Economical order picker routing by consideration of travel distance and vehicle energy consumption

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Abstract

The order picking process is one of the significant operations since it takes a long processing time and uses a lot of movements. Improving the efficiency of this process plays an important part in reducing warehousing and supply chain costs. One of the main order picker process problems is an order picker routing problem. Most researches have considered the order picker routing problem in term of total travel distance. This paper gives an attempt to determine the economical order picker routing by considering both travel distance and vehicle energy consumption. A typical block stacking warehouse or parallel aisle warehouse is considered in this research. Only one picker with his vehicle is utilized in the order picking process. A multi-objective mathematical model is proposed and an example is given. Finally, the advantages of considering both travel distance and energy consumption are given. By using the proposed model, both travel distance and energy consumption have minimized. Comparing to the typical model, travel distances of typical model and the proposed model are equal whereas energy consumption of the typical model is higher than that of the proposed model.

Keywords: Order-picking, Routing, Energy, Mathematical models, Multi-objective

1. Introduction

Typical warehouse operations include receiving, transferring and putting away, order picking, accumulation and sortation, cross-docking and shipping. The order picking process is one of the significant operations since it takes long processing time and uses a lot of movements. It may consume as high as 60% of all labor activity time [1] and the cost relating to the order picking process estimates around 55% of the total warehouse operating costs [2]. The order picking process consists of many activities e.g. setting up, travelling, searching, picking, and others. Koster et al. [1] state that travelling activity consumes up to 60% of total time in the order picking process. The long time-consuming is caused by travel distance. Improvement in order picker routing would directly lead to reduce time consuming and affect to raise the service level. Therefore, researchers and practitioners have given attempts to find a means to reduce travel distance in this process. To decrease travel distance, routing methods normally are considered.

Typically, routing methods can be classified into two types: heuristic and optimal routing methods. Heuristics routing method normally uses simple rules for pickers traveling along aisles [1, 3]. Well-known heuristics routing methods include s-shape, return, large gap, midpoint, and composite. Using optimal routing method seems to be more complicated.

In fact, by considering the order picking process, not only time and distance are of interest, but also operating costs. The main cost of the process is energy. This paper then integrates the energy consumption in the consideration. Even though there are many researches involving in this problem, no research considers traveling distance and energy usage simultaneously. Therefore, this research proposes the optimal routing method by considering both traveling distance and energy usage. A multi-objective mathematical model is developed to determine the optimal routes of travel. Examples are given and analyzed. Finally, conclusions and discussions are given.

2. Problem description and literature review

The parallel aisle warehouse used in this research is shown in Figure 1. Only one picker with his vehicle is considered. There are two types of aisles, parallel and cross aisles.

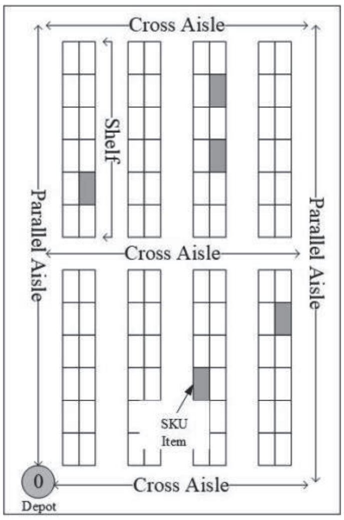

Figure 1 Parallel aisle warehouse crosses aisles.

The point that the picker enters the parking area and where they afterwards return to in order to deposit all picked items is called depot. In Figure 1, the depot is shown in the bottom left corner of the warehouse. An electric motor vehicle is used by the picker to travel in order to pick up all required items assuming that the vehicle has enough capacity to pick up all required items in a single trip.

In the beginning, the picker starts from depot with a list of required items and then he may travel through some points (non-required vertices) to collect all required items at the required points (required vertices) and then return to the depot after all required items have been picked. Such a problem is called a Steiner travelling of salesman problem (STSP), which is one of the NP-hard problems [1, 4].

