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Research Article

Method for zoning operation of roundabout warehouse for packaging dangerous goods under safety red line

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Abstract
In order to comprehensively consider the safety, efficiency, and other factors in the in-and-out operation of dangerous goods, this article takes the setting of forklift rounding rules as the research background and uses optimization theory and the newly proposed cost formula to study the partitioning question of a warehouse. Numerical simulation is also used in this essay, and 2 rules for the storage area zoning of the warehouse are obtained. The practical innovation of this article is to propose the concept of the safety red line, as well as obtain the safety formula under these circumstances. The theoretical innovation of this paper is to combine the labyrinth path finding algorithm and the utility theory together to solve the problem of in-and-out operations of dangerous goods. Finally, this article takes the actual data of the Shanghai Lingang Dangerous Goods Warehouse as parameters and uses the dual-container-truck out operation and single-container-truck in operation as examples. Simulation technology is also used to verify the newly proposed model, as well as its validity and feasibility.

1. Introduction

Dangerous goods accidents have happened frequently in China. Current dangerous warehousing processes in China are mainly based on paper documents and have very low automation levels. Taking the workers in the Lingang Dangerous Goods Warehouse as an example, the workers obtain a cargo document before entering the warehouse. The workers then drive forklifts to fetch dangerous goods, such as LNG tanks. Without the combination of computer science or intelligence algorithms, the whole process is exposed to danger. In order to solve this problem, this study pays attention to the latest research results of dangerous goods warehouse management on the basis of Practice of Safety Management Staff of Dangerous Goods Storage Units in Ports (Vocational Qualification Center of the Ministry of Transport, 2016a; Vocational Qualification Center of the Ministry of Transport, 2016b). Zhang et al. (2018) presented a method based on the improvement of the geometric structure of an existing packaging dangerous goods

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warehouse and disclosed an interoperable warehouse forklift operation route decision-making method to improve the efficiency of packing dangerous goods in and out of the warehouse. Liu et al. (2017) proposed a risk management technology system framework for flammable and explosive dangerous chemical warehouses, combined it with the dynamic changes of hazard sources based on the Bow-Tie model, and carried out a risk analysis of dangerous goods warehouses. Yachba (2016) proposed a tool that can locate the optimal container placement based on genetic algorithms. Secondly, the main practical innovation of Hua-wei et al. (2014) was taking an explosives warehouse storage as an example, using RFID technology to obtain inventory information in real time, and proposing a warehouse location zoning strategy to improve warehouse utilization. Zhang et al. (2018) proposed a decision method for the use of isolation doors for dangerous goods warehouses, based on hesitant distance set, and gave out several sets of storage solutions for dangerous goods based on the total storage capacity and the use of isolation doors. In terms of multi-attribute decision-making, Quintanilla et al. (2015) proposed a model that seeks the optimal cargo allocation scheme to maximize the utilization of warehouse space, and uses heuristic algorithms to solve the problem of storage location allocation in chaotic warehouses. Nazemi and Omidi (2013) proposed a neural network model to solve the shortest path problem. The main idea is to replace the shortest path problem with a linear programming (LP) problem.

2. Problem description

Based on the actual investigation and on extensive opinion gathering, this article discusses the setting conditions of the zoning problem in the following situations. Therefore, it is possible to optimize the path of a forklift by rationally arranging the positions of the cargo stacking positions. The decrease in both the distance and the probability of the forklift can also increase the safety factor of the warehouse and remove potential risks. According to practical data, the width of the main road in **Figure 1** is 5 m. The length of the dangerous goods warehouse is 100 m. For every stack, the width and the length are 3.6 and 5 m, respectively.

Figure 1 Zoning setting under roundabout driving rules.

