2014 Proceedings of PICMET '14: Infrastructure and Service Integration.

A Sequential Order Picking and Loading System for Outbound Logistics Operations

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Abstract--**With short product life-cycles, frequent delivery schedules of products are demanded by customers. Efficient outbound logistics operations are key goals of companies wishing to maintain customer satisfaction and achieve competitive advantage. However, in current warehouse operations, order picking and loading are performed separately and products are picked manually from warehouses according to customer orders and stored temporarily in staging areas in order to fully utilize the capacity of carriers. In practice, the separation of order picking and the loading process usually results in problems of excess storage buffers, long operation time, and quality deterioration of sensitive products left in the staging area. In this paper, in order to tackle these problems, a sequential order picking and loading system (SOPLS) integrating order picking and loading processes is proposed. The Genetic Algorithm (GA) technique is adopted in the system to identify the optimum picking sequence of tours with minimal travel distance. In addition, parameter settings for GA generation are tested in the simulation to find the optimal solution. The validation of the feasibility of the proposed system is illustrated through a red wine storage scenario. By using the SOPLS in the case company, it is found that operation time for outbound logistics and product deterioration are greatly reduced.**

I. INTRODUCTION

With increasingly competitive markets and compressed product life-cycles, short product development cycles are popular trends nowadays [11]. In such circumstance, customers need frequent delivery schedules of products. In order to meet customers' requirement and respond quickly to markets, efficient warehouse operations are essential. Generally, order-picking is identified as one of the most labour- and capital intensive activities in warehouses. Products are picked from storage locations according to customers' requirement and stored in the staging areas to maximize the utilization rate of transport carriers. However, problems arise due to the separation of order picking and the loading process during outbound operations. One of these problems is that extra storage buffers are needed for temporary storage of picked products, resulting in an increase of rental costs. On top of that, a relatively longer time is required to locate the picked products in the staging area and load them onto a container, thus increasing the time spent on this already long operation. In addition, deterioration of products is another possible problem resulting from the use of the staging area. The environment of the staging area is not customized to products' storage requirements. For fragile and sensitive products like wine which should be handled under special conditions (i.e. a specific range of temperature and humidity), being left on the staging area could be a threat to the quality of the product [18]. Thus, it is crucial to develop a system to integrate picking and loading processes in order to optimize warehouse operation efficiency and eliminate problems that arise from the separation of order picking and loading processes. In this paper, a sequential order picking and loading system (SOPLS) is proposed with the adoption of the Genetic Algorithm technique to formulate the picking and loading plan with the shortest travel distance by optimizing the picking sequence of each tour.

This research paper is divided into six sections. Section 2 contains a literature study that includes a review of current warehouse operation environments, genetic algorithm based picking and loading approaches. This is followed by the architecture of SOPLS in section 3. Section 4 is a case study conducted to validate the feasibility of the proposed system. Results and advantages of adopting the SOPLS are presented in Section 5. Section 6 is the conclusion of this paper.

II. LITERATURE REVIEW

A. *Current warehouse operation environment*

The warehouse is an important connection between the upstream suppliers and downstream customers functioning as a place for good storage [23][26]. The basic warehouse operations include receiving, storage, order picking and packaging, and shipping [3]. Among the four processes, order picking is regarded as the most labour demanding and costly activity that deserve greatest attention [27]. Many researchers have proposed different methods related to optimization of the order picking process in order to minimize the operation costs [2][12][14][21]. However, little attention has been paid to integrating the order picking and loading processes.

B. *Order-picking*

In general, order picking is considered as the process of retrieving finished products from storage areas to fulfill customers' requirements [6-7]. Different order-picking methods can be found in the industry such as sequential zone picking, batch-picking, wave picking and basic (single)-order picking [29]. According to Baker [1], selection of an appropriate order-picking method is a complex process as it is closely related to warehouse layout and operation. In common practice, several decisions have to be considered in order to have efficient order-picking [25]. Due to the complicated nature of the order picking process, many researches focused on the improvement of the order- picking process by optimizing the travel time and distance [5][8]. In particular, De Koster et al. [4] proposed a mixed-integer linear program to find out the optimal number of zones in a synchronized zoning system such that the total order-picking time and assembly time is minimized. Gademann and Van de

Velde [9] considered the order batching problem with minimization of the total travel time. From the past literature, it can be seen that major consideration in the order-picking problem is on minimization of the picker's travelling distance and time.