As stated above, there are two utilized routing methods: heuristic routing method and optimal routing method. The comparisons between heuristic routing method and optimal routing method are given by [5] and [6]. Many researchers have focused on optimal routing method [7-9] and the main considerations of those researches are distance and travel time. However, some researchers consider other criteria include energy consumption, packing cost, stock rotation, or space utilization [10-13].

Chiang et al. [9] present a branch-and-bound and tabu search algorithm to solve optimal routing problem. Makris et al. [10] use either travel time or energy consumption as criteria to determine an appropriate route for transporting shipments. Shiau et al. [11] use travel distance and packing costs as criteria to solve travel routing problem. Ramirez-Rios et al. [12] use travel distance, stock rotation, and space utilization as criteria. Çelik & Süral [13] present a multi-objective mathematical model and apply ε-constrained method to solve travel routing problem. Further, Letchford et al. [14] develop three compact formulations based on [15-18] including single-commodity flow, multi-commodity flow and time stage. Based on the review, none of the literatures considers both travel distance and energy consumption of the pick vehicle as criteria. This research gives an attempt to construct a mathematical model to determine an optimal routing in block stacking warehouses by considering both travel distance and energy consumption.

3. Notations

The parameters, decision variables, indices, and sets of models are defined in Table 1.

Table 1 Definitions.

Variable	Meaning
d_a	Distance of arc a.
r_a^k	0-1 variable. = 1 when arc a is selected to travel in step k. = 0 otherwise.
f_a^k	Transporting weights passing by arc a in step k.
W_c	Weight of picker and vehicle.
W_T	Weight of all items in pick list.
w_i	Weight of item to be picked at vertex i.
w	Weighting factor.
$\delta^+(i)$	Outgoing arcs of vertex i.
$\delta^-(i)$	Incoming arcs of vertex i.
k	Order of traveling step.
A	Set of all arcs.
V_R	Set of required vertices (items and depot).
V	Set of all vertices.
μ_r	Rolling resistance coefficient.

4. The Mathematical Models

Letchford et al. [14] has proposed a model to determine an optimal route for this problem. The objective of the model is to minimizing total travel distance. In this research, this model is called D model since it considers only distance.

$$\boldsymbol{min} \quad \sum_{k=1}^{2(|V|-1)} \sum_{a \in A} r_a^k\, d_a \tag{1}$$

$$\boldsymbol{st} \quad \sum_{a \in \delta^+(0)} r_a^1 = 1 \tag{2}$$

$$\sum_{a \in A} r_a^1 = 0 \qquad (\, a \in A \setminus \delta^+(0)\,) \tag{3}$$

$$\sum_{k=1}^{2(|V|-1)} \sum_{a \in \delta^+(i)} r_a^k = 1 \qquad (\,\forall\, i \,\epsilon\, V_R\,) \tag{4}$$

$$\sum_{a \epsilon \delta^-(i)} r_a^k = \sum_{a \epsilon \delta^+(i)} r_a^{k+1} \quad (\,\forall\, i \,\epsilon\, V \setminus \{0\}; 1 \le k \le 2(|V|-1)-1) \tag{5}$$

$$r_a^k \in \{0,1\} \quad (\,\forall\, a \in A\,;\ 1 \le k \le 2(|V|-1)\,) \tag{6}$$

Eq. (1) shows the objective of the D model, which is minimizing total distance. Eqs. (2-3) are used to ensure that the picker starts at the depot and no arc is selected in the first step. Eq. (4) ensures that the required vertices and depot are visited. Eq. (5) ensures that the picker enters and leaves from any vertex in the next step. Eq. (6) ensures that all decision variables are binary.