3. Zoning decision model for roundabout storage of dangerous goods

3.1 Suitability model in dangerous goods warehouse

In order to conduct further research on the dangerous goods warehouse, a mathematical abstract is needed. **Figure 2** is an abstract matrix of **Figure 1**. According to practical simulation of the route length for every single stack, a matrix of **Figure 2** can be obtained. Considering the fact that many stacks are on just 2 sides of the road, the distance can be divided into 10 groups, presented as 1 - 10. In the matrix, '0' presents the main road, while other numbers present the distance ranks for every single stack to make inbound operations and outbound operations.

$$D = \begin{pmatrix} 5 & 0 & 3 & 2 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 2 & 3 & 0 & 5 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 5 & 4 & 3 & 2 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 2 & 3 & 4 & 5 \\ 2 & 1 & 1 & 1 & 0 & 6 & 6 & 6 & 6 & 6 & 0 & 7 & 8 & 9 & 10 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 1 & 1 & 0 & 6 & 6 & 0 & 6 & 6 & 0 & 7 & 8 & 0 & 10 \end{pmatrix}$$

Figure 2 Groups of studied dangerous goods warehouse.

Since there are 10 groups of applicability of the storage position, the goods can be divided into 10 groups, according to the storage bit ratio. The applicability of every single storage position can be presented as, $\varphi = S \times n \times \alpha$. In the formula, φ represents the applicability for every single storage position, S represents the distance traveled by the forklift when performing a complete storage operation, n represents the quantity of goods stored on that type of storage positions, andα represents penalty coefficient. When goods with a longer storage period appear at a storage location with a short-term applicability degree, α can be presented as 0.6. When goods with a shorter storage period appear at a storage location with a long-term applicability degree, α can be presented as 0.4. It should be noticed that α is a given parameter which has no fixed value. The value of α is roughly related to the length of the cargo's storage time. The longer the storage time is, the greater α is. The conclusion is obvious; when a set of cargo which needs to be stored in the warehouse for a long time is placed near the gate, the cargo would create a great negative influence on warehousing efficiency.

3.2 Warehouse safety model at a given forklift speed

The specific calculation method of safety degree can be presented as follows. Assume that the distance during time (t_i, t_{i+1}) between the 2 forklifts is less than d_0. The shortest distance between 2 forklifts F_1, F_2 in this period is d. μ stands for the probability of packaging leakage during 1 single warehouse operation. The safety degree ξ can be obtained by summing the time integrals within each safety distance. The formula is as follows:

$$\xi = \frac{1}{t} \times \sum_{i=0}^{N} \int_{t_i}^{t_{i+1}} d_i dt$$

Among them, $d_i \leq d_0$, w_1, and w_2 are weights. The definition of safety degree can be identified as the density of the forklift in a certain area within unit time.

According to the rule that, the greater the speed, the smaller the safety factor, the relationship between safety and speed can be presented as follows: $v \times \xi = a$. Among them, a is defined as the safety factor, and its value is comprehensively determined by the long-term purpose of the warehousing enterprise. The purpose of a is to consider the anti-dependence relationship between safety and efficiency. A higher safety degree could bring a slower operation speed of the forklifts and lower efficiency. According to the formula above, assume the safety factor is the same, v_1 represents the speed of the forklift when setting zoning rules, ξ_1 represents the safety degree, v_0 represents the speed of the forklift without setting zoning rules, ξ_0 represents the safety degree, and $\frac{v_0}{v_1} = \frac{\xi_1}{\xi_0}$ can be obtained. The efficiency ratio between a partitioned warehouse and an unpartitioned warehouse can be presented as follows:

$$\lambda = (s_1 \times v_1^{-1})/(s_0 \times v_0^{-1}). \tag{1}$$

By substituting the relationship between safety and speed into the formula, it can be obtained that the relationship between the forklift operation distance and the safety of the warehouse under the condition of constant efficiency ratio is:

$$\lambda = (s_1 \times s_0^{-1}) \times (\xi_1 \times \xi_0^{-1}). \tag{2}$$

3.3 Multi-attribute decision model based on simulation data

In order to make conclusions, the concept of comprehensive utility has been introduced. In this article, the concept of comprehensive utility illustrates that the dangerous goods warehouse has a well-balanced relationship between safety and efficiency. According to the elements discussed in this article, we can identify that the comprehensive utility of the dangerous goods warehouse is related to the following variables, $U = f(c_1, c_2, E)$. Among them, c_1 represents the short-term cost of the warehouse, c_2 represents the long-term cost of the warehouse, and E represents the operational efficiency of the warehouse. The comprehensive utility can be defined as follows.

