Research on Optimization of Stereoscopic Warehouse Delivery Mode Based on EIQ Analysis

Lu Jiang
Department of Mechanical and Electrical Engineering, Shanghai Maritime Academy, Pudong New District, Shanghai, China

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Abstract: In order to improve the shelf delivery efficiency of the stereoscopic warehouse, this paper proposes to establish a discriminant model for the delivery mode based on EIQ analysis, establish a mathematical model by linear regression fitting according to the data obtained from EIQ analysis, and verify the model in the virtual center system according to a large number of actual operating data. The validity of the model is verified by comparing the model calculation with the measured data.

1 INTRODUCTION

Stereoscopic warehouse, also known as elevated warehouse or elevated warehouse, generally refers to a warehouse that uses several, ten or even dozens of layers of shelves to store goods, and uses corresponding material handling equipment for warehousing and outbound operations. The key to improve the efficiency of warehouse out picking operation is to select the appropriate warehouse out method. There are two delivery methods: delivery by order and delivery by consolidated order (An, 2014). Delivery by order picking results in low efficiency due to too many operations. The use of consolidated order delivery reduces the number of operations, but the need for secondary sorting will increase the cost. Therefore, an effective delivery method discrimination model is needed to determine the delivery method of orders in a certain time.

Assuming that the operating proficiency of the staff is fixed, the optimal shipping method and the fastest shipping time can be determined only by determining the order information. In this paper, the EIQ analysis of orders is proposed to determine the functional relationship between order information and delivery time, and the establishment of a judgment model is a method to optimize the delivery mode of stereoscopic warehouse.

The EIQ analysis method is a planning method for the distribution center system under uncertain and fluctuating conditions. It uses three key elements, namely, Entry, Item and Quantity, to discuss its operation mode and plan the logistics system according to the distribution center objectives. Combined with practice, a large amount of real data of a distribution center operation is used as the theoretical basis and modeling basis to build a discrimination model for the delivery mode, and the actual data is solved to verify the feasibility and effectiveness of the model.

2 DISCRIMINANT MODEL OF DELIVERY MODE BASED ON EIQ ANALYSIS

2.1 Model Assumptions

All ordered items are stored in the three-dimensional warehouse area. The operation proficiency of each staff shall not be affected by the external environment. The arrival time of each kind of goods from the warehouse location to the shipping port is the same. The minimum unit of outbound goods is box.

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2.2 Data Acquisition and Processing

2.2.1 Determination of Order Batch Time Range

According to the principle of time window batch method, the orders of the distribution center for one day are batched. Suppose that the total number of daily operation orders of a distribution center is about 150, and the daily working hours are 12 hours. Different time windows are set, the number of order batches per day and the average number of orders per batch are different, as shown in Table 1.

Table 1: Distribution center order batch time setting.

Time window setting(min)	Daily order batch (pcs)	Order of each batch (piece)
40	18	8.33
30	24	6.25
20	36	4.17

When conducting EIQ analysis, if there are too many batches, it is troublesome to handle, and the batch results are meaningless; If it is too small, the number of orders in each batch is large, and the waiting time for orders is long. Taking Table 1 as an example, you can set the time window to 30 minutes, that is, batch the received orders every 30 minutes.

2.2.2 EIQ Outbound Data Statistics

Suppose that a distribution center receives several orders within a period of time after it starts operation on a certain day, and makes statistics on the order information of the first batch. There is an outbound order E_m (m=1, 2, 3...) in this batch. All the orders involved in the shipment items include I_n (n=1, 2, 3...). Q_{mn}=quantity (order E_m, item I_n) is used to represent the quantity of an item ordered by a single order (Liu, 2010). A table is drawn after the order information is counted, as shown in Table 2.

According to the statistics results of EIQ delivery data, specific analysis can be carried out, including:

- Order quantity (EQ) analysis: analysis of the shipment quantity of a single order (Fan, 2004).
- Ordering item number (EN) analysis: analysis of the number of items shipped from a single order (Liu, 2005).
- Item quantity (IQ) analysis: analysis of the total quantity of each item shipped (Wei, 2013).
- Analysis of the number of ordered items (IK): analysis of the number of shipments of each item (Li, 2009).
- IQ and IK cross analysis.
- Comparative analysis of EQ, EN, IQ and IK.

Table 2: EIQ data of the first batch of orders of a day.