C. Loading

Loading is the process that follows order picking. After order picking, picked items will be checked, packed and eventually loaded into containers for transportation. Generally, the packing and loading process attempt to pack items in a container or transport carrier together as densely as possible in order to reduce the waste of space. Therefore, items are stored in the staging area to save space. In general, there are four kinds of container loading problems; they are strip packing, knapsack loading, bin-packing and multi-container loading [22]. Martello [19] also developed an algorithm incorporating both an exact and an approximate algorithm for three-dimensional bin packing problems. Zhang et al. [30] proposed a heuristic block-loading algorithm for three-dimensional container loading problems on the basis of multi-layer searching. Junqueira et al. [15] presented a mixed integer linear programming model to solve the container loading problem taking into consideration the stability of the cargo and the load bearing constraints. To summarize, most researchers focus solely on either picking or loading process. Articles in the literature that consider the relationship between picking and loading are limited.

D. Genetic algorithm based picking and loading approaches

A Genetic algorithm (GA) is a heuristic approach to solve complex optimization problems based on the concept of natural evolution [24]. With the evolutionary optimization technique, the GA starts from the initial solutions and stops searching for the global optimal solution when termination criteria are fulfilled [20]. The GA has been widely adopted in the optimization of warehouse operations. Hsu et al. [13] proposed a GA-based model to handle order batching problems in warehouses by minimizing travel distance. Zhang et al. [32] developed GA-based heuristics for handling item arrangement in a multiple-level warehouse in order to minimize the total transportation cost. Zhang et al. [31] proposed a GA-based heuristic for minimizing the transportation cost of an adjacent paper-reel layout problem. Tsai et al. [28] proposed a batch picking model using a multiple-GA approach for finding the most appropriate batch picking plans. Karabulut and Inceoglu [16] suggested a hybrid GA for formulating a three-dimensional bin packing strategy with a high utilization rate. Lam et al. [17] developed a decision support model with the use of GA to help formulate warehouse order operations by classifying new customer orders and grouping similar orders into case groups. Furthermore, the GA has also been applied in solving loading problems. Gehring and Bortfeldt [10] have proposed to adopt a hybrid GA in container loading problems. From studies in the literature it has been found that the GA approach is a widely used technique for optimization in warehouse operations.

To summarize, previous research efforts have mainly focused on minimization of picker's travelling distance/time on order picking and utilization of space in transport carriers in loading problems. Limited attention has been paid to combining order picking and loading operations to solve scheduling problems. To increase the efficiency of warehouse operations, the GA has been found to be a promising tool for formulating the optimal routing. This paper aims to make use of genetic algorithms to integrate order picking and loading processes in order to optimize the performance of outbound logistics operations.

III. SYSTEM ARCHITECTURE OF SOPLS

To improve the warehouse operations, a sequential order picking and loading system (SOPLS) is proposed which combines order picking and the loading process and finds the shortest travel distance for each picking tour. Figure 1 shows the system architecture of SOPLS, which consists of four modules. They are (i) Data Collection Module (DCM), (ii) Mathematical Module (MM), (iii) Sequence Determination Module (SDM) and (iv) Decision Module (DM).

