RESEARCH ARTICLE

Warehousing Operation Optimization Model of One Storey New Dangerous Goods Warehouse Based on Warehousing Chain and its Application

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Abstract: Introduction: In order to ensure the efficiency and cost of dangerous goods warehouse under the premise of safety, this study takes the dangerous goods warehouse as the research object and implements multitask for dangerous goods warehouse with two forklifts.

Methods: This study takes traversal calculation, novel safety calculation formula and scheduling scheme evaluation model as tools to research the forklift scheduling scheme of one-storey packed dangerous goods warehouse.

Results: Optimal scheme and allocation decision model are obtained through numerical simulation. The innovation of this study is giving the safety formula of forklift operation in dangerous goods warehouse and using numerical simulation to obtain the global optimal solution. Furthermore, this study draws on the concept of the travel chain to propose the idea of warehousing chain. At the same time, optimal schemes for multiple dangerous goods inbound and outbound the warehouse are studied.

Conclusion: With the application of actual data in Shanghai Lingang dangerous goods warehouse, this study combines with the simulation technology to verify the allocation model of warehousing operations and forklift scheduling model. The validity and feasibility of the novel theory are also verified.

Keywords: Dangerous goods warehouse, warehouse chain, multiple attribute decisionmaking, optimization, evaluation model, one storey warehouse.

1. INTRODUCTION

Most of Chinese existing dangerous goods warehouses are one storey warehouses of packaged dangerous goods with two-door design. Although this arrangement ensures a certain safety and space utilization, it is inefficient in inbound and outbound operations. Therefore, on the basis of practice, academia has proposed the concept of interconnected hazards warehouses and the dynamic layout of dangerous goods. Since the safety of dangerous goods warehousing operation is usually excessive pursuit, the efficiency of dangerous goods storage operations is extremely low. At the same time, according to the marginal utility theory, the storage security degree shows a downward trend. Therefore, under the premise of ensuring the safety of the warehouse, it is an important practical issue to improve the efficiency of the warehousing operations. According to the existing phenomenon, this study researches the scheduling scheme of forklifts in warehouses under multi-tasking conditions. Through the overall efficiency and safety factors, a comprehensive evaluation system for the scheduling of forklifts in dangerous goods warehouse is developed.

In order to do this research, this study focuses on the latest research results in dangerous goods warehouse, travel chain, multiple attribute decision making, simulation and optimization theory.

In the field of dangerous warehousing management, Wang Lei et al. (2018) found that accidents mainly occur in the process of dangerous warehousing operations. Such accidents generally occur more frequently in an open warehouse [1]. At the same time, by analyzing the dangerous goods storage accidents in recent years, it was found that uncertainty of subjective factors is the main influencing
factor of such accidents. In terms of travel chain, Pan, D. Dong, Y. et al. (2018) constructed the traffic of the traditional User Equilibrium (UE) model into the traffic of the travel chain based on the analysis of the two theories of the travel chain and the traditional user balance distribution [2-11]. The UE model based on the travel chain; the traditional algorithm and the effective set algorithm are used to solve the balanced distribution problem by analyzing and comparing. In the field of multiple attribute decision making, Zhongjun Wu et al. (2007) proposed, based on the subjective attitude of the decision-maker, a decision-making method based on the deviation minimization model. The proposed method is mainly focused on multiple attribute decision-making problems in which the weight information is completely unknown or partially unknown [12, 13]. Xu, G., Liu, W., Yang, and H. et al. (2018) proposed a railway network traffic assignment model based on safety degree and gave the decision-making idea of traffic assignment problem under the constraint of safety priority [6]. In terms of simulation and optimization theory, Zhongjun Wu et al. (2019) proposed a new Dual Fuzzy Hesitant Rough Sets (DFHRS) utility function and proved the effectiveness of the utility function through traffic engineering examples [8].

Hwang et al. (2016) studied the shortest path problem under random conditions [9]. Wang et al. (2016) studied the constrained shortest path problem in transport networks, where the transport time is assumed to be a random variable defined by the joint probability mass function. Zhang Fangwei and Li Jiaru et al. (2018), based on the improvement of the geometric structure of the existing packaging dangerous goods warehouse, disclosed a decision-making method for the operation of the forklift truck running line of the warehouse for improving the efficiency of packaged dangerous goods [11].