Order	Item				Order quantity	Order item
	I_1	I_2	…	I_n		
E_1	Q_{11}	Q_{12}	…	Q_{1n}	DQ_1	N_1
E_2	Q_{21}	Q_{22}	…	Q_{2n}	DQ_2	N_2
…	…	…	…	…	…	…
E_m	Q_{m1}	Q_{m2}	…	Q_{mn}	DQ_m	N_m
Product quantity	CQ_1	CQ_2	…	CQ_n	Q	N
Delivered frequency	K_1	K_2	…	K_n	-	K

2.2.3 EN Analysis

EN analysis, which is based on the principle of order processing, planning of the pick-up system, and shipment and routing area planning, is usually performed to understand the distribution of the number of items ordered per order, using three indices (Wu, 2011).

- Number of goods delivered in a single order (N_m)

$$N_m = COUNT(Q_{m1}, Q_{m2}, Q_{m3}, ..., Q_{mn}) > 0 \quad m = 1,2,3... \tag{1}$$

- Total number of goods delivered (N)

$$N = COUNT(K_1, K_2, K_3, ..., K_n) > 0 \tag{2}$$

- Cumulative number of goods delivered by order (GN)

$$GN = N_1 + N_2 + N_3 + ... + N_m \tag{3}$$

2.2.4 Establish the Judgment Model of Delivery Method

(1) The method of ex warehouse by order is adopted

The total time required for a batch of orders to be delivered by order is T_d, mainly including T_1 (order processing time), T_2 (stereoscopic shelf running time), T_3 (goods unpacking time) and T_4 (review, packaging, labeling and handling time).

$$T_d = T_1 + T_2 + T_3 + T_4 \tag{4}$$

- Order processing time(T_1)

Test the processing time t_1 of an order in the virtual simulation system, and calculate the average value after five tests, as shown in Table 3.

Table 3: Processing time of an order.

Test	1st	2nd	3rd	4th	5th	Average
Time(s)	58	60	63	67	65	62.6

The average processing time of an order calculated by the test is $t_1=62.6s$, so the order processing time is:

$$T_1 = mt_1 = 62.6m \quad (5)$$

m is the number of orders.

- Running time of stereoscopic shelf (T_2)

Test the running time t_2 of a single order stereoscopic shelf in the virtual simulation system. The time from the start of the stereoscopic shelf to the time when the RGV trolley sends the tray to the tray port, plus the time when the goods are sent back to the stereoscopic warehouse after the tray is removed, is the running time of the stereoscopic shelf, excluding the time when the goods are removed. The test data and results are shown in Table 4.

Table 4: Running time of stereoscopic shelf for one order.

No. order	1	2	3	4	5
items delivered	1	2	3	4	5
Time(s)	134	165	267	320	419

The running time t_2 of the three-dimensional shelf of a single order has a linear relationship with the number of items delivered from the order. The linear regression method is used to fit, as shown in Figure 1. $a_1=72.5$, $b_1=43.5$.

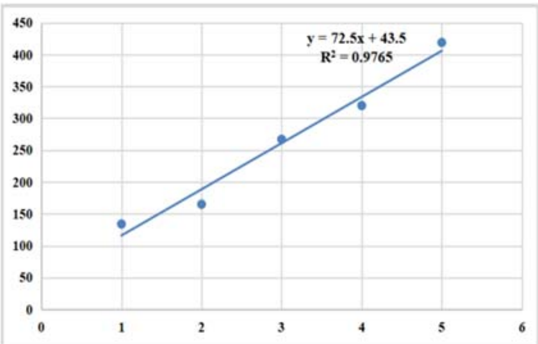

Figure 1: Fitting diagram of running time of three-dimensional shelf for an order.

The stereoscopic shelf running time T_2 is the sum of the stereoscopic shelf running time of all orders.

$$T_2 = a_1 N + b_1 m = 72.5N + 43.5m \quad (6)$$

N is the total number of goods delivered.

- Time of goods unpacking(T_3)

In the virtual simulation system, test the time T_3 required for disk disassembly. Add orders by yourself for five experiments. The total shipment is set to 5, 10, 15, 20, and 25 boxes. The test results are shown in Table 5.

Table 5: Disengaging time corresponding to different total shipments.

