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Robust Counterpart Open-Capacitated Vehicle Routing Problem with Time Windows and Deadline (RCOCVRPTWD) Model in Optimization of Waste Transportation in Subdistrict Kalidoni, Palembang Using LINGO 13.0

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Robust Counterpart Open-Capacitated Vehicle Routing Problem with Time Windows and Deadline (RCOCVRPTWD) Model in Optimization of Waste Transportation in Subdistrict Kalidoni, Palembang Using LINGO 13.0

F M Puspita[*], R Melati, A S Br Simanjuntak, E Yuliza, S Octarina

Mathematics Department, Faculty of Mathematics and Natural Sciences, Sriwijaya University, Indralaya, Ogan Ilir, Indonesia

*fitrimayapuspita@unsri.ac.id

Abstract. Robust Counterpart-Open Capacitated Vehicle Routing Problem with time windows and deadline (RC-OCVRPTWD) model which was formed and explained in this paper, is a model used to design solid waste control routes to minimize the distance and time needed for vehicles to complete waste transportation in Kalidoni Sub-District, Palembang. The completion of this route is expected to be able to overcome the occurrence of solid waste accumulation in Kalidoni District, Palembang that involved two characteristics the time that takes for the vehicle to across the route and the time needed to transport waste to the vehicle, which is called time windows. The second combination of time above is deadline. Waste that are transported every day are divided into working areas where the distance of temporary disposal to other disposal in one working area and the volume of waste transported will affect the length of deadline needed. This RC-OCVRPTWD model uses the LINGO 13.0 application to obtain optimal routes and deadlines. The results show that the working route for Kalidoni Sub-District in working area 1 is completed within 28.6 km and a deadline of 2 hours 51 minutes. In working area 2, is with a distance of 23.6 km and a deadline of 1 hour 42 minutes, and in working area 3 is with a distance of 38 km and a deadline of 3 hours 16 minutes.

1. Introduction

The first Indonesian population of productive age continues to increase every year. In 30 years after 1970, the population aged 15-64 years has reached around 133-135 million inhabitants, doubling compared to the beginning of 1970 with a population of around 63-65 million [1]. This increase in population is supported by the development of the population in Palembang city which is the second largest city in Sumatra after Medan, especially the growing population in the Kalidoni Sub-District, Palembang. This sub-district, which is located quite far from the city center, only has 5 sub-districts but according to data from the Palembang City Population and Civil Registration Service, this sub-district has contributed the fifth largest population in Palembang, which is 122,672 out of 1,708,413 residents throughout Palembang City.

The rapid development of the population in the City of Palembang, especially in the Kalidoni sub-District, Palembang, affects the number of waste populations in the area. Waste is always a problem for developments in big cities. For this reason, special strategies are needed to overcome them. One of

the government efforts that continues to be carried out by the environmental service and the cleanliness of the city (DLHK) is to clean up waste in the City of Palembang. The waste collection is carried out in stages carried by trucks carrying waste from waste containers in each waste collection place (TS) in each working area, then after fulfilling the capacity of the car, the waste is transported to Karya Jaya final waste collection place (FS). TS can be in the form of containers, trash cans made of fibre or trash cans made of concrete. The waste from each TS is transported using DLHK trucks in the form of arm-roll or dump trucks that have a capacity of 4 tons.

There are several factors that affect the process of transporting waste from TS to FS, including transportation capacity, waste volume of each TS, and distance travelled that creates the shortest path for routes [2,3]. Waste transportation is one example of a Capacitated Vehicle Routing Problem (CVRP) [4–8] to find the minimum route. The application of VRP in waste transportation can reduce the amount of waste collected at each special polling station in Kalidoni Sub-District, Palembang. Problems of VRP is referred to as a problem by finding efficient routes, beginning and ending at the center of the depot, for the fleet of vehicles serving the number of customers.

Uncertainty in CVRP, for example, a time window and a deadline that state about the waiting time for waste collection and the deadline for transportation at each polling station. The emergence of robust optimization as approved by the model supported by existing data is called robust counterpart (RC) [9–12]. Therefore, the RC formulation of CVRP with additional parameters time window and deadline was attempted on the problem of designing waste management routes in Kalidoni Sub-District, Palembang.

The emergence of new problems that must be resolved because the waste transport truck can start from anywhere which means the lane and trajectory that is made not closed, making it easier to become OCVRP [13–16]. OCVRP issues are important to be developed because they are related to the transportation of commodities such as waste. So this problem has a resolution, where the results to be obtained greatly.

