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Functional Area Layout Method of Underground Logistic Terminal based on Genetic Algorithm and Automod Simulation Platform

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Abstract: Functional area layout of underground logistic terminal is an important part of urban underground logistic system planning so that it will indirectly affect the building and development of underground logistic terminal and even the whole urban underground logistics system. Based on genetic algorithm and Automod simulation platform, the functional area layout planning method of underground logistic terminal was built in order to avoid underground operation invalidation because of the illogical functional area layout. First by analyzing relative operation of underground logistic terminal, multi-objective 0-1 mixed integer programming model of functional area layout was built based on two indexes of relativity and transit cost between every two functional areas. Then the genetic algorithm was used to solve the mathematical model and find out the layout scheme after quantifying the indicators. Finally the final layout was gained by simulation and optimization based on Automod simulation platform. There was an example for proving the feasibility of the method. The results showed that the method was available to analyze the functional area layout impact and it was very important for decision-making of building the underground logistic terminal.

Key words: Underground logistic terminal, modeling, simulation, automod, optimization

INTRODUCTION

Underground logistic terminal is the main carrier of underground logistics system function which is the primary logistics point directly facing to end-users. It is mainly under the ground to achieve distribution function for cargos. There are much difference from the traditional ground distribution center about its organizational structure and functional area layout. They mainly inflect in: first the underground logistics system uses the AGV and dual-use and the surface road system. Thirdly there should be enough underground space to handle the cargo, operate AGV and maintain the system (Qian and Guo, 2007; Visser, 2005). There is a big difference of truck as the main ferry truck. Secondly, underground logistic terminal should be connected with underground logistics system infection factors between ground and underground logistic terminal including the regional natural conditions, traffic conditions, land conditions, the relation of functional area and regional transportation, goods characteristics, environmental impact and so on without reference to relative indexes of the ground distribution center.

There are few relevant literatures on functional area layout method of underground logistic terminal but some on functional area layout method of ground logistics establishments including Apple (1997)'s factory layout method, Reed Jr (1961)'s system work planning, Muther (1973)'s Systematic Layout Planning (SLP). SLP method is the most commonly used method of facility layout. Its steps are specified(Richard and Liu, 1988). But this method has certain drawbacks. First, SLP method is based on internal facility layout method of push-type manufacturing enterprises. When it is applied to customer service-oriented layout, there are not small differences in terms of processes or in the layout of the concept. Second, underground logistic terminal, a socialized logistics services facility, has more clients, more kinds of goods, more random factors than manufacturing enterprises. These dynamic factors are reflected in the lack of SLP method. Again, transportation organization of underground logistic terminal has more complex dynamic line compared to manufacturing company dynamic line including both material and people flow line. There are some traffic factors in the lack of SLP including analyzing traffic control and contact internal and external traffic.

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Finally, due to technical limitations, SLP method does not include information technology as layout factor and simulation experiment about the facility layout testing and adjustment. It is difficult to objectively evaluate the effects of the layout.

FUNCTIONAL AREA LAYOUT METHOD FRAMEWORK OF UNDERGROUND LOGISTIC TERMINAL

Underground logistic terminal layout method was an improved layout method based on SLP method and computer-aided facility layout method. The layout method not only considered the relation among functional areas and the regional peripheral integrated environmental impact to functional area layout, but also improved defects of the SLP method in logistics facilities layout process so that model solution and simulation evaluation were made by modern computer technology. The method was shown in Fig. 1. First, underground logistic terminal layout factors were analyzed including peripheral integrated environmental analysis, underground logistic terminal functional requirements analysis, underground logistic terminal goods analysis, underground logistic terminal work flow analysis and traffic organization analysis. Base on relevant results of functional area analysis, the correlation of functional area was calculated. Then multi-objective 0-1 integer programming model was established based on the relativity and handling cost. In the transformation process from the mathematical model to physical model, the designer needed to adjust and refine the layout according to the building structure and requirement of equipment lay and traffic organization. Because it was difficult to analyze and optimize the layout by symbol model, mathematical model or physical model, AutoMod simulation model was introduced to analyze the operation problem caused by underground logistic terminal layout and adjust the layout scheme. If the layout scheme was not unique, the optimal solution was selected trough the comparative analysis by AutoMod simulation platform.

