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Research Article

Entry-Item-Quantity-ABC Analysis-Based Multitype Cigarette Fast Sorting System

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Numerous items, small order, and frequent delivery are the characteristics of many distribution centers. Such characteristics generally increase the operating costs of the distribution center. To remedy this problem, this study employs the Entry-Item-Quantity (EIQ) method to identify the characteristic of the cigarette distribution center and further analyzes the importance degree of customers and the frequently ordered products by means of EQ/EN/IQ-B/IK statistic charts. Based on these analyses as well as the total replenishment cost optimization model, multipicking strategies and combined multitype picking equipment allocation is then formulated accordingly. With such design scheme, the cigarette picking costs of the distribution center are expected to reduce. Finally, the specific number of equipment is figured out in order to meet the capability demand of the case cigarette distribution center.

1. Introduction

With the need for small-volume order fulfillment and extremely high accuracy, distribution center (DC) is playing an important role in modern logistics market. In [1], order picking function which is commonly considered the most critical part in a distribution system accounts for about 55% of operating costs within the DC warehouse. In fact, customer orders may be large bulk shipments or single-unit orders sent to an end user. Especially in high throughput capacity DC, such as pharmaceutical, tobacco, the volume of such orders per day could usually number in the thousands. Nowadays, picking product tends to be the most labor-intensive operation and can affect customer satisfaction levels, so there have been increasing numbers of process improvements proposed to help companies with this distribution issue [2].

When it comes to improving the order picking efficiency and technologies, first of all, order profiles should be fully understood with the mix of products, the size of orders, and the number of items per order. EIQ (entry, item, and quantity) analysis methodology proposed by Suzuki Sin provides support in this area and related researches can be seen in literature. In the work of [3], EIQ and EIQNK curve method for the selection of machine and equipments in the design of distribution center or warehouse was discussed. For more analytical generalizations on EIQ, we refer readers to [4, 5] and the references therein. However, the final aim of EIQ analysis is to support designing a sorting system with rule-based equipment setup. Manual management of an order picking system can be poorly efficient even if largely practiced [6]. Significant economic benefits may result from modern integrated equipment system instead of the traditional manual decision approach. In [7], CAOPS (complex automated order picking system) is proposed that it is a kind of dispenser-based, conveyor-aided, single-piece order picking system with high order picking automation level. Automatic dispensers have been applied in picking cigarette orders with the characteristics of high-speed, high-accuracy, and low-labor-intensity [8–12].

The remainder of the paper is organized as follows. In the next section, we present the order picking data analysis methods and picking strategies in DC. In Section 3, the steps and application of EIQ analysis for cigarette are conducted in details firstly, and then a "multimodal" blend of picking strategies is proposed based on the analysis of EIQ. In Section 4, the total replenishment cost model is derived, the curve for total replenishment cost is described, and optimal combined multitype picking equipments allocation is then formulated accordingly. In Section 5, the specific number of equipments is figured out in order to meet the capability demand of the case cigarette DC.

2. Order Picking Data Analysis Methods in Distribution Center

Order picking can be defined as the activity by which multivarieties and small-batch products are extracted from a warehousing system, to satisfy a number of independent customer orders. Confronting with tens of thousands of orders, it is important to conduct data analysis and find the order picking characteristics to design order picking systems. There are some order data analysis methods as follows.

2.1. EIQ Analysis Methodology

One has

$$M_{\mathrm{EIQ}} = \begin{pmatrix} Q_{11} & Q_{12} & Q_{13} & \cdots & Q_{1n} \\ Q_{21} & Q_{22} & Q_{23} & \cdots & Q_{2n} \\ Q_{31} & Q_{32} & Q_{33} & \cdots & Q_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ Q_{m1} & Q_{m2} & Q_{m3} & \cdots & Q_{mn} \end{pmatrix}. \tag{2.1}$$

EIQ analysis methodology which was proposed by Suzuki Sin is the analysis about three logistics factors of distribution center, which are E (Order Entry), I (Item), and Q (Quantity) [13]. EIQ analysis is applied to identify the characteristic of a distribution center and further analyzes the important customers and the frequently ordered products, so that it can support distribution center layout.

Table 1: EIQ analysis content.

