Customer Satisfaction and Timely Delivery: The Order Picking Scheduling Problem

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Abstract: In recent years, electronic commerce (EC) using a portable terminal has become familiar, and the number of people using online shops is increasing. Moreover, the number of companies entering the online shopping market is increasing, thus intensifying the competition between companies. As a result, a company that manages business to consumer (B2C) EC sites must consider providing more and varied services to attract customers. To capture more customers, these companies may also introduce protocols to optimize current service provision by, say, ensuring timely delivery. Therefore, cooperation is essential between companies that manage B2C EC sites and those that deliver the goods. This study aims to develop an order picking scheduling model that considers parcel pickup time and investigates the influence of various parameters.

Key Words: Electronic Commerce, Distribution Center, Delivery Company, Last parcel pickup time, Picking time

1. Introduction

In recent years, electronic commerce (EC) using portable devices, such as mobile phones and tablets, has become widespread and the number of people shopping online is increasing. Moreover, the number of companies entering the online shopping market is also increasing, leading to intense competition among companies. Therefore, a company that manages an EC site must consider providing more and varied services to attract customers. For example, Amazon Prime is a membership service offering special services to its members. Prime members receive a two-day delivery option on 20 million eligible items without any shipping charges [1]. Prime members also receive same-day delivery on over one million items when shipping to selected metropolitan areas across the U.S. Furthermore, Amazon is offering a new service called Prime Now, which provides a one-hour delivery option in certain geographical areas [2]. Thus, these companies only deal with those online shops which offer the fastest shipping services to attract customers. However, as many responsibilities are imposed on delivery companies to perform this service, this business model is not sustainable [3].

To address the issue of delivery scheduling, many extant studies have based their models on distribution center operations [4] [5]. In these studies, it is assumed that the distribution center operates according to the customer’s order list and items will be delivered to delivery companies when all items are picked up. In other words, scheduling to minimize the total travel time was conducted under the premise that these orders will be processed on the same day [6] [7] [8]. However, it is not necessary to process an order on the same day because of the due date.

In addition, effective scheduling of operations in distribution centers and cooperative relations with delivery companies are necessary to reduce the burden on the latter. Some studies integrate the order picking problem with order batching and delivery. However, no study has yet integrated the order picking problem with picker routing and delivery by multiple pickers.

This study proposes a method for enhancing order picking efficiency that considers the coordination between the distribution centers and delivery companies. We schedule the sequence of delivery of orders (order sequence) and picker routing considering the last parcel pickup time. In numerical experiments, the influence of cooperation between distribution centers and delivery companies is investigated by changing the number of pickers $K$ and the picking time $q$.

2. Literature Review

Many studies have examined the optimization of order picking operations for minimizing the makespan, which is affected by order batching, storage allocation of goods, and picker routing.

Gademann and Van de Velde [5] proposed a method whereby some orders are pooled into one batch to minimize the travel time.

Le-Duc and De Koster [9] classified goods according to order frequency and proposed the storage assignment method of goods, which determines the storage location for each product group to shorten the travel distance.

Pertersen [6] and Theys et al.[7] focused on the block structure of the storage shelf and proposed a heuristic...
method for generating picking routes by taking advantage of each of the structures. Pertersen proposed a construction heuristic for picker routing schedule for a single-block warehouse. Theys et al. extended Pertersen’s method to a plurality of blocks and applied the traveling salesman problem heuristic solution to the order picking problem. Compared with Pertersen’s methods, the solution proposed by Theys et al. was shown to reduce the picking operation completion time by 47 percent, up from 18 percent.

However, these studies do not consider picker congestion. Distribution centers in Japan occupy narrow building sites; hence, the aisle width is set to a minimum. As a result, other pickers may become an obstacle and delay the order picking operations in the aisle. This phenomenon is called “picker congestion.” There are two types of picker congestion: aisle congestion and shelf congestion. This study focuses on the latter; multiple pickers cannot work simultaneously on one shelf [8].

Additionally, most previous studies have addressed only the efficiency in distribution centers; however, one small study takes into account the cooperation between the distribution centers and delivery companies. Zhang et al. [10] proposed a model that processes order picking in accordance with the last parcel pickup time. In that study, the problem was modeled as a two-objective problem: minimization of makespan and maximization of the number of completed orders until pickup time. Order batching and the assignment of orders are scheduled by rule-based solutions. However, this study focuses on the next day’s workload and models it for minimizing the makespan of the remaining order problem. This study also examines picker routing and assignment and sequencing of orders to the picker. The relationship between this study and previous studies in this domain is summarized in Table 1.