Our proposed model consists two objective functions including minimizing travel distance and energy consumption. The function of travel distance is shown in Eq. (7) whereas that of energy consumption is shown in Eq. (8). As seen in Eq. (7), the total travel distance is the summation of the products of the selected route (r_a^k) and its distance (d_a). For the energy consumption, this research considers only energy uses in resisting the motion relating to a cart wheels rolling on a surface ($\mu_r(r_a^k W_c + f_a^k)$) and distance (d_a) of selected route (r_a^k). Therefore, the energy usage is depended on the weight of picker, vehicle, carrying units and travel distance.

$$Total\ distance = \sum_{k=1}^{2(|V|-1)} \sum_{a \in A} r_a^k\, d_a \tag{7}$$

$$Energy\ consumption = \sum_{k=1}^{2(|V|-1)} \sum_{a \in A} d_a \mu_r (r_a^k W_c + f_a^k) \tag{8}$$

Two objectives (Eqs.7-8) both are normalized into same scale functions and combined by using weighting method which each term added by w factor as shown in Eq. (9), and its constraints in Eqs. (10-17), these are called DE model.

$$\min \quad w \frac{\sum_{k=1}^{2(|V|-1)} \sum_{a \in A} r_a^k\, d_a}{\sum_{a \in A} d_a} + (1-w) \frac{\sum_{k=1}^{2(|V|-1)} \sum_{a \in A} d_a \mu_r (r_a^k W_c + f_a^k)}{\sum_{a \in A} d_a\, \mu_r (W_c + W_T)} \tag{9}$$

Eqs. (10-17) are the constraints of the model. Eqs. (10-11) are used to ensure that the picker starts at the depot and no arc is selected in the first step. The required vertices and depot are guaranteed to travel through by using Eq. (12). Eq. (13) ensures that the picker enter and leave from any vertex in the next step. Eq. (14) is load conservation constraints. Eq. (15) ensures that the load of the vehicle will be increased when the picker picks up an item at the required storage point. Eq. (16) is a boundary function of load for each arc. Eq. (17) ensures that all decision variables are binary. The subtours can't be occur because in the first step, only one arc from depot can be selected (Eqs.10-11) and it is continuously connected to another selected arc in each step (Eq. 13) until that all required vertex (V_R) has been visited (Eq. 12).

$$\sum_{a \epsilon \delta^+(0)} r_a^1 = 1 \tag{10}$$

$$\sum_{a \in A} r_a^1 = 0 \qquad (\, a \in A \setminus \delta^+(0)\,) \tag{11}$$

$$\sum_{k=1}^{2(|V|-1)} \sum_{a \epsilon \delta^+(i)} r_a^k = 1 \qquad (\,\forall\, i \,\epsilon\, V_R\,) \tag{12}$$

$$\sum_{a \epsilon \delta^-(i)} r_a^k = \sum_{a \epsilon \delta^+(i)} r_a^{k+1} \quad (\,\forall\, i \,\epsilon\, V \setminus \{0\}; 1 \le k \le 2(|V|-1)-1) \tag{13}$$

$$\sum_{a \epsilon \delta^+(i)} f_a^{k+1} - \sum_{a \epsilon \delta^-(i)} f_a^k = 0 \quad (\,\forall\, i \,\epsilon\, V \setminus V_R;\ 1 \le k \le 2(|V|-1)-1) \tag{14}$$

$$\sum_{a \epsilon \delta^+(i)} f_a^{k+1} - \sum_{a \epsilon \delta^-(i)} f_a^k = w_i \sum_{a \epsilon \delta^+(i)} r_a^k \quad (\,\forall\, i \,\epsilon\, V_R \setminus \{0\};\ 1 \le k \le 2(|V|-1)-1) \tag{15}$$

$$0 \le f_a^k \le W_T r_a^k \quad (\,\forall\, a \,\epsilon\, A \setminus \delta^+(0);\ 1 \le k \le 2(|V|-1)) \tag{16}$$

$$r_a^k \in \{0,1\} \quad (\,\forall\, a \in A\,;\ 1 \le k \le 2(|V|-1)\,) \tag{17}$$

5. Results and discussions

In the simulation, four examples are given. The five items (A, B, C, D and E) are randomly located as shown in Figure 2 and related parameters are shown in Table 2.