The comprehensive utility function with partition rules:

$$U_1 = 1 - (w_1 \times c_{11} + w_2 \times c_{12} + w_3(1 - E_1)),$$

The comprehensive utility function without partition rules:

$$U_2 = 1 - (w_1 \times c_{21} + w_2 \times c_{22} + w_3(1 - E_2)).$$

Assume $U_1 - U_2 > 0$,

$$(c_{11} - c_{21}) \times w_1 + (c_{22} - c_{12}) \times w_2 + (E_1 - E_2) \times w_3 > 0. \tag{3}$$

Assume $U_1 - U_2 < 0$,

$$(c_{11} - c_{21}) \times w_1 + (c_{22} - c_{12}) \times w_2 + (E_1 - E_2) \times w_3 < 0. \tag{4}$$

4. Numerical examples

4.1 Warehouse case and parameter determination

In order to effectively and accurately assess the safety degree of the warehouse operation, this article defines w_1 as 0.7, w_2 as 0.3, and d_0 as 10.8 m.

According to **Figures 3** and **4**, it can be obtained that the setting of partition rules does not significantly affect the safety degree. The safety degree is calculated by using the formula defined in 2.2. At the same time, the variance of the warehouse when partitioned is 0.238, and the variance of the warehouse when not partitioned is 1.125.

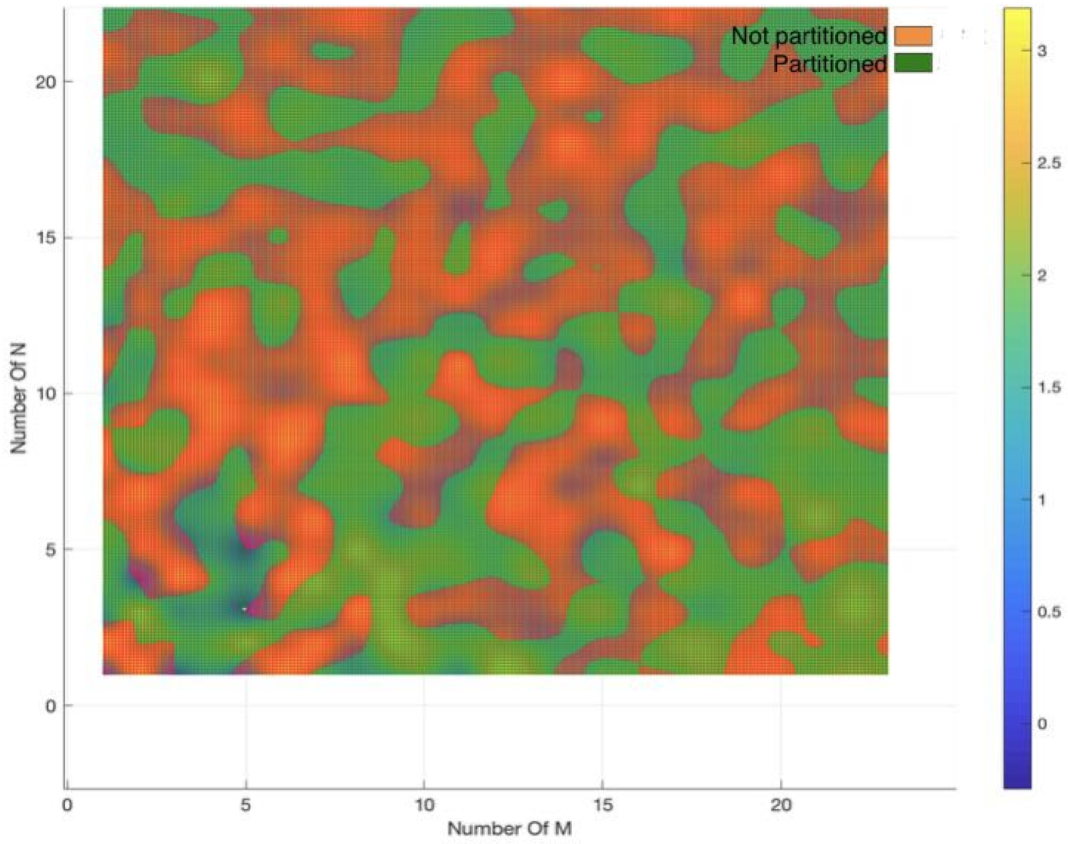

Figure 3 Comparison chart in the 2 situations.