3. Problem Description

Figure 1 illustrates the process functions that take place in a distribution center starting with the customer’s order coming in to the center. Delivery companies decide on the distribution center’s last parcel pickup time at the very first step. In subsequent steps, the orders are assessed at the distribution center based on priority and the processing orders for the day are determined. In the final step, only the loads for that day’s delivery are transferred to the delivery companies.

In this study, we focus on the distribution center’s last parcel pickup time and consider distinguishing between the order that can be processed by the last parcel pickup time and the remaining orders. In compliance with the last parcel pickup time, the orders assigned before the last pickup time are picked up on the same day and the orders assigned after the last pickup time are carried forward to the next day. Therefore, this study assumes that we can minimize the burden on the delivery company by observing the last parcel pickup time. New orders arrive every day and the orders carried forward to the next day are rescheduled along with newly received orders.

Based on the above assumptions, this study aims to minimize the processing time for orders carried forward to the next day, subject to not causing a delivery delay. In other words, the aim is to reduce the burden on the delivery companies by complying with the last parcel pickup time and minimizing the processing time for postponed orders so as to reduce the workload at the delivery center for the next day. By doing this, we believe that it will be easier for the delivery centers to meet their delivery dates without imposing a burden on the courier services.

3.1 Assumptions

In modeling this system, we apply the following assumptions:

- A picker can process one order at a time
- One order includes n types of items
- Picking time at one shelf is constant and independent of the batch size
- A picker travels by the shortest path on the aisle
- One type of item is stored on one shelf
- Items are never out of stock
- Enough width exists for several pickers to pass through the aisle
- Several pickers cannot work on one shelf simultaneously
- The distance between the shelves is defined by the Manhattan distance and travel time is dependent on the distance
- The allocation of goods to shelves cannot be changed while working. This paper ignores the storage assignment
- New orders arrive every day and the orders are fixed at the start of the period
- Zero delivery delays
- Orders that arrive after the orders for the day are fixed are processed the next day
- The delivery deadline of the order is set after the order arrival date
is expressed using the parameters and variables below:

- \( K \): number of pickers \( (k = 1, \cdots, K) \)
- \( O_{k,j} \): order process schedule for picker \( k \)
- \( o_{k,j} \): number of orders that picker \( k \) processes until the \( j \)th order
- \( N^t_k \): number of orders processed in period \( t \) for picker \( k \)
- \( n \): number of items included in one order
- \( x_{k,i} \): the shelf number that picker \( k \) picks up until the \( i \)th shelf
- \( S^t_k \): order picking schedule by the \( i \)th shelf for picker \( k \) at period \( t \)
- \( S^1 \): order picking schedule before the last parcel pickup time \( t = 1 \) \( S^1 = (S^1_{1,(n+1)N^1_k}, \cdots, S^1_{K,(n+1)N^1_k}) \)
- \( S^2 \): order picking schedule after last parcel pickup time \( t = 2 \) \( S^2 = (S^2_{1,(n+1)N^2_k}, \cdots, S^2_{K,(n+1)N^2_k}) \)
- \( S_{k,i} \): order picking schedule at the \( i \)th shelf for picker \( k \)
- \( S \): all order picking schedules \( S = (S_{1,(n+1)N}, \cdots, S_{K,(n+1)N}) \)
- \( f(S_{k,i}) \): completion time of schedule \( S_{k,i} \)
- \( P_{S_{k,i}} \): total picking and unloading time for schedule \( S_{k,i} \)
- \( T_{S_{k,i}} \): total travel time for schedule \( S_{k,i} \)
- \( W_{S_{k,i}} \): total waiting time for schedule \( S_{k,i} \)
- \( q \): picking time at one shelf
- \( C \): last parcel pickup time
- \( D(l) \): Due delivery time for order \( l \)

The order picking scheduling problem is a problem of determining order sequence (order schedule) and picker routing (picking schedule). That is, the order schedule of picker \( k \) is defined as below:

\[ O_k = [o_{k,1}, \cdots, o_{k,N}]. \]  

Furthermore, if we represent the picking schedule for the \( j \)th order of picker \( k \) as \( [x_{k,1,(n+1)(j-1)+1}, \cdots, x_{k,1,(n+1)j-1}, 0] \), then the order picking schedule for picker \( k \) \( S_{k,n,N} \) is shown as below:

\[ S_{k,(n+1)N} = [x_{k,1}, \cdots, x_{k,n}, 0, x_{k,n+2}, \cdots, x_{k,2(n+1)-1}, 0, \cdots, x_{k,(n+1)N-1}, 0] \]  

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The completion time of schedule \( S_{k,i} \) is denoted by the sum of total picking time, total travel time, and total waiting time on a shelf:

\[ f(S_{k,i}) = P_{S_{k,i}} + T_{S_{k,i}} + W_{S_{k,i}}. \]  

Herein, a Gantt chart is used to calculate the completion time of schedule \( S \) (Figure 2). The procedure for determining the completion time using this Gantt chart is as follows:

Step 1: Each picker’s schedule, travel time, and picking time are arranged in a Gantt chart (Figure 2(a))

Step 2: In case work exists at the same shelf for several pickers simultaneously, the start time is delayed until the completion time of the work started earlier (Figure 2(b)).