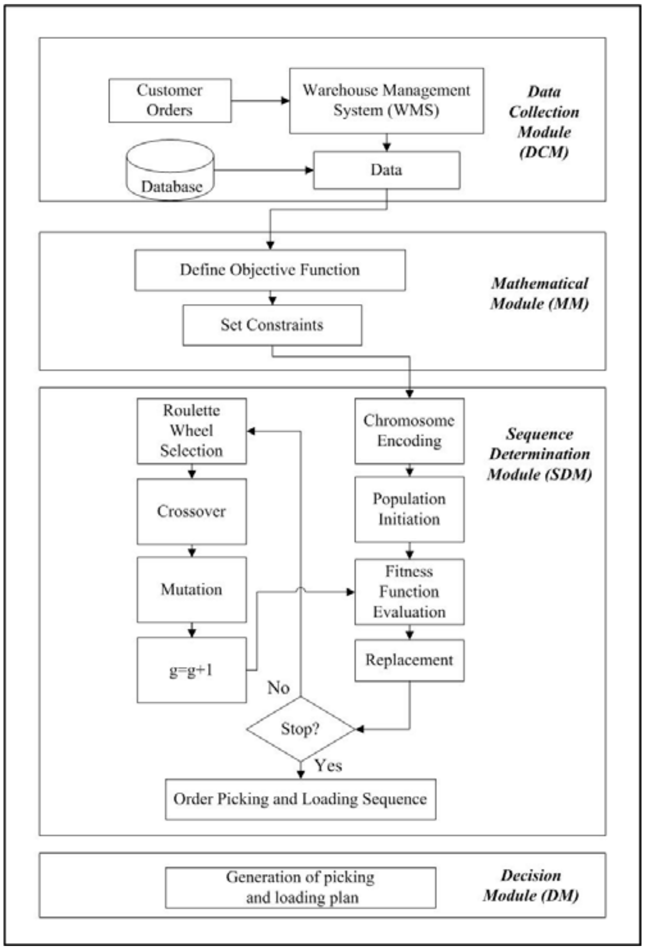


Figure 1 - Architecture of the SOPLS

(i) Data collection module (DCM)

Data provided from customers' orders such as order quantity, delivery date and handling requirements are evaluated and transformed by the warehouse management system (WMS). On the other hand, inventory information is sorted into different categories by WMS based on its properties and stored in a database system. In this module, product data such as storage location, inventory level, size, weight, picking, packing and loading properties together with data related to the loading operation, including the weight, capacity, size, type and number of available transport carriers such as delivery truck, are collected and stored in a centralized database.

(ii) Mathematical module (MM)

In this module, mathematical formulation of the proposed model is presented. Table 1 shows that notation of the proposed GA-based model. The objective function presented in (1) is to minimize the total travelling distance of order pickers from the starting point (I/O) to final storage location. Constraint (2) and (3) are the volume and weight limit of each vehicle. Constraint (4) is to check if vehicle *v* travels on arc (i, j). Constraints (5) and (6) are about each customer's entry and exit. Constraint (7) and (8) define the depot's entry and exit. Constraint (9) ensures the route continuity.

TABLE 1 - NOTATION OF A GA-BASED MODEL

Notation	Definition
Indices and Sets	
p:	index for vehicle
i,j	index for storage locations
P	set of all vehicles
N	set of all storage locations
Data and parameters	
v_i	Volume of items at location i
w_i	Weight of items at location i
V_p	Volume limit of vehicle
W_p	Weight limit of vehicle
c_{ij}	Distance between location i and j
Decision variables	
x_{ij}^p=1 if the vehicle p covers arc (i,j); 0 otherwise	
y_{ij}=1 if the location j follows location i in the same visiting sequence; 0 otherwise	

Objective Function

$$\min d = \sum_{p\in P}\sum_{i\in N}\sum_{j\in N} c_{ij}x_{ij}^p \qquad (1)$$

Subject To

$$\sum_{i\in N}\sum_{j\in N} v_i x_{ij}^p \le V_p \qquad \forall p\in P \qquad (2)$$

$$\sum_{i\in N}\sum_{j\in N} w_i x_{ij}^p \le W_p \qquad \forall p\in P \qquad (3)$$

$$\sum_{p\in P} x_{ij}^p = y_{ij} \qquad \forall i,j\in N \qquad (4)$$

$$\sum_{\substack{i\in N\\ i\neq j}} y_{ij} = 1 \qquad \forall j\in N \qquad (5)$$

$$\sum_{\substack{j\in N\\ j\neq i}} y_{ij} = 1 \qquad \forall i\in N \qquad (6)$$

$$\sum_{j\in N} y_{0j} = |P| \qquad (7)$$

$$\sum_{i\in N} y_{i0} = |P| \qquad (8)$$

$$\sum_{\substack{j\in N\\ j\neq i}} x_{ij}^p = \sum_{\substack{j\in N\\ j\neq i}} x_{ji}^p \qquad \forall i\in N, p\in P \quad (9)$$

In the above model, c represents the distance between two storage locations for each order picking operation. In a warehouse, products stored at different locations within an area. The storage locations are represented by x-coordinate and y-coordinate. The distance is therefore represented as follow:

$$c = \sqrt{(a_1 - a_2)^2 + (b_1 - b_2)^2}$$

where

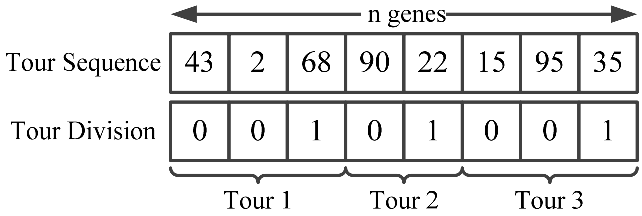
a : x-coordinate of the storage location

b : y-coordinate of the storage location

(iii) Sequence determination module (SDM)