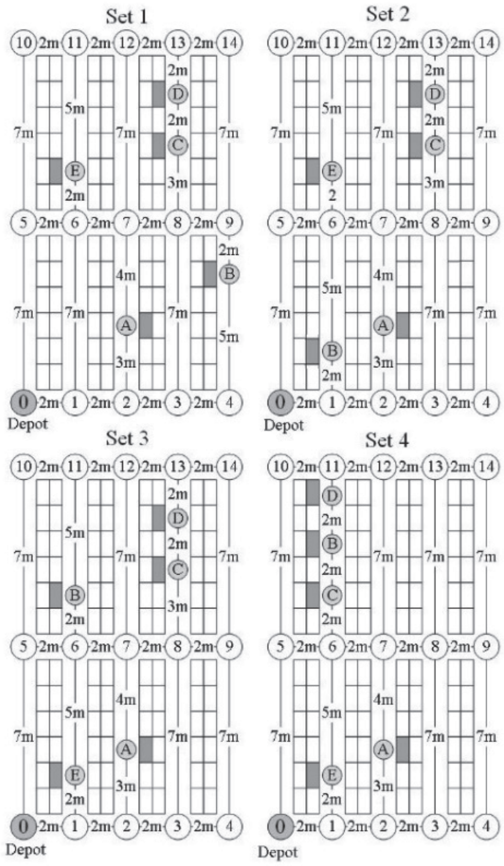

Figure 2 Item Location Sets

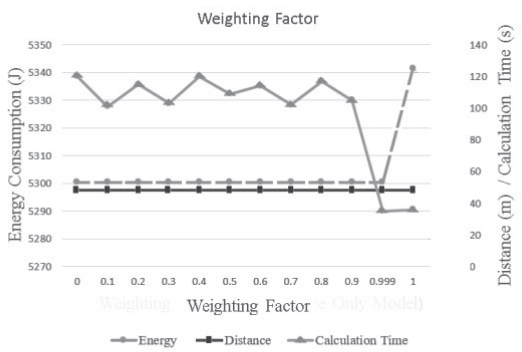

Figure 3 Weighting factor

Table 2 Example parameters

Parameter	Value
Weighting factor (W).	0.999
Rolling resistance coefficient (μ_r).	1
Weight of picker and vehicle (W_c)	100N
Weight of Items A, B, C and D	2N
Weight of Items E	20N
Number of vertices ($\lvert V \rvert$).	20
Number of required vertices ($\lvert V_R \rvert$).	6
Number of items	5
Number of blocks	2
Number of shelves per block	4
Number of storage locations (2 sides).	12
Parallel aisle spacing.	2m
Parallel aisle depth.	7m

A computer software using python language is developed to simulate these models (D and DE) and Pymprog 1.0 is used as an optimizer library. The computer that is used in this simulation is the Intel core i7-2600 CPU with 16GB memory. Figure 3 shows the effects of weighting factor to distance, energy consumption, and calculation time. It can be seen that w equals to 0.999 is the most appropriate. By comparing between 0.9 and 0.999, calculation time is considerably reduced whereas energy consumption is of interest. Without energy consideration ($w = 1$) energy consumption is highly increased. Therefore, the examples are analyzed by assuming that w = 0.999.

By plugging in the parameters into D and DE models as discussed in the previous section, three run times are applied to each model. The results are shown in Figures 4-5. It can be seen from Figure 4 that both models give the same distance values for all four examples in every run. By considering consumption, Figure 5 shows that using most runs of D model give higher energy consumption than DE model.

By integrating the results, it can be concluded that both models give the same values of distance but different energy consumption. The energy consumes less when using the DE model. About the travel routes, DE model's route tends to pick up low weight item and low-density location first.

