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Research paper

A computer simulation for economical order picker routing when considering travel distance and vehicle energy consumption

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Abstract

Order picking process is considered to be costly processes since takes long processing time and uses a lot of movements. This paper presents a simulation software that utilizes multi-objective mathematical model with a consideration of travel distance and vehicle energy con-sumption. A block stacking warehouse or parallel aisle warehouse is considered in this research and only one picker with his vehicle is utilized. Optimal results of example problems are validated and verified. Finally, conclusion and discussion are given.

Keywords: *Order-picking; Routing; Energy; Model; Simulation*

1. Introduction

Order picking has been identified as the most time intensive and costly process in warehouse and distribution centres since it uses a lot of movements and a lot of labour. It may consume as much as 60% of all labour activities time [1] and the cost of order picking is estimated as much as 55% of the total the total warehouse operating cost [2]. There are many activities in order picking process e.g. setting up, travelling, searching, picking, and others. Particularly, travelling activity may consume up to 60% of time in the order picking process [1]. Improvement in order picker routing would affect to raise the service level as well as reduce costs. For these reasons, many routing methods have been proposed to reduce the distance of the travelling activity.

In Major, there are two types of routing methods: Heuristics routing method and optimal routing method. Heuristics routing methods include s-shape, return, large-gap, mid-point, and composite, all of them use simple rules for pickers traveling along aisles [1], [3]. Optimal routing method is more complicated. Especially, the optimal routing in parallel aisle warehouse problem that contains some required points which must be visited and some Steiner points which can be visited, this kind of problem is called Steiner travelling of salesman problem (STSP), which is one of the NP-hard problems [1], [4]. Such a problem may have various equal distance optimal solutions but the energy consumption may be different. Shortest route with less energy consumption would be preferred.

This research, we developed a simulation software to determine the optimal routes when considering travel distance and vehicle energy consumption. Multi-objective mathematical models have been de-veloped at first to describe a problem and then a simulation soft-ware call "Eco-Pick" was built and applied to solve the problem. We set up the experiment to validate the results and verify the ener-gy saving performance when routing by considering with both criteria. Finally, conclusion and discussion are given.

2. Problem description and literature review

Warehouse in this research can be illustrated by Fig.1. It is made of shelves which contain product storage locations and aisles where enable the order picker to navigate in the warehouse. The aisles can be parallel or cross aisles. The area between two adjacent cross aisles is called block and cross aisles not have any storage locations. Moreover, the warehouse can also be represented by a graph.

This research, only one picker is considered, he starts travelling with electric motor vehicle from the depot which located in the bottom left corner of the warehouse and then visits all pick locations before return to the depot in order to deposit all picked items. To develop a simulation software, it necessary to find out, how to get the optimum route for this kind of problem? This reason makes us start with studying about routing methods and the mathematical model formulation.

As stated above, we found that there are two utilized routing methods: heuristic routing method and optimal routing method. Comparisons between heuristics routing method and optimal routing method are given by [5] and [6]. Many researchers have focused on the optimal routing method for examples [7], [8] and [9]. 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 (e.g. [10], [11], [12] and [13]).

Many researchers emphasize in using distance as a criterion to define optimal routing for examples in [7] and [8].

In [9] authors propose branch-and-bound and tabu search algorithm to solve the optimal routing problem. In [10] authors use either travel time or energy consumption as criteria to determine an appropriate route for transporting shipments. In [11] authors use travel distance and packing cost as criteria to solve travel routing problem. In [12] authors use travel distance, stock rotation, and space utilization as criteria. In [13] authors present a multi-objective mathematical mod-el and apply ε-constrained method to solve travel routing problem.