In this module, GA is used to determine the optimal order picking and loading sequence based on the defined objective function and constraints in the mathematical module. Evolver 5.5 developed by Palisade Corporation is used to perform the GA calculations and a number of simulation experiments are conducted by applying different GA parameter settings.

In SOPLS, real integer numbers and binary numbers are used to encode the tour sequence and tour division respectively. The tour sequence denotes the sequence of visiting a location while tour division separates different divisions of visiting. In the tour division region, 1 means that the tour will end after visiting the corresponding location. The separation point of visiting depends on the constraints of the objective function. Each pick tour ends before the total volume or weight of picked items is greater than the volume or weight capacities of a transport carrier. Figure 2 shows an example of chromosome encoding.



Tour Sequence	43	2	68	90	22	15	95	35
Tour Division	0	0	1	0	1	0	0	1

Figure 2 - Illustration of chromosome encoding

For example, picker first visits location 43, followed by location 2 and finishes at location 68. The total volume or weight of picked items from location 43, 2 and 68 is smaller than the volume or weight capacity of a transport carrier. However, if the picker continues the pick tour and visits location 90, the total volume or weight of picked items including location 90 will exceed the volume or weight capacity. As a result, pick tour 1 should terminate at location 68. All picked items are then loaded into a delivery truck. The same operation plan applies to other picking tours.

Tour 1: I/O point → location 43 → location 2 → location 68 →I/O point
Tour 2: I/O point → location 90 → location 22→ I/O point
Tour 3: I/O point → location 15 → location 95→ location 35 → I/O point

(iv) Decision module (DM)

The output of SDM is the suggested picking and loading sequence and recommended parameter settings for the GA calculation. The algorithm stops the optimization process in Decision Module (DM). Traditionally, pick lists are the internal orders for order pickers and the design of pick lists is based on external customer orders. With the help of SOPLS, warehouse personnel can more easily prepare operative planning for outbound logistics operations because SOPLS provides a comprehensive way to draw up pick lists. The identification number, pick storage location, pick quantity of each SKU, required material handling equipment and completion time of each picked item are all listed on the pick list. Order pickers perform order picking operations according to the pick list.

IV. CASE STUDY

This section covers (i) company background, (ii) problems in ABC Company and (iii) implementation of SOPLS in ABC Company.

A. Company background

ABC Company is a third party logistics (3PL) service provider with its headquarters in Beijing and which provides warehouse and distribution operations in Shanghai and Guangzhou. The company has half a million square-feet of storage space, over 70 trucks, lorries and container trucks. The major function of the company is to provide third party warehousing and logistics solutions for different commercial goods, mainly wine products, fashion goods, electronic components and cosmetics. In response to the growing consumption and expanding Asian markets for wine, ABC Company began its wine logistics business several years ago. The company offers a one-stop solution for wine logistics services with its own temperature-controlled warehouses and trucking fleet. The cellars have 24-hour guards on duty and CCTV surveillance. Furthermore, an inventory controlled management system is used to help track the real-time delivery status and location of individual wine lots.

B. Problems in ABC Company wine cellars

In order to maintain wine quality, ABC Company offers comprehensive facilities during wine warehousing and transportation. The room temperature of cellars is kept at 14℃ to 18℃ and the humidity around 60% - 80%. In addition, low-intensity lighting is provided in warehouses to prevent harmful ultraviolet light from threatening the quality of the red wines. Other than warehouse facilities, a temperature and humidity controlled trucking fleet is also used to help prevent quality deterioration of red wines during transportation processes. However, wine deterioration may still occur after the picking process. In practice, the picked wines are placed temporarily in the staging area before being loaded onto delivery carriers. As the staging area is only for temporary storage of picked products, the environment there is only at room temperature and has natural light. Therefore, red wines in the staging area are exposed to threats of unspecified temperature range, dryness, vibration or extended periods of natural light. These threatening external environment factors may change the composition of the wine and result in deterioration of wine quality. Besides, the level of security and safety in the staging area is another concern. The staging area is an open area without CCTV or other surveillance appliances. Product security is not guaranteed and incidents of loss of wine may occur. In addition to low security and safety level, extra storage buffering is another issue that needs attention. The staging area occupies extra space in the warehouse that reduces area for storage there. Besides, during the loading process, it may take a relatively long time for operators to find specific wines from amongst large amounts of picked wines before loading them into a truck. This makes the operation time longer, lowering the working efficiency. Therefore, there is a need to implement the SOPLS in ABC Company in order to enhance the performance of warehouse operations.