Test	1st	2nd	3rd	4th	5th
Total	5	10	15	20	25
Time(s)	44	65	107	136	178

The time of goods unpacking is approximately linear with the total shipment, and the linear regression is used to fit as shown in Figure 2. $a_2=6.78$, $b_2=4.3$

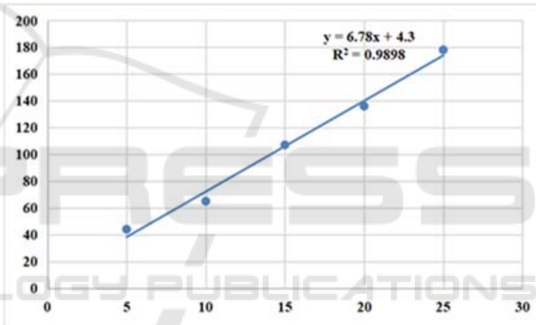

Figure 2: Fitting Chart of Disengaging Time and Total Shipments.

$$T_3 = a_2 Q + b_2 = 6.78Q + 4.3 \quad (7)$$

Q is the total shipment.

- Review, packaging, labeling and handling time(T_4)

The test is carried out in the virtual simulation system. The time from the time when the goods are transported to the review port through the conveyor belt to the time when the storage cage car is pushed to the warehouse exit is the time for a review, packaging, labeling and handling operation. Since the next order has been processed since the review, packaging, labeling and handling of each order starts, the total review, packaging, labeling and handling time T_4 only includes the operation time of the last order. Add orders by yourself for 5 experiments, and the test data are shown in Table 6.

Table 6: Time for review, packaging, labeling and handling of an order.

Test	1st	2nd	3rd	4th	5th
Total	2	4	6	8	10
Time(s)	115	132	159	180	214

The review, packaging, labeling and handling time T4 are approximately linear with the shipment quantity DQ_n of the last order, and the linear regression method is used for fitting, as shown in Figure 3. a_3=12.3, b_3=86.2.

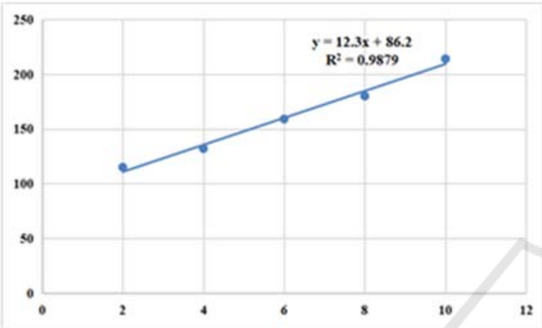

Figure 3: Fitting Chart of Operation Time of Checking, Packaging, Labeling and Handling with Shipping Volume.

$$T_4 = a_3 DQ_m + b_3 = 12.3Q_n + 86.2 \quad (8)$$

(2) Use the consolidated order delivery operation Method

The total time required for the delivery of a batch of orders using consolidated orders is T_h, mainly including T_1' (order processing time), T_2' (stereoscopic shelf running time), T_3'(goods unpacking time), T_4' (review, packaging, labeling and handling time) and T5 '(wave sorting system time).

$$T_h = T_1^{'} + T_2^{'} + T_3^{'} + T_4^{'} \quad (9)$$

- Order processing time(T_1')

Add orders in the virtual simulation system for five experiments, and the number of consolidated orders in each experiment is 2, 3, 4, 5, and 6 respectively. The test data is shown in Table 7.

Table 7: Processing time of consolidated orders.

Test	1st	2nd	3rd	4th	5th
Total	2	3	4	5	6
Time(s)	72	75	89	88	94

The order processing time T_1'is approximately linear with the number of orders m, and the data obtained from the test are fitted, as shown in Figure 4. a_4=5.7 and b_4=60.8.

$$T_1^{'} = a_4 m + b_4 = 5.7m + 60.8 \quad (10)$$

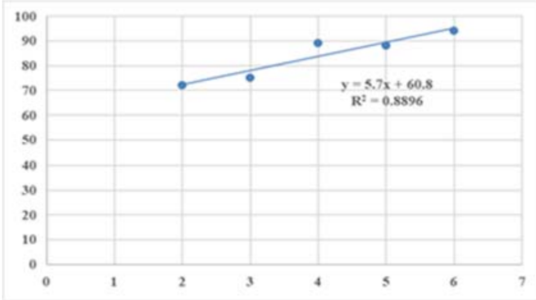

Figure 4: Fitting Chart of Consolidated Order Processing Time.