Then, in this paper, new model of Robust Counterpart Open Capacitated Vehicle Routing Problem (RC-OCVRP) [9,17–19] model by considering the time window [20,21] and deadline [12,22] (RC-OCVRPTWD) were designed into the waste transport route, which is expected to find the minimum distance and costs needed by the waste transport vehicle in Kalidoni Sub-District, Palembang. This method can help find a minimal route with maximum waste capacity. The completion of this route is expected to be able to overcome the accumulation of solid waste in the Kalidoni Sub-District, Palembang.

2. Research Method

The study began from searching for materials and studying RC-OCVRPTWD related material from various literature, including books, journals, and information on the internet. While the required data is obtained from DLHK Office of Palembang City. In addition, surveys and direct observation were also conducted to investigate the distance from the TS to the TS, FS to TS, and TS to the FS in Kalidoni Sub-District. Data was also obtained from direct interviews with waste truck drivers. The data obtained in the form of the average speed of the vehicle when going to TS / FS is 30 km/hour. Truck capacity is 4 tons, where it takes 2 hours to move the waste from TS to loading trucks. The general description of the research of the RC-OCVRPTWD model is described as follows:

1) Collect data in the form of Kalidoni Sub-District's working area, number of cars operating, truck' capacity volume, truck' travel route, volume of waste transported from each TS, distance traveled from TS to TS, TS to FS, and vice versa, the average vehicle speed in the trip to TS / FS and the time to transport waste to be picking up to the truck.
2) Furthermore, rearrange distance data in each work area in Kalidoni Sub-District in a table called the distance matrix.
3) Next step, model the distance data, volume data of waste in each polling station into suitable model that has been formed and formulated.

4) Then, solve the model that has been designed for each working area in the LINGO 13.0 application.

5) The method used in LINGO 13.0 is the Branch and Bound method [23,24]. LINGO 13.0 will display the optimal solution, minimum distance, time limit, vehicle to be passed, and others. Time consists of the time needed to pass all routes (t) and the time needed to transport waste to the vehicle. Additions of t and s are called deadlines.

6) Create a travel route map for each working area from the trip route data that has been obtained and from the minimum distance obtained from the modeling results.

The steps taken in dealing with the improved model of RC-OCVRPTWD are displayed in Figure 1 as follows. Steps taken are explained in detail in each process. The additional process is necessary to be conducted if the routes formed is in valid conditions that violates the actual requirements for visiting the TS. The process is called balancing the process to fit the real condition in transporting the waste.
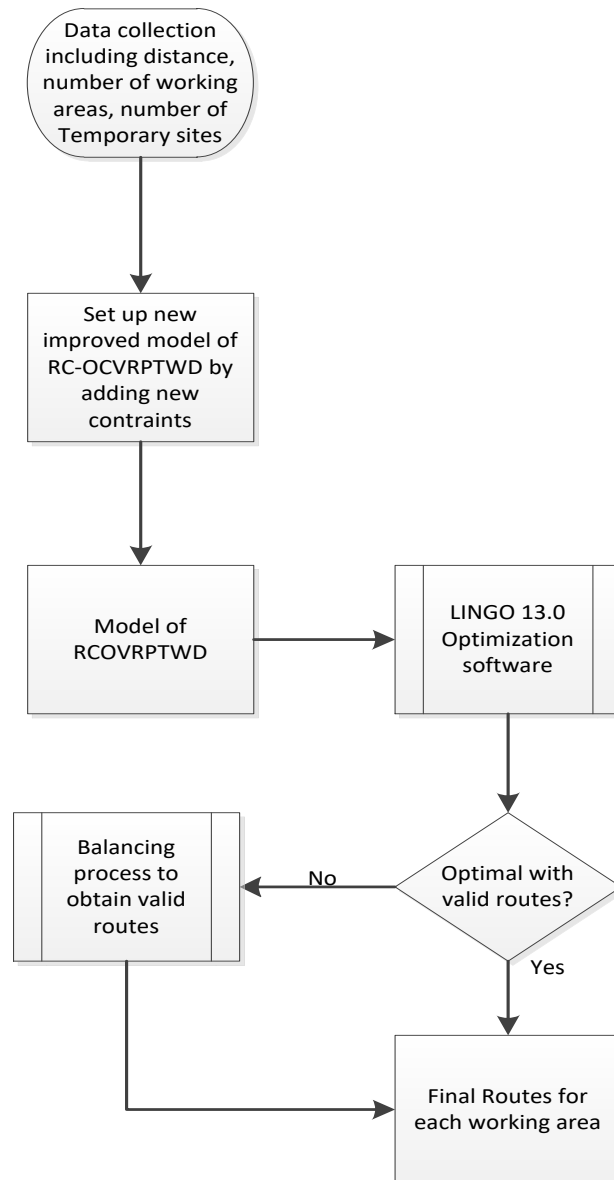

