the building height.

For optimization analysis, this study drew the site conditions based on the initial modular construction plan. Firstly, extract the road conditions and the shape of the site, and then reflect the building layout plan. Apply a grid to the extracted schematic diagram, set (x, y) coordinates for optimization iteration, and divide it into the following areas: trailer navigation area and tower crane navigation area. After setting the search criteria, use Matlab R2018a to perform neural network model calculations and iterative optimization calculations for tower crane and trailer positions. The initial population size is 100, and the mutation rate is set to 0.1. At this point, when the crossover rate is set to 0.5, perform uniform crossover calculation. Under the given optimization conditions, the optimization results were obtained. In this study, many assumptions and limitations were made to select the optimal location for tower crane modular high-rise buildings, but it confirmed cost losses and effective construction management. As long as the input quantity remains unchanged, this study can globally converge to the optimal location for tower cranes. Generally speaking, the ultimate goal of tower crane position optimization research can be divided into improving efficiency and reducing operating costs. Assuming that the weight of the lifted object can be partially adjusted once, the position of the site reflects the characteristics of repeated creation and destruction based on whether materials are used or not. After this process, the contractor manager or construction manager found and contracted a tower crane that could be rented during the lifting period based on the minimum performance condition of the tower crane determined by the research results. The construction period of high-rise modular construction projects is shorter than that of similar scale conventional construction projects, and the proportion of total construction load on site is relatively large. In addition, the controllable part of one-time weight lifting is limited and heavy, so the selection and location of tower crane specifications optimized with limited information in the early stages of construction is crucial for the successful completion of the project.

rank	type	Tower crane height (meter)	Maximum lifting capacity (ton)	cost function
1	Pitch variable amplitude	58.7	16.0	13400
2	Pitch variable amplitude	64.9	16.0	14091
3	Pitch variable amplitude	58.7	19.2	16713
4	Pitch variable amplitude	74.0	24.0	21849
5	Pitch variable amplitude	53.3	23.0	21945
6	Pitch variable amplitude	59.1	23.0	24008
7	Pitch variable amplitude	59.1	22.5	24541
8	Pitch variable amplitude	77.8	32.0	28022

9	Pitch variable amplitude	74.4	32.0	30489
10	Pitch variable amplitude	53.3	27.5	30661

Table 2 Optimization Results of Tower Crane Position

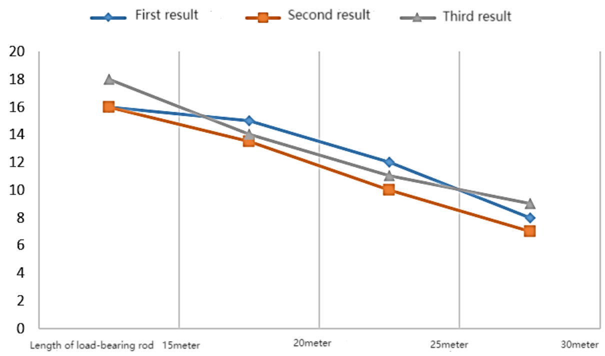

Figure 2: The relationship between the specifications and arm length changes of optimized tower cranes from level 1 to level 3 and the maximum lifting load

4. CONCLUSION

In modular tower crane plans, the optimal position of the tower crane should be considered. Therefore, in this study, a distance minimization optimization model considering the position of the tower crane and trailer was developed to recommend the position of the tower crane. The main conclusions obtained are as follows:

(1) The effectiveness of the model was verified through a case study. In addition, in projects conducted on complex shaped sites, it is expected that there will be significant differences in model results, which will help in the selection of tower crane and trailer positions.

(2) This optimization model can be used to consider the operation plan of tower cranes or to design building layout planning when changing the trailer position during on-site construction. This study also has academic value. When obtaining optimization results, several variables need to be considered, including some combination results and result comparisons. The optimization model established in this study can automatically perform the result comparison process, improving the efficiency of the tower crane position optimization process.

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