- Running time of stereoscopic shelf (T_2')

In the consolidated order picking method, the wave order is regarded as an order for one delivery, so the running time of the three-dimensional shelf has the same rule as the data tested in the delivery by order, that is, the parameters are the same.

$$T_2^{'} = a_1 m + b_1 = 72.5m + 43.5 \quad (11)$$

- Time of goods unpacking(T_3')

Under the condition that the operator's proficiency remains unchanged, the time of goods unpacking is approximately proportional to the total shipment volume. Since the total shipment volume remains unchanged, the time of goods unpacking is the same as that of goods unpacking in the picking by order method, as shown in Formula 7.

- Review, packaging, labeling and handling time(T_4')

After the operation of the wave sorting system is completed, recheck, packaging, labeling and handling operations are carried out. The time T4 'is proportional to the order quantity m. Add order information by yourself and test the review, packaging, labeling and handling operation time in the virtual simulation system. Set the number of orders in each experiment to be 1,2,3,4,5. The test results are shown in Table 8.

Table 8: Review, packaging, labeling and handling time for different order quantities.

Test	1st	2nd	3rd	4th	5th
Total	1	2	3	4	5
Time(s)	79	163	202	289	350

Carry out linear regression fitting according to the test results, as shown in Figure 5. Set the intercept of the regression linear equation to zero, and a_5=71.218.

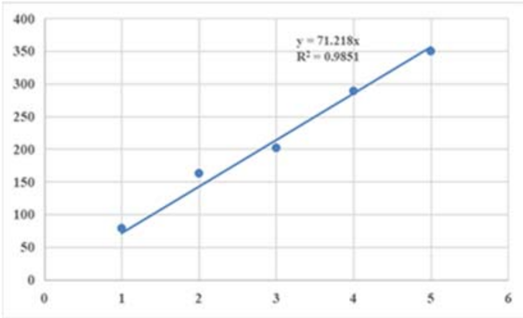

Figure 5: Fitting Chart of Review, Packaging, Labeling and Handling Time.

$$T_4^{'} = a_5 m = 71.218m \quad (12)$$

- Wave sorting system time(T_5')

The time for wave sorting of goods of the nth item is t_{5n}, which has the following relationship with the shipment quantity CQ_n and the shipment times K_n of the item:

$$t_{5n} = a_6 CQ_n + b_6 K_n + C_6 \quad (13)$$

In order to measure the values of a_6, b_6 and c_6, using the control variable method, first set the number of single product shipments K_n as a fixed value, change the value of single product shipments CQ_n, and add order information to test the single product wave sorting time t_{5n} in the virtual simulation system. The test result data are shown in Table 9.

Table 9: Control the number of shipments of single items, wave sorting time.

Items	I_1	I_2	I_3	I_4
frequency of Product shipments	4	4	4	4
Quantity of Product shipments	4	8	16	24
Time(s)	128	160	230	315

Carry out linear regression fitting according to the test data, as shown in Figure 6. a_6=9.3347.

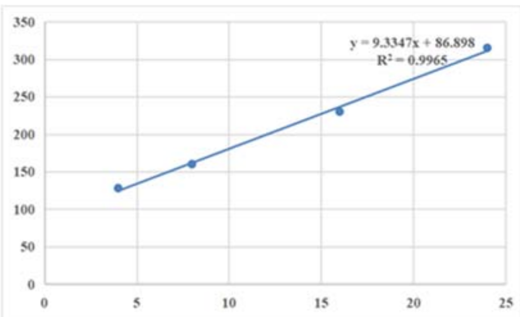

Figure 6: Fitting Chart of Controlling the Number of Shipments of Single Items and Wave Sorting Time.

Set the single product shipment quantity CQ_n as a fixed value, change the value of single product shipment times K_n, and measure the single product wave sorting time t_{5n}. The test results are shown in Table 10.

Table 10: Control shipment volume wave sorting time.

Items	I_1	I_2	I_3	I_4
frequency of Product shipments	1	2	3	4
Quantity of Product shipments	4	4	4	4
Time(s)	53	70	109	125

Carry out linear regression fitting according to the test data, as shown in Figure 7. b_6=25.5, C_6=25.5.