6. Conclusion

After comparing the simulation results of the proposed model (DE model) and distance only criteria model (D model), the travel routes are different but giving the same values of distance. By considering the energy consumption criteria, the energy consumption used of proposed model (DE model) is less than or equal to that of D model.

This research gives a new mathematical model to determine the optimal solution in order picking problem when considering both distance and energy consumption. However, there are other criteria that relate to routing decision, such as the blockage of the aisle and the speed limitation of each aisle, these criteria may be involved in the future works.

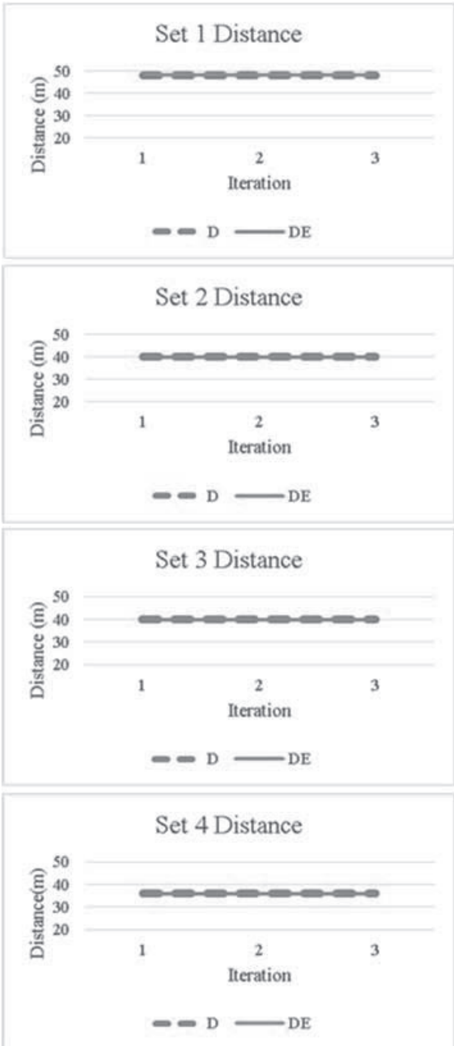

Figure 4 Distance in each tour.

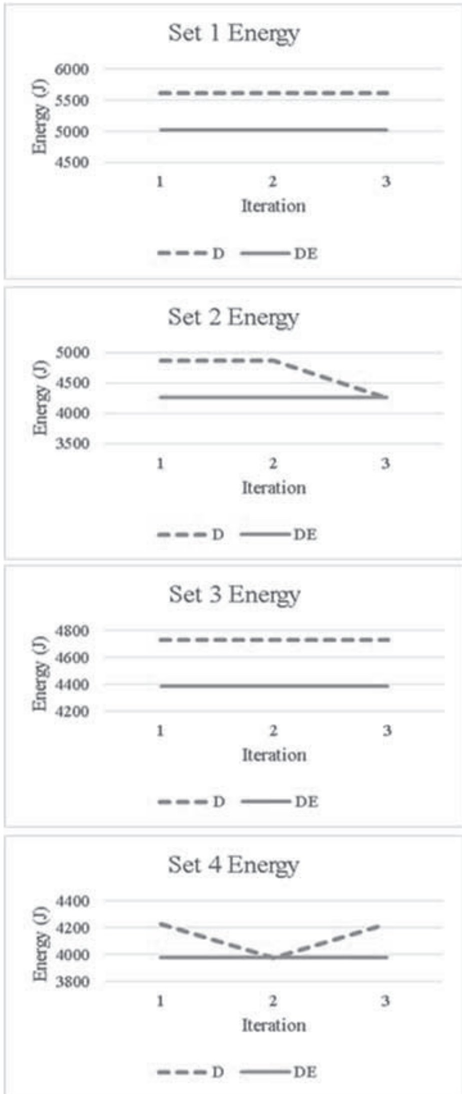

Figure 5 Energy consumption in each tour

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