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Recyclable Waste Collection Routing in Households' Areas Using the Mtz-Tsp Model – A Case Study in Rasah, Negeri Sembilan

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Abstract

Sustainable household waste management is crucial for any nation. Currently, Malaysia relies heavily on landfilling as a waste disposal method. Unfortunately, most of the waste disposed of is recyclable. One of the contributing factors to householders' unwillingness to recycle is inadequate collection systems. The implementation of an efficient system for collecting recyclable waste would contribute to the improvement of Malaysia's waste management infrastructure, particularly regarding the restricted availability of suitable landfill space in the future. Therefore, this study employed the Miller-Tucker-Zimmer Travelling Salesmen Problem (MTZ-TSP) as a framework to address the issue of collection routing for recyclable material within household areas. For our research study, we have selected twelve households in Rasah, a suburban neighborhood located in Negeri Sembilan, as the empirical preliminary work. It took less than 150 minutes to collect the recyclables from these twelve households.

Keywords vehicle routing, collection, waste, recycling, travelling salesman problem.

INTRODUCTION

Sustainable management of household waste is crucial for any nation. In Malaysia, household waste constitutes 44.5% of the overall solid waste collection, amounting to around 6.1 million tonnes annually [1]. This categorizes households as the largest contributors to waste generation in the country. However, it is important to note that landfilling continues to be the prevailing method of disposal, as about 89% of the collected waste is directed into a network of 170 landfills nationwide [2].

Recycling able to minimize the waste sent to landfills [2] would requires a keen awareness of householders through a separation at source action. The national recycling rate is 33.17% in 2022 [3], while the government targeted rate is 40% by 2025 [4]. However, the majority of recycling rates is mobilized by the informal waste sector since waste management companies only collect 0.04% of total municipal waste for recycling [5]. Additionally, Malaysia's recycling rate is remains relatively low when compared to its neighboring nations [6] with over 80% of recyclables being disposed of in landfills [7].

Several factors contribute to the limited engagement in recycling practices, including low collection coverage and irregular collection services [6]. About 70–85% of total solid waste management costs are attributable to the collection system [8], and small improvements to this system can result in substantial savings for municipalities [9]. This includes the collection of recyclables from household waste, which would enhance householders' involvement and dedication.

For these reasons, this paper seeks to determine the shortest distance for recyclable waste collectors so that all households' areas are visited once. It is assumed that each household's area has one curbside recyclable waste collection point and that a vehicle, such as a truck, collects the recyclables. This paper constitutes a component of our research endeavor, with the objective of developing a mathematical framework to efficiently address the vehicle routing problem that optimizing the collection sequence of commodities from multiple nodes and their subsequent dispatch to the originating point. The classical travelling salesmen problem (TSP) foundational concept for our interest, i.e., the collection routing problem.

The TSP is an extension of the Hamiltonian Circuit Problem and is a well-known combinatorial optimization problem that seeks to determine the shortest possible route of a tour that starts and ends at an initial node after visiting a set of nodes exactly once [10]. In other words, the sum of the selected distances in the traverse set must be the smallest combination. Variants of TSP have been established, among which the Miller-Tucker-Zemlin formulation (MTZ-TSP), which is formulated as an integer linear programming problem.

METHODOLOGY

The article encompasses a series of steps, commencing with the formulation of the problem model. The subsequent phase involves the collection of data, which pertains to the parameters outlined in the model's formulation. Subsequently, the model is solved using optimization tools, and a corresponding solution is presented.

Methods: The MTZ-TSP model

The MTZ-TSP was introduced by Miller et al. in 1960, which is the integer linear programming version of the TSP. The indices, parameters and decision variable of the model as follows:

Indices and parameters:

i, j : Set of vertices, $i, j = 1, 2, 3, \ldots, n$, such that $i \neq j$

t_{ij} : Travel distance from vertex i to vertex j.

p : The maximum number of nodes that can be visited by the vendor

Decision Variables:

$x_{ij} = \begin{cases} 1 & \text{if the vendor proceeds to vertex } j \text{ from vertex } i \\ 0 & \text{otherwise} \end{cases}$

u_i = A non-negative variable for eliminating sub-tour revisitation.