Analysis indicator	Indicator description	Formula
EQ	Sum products flow per order	$\mathrm{EQ}_i = \sum_{j=1}^{n} Q_{ij} \ (1 \le i \le m)$
EN	Sum items number per order	$\mathrm{EN}_i = \sum_{j=1}^{n} N_{ij},\ N_{ij} = \begin{cases} 0, & \text{if } Q_{ij} = 0 \\ 1, & \text{otherwise} \end{cases} \ (1 \le i \le m)$
IQ	Sum flow per item	$\mathrm{IQ}_j = \sum_{i=1}^{m} Q_{ij} \ (1 \le j \le n)$
IK	Sum ordered times per item	$\mathrm{IK}_j = \sum_{i=1}^{m} N_{ij},\ N_{ij} = \begin{cases} 0, & \text{if } Q_{ij} = 0 \\ 1, & \text{otherwise} \end{cases} \ (1 \le i \le m)$

EIQ graph can be expressed by EIQ matrix shown in formula (2.1) where m denotes the number of entry orders, n denotes the number of ordered items, and Q_{ij} denotes the quantity of No. j item in No. i order. The main procedures of EIQ analysis are order samples collection, then EQ, EN, IQ, and IK statistics seeing for Table 1, finally analysis through Plato, ABC classification, or other methods. Thus it represents visual basic order picking character and provides necessary information for distribution center planning and equipment choosing.

2.2. ABC Stratification

ABC classifications are generally based on the Pareto Principle (also known as the 80/20 rule), which states that 20% of causes are generally responsible for 80% of effects [14]. The ABC analysis provides a mechanism for identifying items that will have a significant impact on overall inventory cost, while also providing a mechanism for identifying different categories of stock that will require different management and controls. Thus, the inventory is grouped into three (A, B, and C) or more categories in order to estimate their importance. A items are very important for an organization. Because of the high value of these A items, an organization needs to choose an appropriate order pattern (e.g., "Just in time") to avoid excess capacity. B items are important, but of course less important than A items and more important than C items. Therefore B items are intergroup ones. C items are marginally important.

2.3. Order Picking Strategies

Most companies find that their orders follow the 80/20 rule. By identifying the top 20% (the ratio is not absolute) of products, the correct picking strategy can be defined to optimize the majority of your picking workloads. There are five common picking methods: single-order picking, batch picking, multiorder picking, zone picking, and wave picking. Single-order picking, the most widely spread strategy, entails picking to a single order. Batch picking is that multiple customer orders can be combined into a batch to help reduce the walking per pick. Multiorder picking which groups orders by destination or by customer has the benefit of pulling product for multiple orders in a single pass through the pick area. Wave picking is an automated grouping of orders, which are then released to the pick area as a group,

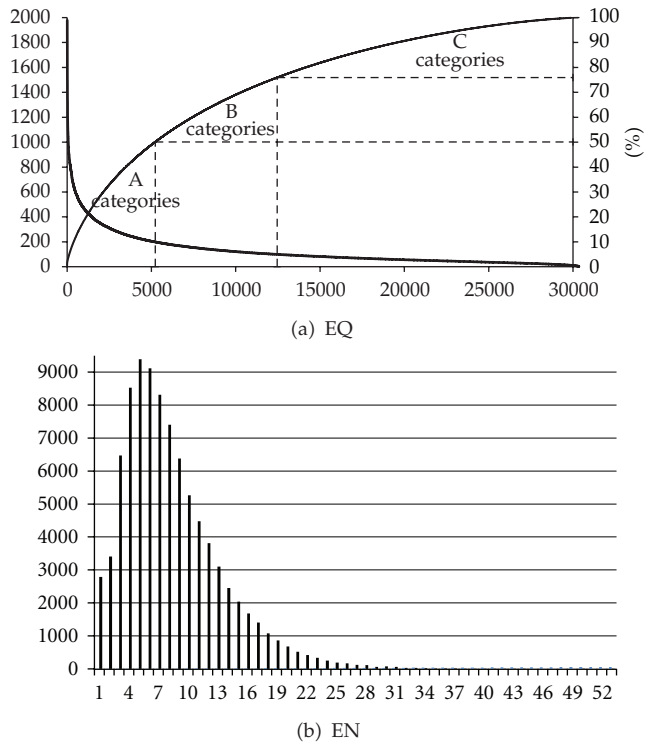

Figure 1: Plato for EQ-ABC and EN-ABC analysis.

by a specific set of criteria which may be priority level, freight carrier. Zone picking means orders may be divided to warehouse zone, such as single-unit pick area, case pick area, or bulk or pallet pick areas.