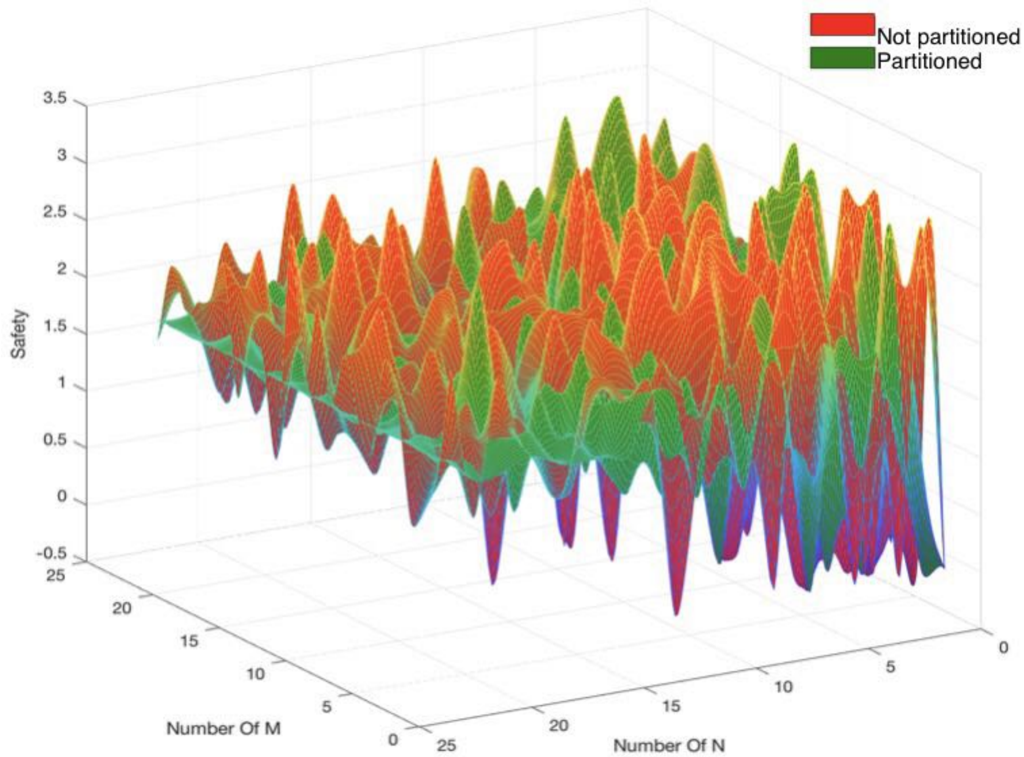

Figure 4 Heat chart in the 2 situations.

Firstly, by calculating possible values of the number of inbound storage locations, m, and outbound storage locations. n, safety degree expectations, $\overline{\xi_0}$, when the warehouse is partitioned is 1.767, and the safety degree expectations, $\overline{\xi_1}$, when the warehouse is not partitioned is 1.676. The ratio between the 2 situations is 0.948. Similarly, the route length expectations when the warehouse is not partitioned is 1547.537, and the route length expectations when the warehouse is partitioned is 1.046. The route length ration between the 2 situations is as follows: $\lambda = 0.99$.

4.2 Costing calculation of warehouse operations

In order to solve the average distance travelled by the forklifts under all possible combinations of the inbound position and outbound position, the method above can be applied to traversal calculate randomly selected 50 warehouse stacking layout matrices for each of $\sum_{i=1}^{45} i$ cases. The applicability is calculated according to the formula proposed in 2.1. The travel distance and applicability of the 2 forklifts $F1, F2$ under the 2 circumstances can be obtained and are shown in **Figures 5 - 8**.