The integer programming model as follows:

$$Min \sum_i \sum_j t_{ij} x_{ij} \tag{1}$$

such that

$$\sum_{i=0; i \neq j} x_{ij} = 1; \qquad \forall j = 1,2,\ldots,n \tag{2}$$

$$\sum_{j=0; j \neq i} x_{ij} = 1; \qquad \forall i = 1,2,\ldots,n \tag{3}$$

$$u_i - u_j + (p)x_{ij} \leq p - 1; \qquad 1 \leq i \neq j \leq n \tag{4}$$

The objective function of the model as presented by (1) which is to minimize the total distance by the salesman. The model constraints are represented by inequalities (2) – (4). Inequality (2) and (3) ensure only one vertex or location is visited for each iteration, and (4) restrict no subtour involved that is less than n vertices. This inequality is also used to eliminate tours that do not begin and end at vertex 0 and tours that visit more than p cities. Next, the process of collecting the data from Rasah area is explained.

Data Collection

The data pertaining to each parameter is acquired from the suburban area, specifically Rasah. Rasah is a suburban locality situated within Seremban, i.e., a city in Negeri Sembilan. It predominantly comprises households' areas. Therefore, the implementation of a comprehensive recyclable waste collection system is critical. The distance measurements between households' areas (nodes n) were acquired using Google Maps. It was anticipated that the data-gathering process would take place on workdays, specifically after 9 a.m. Therefore, the configuration of the setting on Google Maps was adjusted accordingly.

Table 1. The location and proximity of the chosen households' areas (in minutes)

Area	***n***	0	1	2	3	4	5	6	7	8	9	10	11	12
Depot	**0**	∞	0	0	0	0	0	0	0	0	0	0	0	0
Seremban 3 - Seksyen 1B	1	0	∞	2	3	6	7	10	8	7	9	7	9	8
Seremban 3 - Seksyen 4A	2	0	3	∞	1	7	4	8	7	6	7	3	6	10
Seremban 3 - Seksyen 5C	3	0	4	1	∞	4	3	8	5	4	6	2	6	8
Taman Desa Rasah	4	0	8	4	3	∞	2	6	4	3	8	3	8	4
Taman Harapan Baru	5	0	8	4	3	2	∞	3	4	2	7	2	6	4
Taman Kok Ann	6	0	3	4	6	6	2	∞	3	4	10	6	9	4
Taman Koperasi Guru Tamil	7	0	2	4	6	4	5	1	∞	2	10	5	10	2
Taman Merbok Ria	8	0	9	5	4	3	2	3	2	∞	8	4	8	3
Taman Rasah Jaya (Night Market Area)	9	0	9	6	4	7	5	10	9	8	∞	5	4	10
Taman Rasah Jaya (Shoplot Area)	10	0	5	3	2	3	3	6	5	4	7	∞	6	6
Taman Rasah Jaya (Mosque Area)	11	0	10	7	4	8	5	8	10	8	2	6	∞	12
Taman Sri Rasah	12	0	4	7	6	4	4	2	2	3	12	6	10	∞