C. Implementation of SOPLS in ABC Company

In this section, the implementation of SOPLS in the warehouse system of ABC Company, to streamline the outbound logistics operations, is described. Assumptions are made for simpler illustration of SOPLS in the case, which are (i) all transport carriers for delivering red wines are delivery trucks which have identical volume and weight capacities; (ii) wines are of standard sizes and packaging. The implementation of SOPLS in ABC Company consists of two steps:

(i) Data collection

Data to be collected in ABC Company includes storage locations of the wines, volume of a bottle of wine, weight of a bottle of wine, the number of trucks available, volume capacity and weight capacity of a truck. Data of the current situation of company is summarized in Table 2.

TABLE 2 - TRUCK AND STORAGE INFORMATION

Truck Information	
Number of Trucks Available	4
Volume Capacity of a Truck (cm^3)	3,000,000
Weight Capacity of a Truck (kg)	3,500
Storage Information	
Volume of a bottle of wine	750ml/1.25L/1.5L/2L/2.5L
Number of wine bottles in a box	Standard 8 bottle box/ 12 bottle box / 16 bottle box
Number of boxes in a storage location	1/2/3

The volume and weight of a bottle of red wine range from 750ml to 2.5L and from 1kg to 3kg respectively. Wines are stored in rectangular boxes in different locations of the warehouse. In each storage location, from 1 box to 3 boxes of wines are stored. Each box may contain 8 bottles of wine, 12 bottles of wine or 16 bottles of wine. There are five standard volumes available for the bottles of wine. In this pilot study, the total delivery volume is 9,603,000 cm^3 and total delivery weight is 13,700kg. There are 4 trucks available for these orders so the total volume capacity and weight capacity of the trucks are 12,000,000 cm^3 and 14,000kg respectively.

The warehouse in this scenario is a square warehouse. Ordered wines are stored at 250 different locations of the warehouse. Coordinates are used to represent the storage locations of red wines and the unit is the meter. Each location has its own x-coordinate and y-coordinate and both x-coordinates and y-coordinates range from 0 to 100. An I/O point is located at the lower left corner of the warehouse with coordination (0, 0).

(ii) Genetic algorithm setting

After collecting the data, a GA is used to determine the optimal order picking and loading sequence. In this research, Evolver 5.5 is used and two sets of generations are tested. In the experiments, the population sizes, crossover rate and mutation rate are constant. Table 3 shows the parameter settings in GA.

TABLE 3 - GA PARAMETER SETTINGS

Parameter	Settings
Population size	80
Number of Generations	1000/10000
Crossover rate	0.8
Mutation rate	0.05

V. RESULTS AND DISCUSSION

In this section, case study results generated from SOPLS and the advantages of the SOPLS model after conducting the pilot study in ABC Company for three months are presented.

A. Results generated from SOPLS

The GA has been run 10 times with two settings of parameters. GA solutions of SOPLS in two parameter settings are shown in Table 2 including the average distance, average running time and average best generation. Figure 3 and 4 show the fitness values obtained by the setting of population with number of generation 1000 and 10000 respectively. According to the results in Table 4, the number of generation increases with shorter average travel distance but longer average system running time.