3. Cigarette Order Data Analysis Process Based on EIQ-ABC

EIQ-ABC analysis is conducted based on a case of typical cigarette DC in which the order data statistic shows periodic similarity each month. A month of order samples with amount of nearly 800 thousand order records are collected from a city cigarette DC. Substituting the order data of samples into formula (2.1), a matrix (omitted) of $91,111^{*}108$ can be set up. To be mentioned that there are three kinds of unit which are P (Pallet), C (Carton), and B (Bulk) [15]. As storing block in warehouse, a standardized pallet is made up of 24 cartons stacked while a carton contains 50 pieces so-called SKUs (store keeping units).

3.1. EQ-ABC and EN-ABC Analysis

As shown in Figure 1, the statistics for EQ and EN polarized and in the case there are 30,351 customers and 91,111 orders. The thick curve in the Plato for EQ represents the trend line for ordered SKU volumes per customer which are from 21,488 to 2, while the thin one is trend line for cumulative percent. 17.2% of the total customers account for 50.1% of out-flows, 23.8% of the total customers account for 25.8% of out-flows, and the 59% customers account for 24.1%

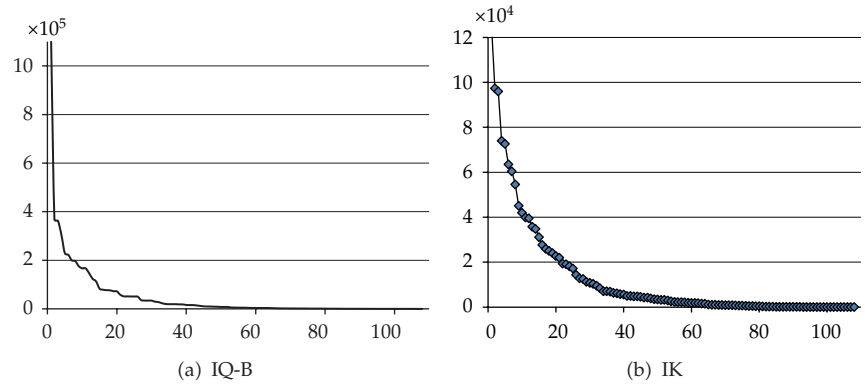

Figure 2: Plato for IQ-B and EN analysis.

of out-flows. Same argument can be got from EN analysis that there are frequent orders with the varieties number from 1 to 18 while only 4.4% orders possess more than 18 varieties.

3.2. IQ-B and IK Analysis

It is also essential to review items pick frequency that is how many times a product SKU is picked, as well as how much per SKU is picked. In this section, Q_{ijB} in EIQ-B matrix changed to the complementation of the number that is equaled by fifty (the number of pieces per carton) divided Q_{ij}. IQ-B analysis is conducted instead of IQ analysis as it can reflect the real character of bulk picking. As shown in Figure 2, all 108 items are ranked depending on their flow (IQ_j) and picking frequency (IK_j) from largest to smallest, as well as different-level categories are gotten. But the key is how to classify the items, namely, the breakpoint for A, B, and C categories. As it is much related to cost of replenishment for picking system, the optimal breakpoint can be decided by quantitative calculation instead of subjective experience. About the calculations see in Section 4.2.

3.3. Picking Strategies for the Case Cigarette DC

For the cigarette picking operation, the optimal solution should be a "multimodal" blend of picking strategies and automation technologies based on the analysis of EIQ. According to the statistics of EQ and EN, some high-volume orders should be divided up so that full-carton cigarettes can be picked directly and manually (as full-carton picking proportion is generally less than 1%) in case pick area when needed. Then the odd parts can be done in bulk pick area. As such, the picking pattern of cigarette is "P" to "C + B". Due to the huge picking workloads, automated sorting machines are suggested to be applied in bulk pick area. However, the sorting machines could not be the same here, as IQ-B statistics show that the flows of each item differ greatly and even polarize. Consequently bulk pick assignments should be allotted to different areas that are high-volume zone, low-volume zone, and bulk manual zone. With zone picking an order may be split and subsequently consolidated in the shipping area. In addition, less than eighteen cigarette varieties were ordered by 95.6% of the orders and 70.4% of the items were picked less than 5000 times this month. That means low-EN and low-IK happened in this DC in this sampling month. S + B (single and batch) picking strategy should be adopted when EN and IK are both low.

