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Research Paper

Waste Collection Vehicle Routing Problem with Time Windows for Route Optimization of Garbage Transport Vehicles

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Abstract
The waste collection vehicle routing problem with time windows is an optimization problem on the route of the waste transport vehicle which aims to determine the route of the vehicle by considering the travel time and windows. Garbage transport vehicles transport garbage in several work areas. This affects the optimal time and distance. The working hours of the garbage collectors are divided into two parts. The first working hours are 07.00 - 11.00 West Indonesian Time (WIT) and 16.00-20.00 WIT. The cleaning staff has a break of 5 hours. This study aims to optimize the route of waste transportation vehicles in the problem of transporting waste so as to minimize travel time and distance. Waste collection vehicle routing problem with time windows on determining the route of a garbage transport vehicle which is simulated on the problem of transporting garbage in the city of Palembang. The waste collection vehicle routing problem with the time windows model is solved with an exact approach using LINGO software. The results of this study indicate that the proposed optimization model provides optimization of the route of the garbage transport vehicle, the total travel time, and break time of the cleaning staff.

Keywords
Waste, Transportation, Vehicle Routing Problem, Travel Time, Break Time

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1. INTRODUCTION

The problem of vehicle routes in optimization can be discussed in the Vehicle Routing Problem (VRP). Dantzig Ramser introduced the Truck Dispatching Problem in 1959 which minimized the distance traveled from trucks with homogeneous characteristics so that they could serve oil demand from a number of gas stations (Ibrahim et al., 2019; Izar et al., 2016; Jepsen and Pisinger, 2011; Mamat et al., 2016). Furthermore, Clarke and Wright in 1964 generalized this problem in the field of logistics and transportation, hereinafter known as the VRP (Braekers et al., 2016; Lahyani et al., 2015). VRP problems have been widely researched and developed in various fields, such as logistics, transportation, economics, and communications (Gounaris et al., 2013). Classical VRP aims to determine vehicle routes starting from the depot, ending at the depot for vehicles with the same capacity so that each customer is visited once and each vehicle only has one route (Atefi et al., 2018; Borcinova, 2017; Izar et al., 2016; Nazari et al., 2018). VRP has been widely studied related to optimization problems that aim to identify efficient and optimal vehicle routes for distance or travel costs (Assaf and Saleh, 2017; Azad and Hasin, 2019; Munari et al., 2019). VRP can be related to the problem of garbage collection routes (Wahyukaton and Rochaeni, 2019; Yuliza et al., 2020; Yuliza et al., 2021). Service for each customer must be started in corresponding time intervals called time windows. The time window can be interpreted as the time interval between departure time and arrival time (Desaulniers et al., 2014; El-Sherbeny, 2010).

The problem of waste collection is a problem faced by an area, especially urban areas Lu et al., 2015. In this paper, we study a variant of the Vehicle Routing Problem (VRP) as a waste collection vehicle routing problem with time windows. Rossit et al. (2021) proposed a simulated annealing algorithm to overcome the route of garbage collection vehicles based on mixed integer programming and metaheuristic methods, large neighborhood search, and genetic algorithms. The waste collection vehicle route problem is modeled with a scheduling strategy and an environmentally friendly solution is sought (Korcyl et al., 2019; Lu et al., 2015). Zhou et al. (2022) proposed a model to optimize the solid waste collection and transport routes that have become an issue in China. Markovic et al. (2019) solve the problem of transporting waste in urban areas with a metaheuristic approach based on the waste collection vehicle routing problem on stochastic demand and travel time.

Perea et al. (2016) analyzed the problem of transporting waste by considering different types of waste based on heuristics. Bee algorithm was applied to overcome Capacitated Vehicle Routing Problem (CVRP) issues which aim to provide a suggested solution regarding the waste hauling route for the upcoming ITF Sunter project. Based on the CVRP, the capacity of the waste transported will not exceed the capacity of the waste transport vehicles (Natalia et al., 2021).

This study will discuss the optimization model of the waste collection vehicle routing problem with time windows on the waste transportation route in the city of Palembang by considering the rest time parameter. This study aims to optimize the route of waste transportation in the city of Palembang against time windows. More specifically, looking for the optimal route that minimizes the total distance traveled by waste transport vehicles. The problem from this research will be modeled as a waste collection vehicle routing problem with time windows. The mixed integer programming formulation of the waste collection vehicle routing problem with time windows was solved using the branch and bound method using LINGO software (Hartono et al., 2018; Puspita et al., 2018; Yuliza et al., 2020). The model will be implemented on the problem of waste transportation routes in the Ilir Barat I District I, Palembang city. An efficient procedure is designed to solve the waste collection route problem in the waste collection vehicle routing problem model so as to minimize the distance and travel time.