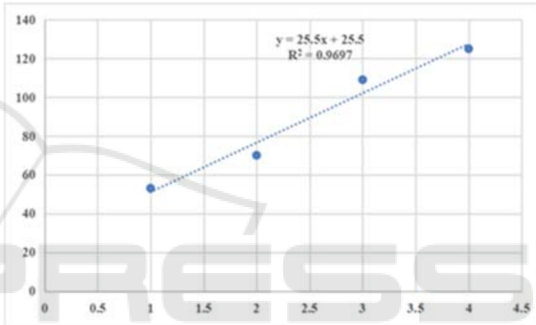

Figure 7: Fitting Chart of Wave Sorting Time for Controlling Single Product Shipment.

$$T_5^{'} = \sum t_{5n} = \sum (a_6 CQ_n + b_6 K_n + c_6) = \sum (9.3347CQ_n + 25.5Kn + 25.5) \quad (14)$$

(3) Objective function formula

The shortest delivery time T of a batch order is the shortest of the two delivery methods.

$$T = \min(T_d, T_h) \quad (15)$$

By comparing the size of T_d and T_h, we can determine which delivery method is more efficient, and select the appropriate delivery method according to the characteristics of the order.

3 INSPECTION OF DELIVERY METHOD JUDGMENT MODEL

The judgment model of delivery mode is a mathematical model based on the time decomposition and summation of the operation process and the simplification and abstraction of the actual operation process. The parameters of the model are calculated based on the data obtained from many experiments. In order to prove the rationality and practicability of the model, the correctness of the model is verified by substituting the actual order information.

The system pre recorded four orders for EIQ analysis, and the analysis results are shown in Table 11. The data obtained are substituted into the delivery method judgment model.

Table 11: Statistics of EIQ data pre-recorded by the system.

m	I_1	I_2	I_3	I_4	Q_m	N_m
1	2	2	2	5	11	4
2	3	2	0	6	11	3
3	1	0	4	6	11	3
4	3	1	2	5	11	4
CQ_n	10	5	9	22	Q	N
K_n	4	3	3	4	44	14

(1) Delivery Time by Order (T_d)

$$\begin{aligned} T_d &= T_1 + T_2 + T_3 + T_4 \\ &= 62.6m + (72.5N + 43.5m) + (6.78Q + 4.3) + (12.3DQ_m + 86.2) \\ &= 62.6\times 4 + (72.5\times 14 + 43.5\times 4) + (6.78\times 44 + 4.3) + (12.3\times 11 + 86.2) \\ &= 250.4 + 1189 + 302.62 + 221.5 = 1963.52(s) \end{aligned} \tag{16}$$

(2) Consolidated order delivery time (T_h)

$$\begin{aligned} T_5^{'} &= \sum (9.3347CQ_n + 25.5Kn + 25.5) \\ &= (9.3347\times 10 + 25.5\times 4 + 25.5) + (9.3347\times 5 + 25.5\times 3 + 25.5) \\ &+ (9.3347\times 9 + 25.5\times 3 + 25.5) + (9.3347\times 22 + 25.5\times 4 + 25.5) \\ &= 220.85 + 148.67 + 186.01 + 322.86 = 878.39(s) \end{aligned} \tag{17}$$

$$\begin{aligned} T_h &= T_1^{'} + T_2^{'} + T_3^{'} + T_4^{'} + T_5^{'} \\ &= (5.7m + 60.8) + (72.5m + 43.5) + (6.78Q + 4.3) + 71.218m + T_5^{'} \\ &= (5.7\times 4 + 60.8) + (72.5\times 4 + 43.5) + (6.78\times 44 + 4.3) + 71.218\times 4 + 878.39 \\ &= 83.6 + 333.5 + 302.62 + 284.87 + 878.39 = 1882.98(s) \end{aligned} \tag{18}$$

It can be seen from the calculation results that the delivery time Th of consolidated orders is slightly less than the delivery time Td of orders, so it is more efficient to select the delivery method of consolidated orders.

The time calculated by the model is compared with the data obtained from the actual experiment. The comparison results are shown in Table 12.

Table 12: Time comparison table between the time calculated by the four order models pre recorded by the system and the actual time.

	Model calculation	Actual measurement	error	Error rate
$T_d(s)$	1963.52	1778	185.52	10.43%
$T_h(s)$	1882.98	1638	244.98	14.95%

Although there is some difference between the time spent in calculation and the actual operation, about 10.43%, the result of using this model to calculate the difference in delivery time is in line with the actual situation.

4 CONCLUSIONS

In this paper, theoretical analysis and mathematical modeling are closely linked when solving the issue efficiency comparison problem between the proposed issue by order method and the issue by consolidated order method. With a large number of specific data obtained through practical operation as the theoretical basis, a discrimination model of delivery mode based on EIQ analysis is established, and the data is brought into the model for solution. Qualitative analysis and quantitative calculation are combined, and its effectiveness is confirmed through verification.

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