TABLE 4 - GA SOLUTIONS

Population size	Generations	Average distance (m)	Average running time	Average best generation
80	1000	3646.2	28.5s	956.5
80	10000	2533.9	222s	9611.9

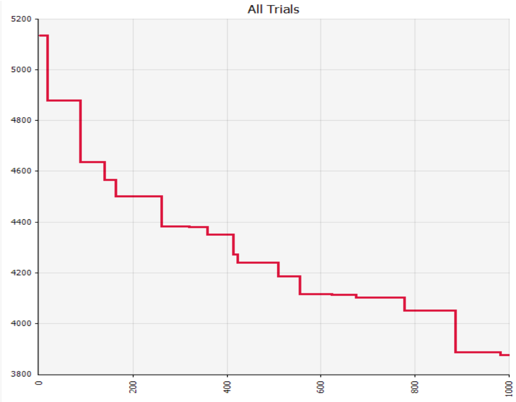


Figure 3 - Fitness value obtained by the setting of population 80 and number of generations 1000

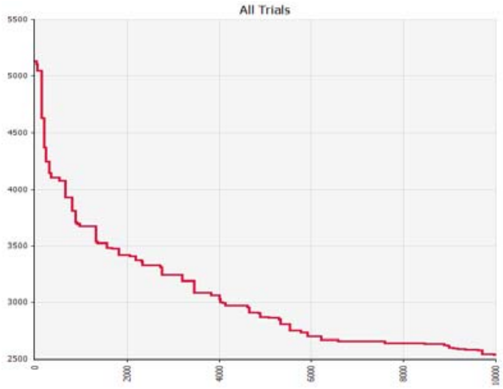


Figure 4 - Fitness value obtained by the setting of population 80 and number of generations 10000

TABLE 5 - TIME REDUCTION AFTER SOPLS

	Before (Separation of Picking and Loading processes)	After (with SOPLS)	Percentage of Improvement
Time to load the wine in staging area	8 min	0 min	
Locate and pick up wine from staging area and place on pallet	10 min	0 min	
Total time in staging area	18 min	0 min	
Total Operation time (Picking and Loading)	37 min	19 min	48.65%

TABLE 6 - REDUCTION IN WINE DETERIORATION AND DAMAGE

	Before (Separation of Picking and Loading processes)	After (with SOPLS)	Percentage of Improvement
Quantity of deteriorated wine per month	62	5	92%
Quantity of wine damaged/ lost per month, in bottles	30	6	80%
Total	92	11	88%

B. *Advantages of SOPLS Model*

With the help of SOPLS, it is found that (i) the operation time and (ii) amount of wine deteriorated, damaged and lost, are reduced.

(i) Improvement in operation time

Compared with the previous method in which order picking and the loading process are separated, the total time saved by eliminating the step of loading the wine into the staging area as well as locating and picking up the wine from the staging area and placing it onto the pallet is reduced by 18 minutes. The total operation time of order picking and loading is reduced by 49%. This is because staging areas are not necessary for temporary storage of goods with the execution of SOPLS. Table 5 summarizes the time reduction in operations after the launch of SOPLS.

(ii) Reduction in wine deterioration and damage

Table 6 shows the reduction in wine deterioration, damage and loss per month. Before SOPLS, wines had to store temporarily in the staging area where the temperature, humidity, light are not controlled according to the requirements of the wine. Since wine is sensitive to surrounding conditions, uncontrolled conditions could cause the wine to deteriorate and depreciate in value. With SOPLS, picked goods are loaded to the transportation carriers directly without waiting in the staging area. This helps prevent the quality of the wine from deteriorating in fluctuating environment of the staging area. Thus, the quantity of deteriorated wine per month is reduced by 92% after the launch of SOLPS. In addition, the problem of low security and safety level in the staging area can also be resolved. Thus, the amount of wine damaged and lost is reduced by 80% after the launch of SOPLS.

VI. CONCLUSION

Order picking and loading are outbound logistics operations but practically considered as independent processes. The separation of them results in temporary storage of goods in a staging area. However, staging areas are open areas with no strict environment and security control, causing problems of extra storage buffering, long operation time, and quality deterioration of products. This paper presents a sequential order picking and loading planning system (SOPLS) to support the warehouse management personnel when making decisions on routing of order pickers and planning of order picking and loading processes. SOPLS integrates the order picking operation with the loading operation by adopting a GA to determine the optimal picking sequence with minimization of travel distance. The validation of the proposed system was illustrated in a red wine storage scenario. After a pilot study in a case company, the operation time and quantity of wine deterioration, damage and loss are reduced. Thus, it is proved that this system is specifically beneficial to warehouse management personnel in planning order picking and loading processes. In order to further validate the SOPLS model, future research work will be considered to conduct more cases in handling different products for enhancing outbound logistics operations.

ACKNOWLEDGMENTS

The authors would like to thank the Research Office of the Hong Kong Polytechnic University for supporting the current project (Project Code: G-UC66).

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