In order to ensure the safety and efficiency of inbound and outbound operation, technical support should be provided for the scheduling scheme of forklifts under multi-tasking conditions. This study takes the interconnected dangerous goods warehouse as the research background, multiple forklifts running line as the condition and five random access locations as samples to study the optimal scheduling scheme of the forklift in the case of the determined location of the inbound and outbound location. The follow-up of this study is mainly discussed in the following aspects: Firstly, in order to facilitate the research, this study grids the dangerous goods warehouse. Furthermore, a series of models such as inbound and outbound point pairing, security evaluation, efficiency evaluation, and scheduling scheme evaluation are served to provide tool support for the evaluation of the scheduling scheme. Finally, taking the parameters of the dangerous goods warehouse in the port as an example, the specific example is solved to verify the model.

2. WAREHOUSING CHAIN OPERATION AND MONITORING PROBLEMS OF NEW DANGEROUS GOODS WAREHOUSE

2.1. Grid Presentation of Novel Dangerous Goods Warehouse

In this study, five inbound points and five outbound points are taken as examples to study the optimal scheduling problem under two operations. The layout of the warehouse and the locations of warehousing points are shown in Table 1. Among them, red is the inbound point and the inbound stack, and blue is the outbound point and the outbound stack (Fig. 1).

This study will grid the geometry structure of the entire dangerous goods warehouse in order to better represent the storage point and the real-time position of the transport forklift. The smallest unit of the grid is the length of the forklift and the coordinate system is established to identify the point location. The details are shown in Fig. (2).

2.2. Warehousing Chain Refining of Dangerous Storage Operations

In the aforementioned research of the research team, the concept of a “closed-loop” is proposed. In essence, this concept is a thought that deals with the cooperation of the forklifts from a single inbound and outbound working area. However, in the process of portraying the safety of the forklift, the single operation cycle time of each forklift doesn’t happen simultaneously. Fig. (3) illustrates that the two forklifts are in the same working cycle only in time period X1 and mismatches in the time period X2 which makes it difficult to describe the safety.

Through research and analysis, this study draws the concept of “travel chain” in traffic behavior to process the concept of warehousing chain. The main thought of this concept is to view an inbound and outbound operation cycle as a first-order round trip and to consider the cooperating problem between these first-order round trip in one inbound and outbound operation cycle. Therefore, the accurate characterization of the security index can be achieved, which has strong practical application significance.

2.3. Monitoring Problems of Dangerous Goods Storage Operations

Based on the particularity of the dangerous goods warehouse, it brings more potential danger to judge whether the forklift scheduling scheme is safe or not by no collision. This study, taking the second type of hazard source as its research target, considers that there will be potential dangers because of brake errors and drivers’ individual differences, etc. when the distance between the two forklifts is close. The distance between the two forklifts is taken as an indicator to divide the working hours into two levels: the focus attention period and the regular attention period. During the focus attention period, the potential danger brought by the close distance of the forklifts will reduce the safety of the whole scheduling strategy. At the same time, the time of the two forklifts are in focus attention period and the distance of the two forklifts has a much bigger influence on the safety indicator of the scheduling scheme. The boundary point is identified by fully research and consulting related experts. On this basis, the operation process can be divided into three levels or more and the monitoring of the operation process can be more refined. Taking two-level monitoring as an example, this study makes a detailed study on the division of two-level operation, the duration of the focus attention period and the safety evaluation model of the forklifts’ distance.
3. OPTIMIZATION MODEL OF DANGEROUS GOODS WAREHOUSE STORAGE OPERATION

3.1. Selection of Research Point

In the selection of the optimal scheduling strategy of the forklifts, there are two research points including the pairing of the inbound and outbound points and the completion order of different inbound and outbound points. For the pairing issues of inbound and outbound points, the total distance taken to complete all the inbound and outbound tasks is used as a criterion for judging the pros and cons of the matching strategy which is \( \min \sum \sum x_{ij} d_{ij} \). In the formula, \( I \) presents the set of inbound points and \( J \) presents the set of outbound points. \( x_{ij} \) is a binary variable which presents whether \( I \) inbound point and \( J \) outbound point have been paired. The number of \( x_{ij} \) is 1 which presents that \( I \) inbound point and \( J \) outbound point have been paired, and 0 presents that the two points have not been paired.

The influence of safety, efficiency and other comprehensive evaluation indicators on the scheduling strategy of the dangerous goods warehouse forklift scheduling process are mainly considered in this study. The completion order of the inbound and outbound points is taken as the research point to refine the safety formula, efficiency model and comprehensive evaluation model. The optimal model of forklift scheduling is summarized through these formulas.