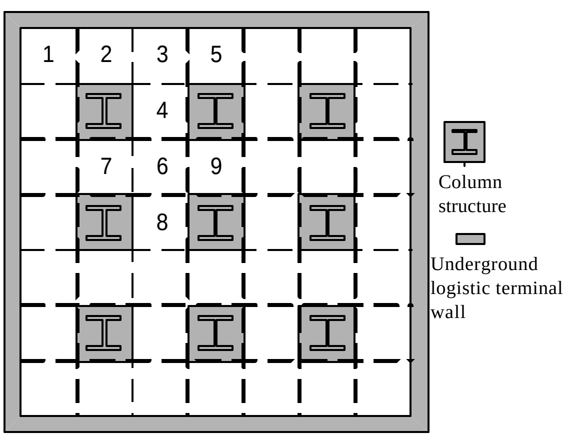


Fig. 1: Underground logistic terminal layout workflow

MATHEMATICAL MODEL OF FUNCTION LAYOUT

Logistics cost and relativity of functional area were selected as optimization objectives of Underground logistic terminal layout optimization model. Combined with features of different regional location and suitability of functional areas (Tong and Zhu, 2009; Li, 2007), restrictive constraints were proposed about functional area location in which quantitative methods of different evaluation indexes were shown in Table 1. By computing the coupling degree of functional area, relativity of functional areas was gained. When number of functional areas was small, the model would be solved by the exact algorithm (e.g., LINGO). When number of functional areas was large, the model would be solved by heuristic algorithms (e.g., genetic algorithms) to solve.

Based on spatial structure of underground facilities and IE Zevgolis *et al*. (2004) proposed the underground warehouse space grid structure, underground logistic terminal functional area layout should be divided into the grid enclosed space by column structure, as shown in Fig. 2. Its layout problem was different from general ground logistics node, so there were some following assumptions:

Table 1: Functional area description

Functional area	Functional area description
Comprehensive service area	Order processing, shipping information transaction, vehicle management services and AGV scheduling management.
ASRS area	Operating units in the tray about a week for the semi-automated warehousing services and warehousing services to provide automated, standard tray can hold 2640
Storage area	Pallets of goods in temporary storage units to provide services to approximately 450 standard trays can be stored
Distribution area	light truck management, park 25 vehicles
Cargo management area	Of access to inspect the goods, stacking, secondary packaging, handling and other services.
Sorting area	Sorting sorting area is equipped with 9 points, the ground provided the logistics needs of cargo sorting, packing, loading and unloading services.
Transfer area	To AGV to transport cargo to the belt and to provide temporary services.
AGV scheduling area	To manage and control of AGV vehicles within the terminal, arranged to send jobs out vehicles AGV, AGV organization completed loading and unloading, parking, ferry and other operations.