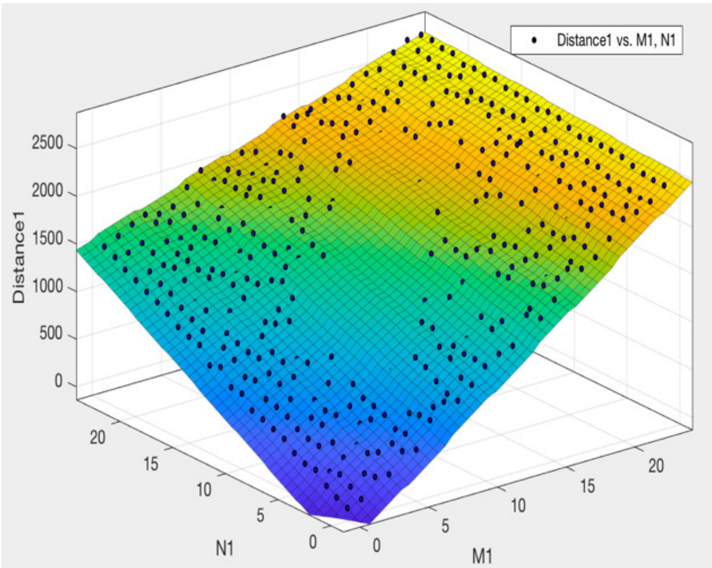

Figure 5 Travel distance in partitioned warehouse.

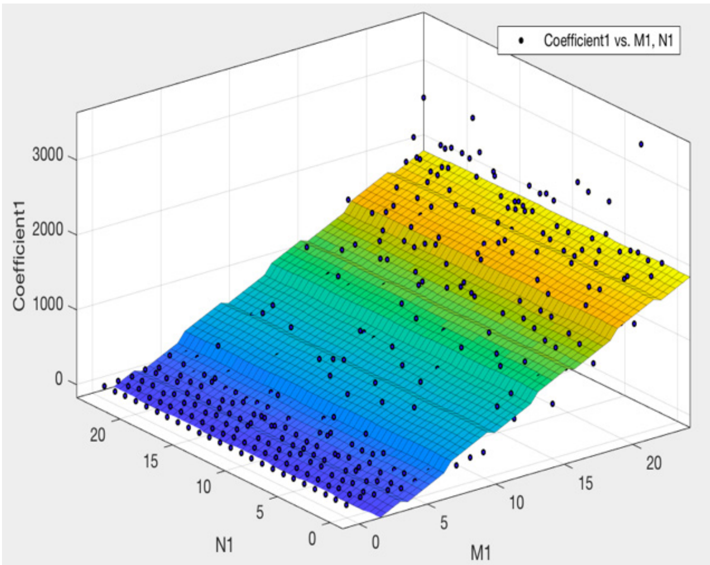

Figure 6 Applicability degree in partitioned warehouse.

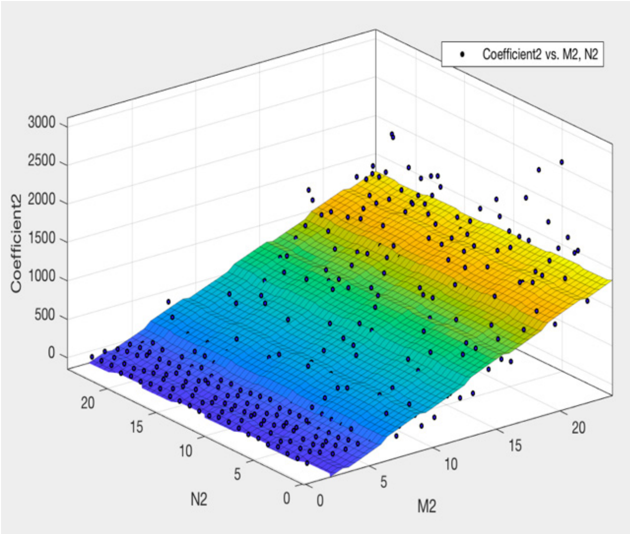

Figure 7 Travel distance in unpartitioned warehouse.