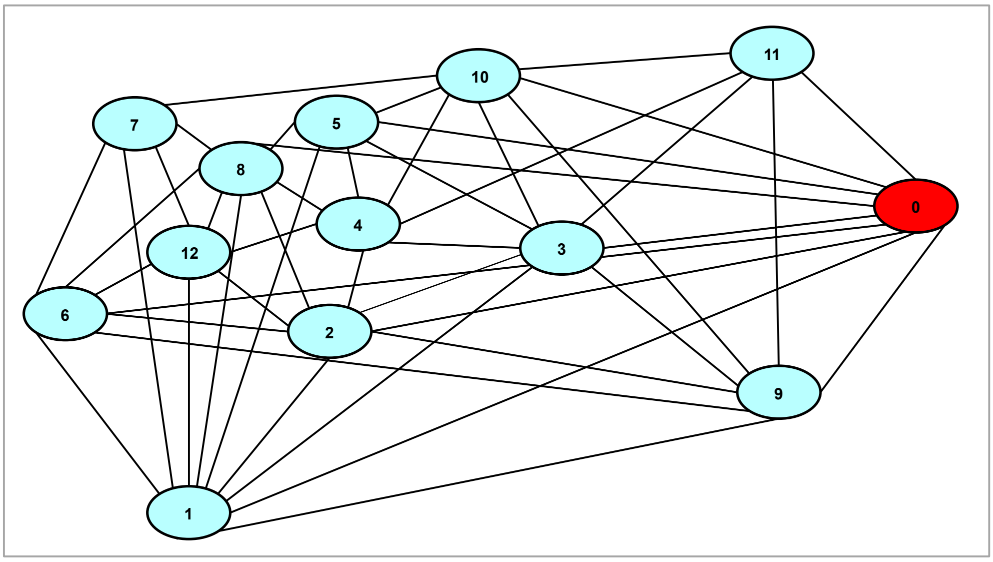

Figure 1. Network of the area of study, i.e., Rasah, Negeri Sembilan

The distance between these nodes is displayed in table 1 along with the households' areas. The table also displays the distance between nodes in minutes. The minimum distance is one minute, and the highest distance is ten minutes. For example, the distance between nodes 2 and 3 is the shortest at one minute, while the distance between nodes 2 and 12 is the longest at 10 minutes. Meanwhile, the '∞' symbolized no distance between the same n. In addition, a dummy node labeled 0 was incorporated into the system to represent the start point of the collector's vehicle. The purpose of this measure is to guarantee that the path of the collector begins and ends at a similar point. In order to designate any subsequent node as the initial node to be visited, the distance from node 0 to all other nodes is assigned a value of zero. However, this assumption can be relaxed if the decision-maker does not intend to do so. Then, the distances and position of the nodes are visualized in a graphical network representation.

Figure 1 is a visual representation of a network of the households' areas that have been specifically selected. It is important to note that these areas are adjacent to each other and the distance between these locations is asymmetrical. Other assumptions were also made, specifically:

i) All household areas encompass a single curbside recyclable waste collection location that is conveniently accessible to their occupants.
ii) The collector is responsible for collecting the recyclables provided by the local municipalities and no scavengers interfering with the collection process.
iii) The driving speed of the collector's vehicle is always constant, and the collection procedure is interrupted solely for the purpose of collecting materials.
iv) The capacity of the vehicle utilized by the collector is relaxed.
v) The condition of the roads is satisfactory, with low traffic congestion, and it is assumed that the weather is favorable.

The MTZ-TSP model was solved using CPLEX 20.0 optimization software. A computer with a 2.71 GHz Intel Core i5-7200 processor and 12 GB of RAM executed the procedure.

RESULTS AND DISCUSSION

The outcome acquired is presented in Table 2. The initial node is represented by the first column, while the following node in the selected path is represented by the first row. From the table, assume the journey begins at node '0'. All the entries in row '0' are assigned a value of zero, except for the value 1 at node '11'. Next, node '11' is selected as the initial node, and the value '1' within the row is located at node '9'. This procedure is iteratively executed until all nodes are encompassed within the traversal sequence. As results, the collection routing of the collector begins at node 0, followed by a sequence of nodes traversed in the order of 11→9→3→2→10→4→5→8→7→12→6→1→0.

Table 2. The visit sequence of the nodes

n	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0	0	0	0	0	0	0	0	0	0	0	1	0
1	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	1	0	0
3	0	0	1	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	1	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	1	0	0	0	0
6	0	1	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	1
8	0	0	0	0	0	0	0	1	0	0	0	0	0
9	0	0	0	1	0	0	0	0	0	0	0	0	0
10	0	0	0	0	1	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	1	0	0	0
12	0	0	0	0	0	0	1	0	0	0	0	0	0

Table 3. The travel times between start and subsequent nodes.

Start node	Subsequent node	Travel times (minutes)
Depot	Taman Rasah Jaya - 3 (Mosque Area)	0
Seremban 3 - Seksyen 1B	Depot	0
Seremban 3 - Seksyen 4A	Taman Rasah Jaya - 2 (Shoplot Area)	3
Seremban 3 - Seksyen 5C	Seremban 3 - Seksyen 4A	1
Taman Desa Rasah	Taman Harapan Baru	2
Taman Harapan Baru	Taman Merbok Ria	2
Taman Kok Ann	Seremban 3 - Seksyen 1B	3
Taman Koperasi Guru Tamil	Taman Sri Rasah	2
Taman Merbok Ria	Taman Koperasi Guru Tamil	2
Taman Rasah Jaya - 1 (Night Market Area)	Seremban 3 - Seksyen 5C	4
Taman Rasah Jaya - 2 (Shoplot Area)	Taman Desa Rasah	3
Taman Rasah Jaya - 3 (Mosque Area)	Taman Rasah Jaya - 1 (Night Market Area)	2
Taman Sri Rasah	Taman Kok Ann	2
TOTAL TRAVEL TIMES (minutes)		**26**