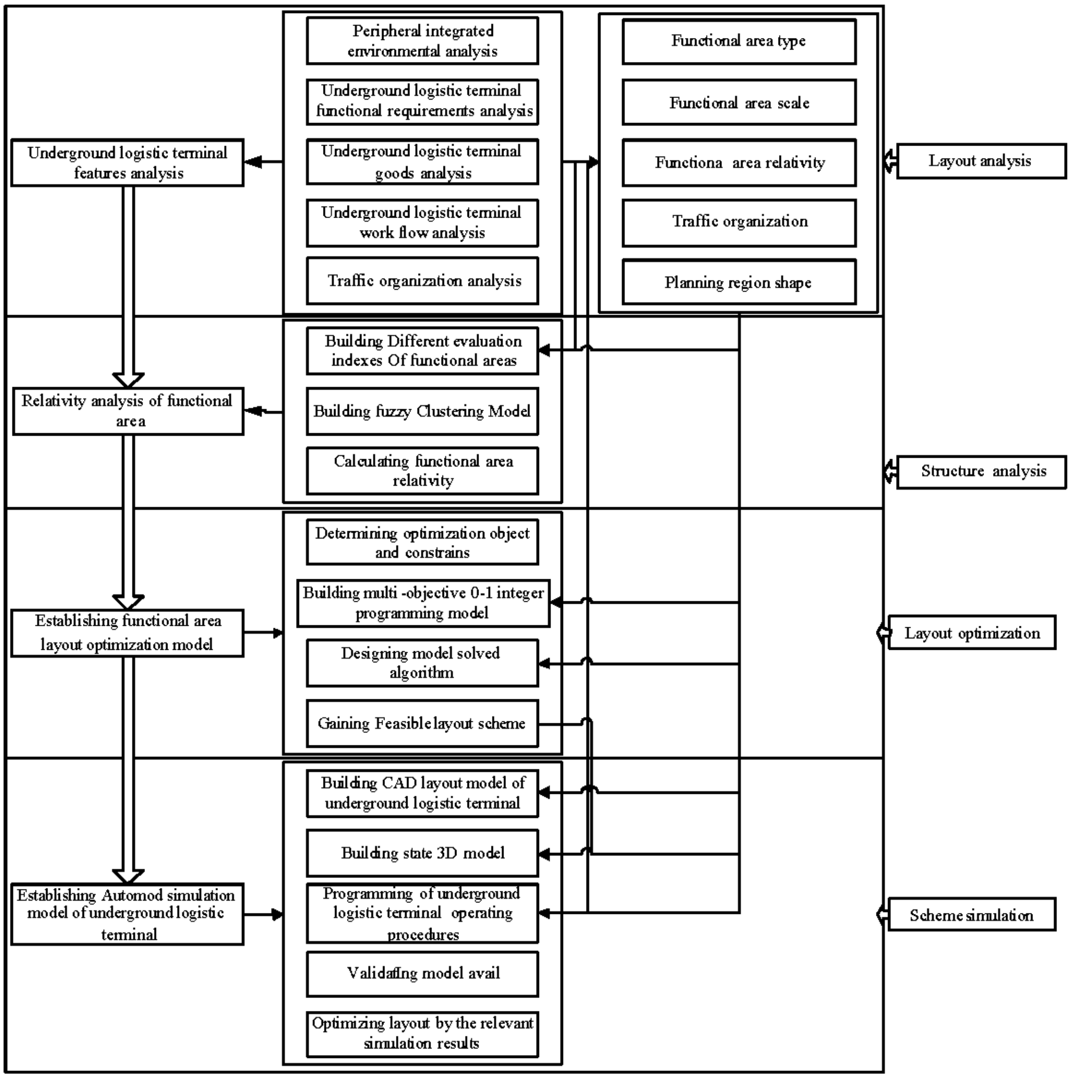


Fig. 2: Underground logistic terminal space structure sketch map

- Each functional area was seen as a cell with regardless of shape
- According to the functional area size, functional area could be accounted for multiple cells. Functional area size, less than a cell size, was seen as a grid cell. Functional area size, more than a cell size was set to add a new grid cell. the new one was seen as a new functional area. It had great amount of closeness and transshipment volume with the former one. Its closeness and transshipment volume with the other functional areas were the same as the former one
- The distance between functional areas was calculated the urban distance
- The number of functional area must be less than or equal number of grids
- The adjacent functional area was only left and right or up and down one. For example Functional area 2 was adjacent with Functional area 1,3 without Functional area 4, as shown in Fig. 2
- Functional areas were on the same floor layout

Object function:

$$\begin{cases} F_1 = \min\left[\sum_{l=1}^{n-1}\sum_{k=l+1}^{n} v_{lk} b_{lk} (|x_l - x_k| + |y_l - y_k|)\right] \\ F_2 = \max\left[\sum_{l=1}^{n-1}\sum_{k=l+1}^{n} z_{lk} c_{lk}\right] \end{cases}$$