In this study, the following problems are solved by determining a schedule that minimizes the remaining orders’ completion time:

\[ \min_k \max f(S^k_{(n+1)N^2}) \]  

s.t. \( f(S^1_{k,(n+1)N^1}) \leq C, (k = 1, \cdots, K) \)  

\[ f(S_{k,(n+1)j}) \leq D(o_{k,j}), (j = 1, \cdots, N, k = 1, \cdots, K) \]  

Equation (4) shows an objective function that minimizes the maximum value of each picker’s completion time for the remaining orders. Equation (5) shows that the schedule at period 1 satisfies the last parcel pickup time constraint. Equation (6) shows that all orders satisfy the due time constraint.

Figure 3 shows the differences between the conventional and proposed models. Numbers in boxes (rectangles) indicate the order number and the width of each rectangle.
indicates the processing time for each order. The shaded area indicates picker congestion. The conventional model minimizes the makespan for all orders, whereas the proposed model minimizes the processing time for remaining orders.

4. Numerical Experiments

Numerical experiments are performed to clarify the influence of model parameters. Numerical experiments are carried out when all items are uniformly included in the order (i.e., no demand bias) and when the items are not uniformly included in the order (i.e., demand bias). We create numerical examples of 100 cases for each situation and obtain the schedule by enumeration method.

4.1 Experiment Environment

Numerical experiments are conducted assuming that the warehouse has two blocks (Figure 4). Three cross aisles and five pick aisles are located in the warehouse and pickers only pick items from the pick aisles. Shelves are prepared to accommodate 100 units and each different item is displayed on the shelf. It is assumed that no item is ever out of stock. Enough width exists on the aisles to allow pickers to pass each other in any aisle, but not more than one picker can pick at a time and one picker must wait on the spot until the other picker’s work at that spot is completed. In the warehouse’s lower left corner is an input and output (I/O) point for receiving and dispatching orders. All pickers start at the same time from the I/O point to collect items in accordance with their picking schedule and return to the I/O for receiving and unloading the order. The movement of these pickers is referred to as a “tour.” For the sake of simplicity, the picker is assumed to process only one order per tour. If there are $n$ different items in an order, then the picker visits $n$ points on a single tour. Each picker processes $N$ number of orders in total. The time required for picking in one shelf is set as $q$. Parameter values are shown in Table 2. A schedule is generated by enumeration. Under these conditions, differences in the schedule are revealed by changing the number of pickers ($K$) and the picking time ($q$).

Table 2 Parameters

| constant | value |
|----------|-------|
| $n$: Number of items included in one order | 3 |
| $N$: Number of orders processed | 8 |
| $q$: Picking time | 5, 10, 15 |
| $K$: Number of pickers | 1, 2, 4 |
| $C$: Last parcel pick up time | 300 |

4.2 Result

We discuss customer satisfaction in the following two cases: no demand bias exists for orders and demand bias exists. We compare the proposed model with the conventional model. We also discuss the influence of changing the number of pickers ($K$) in Section 4.2.1 and the influence of changing the picking time ($q$) in Section 4.2.2.

We investigate the differences in customer satisfaction between the conventional model and the proposed model. The evaluation function is defined as follows:

We investigate the differences in customer satisfaction between the conventional model and the proposed model. The evaluation function is defined as follows:
(1) $f(S^*)$: makespan for all orders in the conventional model

(2) $f((S^1)^*)$: makespan for processed orders before the last parcel pickup time in the conventional model

(3) $f((S^2)^*)$: processing time for remaining orders after the last parcel pickup time in the conventional model

(4) $f(S^{12})$: makespan for all orders in the proposed model

(5) $f(S^1)$: makespan for processed orders before the last parcel pickup time in the proposed model

(6) $f(S^2)$: processing time for remaining orders after the last parcel pickup time in the proposed model

4.2.1 Influence of the number of pickers $K$

Tables 3 and 4 show the average of each value of the evaluation function for cases where no demand bias exists and cases where demand bias exists, respectively.

We compare values of (1) and (4) and find the value of (4) to be larger than that of (1). Hence, this result shows a bad value if the evaluation only considers the distribution center.