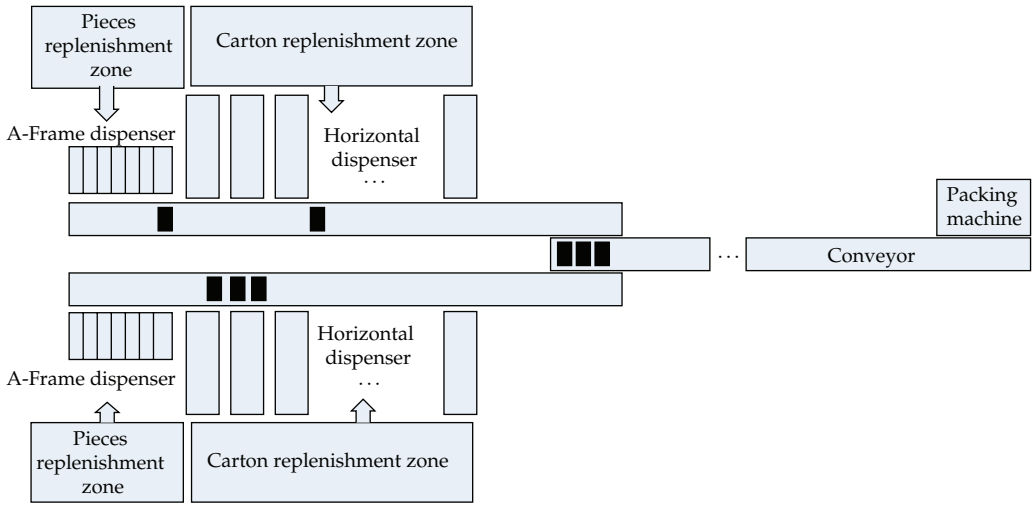

Figure 3: Layout of CFSS.

4. The Model Design for Cigarette Fast Sorting System

4.1. Layout of the Cigarette Fast Sorting System

CFSS (cigarette fast sorting system) is mainly composed of four subsystems that are restocking, fast-picking, conveying, and packaging, as shown in Figure 3. Restocking subsystem ensures that on-hand inventory is always available for the fast-picking subsystem when needed. There are two kinds of machines (Horizontal dispensers and A-Frame dispensers) allocated in fast-picking subsystem which can eject cigarette pieces onto the conveyor with the required number according to customer orders. Appropriate number of Horizontal dispensers and A-Frame dispensers are combined together to serve in the fast-picking subsystem of CFSS. Packaging subsystem packs each order into one or more totes.

4.2. Allocation for the Combination of Multitype Dispensers

The combined configuration of Horizontal dispensers (H) and A-Frame dispensers (AF) relied heavily on the order IQ-B analysis. H has higher efficiency than AF in terms of store volume, sorting cigarette, and being replenished. From Section 3.2 it can be got that top-ranked items are responsible for a great portion of the total out-flows, so it is straightforward to consider allocating large sales items to H and small sales items to AF.

As the variable cost part, the total replenishment cost can be the total picking cost of CFSS which determines the allocation result. Here the fixed cost such as the cost of machine acquisition and issues management is ignored in our decision. The replenishment cost per item is the product of replenishment times and the cost of per replenishment. Replenishment times can be estimated by rounding the sum volume per item divided by replenishment volume per time. Due to the manual replenishing services, the cost of per replenishment should consider labor wages, working hours, and so forth. Therefore, the total replenishment cost of CFSS equals to the sum of every item replenishment cost. Assuming k ($0 \leq k \leq 91$, remove the 17 C items in bulk manual pick zone) items to H, so (91-k) items to AF, let us see

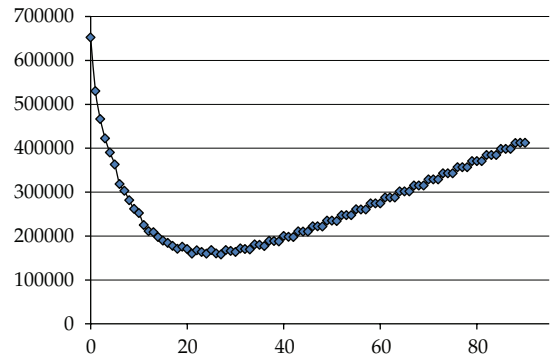

Figure 4: Curve of total replenishment cost.