Constraint condition:

$$1 \le x_l \le n_i, l \in L$$

$$1 \le y_l \le n_j, l \in L$$

$$x_l \ne i, l \in L, i \in I_i$$

$$x_l \ne j, l \in L, j \in I_j$$

$$x_l = [i, j], i, j \in I_i$$

$$y_l = [i, j], i, j \in I_j$$

was natural numbers:

$$z_{lk} = \begin{cases} 1, |x_l - x_k| + |y_l - y_k| = 1 \\ 0, |x_l - x_k| + |y_l - y_k| > 1 \end{cases}$$

where, n was the number of functional areas. v_{ij} was the transit amount among functional areas. c_{ij} was closeness degree of functional areas. b_{ij} was transport carriage rates among functional areas. z_{lk} was 0-1variable. If Functional area l and k were adjacent,then $z_{lk} = 1$, else $z_{lk} = 0$. x_l was the abscissa of Functional area l, $x_l \in i$◦y_l was the ordinate of Functional area l, $y_l \in j$.

ALGORITHM DESIGN BASED ON GENETIC ALGORITHM

Facility layout problem was NP-hard problem (Amaral, 2006),so that genetic algorithm was selected to solve this problem. The following was the main step.

Coding design: Using integer coding method, coding was composited by the natural numbers and 0. The natural number was used to show functional area and 0 was shown as column structure.

Coding method: If the grid layout was $n_i \times n_j$, then the chromosome number was $n_i n_j$. 0 was in the chromosomal location:

$$(2i-1)n_j+2, (2i-1)n_j+4, \cdots (2i-1)n_j + 2 * \text{int}(\frac{n_j}{2})$$

Where:

$$i = 1, 2, \cdots, \text{int}(\frac{n_i}{2})$$

The natural number was arranged randomly in the other chromosomal location.

Decoding method: If the first 0 was Bit i in the N bits chromosome, then:

$$n_j = (i-2), n_i = \frac{N}{n_j}$$

In order of priority arrangement, the matrix $n_i \times n_j$ was gained. For example chromosome x = (5, 9, 16, 14, 17, 11, 0, 21, 0, 6, 719, 15, 2, 18, 8, 0, 3, 0, 10, 13, 20, 12, 4, 1) indicated in the range of the grid:

$$n_j = (7-2), n_i = \frac{25}{(7-2)}$$

its corresponding layout structure:

$$O = \begin{pmatrix} 5 & 11 & 7 & 8 & 13 \\ 9 & 0 & 19 & 0 & 20 \\ 16 & 21 & 15 & 3 & 12 \\ 14 & 0 & 2 & 0 & 4 \\ 17 & 6 & 18 & 10 & 1 \end{pmatrix}$$

Fitness evaluation: The multi-objective functions were transformed into single objective function. Then it was made into calibration. Specific steps are as follows:

Step 1: Processing the objective function:

$$F = \frac{\sum_{l=1}^{n-1} \sum_{k=l+1}^{n} v_{lk} b_{lk} (|x_l - x_k| + |y_l - y_k|)}{\sum_{l=1}^{n-1} \sum_{k=l+1}^{n} z_{lk} c_{lk}}$$

Step 2: F was made into calibration to obtain appropriate evaluation function:

$$f = \alpha \frac{\sum_{l=1}^{n-1} \sum_{k=l+1}^{n} v_{lk} b_{lk} (|x_l - x_k| + |y_l - y_k|)}{\sum_{l=1}^{n-1} \sum_{k=l+1}^{n} z_{lk} c_{lk}} + \beta$$

Genetic arithmetic: There were some illegal chromosomes in the genetic algorithms, so the new chromosomes were made legitimacy test:

- The designation “0” is 0. If not, it would become 0
- There was not 0 in the other location, except in the appointed location. Else 0 became a natural number
- The natural number should contain all natural numbers [1, n]. Otherwise, the repeated number became the missing natural number

SIMULATION AND MODEL OF UNDERGROUND LOGISTIC TERMINAL BASED ON AUTOMOD SIMULATION PLATFORM

Underground logistic terminal simulation experiment based on Automod simulation platform could make simulation materialization about establishment, equipment, workers and workflow. It could almost simulate the actual process of underground logistic terminal operations to effectively analyze the problems of static and dynamic operation of the functional areas layout. Modeling and Simulation of underground logistic terminal should be divided into three main stages including the describing stages of system simulation, the modeling stage of system simulation and the analysis and optimization stage of simulation model. The Describing stage was including collecting basic data of underground logistic terminal planning, determining the simulated target, determining the initial program of simulation system by various theories of underground logistic terminal planning. System Simulation and optimize stage was including identification of dynamic run, simulation results analysis and optimization and finding out the final satisfactory solution repeatedly.