Next, the distances of the traverse nodes are determined by aligning them with the corresponding values presented in Table 1, and the results are shown in Table 3. The table displays the travel times between the first node and the next node. In the first two rows, the travel times have a value of zero to indicate the starting and ending nodes of the collector's route. As a result, it is found that the total travel time for the collector's vehicle is 26 minutes. Figure 2 illustrates the route traversed by the collector. As illustrated in Figure 2, the route begins at node '0' and returns to the same node while the traversed sequence is 11→9→3→2→10→4→5→8→7→12→6→1.

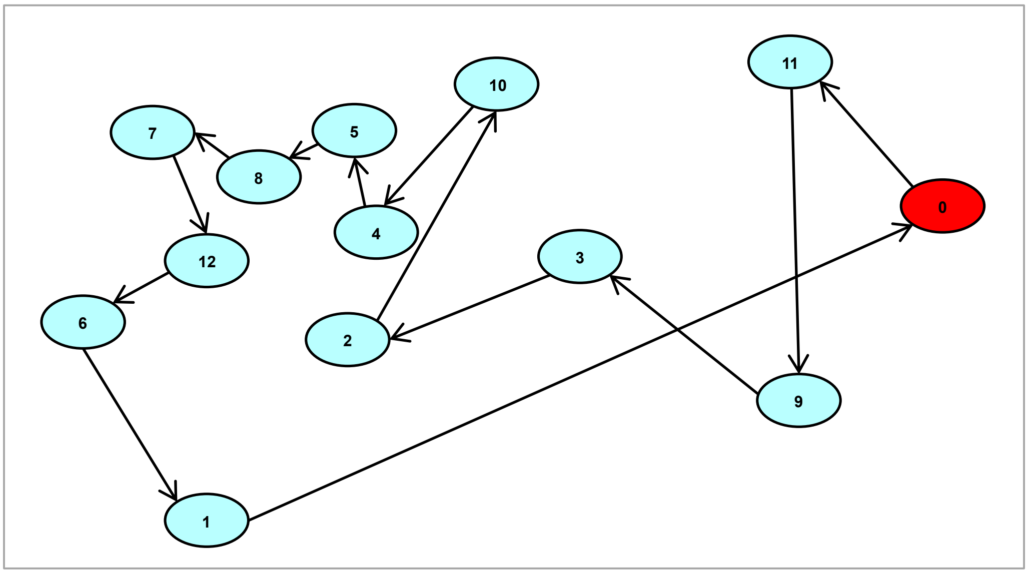

Figure 2. Suggested collection route for the area of study, i.e., Rasah, Negeri Sembilan

From these results, the collector would require at least 26 minutes to traverse the selected households' areas in Rasah. Assuming an average collection processing time of around 10 minutes per household's area, it can be inferred that a cumulative duration of 146 minutes would be expected for collecting the recyclable materials from the designated curbside points.

CONCLUSIONS

The primary objective of this study was to determine the optimal routing strategy for the collection of recyclable materials from specified curbside locations. Rasah, an area within Seremban, was selected as the focal point of our case study due to its largely residential status. A total of twelve households' areas were chosen for the study, with the assumption that each neighborhood included a single recycling point located on the curbside of the road. In this study, the MTZ-TSP method was employed as an approach to establish the collection route connecting these collecting points. As a result, only 26 minutes were needed to collect the recyclable waste. Clearly, the process of achieving a cleaner environment and promoting domestic recycling is feasible.

This study represents our ongoing works in the field of collection routing using mathematical modeling techniques. Thus, for future work, it would be recommended that the clustering procedure is implemented for larger households' areas. This is to resemble the daily collection procedure. To achieve this, it is suggested that the cluster be represented by adding additional dimensions to the model. In addition, a two-stage mathematical model is applied where the first stage concentrates on clustering the households' areas.

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