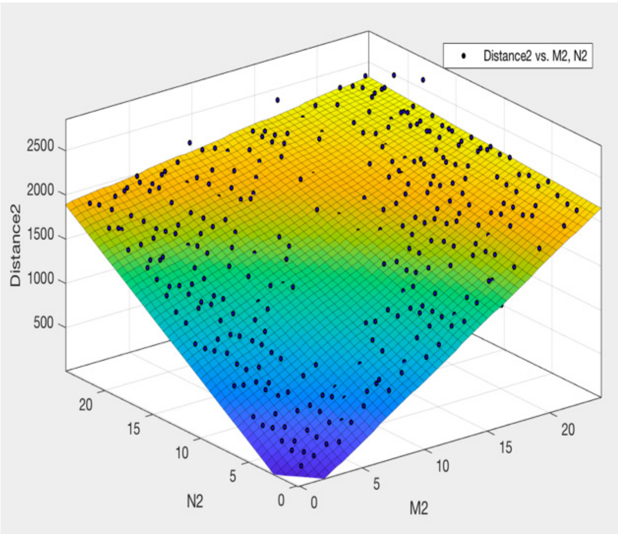

Figure 8 Applicability degree in unpartitioned warehouse.

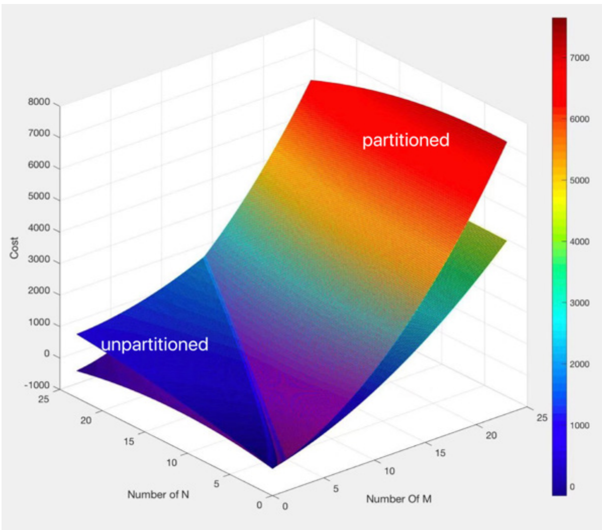

Figure 9 Applicability comparison of 2 conditions.

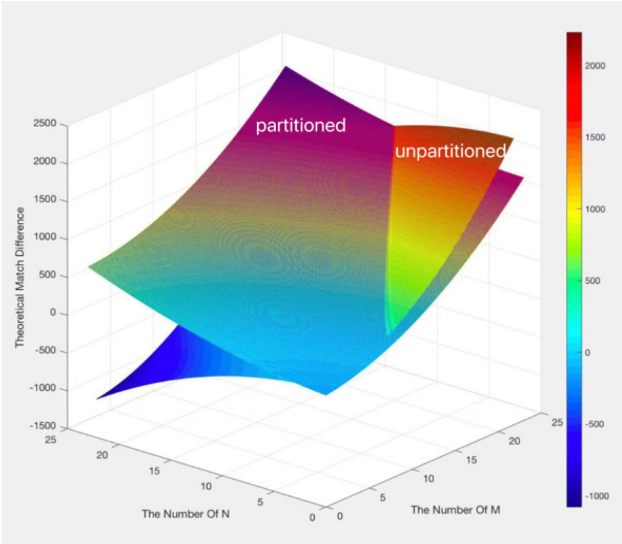

Figure 10 Cost comparison of 2 conditions.

In the picture above, the x-axis is the number of outbound locations, the y-axis is the number of inbound positions, and the Z-axis in **Figures 5** and **7** is the forklifts' travel distance. The Z-axis in **Figures 6** and **8** is the Applicability Degree. Therefore, it can be obtained that, when the partition management rules are applied, the simulation data results have less fluctuation, and there is better controllability in the dangerous goods warehouse.

According to **Figures 9** and **10**, it can be obtained that the ruling guideline, that is, the intersection of the 2 curved surfaces, is affected by the number of inbound locations and outbound locations. The influence of the storage locations on cost and applicability difference can also be obtained.