Figure 1. Framework of Designing and Implementing the RC-OCVRPTWD Model

3. Result and analysis

Finding the optimal distance for the route of the waste transportation truck since leaving to the TS, transporting the garbage at the TS, emptying the load to the FS, and then returning to transport the garbage at the TS and returning to the FS. In this case, there is a problem that with limited truck capacity, where each garbage truck must serve every TS that has a load that exceeds the capacity limit of the truck so as to make the garbage truck have to go back and forth from the TS to the FS where road conditions are assumed to be smooth and not jammed, road conditions are ignored and routes that are considered symmetrical (the distance between TS-k to TS-j is considered to be the same as the distance between TS-j to TS-k as well as the distance between TS to FS or vice versa ($x_{kj} = x_{jk}$).

Data obtained is from direct investigation by measuring the distance in each working area in Kalidoni. The data are displayed in Table 1-3. Since Kalidoni has 3 working areas, then the table is explained in each working area.

Table 1. Distances (in km) between FS and TS in Working Area 1

	FS	1	2	3	4
FS	0	19.4	16.7	20	18
Kebon Sririh(1) TS	19.4	0	2.7	3.3	1.4
Jl.R Sukamto(2) TS	16.7	2.7	0	3.4	1.3
Halte Simpang Sekojo B(3) TS	20	3.3	3.4	0	4.6
Jl.Seduduk Putih(4) TS	18	1.4	1.3	4.6	0

Table 2. Distances (in km) between FS and TS in Working Area 2

	FS	1	2	3
FS	0	17.8	20	20.1
Simpang Palapa Permai (1) TS	17.8	0	2.2	2.3
Jl.Tanjung Harapan(2) TS	20	2.2	0	1.3
MP Mangkunegara(3) TS	20.1	2.3	1.3	0

Table 3. Distances (in km) between FS and TS in Working Area 3

	FS	1	2	3
FS	0	25.2	28.5	23.5
Jl. Dr Sutami(Sungai Selayur)(1) TS	25.2	0	4.5	6.7
Jl.Taqwa Mata Merah(2) TS	28.5	4.5	0	10
Jl. Brigen Hasan Kasim(3) TS	23.5	6.7	10	0

The RC-OCVRPTWD model for transporting waste at each working area, assumes that every vehicle that transports waste can start anywhere and move to transport garbage at the TS and clear the cargo at Karya Jaya FS. Each TS visited can be passed exactly on one route with the total volume of TS on each route not exceeding the capacity of the transport vehicle. In Kalidoni Sub-District Palembang City, there are 3 waste transport vehicles in with capacity of every vehicle 4 tons. Each waste transport vehicle is divided into every working areas. So, there are 3 Working Areas in Kalidoni Sub-District. The RC-OCVRPTWD model that has been formed is a combination of the Robust Counterpart model and OCVRP model with time windows and deadlines. The RC-OCVRPTWD model used is as follows:

Minimize δ;

$$z = \sum_{k \epsilon S} c_{0k} y_{0k} + c_{k0} y_{k0} + \sum_{k,j \epsilon S} c_{kj} x_{kj} \geq \delta \tag{1}$$