3.2. Refining of the Safety Formula of the Forklifts

In this study, the safety threshold between the two forklifts is defined by the consulting warehouse manager. When the distance between the two forklifts is less than the threshold, the forklifts will enter the focus attention period from the regular attention period due to the potential collision probability caused by the close distance. Since the dangerous degree is determined by the duration of the two forklifts in a dangerous area and the distance between the two forklifts, this study combines two factors to characterize the safety evaluation model.
\[ S = \left( \frac{t - t_{min}}{t_{max} - t_{min}} + 1 \right)^{-\alpha_1} \times \left( \frac{d - d_{min}}{d_{max} - d_{min}} + 1 \right)^{\alpha_2}. \]  

(1)

Fig. (3). Matching diagram of the operation cycle.

Among them, \( S \) stands for the safety evaluation factor; \( t \) stands for the duration of the two forklifts in a dangerous area; \( d \) stands for the average distance of the two forklifts in focus attention period during the whole working cycle; \( \alpha_1, \alpha_2 \) are two weights stand for the time in focus attention period and the distance between the two forklifts, respectively. The formula above has constructed a safety evaluation index. It can be seen from the formula that the constructed index has a negative correlation with the time when the two forklifts are in danger distance, and has a positive correlation with the mean distance of the two forklifts in one working period. Different weights have been set to this index to evaluate the safety degree of the forklifts.

Furthermore, there may be cases that the two forklifts could not complete the task at the same time because of the possible imbalance and difference in working hours of the two forklifts. If anyone of the forklifts completes the mission and stops at the starting point, there will be no insecure factors due to potential collisions. Therefore, when calculating the size of the safety evaluation factor, the calculation stops when one of the forklifts stops working.

3.3. Model Refining and Working Process Based on Warehousing Chain

This research studies the movement of two forklifts during the whole working process to refine the efficiency evaluation model and comprehensive evaluation model.

Step 1: In the initial time, both of the two forklifts are at the position of the inbound container truck. The coordinates of the two forklifts are \( F_1(a_x, b_y) \) and \( F_2(x_0, y_0) \). Then, the two forklifts take goods from the inbound container truck which will take \( t \) minutes to prepare for the inbound operation. After that, the forklift randomly goes to any inbound point to complete the inbound operation, \( t \) minutes will be taken for the forklift to put down its goods. At the same time, according to the result of the inbound and outbound pairing model, the forklift will head to the outbound point corresponding to the inbound point to take out the outbound goods.

Step 2: The forklift takes the goods and head to the outbound container truck. After the goods are put down, the condition that whether there is still a warehousing operation to be completed is judged by the forklift. If there is, the forklift heads to the inbound container truck through a road that connects the inbound container truck and the outbound container truck. At this time, an inbound and outbound working cycle is completed. If there is no warehousing operation to be completed, then the truck will stop at the outbound container truck. The safety index calculation will also stop and the entire operation cycle will be completed.

Step 3: Calculate the distance between the two forklifts before any of the forklifts stops working. Because the forklift, in most cases, runs a straight or broken line in dangerous goods warehouse, this study selects the folding line distance \( d \) between the two forklifts as the embodiment of the forklifts distance, \( d = |a_i - x_i| + |b_i - y_i| \). Among them, \( (a_i, b_i), (x_i, y_i) \) are the coordinates of the two forklifts at the \( i-th \) moment separately. By real-time monitoring of the distance \( d \), the safety is calculated until any of the forklifts stops working when \( d < d_{safe} \). \( d_{safe} \) is the forklift braking distance according to the operating speed and consulting experts.

Step 4: Evaluate the efficiency of the forklift scheduling strategy by completing the time spent combined with the number of tasks. The efficiency function is charged as \( \eta = \frac{T}{n} \), where \( n \) indicates the number of tasks completed by the forklift in the operation cycle. In the formula, \( T = T_1 + T_2 \), \( T_i \) indicates the time required for the \( i-th \) forklift to complete its each task, \( i = 1, 2 \).

Step 5: This step comprehensively considers two indicators of efficiency and safety and builds an overall evaluation model for the scheduling scheme. According to the characteristics of the dangerous goods warehouse itself, high security is always preferred. Therefore, different weights are given to efficiency and security, and the scheduling scheme evaluation model is built as:

\[ P = \left( \frac{S - S_{min}}{S_{max} - S_{min}} + 1 \right)^{\alpha_1} \times \left( \frac{\eta - \eta_{min}}{\eta_{max} - \eta_{min}} + 1 \right)^{\alpha_2}. \]  

(2)

In the formula, \( \alpha_1, \alpha_2 \) are the proportion of safety and efficiency in evaluating the scheduling plan respectively; \( S \) presents the safety evaluation index and \( \eta \) presents the working efficiency. The optimal scheduling scheme with two factors is found through the evaluation of different scheduling strategies.