EXAMPLES

In the main city zone of certain megapolis, underground logistic terminal was proposed to be built, whose planning area was 6050 m^2 and the specific dimensions of 110×55 m. the effective used area was 4840 m^2 which has 10 column made of 11×11 m square column (Zevgolis *et al*., 2004). These square columns divided the whole underground logistic terminal into 40 11×11 m grid structures. Functional areas were including comprehensive service area, ASRS area, storage area, distribution area, cargo management area, sorting area, transfer area, AGV scheduling area. Comprehensive service area, AGV scheduling area and distribution area were determined because of geographical conditions and operating constraints. The other areas was made layout and optimize. The standardization matrix of their handling cost and relativity showed as the below equation. The layout size was 5×6 grid size and ratios of the five functional areas were 2:3,2:2,5:1,2:4,1:5. It was solved using MATLAB software. The results were shown in Fig. 3. underground logistic terminal finally got the layout of functional areas shown in Fig. 4.

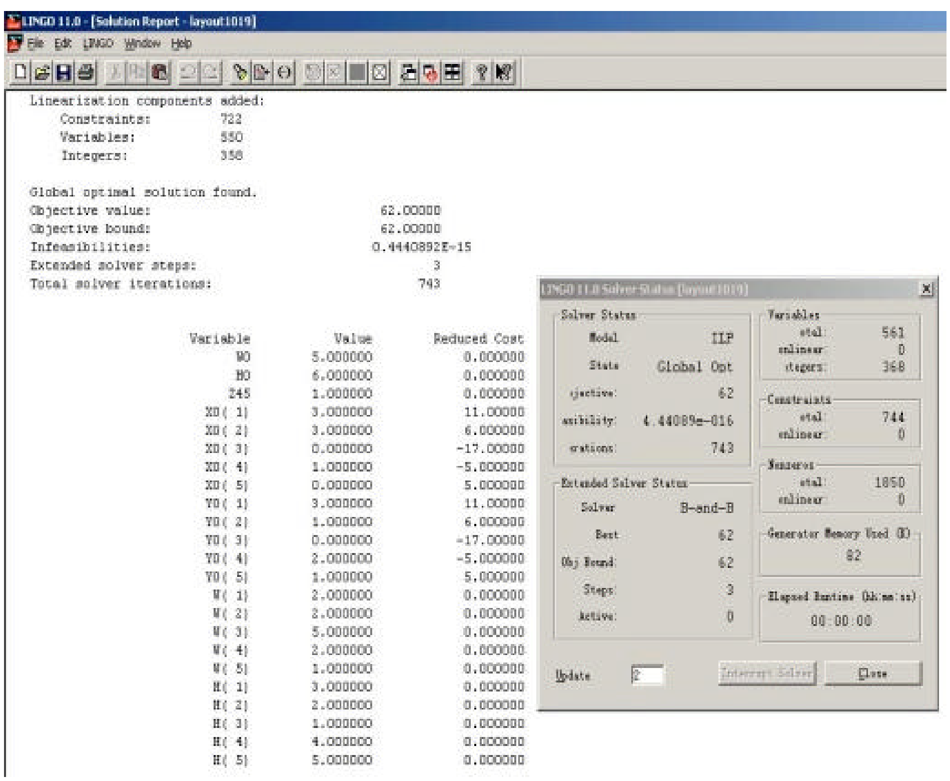
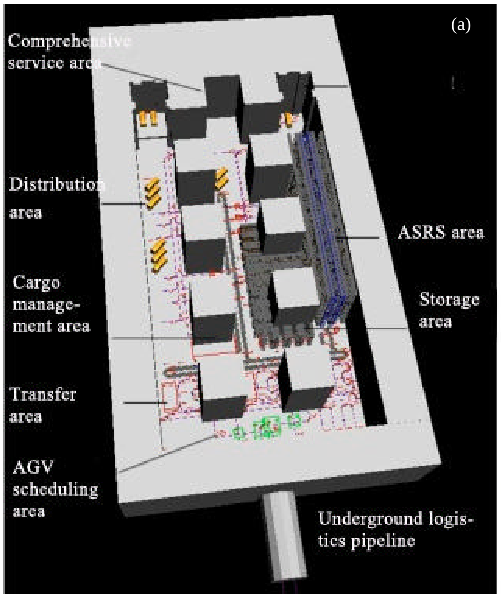
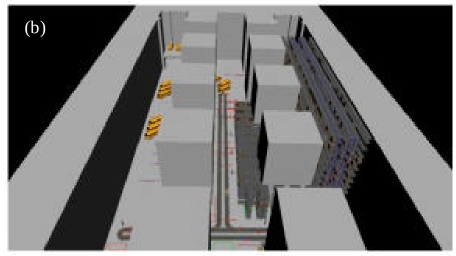