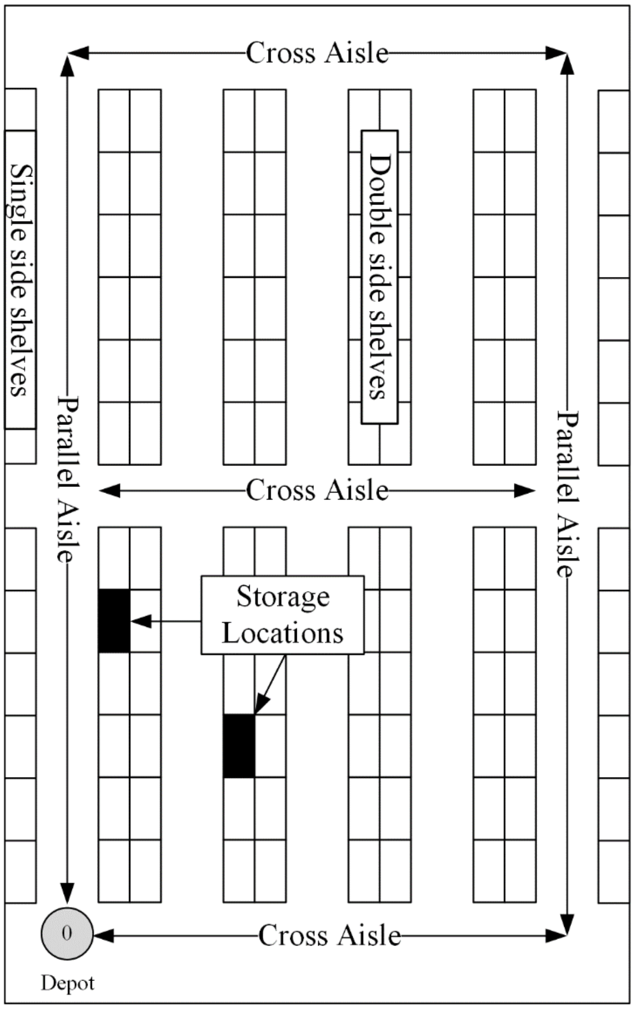

Fig. 1: Parallel aisle warehouse and its graph representation.

Further, because the computer can’t directly understand a problem. It needed a mathematical model for describing a problem before solving. In [14] authors develop three compact formulations based on [15], [16], [17] and [18] including single-commodity flow, multi-commodity flow and time stage.

Based on the review, it can be seen that none of the literature considers travel distance and energy consumption of pick vehicle as criteria. This research gives an attempt to construct a simulation software to determine the optimal routes by using the mathematical models that consider both travel distance and vehicle energy con-sumption.

3. Notations

Based on problem description (Fig.1). The problem converted to the Steiner STSP by define the directed graph $\boldsymbol{D} = (\boldsymbol{V}, \boldsymbol{A})$,$\boldsymbol{V_R} \subset \boldsymbol{V}$ and $\boldsymbol{a} \in \boldsymbol{A}$ (Fig. 2). The route between possible vertices is called arc $\boldsymbol{a}$. The distance of arc $\boldsymbol{a}$ is called $\boldsymbol{d_a}$. $\boldsymbol{r_a^k}$ is a decision variable of traveling on arc $\boldsymbol{a}$ in step $\boldsymbol{k}$ where $\boldsymbol{k}$ is 1 to 2(|$\boldsymbol{V}$|-1) [14]. $\boldsymbol{r_a^k}$ equals to 0 when the picker does not travel on arc $\boldsymbol{a}$ in step $\boldsymbol{k}$. On the other hand, $\boldsymbol{r_a^k}$ equals to 1 when the picker travel on arc $\boldsymbol{a}$ in step $\boldsymbol{k}$. $\boldsymbol{A}$ is a set of all arc $\boldsymbol{a}$’s. other notations are given in Table 1.

Table 1: Notations

Variable	Meaning
d_a	Travel 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 $\boldsymbol{a}$ 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	Objective weight.
$\delta^+(i)$	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
V	Set of all vertices
μ_r	Rolling resistance coefficient