3.4. Additional Explanation

According to the research content, two additional explanations should be added. Firstly, the safety formula is proposed for the first time in this study and can be expressed by
a variety of functions. On the basis of the warehousing chain, taking the two-level operation as the base, this study considers two indicators to evaluate the safety including the time of focus attention period and the distance of the forklifts. Furthermore, compared with existing working monitoring, this study, using the safety calculation formula, not only works out the optimal route but also divides the entire working period of the forklifts into two parts: focus attention period and regular attention period to deepen the understanding of the source of working hazards of the dangerous goods working process.

4. CALCULATION EXAMPLE

4.1. Problem Introduction

In order to verify the feasibility of the aforementioned new dangerous goods warehouse model, the following parameters are obtained through the author’s full investigation and reference to the layout of the dangerous goods warehouse in Shanghai.

Based on the parameters of Shanghai Lingang dangerous goods warehouse and the layout of the new dangerous goods warehouse, taking 5 inbound points and 5 outbound points as an example, this study researches the optimal scheduling strategy of the forklifts in the case of known storage points.

4.2. Problem Solving Process

In this subsection, this study uses MATLAB to traverse all possible routing lines. Firstly, traversing the pairing of inbound and outbound tasks. There could be a total of 125 matching schemes in the case of five outbound points and five inbound points. It can be seen from the traversing results that the total distance in the 38th pairing scheme is a minimum of 150 meters. At this time, the matching scheme of the inbound and outbound tasks is as follows: 1st inbound point cooperates with 4th outbound point; 2nd inbound point cooperates with 3rd outbound point; 3rd inbound point cooperates with 5th outbound point; 4th inbound point cooperates with 1st outbound point; and 5th inbound point cooperates with 2nd outbound point. In the pairing scheme of inbound point and outbound points mentioned above, the distance traveled by the two forklifts is the shortest which is 150 meters.

The next step is to determine the order of the tasks in this scheme. Traversing possible results is still used in this essay to traverse the order of tasks that may exist. The safety evaluation model, efficiency evaluation model and comprehensive evaluation model are also used to evaluate the order. In the process of safety evaluation, the distance between the two forklifts and the time of the two forklifts in the focus attention period are important evaluation factors. The variation curve of the distance between two forklifts over time in optimal scheduling strategy is shown in Fig. (4).

Excluding the scheme that may cause the two forklifts to collide, the optimal scheme should be found by taking no collusion as a premise, and high safety and efficiency as a target. The safety and efficiency distribution for all non-collision schemes is shown in Fig. (5).

By analyzing the results mentioned above, it can be concluded that the comprehensive evaluation result of scheme 8th is the highest. The time efficiency of scheme 8th is 2.04 minutes; the safety index is 1.2651, and the evaluation index is 1.56165. At this time, the specific scheduling strategy of the two trucks is shown in Fig. (6). The curve in the figure shows the motion track of the forklifts’ position over time in the whole task process.
Fig. (5). Safety and efficiency distribution with no collision. *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

Fig. (6). Motion track of two forklifts in the optimal scheme. *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

CONCLUSION

Through the aforementioned example, this study verifies the new theory. On the whole, by choosing optimal scheduling strategy, this study improves the overall scheduling efficiency on the premise of ensuring the safety of dangerous goods warehouse and could play a key role in the whole dangerous goods warehousing logistics.

Through the research and analysis of the task scheduling strategy of the dangerous goods warehouse, the detailed steps are as follows. Firstly, based on the warehouse chain, the optimal pairing scheme between the inbound point and the outbound point should be built. After that, in the optimal pairing strategy, the safety evaluation model and efficiency evaluation model should be built to evaluate all possible scheduling strategy. Furthermore, two indicators which are efficiency and safety should be built to establish the scheduling scheme evaluation model. Finally, the optimal scheduling scheme is decided by traversing all possible scheduling schemes. When the data of a dangerous good warehouse or the position of inbound point and outbound point change, the theory can also work out the optimal scheduling strategy in the corresponding circumstances, which has good practicability and compatibility.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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CONFLICT OF INTEREST

Authors declare no conflict of interest financially or otherwise.

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