Fig. 3: LINGO result





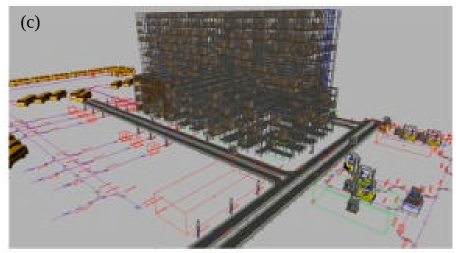


Fig. 4(a-c): AutoMod simulation model (a) General plan, (b) Partial plana and (c) Terminal internal scenograph

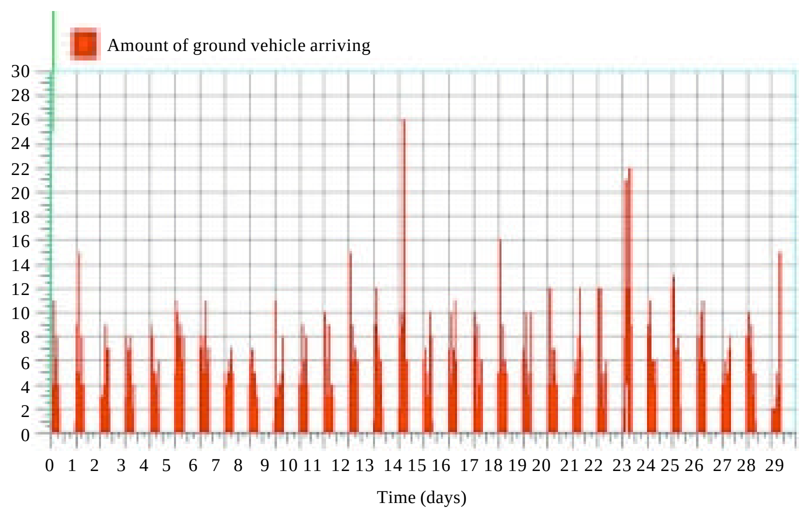


Fig. 5: Surface vehicle number arrived in 30 days

Table 2: Underground logistic terminal work capability

	AGV arrived (veh)	Time interval (min)	ASRS area (pallet)	Storage area (pallet)	Transfer area (pallet)
Comparison state	U (20,5)	U (30,5)	5400	1100	10
Recommended status	U (20,5)	U (60,5)	2600	500	9
		Design capacity	2640	550-600	30

Based on the above analysis result of underground logistic terminal, Automod simulation model of underground logistic terminal was established as shown in Fig. 4. Its transport system, AGV scheduling system and workflow system were made dynamic testing and its capacity was analyzed. The results showed that the layout was reasonable and it was not found vehicles in congestion, flow stagnation and other phenomena. The recommended values of relative system capacity were shown in Table 2. Some analysis data was shown in Fig. 5-8.