Subject to

$$\sum_{k,j \epsilon S} y_{0k} + y_{k0} + x_{kj} = 2 \; \forall (k = 1,2,\dots n) \tag{2}$$

$$\sum_{k \epsilon S} y_{0k} + \sum_{k,j \epsilon S} x_{kj} \geq \frac{q(s)}{Q} \tag{3}$$

$$\sum_{k \epsilon S} y_{k0} + \sum_{k,j \epsilon S} x_{kj} \geq K \tag{4}$$

$$\sum_{k \epsilon S} y_{0k} = 1 \tag{5}$$

$$d_k \leq l_k \leq Q \quad \forall k \epsilon S \backslash \{0\} \tag{6}$$

$$l_k - l_j + Q \, x_{kj} \leq Q - d_j \quad \forall k,j \in A, k \neq 0, j \neq 0 \tag{7}$$

$$D = \sum_{k \epsilon S} t_{0k} + \sum_{k \epsilon S} t_{k0} + \sum_{k,j \epsilon S} t_{kj} + \sum_{j \epsilon S} s_j \tag{8}$$

$$V \geq 0 \tag{9}$$

$$k \geq 0 \tag{10}$$

$$t_{0k} = \frac{c_{0k}}{V} \tag{11}$$

$$t_{k0} = \frac{c_{k0}}{V} \tag{12}$$

$$t_{kj} = \frac{c_{kj}}{V} \tag{13}$$

$$s_j = \frac{l_j}{k} \tag{14}$$

$$y_{0k} \in \{0,1\} \tag{15}$$

$$y_{k0} \in \{0,1\} \tag{16}$$

$$x_{kj} \in \{0,1\} \tag{17}$$

$$x_{kj} \in \{0,1\} \text{ for } (1 \leq k \leq j \leq n) \tag{18}$$

$$y_{0k} y_{ko} \in \{0,1\} \; (k = 1,2,\dots,n) \tag{19}$$

$$t_{kj} \in \{0,1\} \text{ for } (1 \leq k \leq j \leq n) \tag{20}$$

$$t_{0k} t_{ko} \in \{0,1\} \; (k = 1,2,\dots,n) \tag{21}$$

$$y_{0k} y_{ko} \in \{0,1\} \; (k = 1,2,\dots,n) \tag{22}$$

$$s_j \in \{0,1\} \; (j = 1,2,\dots,n) \tag{23}$$

The minimum function in the RC-OCVRPTWD Model explains that the route with the minimum distance from garbage transport will be searched by defining the set of all TS as *S*, the trip route from TS-*k* to TS-*j* is x_{kj}, and the route of travel from FS to TS-*k* is y_{0k}. Then, the parameters used, are presented in Table 4.

Table 4. Parameters Used for RC-OCVRPTWD

Parameters	
δ	Function to be minimized
C_{0k}	Distance travelled from FS to TS-k
C_{k0}	Distance travelled from TS-k to FS
C_{kj}	Distance travelled from TS-k to TS-k
y_{k0}	Travel Route travelled from TS-k to FS
y_{0k}	Travel Route travelled from FS to TS-k
x_{kj}	Travel Route travelled from TS-k to TS-k
K	Vehicle Numbers
$K(s)=q(s)/Q$	Minimum Limit for number of vehicles needed to visit TS(s)
$q(s)$	Waste volume that must be taken from the TS
Q	Capacity of vehicle
A	Set consisting of all nodes
S	Set consisting of all TS
d_k	Capacity of TS-k
l_k	Capacity of vehicles when leaving TS-k
D_j	Capacity of TS-j
l_j	Capacity of vehicles when leaving TS-j
D	Time needed to finish the routes
t_{0k}	The time requirement for vehicle to travel from FS to TS-k
T_{k0}	The time requirement for vehicle to travel from TS-k to FS
T_{kj}	The time requirement for vehicle to travel from TS-k to TS-j
s_j	The time requirement to move waste from TS to the vehicle
V	Speed of Vehicle
K	The speed picking up the waste to a vehicle

The model is used to find the minimum distance of waste transportation routes and the time needed to complete waste transportation. That consists of the time needed for the vehicle to pass through the route (t_{kj}) and the time needed to move the waste to the truck (s_j).Then, calculate the minimum distance of the waste transport route and the time needed to complete the transportation of waste in Working Area 3 in Kalidoni Sub-District, Palembang into the model of LINGO 13.0 syntax, as follows.

```
min =del;
25.2*y01+28.5*y02+23.5*y03+25.2*y10+4.5*x12+6.7*x13+28.5*y20+4.5*x21+10*x23+23.5*y30+
6.7*x31+10*x32<=del;
X32=1;
X21=1;
y01+y10=1;
y01+y02+y03+x12+x13+x21+x23+x31+x32>=1;
y10+y20+y30+x12+x13+x21+x23+x31+x32>=1;
y01+y02+y03=1;
L1<=4000;
L1>=1800;
L2<=4000;
L2>=1500;
L3<=4000;
L3>=600;
L1-L2+4000*x12<=2500;
```

```
L1-L3+4000*x13<=3400;
L2-L1+4000*x21<=2200;
L2-L3+4000*x23<=3400;
L3-L1+4000*X31<=2200;
L3-L2+4000*x32<=2500;
D=t32+t21+t10+s1+s2+s3;
V<=30;
k<=4000/120;
t32=(10/V)*60;
t21=(4.5/V)*60;
t10=(25.2/V)*60;
s1=1800/k;
s2=1500/k;
s3=600/k;
y01>=0;
y02>=0;
y03>=0;
y10>=0;
x12>=0;
x13>=0;
y20>=0;
x21>=0;
x23>=0;
y30>=0;
x31>=0;
x32>=0;
@bin(y01);
@bin(y02);
@bin(y03);
@bin(y10);
@bin(x12);
@bin(x13);
@bin(y20);
@bin(x21);
@bin(x23);
@bin(y30);
@bin(x31);
@bin(x32);
End
```