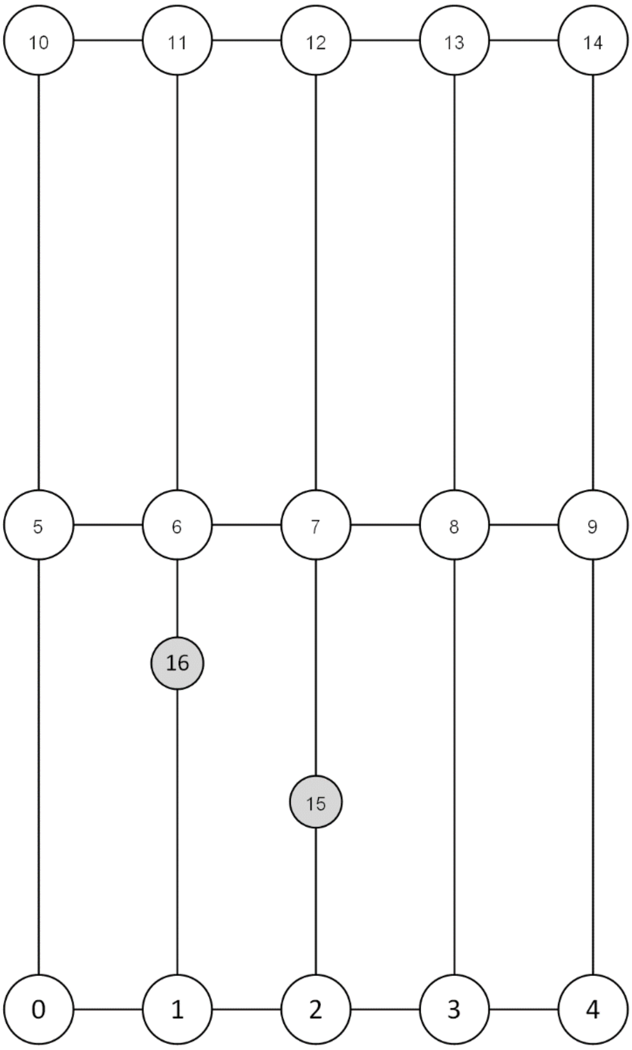

Fig. 2: Graph representation of Parallel aisle warehouse.

4. The mathematical model

The objectives of the mathematical model are minimizing the total travel distance and reduces the energy consumption. Since the total energy consumption is not only depended on travelling distance but the sequence of picking is also having the effect, that's why two-objective model are needed. In (1), the total travel distance is the summation of the product of the selected route and its distance. The selected route of r_a^k is 0-1 variable. That means if r_a^k is selected or 1, it costs its distance of d_a. On the other hand, if r_a^k is not selected or 0, there is no travel distance added in the total distance. (2) describe the energy consumption of order picking trip. This research considers only the energy that relate to routing decision, not total energy uses. The energy is assumed to be depended on the weight of picker and vehicle and the carrying units; and the travel distance. It is called resistance. μ_r is a rolling resistance coefficient.

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

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

Two objectives, (1) and (2) are combined and normalized into the same scale functions as shown in (3).

$$\min \quad w \frac{\sum_{k=1}^{2(|V|-1)} \sum_{a \in A} r_a^k\, d_a}{\sum_{a \in A} d_a} + (1-w) \frac{\sum_{k=1}^{2(|V|-1)} \sum_{a \in A} d_a \mu_r (r_a^k W_c + f_a^k)}{\sum_{a \in A} d_a\, \mu_r (W_c + W_T)} \qquad (3)$$

(4) to (11) are the constraints of the model. (4) and (5) are used for ensuring that the picker starts at the depot and no arc is selected in the first step. The required arc is guaranteed to travel through by using (6). (7) is used for ensures that the picker enters and leaves from any vertex in the next step. (8) is load conservation constraints. (9) is used for ensures that the load of the vehicle will be increased when the picker picks up an item at the required storage point. (10) is a boundary function of load for each arc. (11) guarantees that all decision variables are binary.

$$\sum_{a \in \delta^+(0)} r_a^1 = 1 \qquad (4)$$

$$\sum_{a \in A} r_a^1 = 0 \qquad (\, a \in A \setminus \delta^+(1)\,) \qquad (5)$$

$$\sum_{k=1}^{2(|V|-1)} \sum_{a \in \delta^+(i)} r_a^k = 1 \qquad (\forall\, i \in V_R\,) \qquad (6)$$

$$\sum_{a \in \delta^-(i)} r_a^k = \sum_{a \in \delta^+} r_a^{k+1} \quad (\forall\, i \in V \setminus \{0\};\, 1 \le k \le 2(|V|-1)-1) \qquad (7)$$

$$\sum_{a \in \delta^+(i)} f_a^{k+1} - \sum_{a \in \delta^-(i)} f_a^k = 0 \quad (\forall\, i \in V \setminus V_R;\ 1 \le k \le 2(|V|-1)-1) \qquad (8)$$

$$\sum_{a \in \delta^+(i)} f_a^{k+1} - \sum_{a \in \delta^-(i)} f_a^k = w_i \sum_{a \in \delta^+(i)} r_a^k \quad (\forall\, i \in V_R \setminus \{0\};\ 1 \le k \le 2(|V|-1)-1) \qquad (9)$$

$$0 \le f_a^k \le W_T r_a^k \qquad (10)$$

$$r_a^k \in \{0,1\} \qquad (\forall\, a \in A\,;\ 1 \le k \le 2(|V|-1)\,) \qquad (11)$$