However, the value of (6) is smaller than that of (3). That is, the schedule generated by the proposed model can reduce the processing time for remaining orders. Thus, this schedule makes it possible to process more orders arriving the next day and these orders will be able to meet the due time constraint. From the viewpoint of customer satisfaction, the schedule generated by the proposed model is good.

Makespan for all orders is reduced by increasing the number of people. When you increase the number of people, the width available to the pickers will be less and picker congestion occurs frequently. So, even if you double the number of pickers, the makespan for all orders cannot be reduced by half. Further, from the viewpoint of customer satisfaction, there is a point where the processing time for the remaining orders becomes 0 ($K = 4$), customer satisfaction does not increase even if the number of pickers is increased.

The processing time for an order in the case of demand bias is small compared to that with no demand bias. This is because when there is demand bias, more popular products are stocked near the I/O point, and travel distance for the tour is small. The difference between the values of (3) and (4) in this case is larger than in the case of no demand bias.

Table 3 Influence of the Number of Pickers K (no demand bias)

| $K$ | $q = 5$ | $q = 10$ | $q = 15$ |
|-----|----------|----------|----------|
|     | conventional model | proposed model | conventional model | proposed model | conventional model | proposed model | conventional model | proposed model |
|     | $f(S^*)$ | $f(S^{12})$ | $f(S^1)$ | $f(S^2)$ | $f(S^*)$ | $f(S^{12})$ | $f(S^1)$ | $f(S^2)$ |
| 1   | 457.08   | 149.92   | 331.12   | 318.91   | 457.08   | 149.92   | 331.12   | 318.91   |
| 2   | 418.56   | 188.48   | 82.85    | 72.67    | 418.56   | 188.48   | 82.85    | 72.67    |
| 3   | 126.22   | 126.22   | 0.00     | 0.00     | 126.22   | 126.22   | 0.00     | 0.00     |

4.2.2 Influence of the picking time ($q$)

Tables 5 and 6 show the averages of each evaluation function for cases with no demand bias and cases with demand bias, respectively.

Comparing the values of (3) and (6), the difference between each value becomes larger with increasing picking time ($q$). In addition, processing time for remaining orders becomes larger with increasing picking time ($q$); thus, we should rethink the last parcel pickup time when the picking time is too large. When we rethink the setting of the last parcel pickup time, our model should measure the processing time for the remaining orders.

Table 5 Influence of the Picking Time $q$ (no demand bias)

| $K = 2$ | $q = 5$ | $q = 10$ | $q = 15$ |
|---------|---------|---------|---------|
|        | conventional model | proposed model | conventional model | proposed model | conventional model | proposed model | conventional model | proposed model |
| $f(S^*)$ | $f(S^{12})$ | $f(S^1)$ | $f(S^2)$ | $f(S^*)$ | $f(S^{12})$ | $f(S^1)$ | $f(S^2)$ |
| 5      | 149.78  | 196.50  | 199.94  | 195.19  | 191.05  | 191.05  | 191.05  | 191.05  |
| 10     | 101.22  | 101.22  | 101.22  | 101.22  | 101.22  | 101.22  | 101.22  | 101.22  |
| 15     | 149.78  | 196.50  | 199.94  | 195.19  | 191.05  | 191.05  | 191.05  | 191.05  |

Table 6 Influence of the Picking Time $q$ (demand bias)

| $K = 2$ | $q = 5$ | $q = 10$ | $q = 15$ |
|---------|---------|---------|---------|
|        | conventional model | proposed model | conventional model | proposed model | conventional model | proposed model | conventional model | proposed model |
| $f(S^*)$ | $f(S^{12})$ | $f(S^1)$ | $f(S^2)$ | $f(S^*)$ | $f(S^{12})$ | $f(S^1)$ | $f(S^2)$ |
| 5      | 149.78  | 196.50  | 199.94  | 195.19  | 191.05  | 191.05  | 191.05  | 191.05  |
| 10     | 101.22  | 101.22  | 101.22  | 101.22  | 101.22  | 101.22  | 101.22  | 101.22  |
| 15     | 149.78  | 196.50  | 199.94  | 195.19  | 191.05  | 191.05  | 191.05  | 191.05  |

5. Conclusion

In this study, the scheduling of order picking operations in a distribution center is analyzed, taking into account the distribution center’s last parcel pickup time. A model of cooperation between the distribution centers and delivery companies is designed and logistical efficiency is improved. The analysis reveals the influence of the picking time and the number of pickers $K$ on the evaluation value. By minimizing the makespan of the remaining orders in accordance with the last parcel pickup time, it is possible to order picking scheduling by simultaneously considering customer satisfaction and the delivery company’s load. However, this study is limited in the sense that it only considers a small size problem. Therefore, further investigation in this field is needed.

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