formula (4.1) for total replenishment cost model, where Q_i represents the sum volume of each item, q_{H} and q_{A} represent replenishment volumes per time to H and AF, respectively, T_{H} and T_{A} are replenishing time per time, n_{H} and n_{A} are the numbers of dispenser managed by per replenishment labor, and finally C_{la} and h_d are the cost per labor per day and working hours, respectively. To minimum the total replenishment cost, the optimal k^* can be got:

$$\begin{aligned} C_r = &\sum_{i=1}^{k}\left[\mathrm{Int}\left(\frac{Q_i}{q_{\mathrm{H}}}\right)+1\right]\cdot\frac{T_H[\mathrm{Int}(k/n_{\mathrm{H}})+1]C_{la}}{3600h_d} \\ &+\sum_{i=k+1}^{n}\left[\mathrm{Int}\left(\frac{Q_i}{q_{\mathrm{A}}}\right)+1\right]\cdot\frac{T_A[\mathrm{Int}((n-k)/n_{\mathrm{A}})+1]C_{la}}{3600\,h_d}. \end{aligned} \tag{4.1}$$

Let us conduct the optimal computing with the data of IQ-B statistics and the parameters' values are given by Table 2. As shown in Figure 4 the total replenishment cost reaches the minimum when k^* equals 27 (both the breakpoint between A and BC categories). As a result the first ranked 27 items are allocated to H area, while the next 64 items to AF area.

4.3. The Number of Fast Sorting Lines

The efficiency of sorting machines is regarded as the key factor for the configuration. The total sorting capability of one combination fast sorting line can be calculated by formula (4.2) where p_{A} and p_{B} denote the flow proportions of A and B items, respectively, from IQ-B analysis. The time of ejecting one piece can be got from the Timers in equipment's PLC programs [16]. Considering interval time between two orders, the average time ejecting one piece (denoted by t_{H} and t_{A}) are 0.25s and 0.5s, respectively,

$$e_{\mathrm{H+A}} = \frac{3600}{t_{\mathrm{H}}\times p_{\mathrm{A}} + t_{\mathrm{A}}\times p_{\mathrm{BC}}}. \tag{4.2}$$

See the formula (4.3) for the number of some type sorting machine where Q_T denotes the sum flow of the T period, e_T denotes the sorting capacity of the T period, and while α and

Table 2: The given values each parameter in formula (4.1).

q_H	50 pieces	T_H	40 s	n_H	3	C_{la}	100 rmb/day
q_A	5 pieces	T_A	10 s	n_A	5	h_d	8 hours

Table 3: IQ-B analysis content.

Classification	Items number	Flow proportion	Fast sorting line allocated	Sorting capability	Number of the sorting line
Super A	18	79.6%	H sorting line	14400 ps/h	2.0
A	9	37.3	Combined fast sorting line	7700 ps/h	0.95
B	64	10.6%			
C	17	0.1%	Manual zone		

β denote fluctuation coefficient of out-flows and service rate of the machine. *Assume* $\alpha = 1.2$, $\beta = 0.8$, 26 working days per month and 8 working hours per day:

$$N_k = \frac{\alpha \times Q_T}{\beta \times T \times e_T}. \tag{4.3}$$

Here we have got 27 A items and 64 B items which, respectively, account for 89.3% and 10.6% of the total flows. Substitute these values into formula (4.2) and (4.3) and then N_k equals 2.8 which means three (round 2.8) combined fast sorting lines need be built to serve parallel. However, it is not optimal to merely treble the whole combined sorting line. Then the problem is to find the items that have a significant impact on the whole system greatly and double H sorting lines for them. As shown in Table 3, the first ranked 18 items in IQ-B list are defined as super A items and assigned by double H_s each, while next 9 A items are assigned by one (round 0.95) H each and 64 B items by AF each.

5. Conclusions

On the whole, a design of multitype CFSS with 109 fast sorting machines which were divided into two parallel serving lines has been proposed based on EIQ-ABC analysis in this paper. Traditional EIQ analysis outcome from experimental data which existed in some researches could not be used in practical environment. Moreover, in this paper when it came to decide the breakpoint for differentiating A and B items, quantitative evaluation was adopted for this issue instead of subjective judgment like 80/20 rule singly. So the optimal breakpoint was helpful in reducing the total replenishment cost. CFSS design of this paper has been applied in real life and demonstrated the value and the feasibility for cigarette physical distribution industry.

E (Order Entry), I (Item), and Q (Quantity) are the key elements of logistics, and EIQ analysis has been got increasing attention by many industries and commerces so far. However, the definition of the orders specialty is vague, it is infeasible to do that through simple figures in traditional EIQ analysis. Therefore, more future research should be conducted for this issue via applied mathematics methods.

Acknowledgments

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