5. Simulation software

After the model has been formulated, we then develop a computer simulation software to solve the problem and display the results. We call it "Eco-Pick" It's built with C# on .NET 4.0 framework and Python 2.7 with Pymprog 1.0 solver library and use Visual Studio 2015 Community as an integrated development environment (IDE). A screenshot of the user interface is shown in Fig. 3. Start using this software is simple, first enter related parameters in "Warehouse Configuration" section and then, in "Pick list" section, select the picking list in PID dropdown or generate a new one. Finally, start solve the problem in "Exact Method" section, in this section, it has three options for selecting, option one use distance only consideration (D) with simplex method, or option two, distance and energy consideration (DE) with simplex method and last option, directly solving a problem by brute-force method (B) that list all possible ways and finding the best solution (used for validation purpose only). However, currently limitation of this software is that, the maximum items per order list are 8 items per order.

After solving, our software graphically shows the result as a navigation path in "Navigation Path Display" section it can explain the direction for each movement and shows the operational details with cumulative load in the "Navigation Step Table". Finally, total distance, total energy consumption and the calculation time were being calculated and show in a bottom-left.

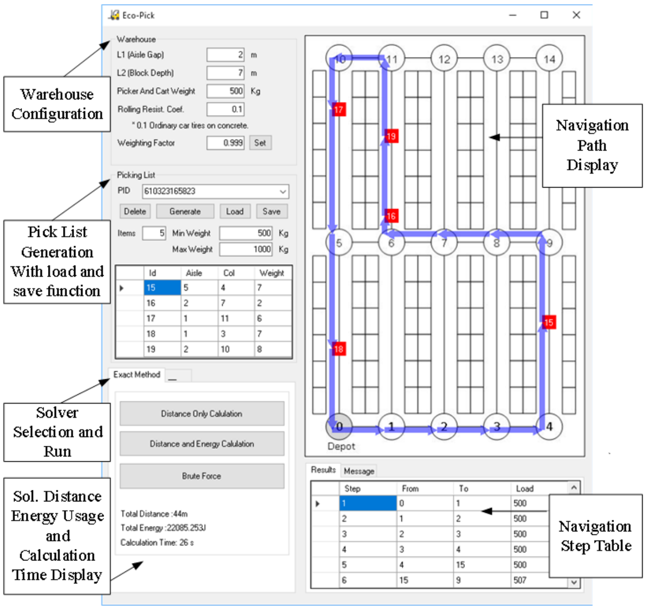

Fig. 3: User Interface of Eco-Pick.

6. Results and discussion

In order to validate the results and verify a performance, we have to set up an experiment and divided it in two stages, first stage for validate the solutions that given from solving our models are true-optimum solutions and second stage, for verify the energy saving performance.

In the problem, warehouse has two-blocks and each block has two single side shelve at the leftmost and rightmost of block and four double-sided shelves in the middle of block. Each shelf contains 6 storage locations in each side. The distance between aisles is 2 meters and each block has 7 meter long. We set the weighting factor to 0.999 because this example needs to maximize service level as the first priority and use the energy as less as possible and from previous experiments we found that when use this value the calculation times are more reduced while the energy consumption can reach the optimum point, as show in Fig 4 and the other values of parameters are shown in Table 2 and the computer that use in this experiment has intel core i7-2600 CPU, 16GB memory.

Table 2: Parameters

Parameters	Value
Weighting factor (w).	0.999
Rolling resistance coefficient (μ_r).	0.1
Weight of picker and vehicle (W_c)	500
Number of items per pick list	2 , 5 , 8
Number of pick list	15
Item weight class	1-10kg, 10-100kg, 100-500kg, 500-1000kg
Parallel aisle spacing	2m
Parallel aisle depth	7m

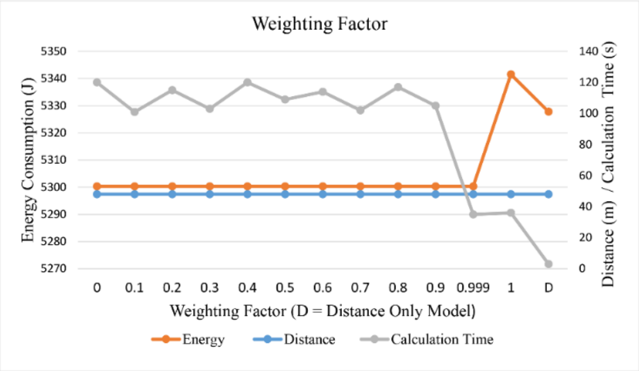

Fig. 4: The varying of weighting factor.