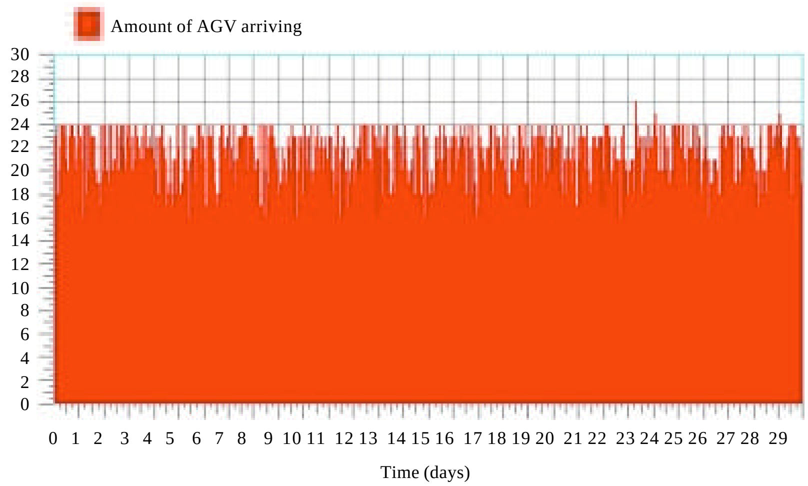


Fig. 6: AGV number in 30 days

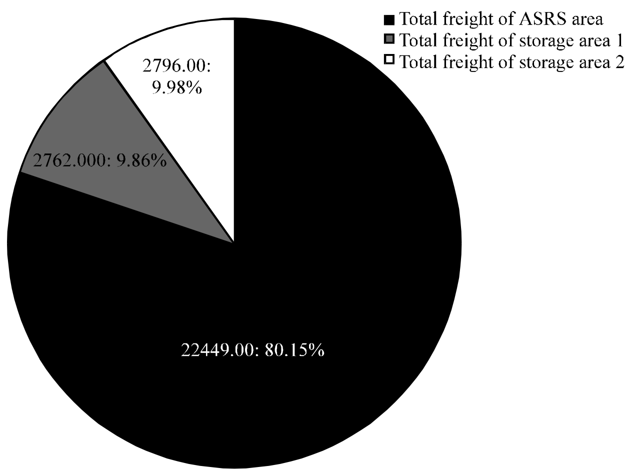


Fig. 7: Quantitative flowchart from Transfer area to Storage area 1,2 and ASRS area

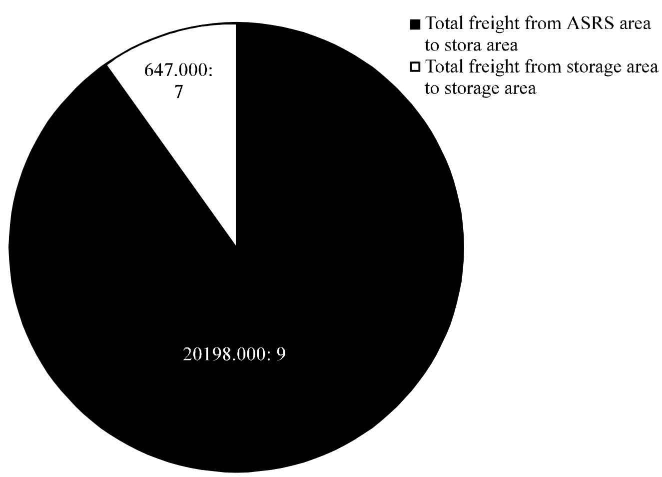


Fig. 8: Quantitative flowchart from ASRS area to sorting area

CONCLUSION

Although, underground logistic terminal scale was limited, the facilities, structures, transportation and handling line were complex, so it was difficult for the mathematical model and physical model to ensure the normal dynamic operation of the underground logistic terminal. This method could effectively gain the layout of underground logistic terminal functional areas and predict the equipment operational effectiveness and operational capacity, as well as the decision-making of underground logistic terminal construction was also provided.

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