4.3 Multi-attribute decision model based on simulation data

In this section, we make a decision on whether to set up the ruling management. According to formula (3) and formula (4), we obtain:

$$U_1 - U_2 = 0.571w_1 - 0.088w_2 - 0.01.$$

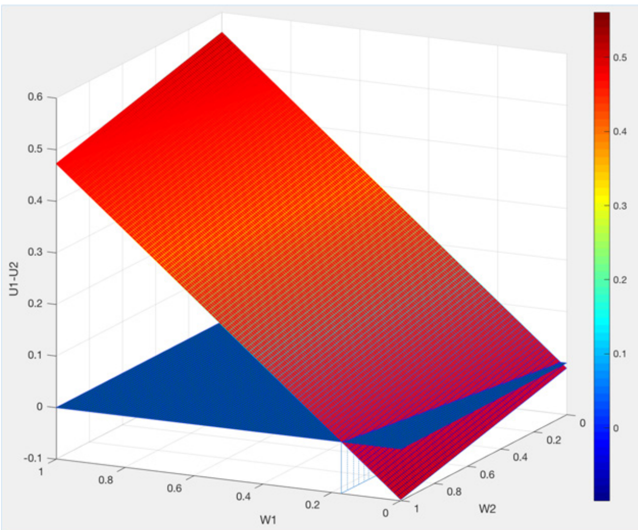

Figure 11 Comprehensive utility evaluation datum.

By finding the equation of the line intersection with the surface xOy, we can find $0.571w_1 - 0.088w_2 > 0.01$ choosing partitioned management. Choosing a zoning setting can make the utility of a dangerous goods warehouse more effective. Furthermore, the difference between U_1 and U_2 is shown in **Figure 11**.

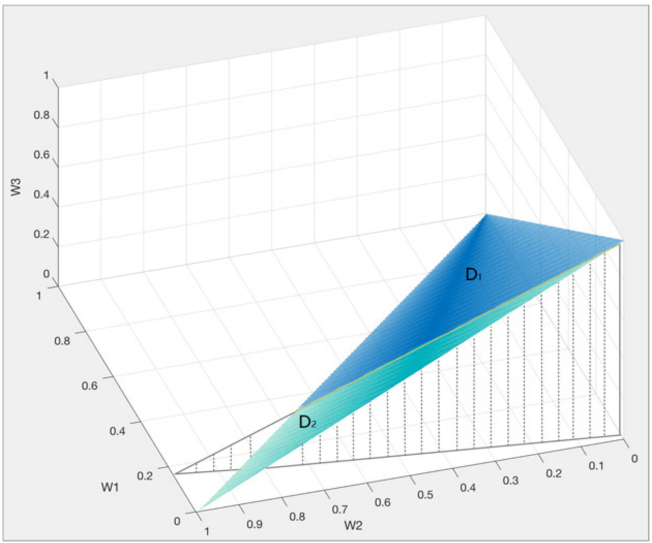

Figure 12 Decision preference space under 2 conditions.

It should be noted that, in **Figure 12**, D_1 is the decision preference space which supports unpartitioned management of a dangerous goods warehouse, while D_2 supports partitioned management.

5. Conclusions

Synthesizing the above studies, this paper draws the following 2 conclusions.

First, compared to conventional warehouses, packaging dangerous goods warehouses have higher safety requirements. In order to comprehensively consider the safety, efficiency, and other factors in the in-and-out operation of dangerous goods, this article takes the setting of forklift rounding rules as the research background and uses optimization theory and the newly proposed cost formula to study the partitioning question of a warehouse. Numerical simulation is also used in this essay, and 4 rules of storage area zoning of the warehouse are obtained. Under the premise of ensuring safety, it provides targeted services for different warehousing customers and provides technical support for round-storage warehouses.

Secondly, the biggest practical innovation of this article is to give the safety formula when a forklift conducts warehouse operations, and the calculation method of safety when the safety red line is given. The biggest theoretical innovation of the article is to combine the maze path finding algorithm and the utility theory to study the problem of dangerous goods warehouse operations.

The application of the study results could greatly enhance both the operation efficiency and safety degree in the processes of dangerous warehousing operations. The enhancement in this field has a positive influence in ensuring the safety of the warehousing industry and in refraining from economic loss from warehousing accidents.

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