6.1. First stage

To validate the results that given by a software, we compare both the optimal solutions that use distance and energy consideration model ("DE" for short) and distance only consideration model ("D" for short) with optimal solutions that given by brute-force method ("B" for short) that list all possible path and then select the shortest distance path. Items weight class is use in this stage is 1-10 Kg class only and items per order are 2, 5, 8 items and the items locations are randomly assigned.
After solving B, D and DE, the results are shown in Table 3. We found that the optimal distance of B D and DE always be the same but the energy usage are difference, that be investigate more in the second stage.

6.2. Second stage

To verify energy saving performance of the DE model, we solve the problems by varying item per picking list and items weight class. The order in each item weight class problem includes 5 of 2 items per order, 5 of 5 items per order and 5 of 8 items per order and the location are randomly assigned. After the calculations, we then compare the energy usage of DE with D in the same problem. Finally, different values be calculated as saving percentage. The results are shown in Table 4 and Fig 5.

Table 4: The energy usage comparison of D and DE.

Items weight class	Distance (m)		Energy Consumption (J)		Energy saving (%)
	D	DE	D	DE	
1-10kg	585	585	295,203	293,761	0.24%
10-100kg	614	614	394,800	373,146	2.82%
100-500kg	586	586	766,862	695,624	4.87%
500-1000kg	618	618	1,614,331	1,382,338	7.74%

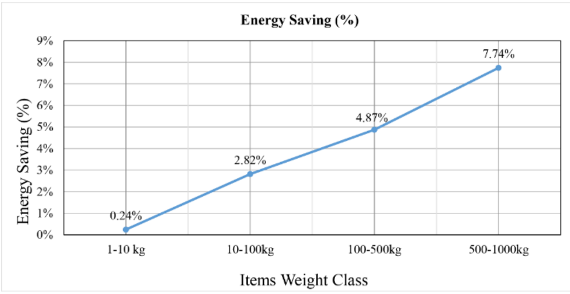

Fig. 5: Energy saving % for each items weight class.

7. Conclusion

This research has been built a new computer simulation software with a mathematical model to determine the optimal solution in order picking problem when considering both distance and energy consumption. Comparing the use of energy consumption criteria, it is found that the travel routes have been altered but giving the same values of distance. By considering the energy consumption criteria, the energy consumption used is less. Moreover, when items in the order have more weight, using the model that considering both distance and energy consumption will more to save the energy. Our software currently has a problem size limitation it will be improved in future work which meta-heuristics method such as ant colony should be applied instead of the exact method.

Table 3: The optimal results that given from solving B, D and DE (1-10Kg Items Class).

Order Id	Items	Distance (m)			Energy Consumption (J)			Calculation time (s)		
		B	D	DE	B	D	DE	B	D	DE
1	2	27	27	27	12,832	12,832	12,801	812	1	3
2	2	22	22	22	10,852	10,859	10,852	875	1	2
3	2	30	30	30	14,885	14,885	14,840	593	2	3
4	2	26	26	26	12,885	12,885	12,850	838	1	2
5	2	18	18	18	8,953	8,953	8,953	601	1	3
6	5	36	36	36	18,319	18,319	18,056	324	1	10
7	5	38	38	38	19,040	19,040	19,026	135	1	10
8	5	46	46	46	23,299	23,299	23,090	299	1	12
9	5	46	46	46	22,914	22,914	22,874	164	1	15
10	5	38	38	38	19183	19183	18,952	152	1	16
11	8	52	52	52	26,570	26,570	26,448	170	21	486
12	8	46	46	46	23,491	23,491	23,485	180	10	125
13	8	48	48	48	24,162	24,162	24,162	140	7	116
14	8	54	54	54	27,804	27,804	27,364	127	9	127
15	8	58	58	58	30,005	30,005	30,005	270	14	270
Total	75	585	585	585	295,194	295,201	293,758	5,380	72	1,200

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