The city of Palembang has a Department of Environment and Hygiene (DEH) which oversees and is responsible for the environment and cleanliness in the city of Palembang. Each DEH officer is responsible for one work area. The officers are assigned to one particular area and serve several Temporary Disposal Sites (TDS) to Final Disposal Sites (FDS) by using waste transport vehicles such as containers, dump trucks, or arm rolls. The process of transporting waste is divided into two periods. The first working hours are from 07.00-11.00 West Indonesian Time (WIT) and 16.00-20.00 WIT. There are a break 5 hours for the officers.

This study will also discuss the break time of the officers. The free 5 hours between the working hours of the first session and the second session can be used by officers to rest. Garbage transport vehicles will pick up waste from several TDS and take it to the FDS. Garbage transport routes are carried out randomly so that the time and distance traveled are not optimal.

2. EXPERIMENTAL SECTION

2.1 Materials

Data on waste transportation routes were obtained from DEH. The problem of transporting waste can be viewed as a weighted directed graph. The set of all TDS and FDS can be expressed as nodes and the journey from TDS i to TDS j can be expressed as arc, written $G= (V,A)$ where $G= 1,2,\cdots,n$ and $V=(i,j)|i= 1,2,\cdots,n$, and $j= 1,2,\cdots,n$. Some assumptions in this study are as follows: Vehicle capacity Some assumptions the average speed of garbage transporting vehicles is 40 km/hour, traffic jams are ignored, traffic lights are ignored, engine damage is neglected, the distance from TDS i to TDS j is considered the same or the matrix is symmetrical, service time about 5 minutes and the capacity of the garbage vehicle is assumed to be 8 tons.

2.2 Methods

The waste collection vehicle routing problem with the time windows model is formulated which is implemented on the waste transportation route problem. This model is solved by the branch and bound method with the help of LINGO software. The procedure of this research is shown in Figure 1.

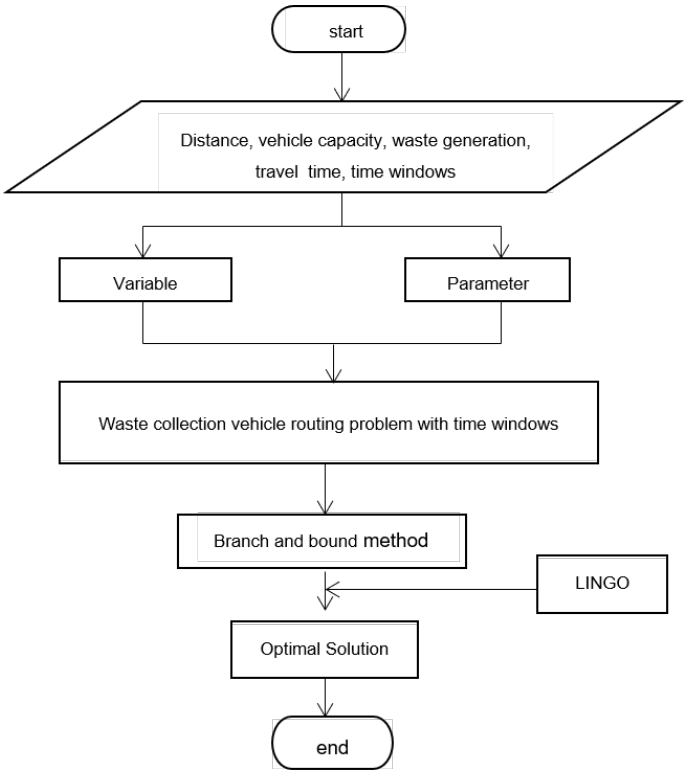

Figure 1. Illustration of Research Flow

3. RESULT AND DISCUSSION

The mathematical model of the waste collection vehicle routing problem with time windows is formulated as follows:

$$\min Z = \sum_{(i,j)\epsilon A} d_{ij}x_{ij} \quad (1)$$

$$\sum_{j\epsilon V} x_{ij} = 1, \text{ for } i\epsilon V \quad (2)$$

$$\sum_{j\epsilon V} x_{ji} = 1, \text{ for } i\epsilon V \quad (3)$$

$$q_i \le y_i \le Q, \text{ for } i\epsilon V \quad (4)$$

$$y_i - y_j + q_j \le Q(1 - x_{ij}), \text{ for } (i,j)\epsilon A \quad (5)$$

$$\sum_{(j,i)\epsilon A, j\neq i} x_{ji} - \sum_{(i,j)\epsilon A, i\neq j} x_{ij} = \begin{cases} -1, \text{for} = 0 \\ 1, \text{for} = d \\ 0, \text{the others} \end{cases} \quad (6)$$

$$a_i \leq t_i \leq b_i, \text{for } i\epsilon V \quad (7)$$

$$t_i - t_j + (b_i + t_{ij} - a_j)x_{ij} \leq b_i - a_j, \text{for } (i,j)\epsilon A \quad (8)$$

$$\sum_{(j,i)\epsilon A} y_{ij} = 1, \text{for } i\epsilon V \quad (9)$$

$$y_{ij} \leq i_{ij}, \text{for } (i,j)\epsilon A \quad (10)$$

$$x_{ij}\epsilon\{0, 1\}, \text{for } (i,j)\epsilon A \quad (11)$$

$$y_{ij}\epsilon\{0, 1\}, \text{for } (i,j)\epsilon A \quad (12)$$

The journey from TDS i to TDS j is denoted by x_{ij}. The generation transported at the TDS to i and the generated transported at the TDS to j are denoted by y_i and y_j. Departure time from TDS to i and travel time from TDS to j are denoted by t_i and t_j. The officer's rest time from TDS i to TDS j is denoted by y_{ij}. The distance from TDS i to TDS j is denoted by d_{ij}.The departure time of vehicles when transporting waste at TDS to i is denoted by a_i.The arrival time of vehicles when transporting waste to TDS j is denoted by b_j. Garbage load at TDS to i is denoted by q_i. Vehicle capacity is denoted by Q.The travel time from TDS i to TDS j is denoted by t_{ij}. The definitions of each variable and parameter are given in Table 1.

Table 1. Variable and Parameter for the Waste Collection Vehicle Routing Problem with Time Windows

Variable	Parameter
x_{ij}	d_{ij}
y_i	a_i
y_j	b_j
t_i	q_i
t_i	t_{ij}
y_{ij}	Q

The waste collection vehicle routing problem with the time window model is implemented on the problem of waste transportation routes in Ilir Barat I District, Palembang city.

The solution of the waste collection vehicle routing problem with time window model is solved by LINGO software. The solver of LINGO is the branch and bound method. The calculation results are as in Table 3.

The calculation results of the waste collection vehicle routing problem with the time window model produce a minimum total distance of 264.05 km and a total travel time of 6.6 hours (Assumption that the average speed of garbage transporting vehicles is 40 km/hour). In the first session, the working hours of officers are 4 hours and in the second session, the working hours of officers are 2.6 hours. The total working hours of the first session and the second session are 8 hours so the officer has a waiting time of 84 minutes. This shows that the waste collection vehicle route using the waste collection vehicle routing problem with the time window model produces an optimal total distance and travel time.

Table 2. Data on Transportation Type and Amount of TDS in Ilir Barat I District

District	Vehicle code	Transportation type	Amount of TDS
District 1	20	container	1
District 2	27	dump truck	7
District 3	28	container	2
District 4	29	dump truck	5
District 5	30	dump truck	6
District 6	31	amroll	4
District 7	32	dump truck	7
District 8	33	dump truck	3
District 9	34	dump truck	7

Table 3. Solution of the Waste Collection Vehicle Routing Problem Model with Time Window

Vehicle code	Minimize distance (km)	Transport route
20	0.95	A1-A2
27	21.01	A1-T-B6-B5-B7-B2-B3-B4-T
28	31.4	A1-T-C2-C1
29	26.57	A1-T-D4-D2-D5-D3-T
30	40	A1-T-E6-E2-E4-E3-E5-T
31	34.5	A1-T-F3-F2-T
32	19.68	A1-G3-G2-G5-G4-T-G7-G6-T
33	43.8	A1-T-H3-H2-T
34	46.14	A1-I6-I4-T-I2-I5-I3-T

Where node A1: 1^{st} TDS and node T: FDS, The others: another TDS

4. CONCLUSION

The waste collection vehicle routing problem with the time window model can be implemented on the waste transportation route problem. This model observed to time windows and officer rest periods. Solution of the waste collection vehicle routing problem with time window model obtained optimal mileage and travel time.

5. ACKNOWLEDGMENT

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