By solving the model, then the solution of decision variables are shown in Table 5.

Table 5. RC-OCVRPTWD Working Area 3 in Kalidoni Sub-District

Variable	Value	Variable	Value
δ	38	32	1
01	0	l_1	1800
02	0	l_2	1500
03	1	l_3	600
10	0	T_{32}	20 minutes
12	1	T_{21}	9 minutes
13	0	T_{10}	50.4 minutes
20	0	S_1	54 minutes
21	0	S_2	45 minutes
23	1	S_3	18 minutes
30	0	D	196.4 minutes
31	0	V	30 km/jam
32	0	K	33.33

Working Area 3 of Kalidoni Sub-District has 3 TS with 1 vehicle used to transport waste from 3 TS. Table 2 describes the solution for searching the waste transportation routes in Working Area 3 in Kalidoni Sub-District. Variable value of 1 means that the route is passed through, while variables with 0 are not passed. The minimum distance obtained was of 38 km with a deadline time of 196.4 minutes or 3 hours 16 minutes.
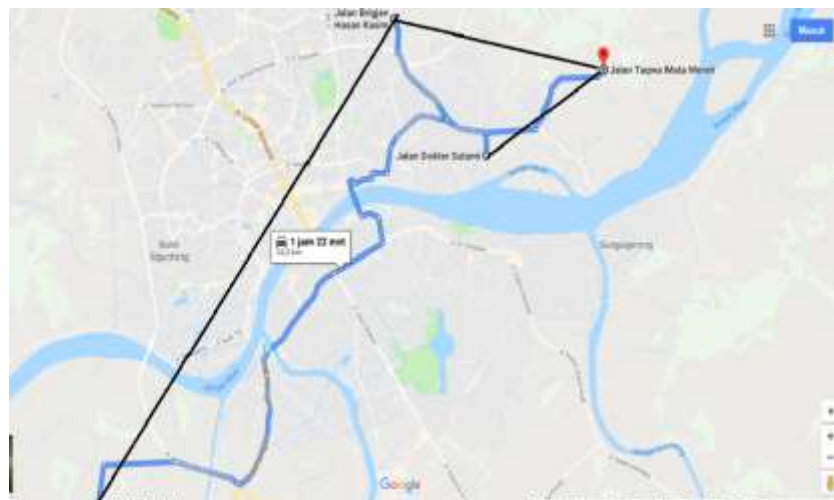

Figure 2. Route of Working Area 3 in Kalidoni District

The transportation route will be TS Jl.Dr.Sutami (Sungai Selayur) - TS Jl.Taqwa Mata Merah - TS Jl.Brigjen Hasan Kasim - FS Karya Jaya. Routes are as Figure 2 shown.

Table 6. Solution of RC-OCVRPTWD in Kalidoni Districts

Solver Status	Working Area 1	Working Area 2	Working Area 3
Model Class	MILP	MILP	MILP
State	Global Optimal		
Objective	28.6	23.6	38
Infeasibility	0	0	0
Iterations	13	12	12
Deadline	2 hours 51 minutes	1 hour 42 minutes	3 hours 16 minutes

In Table 6, the solutions of three working areas are presented. As Table 6 shown, Working Area 2 has the most minimum value of routes travelled with the minimum deadline of 1 hour 42 minutes to finish the route after collecting all waste. Finally, the other routes for collecting waste in Kalidoni Sub-District in other working areas are depicted in Figure 3(a) and 3(b).
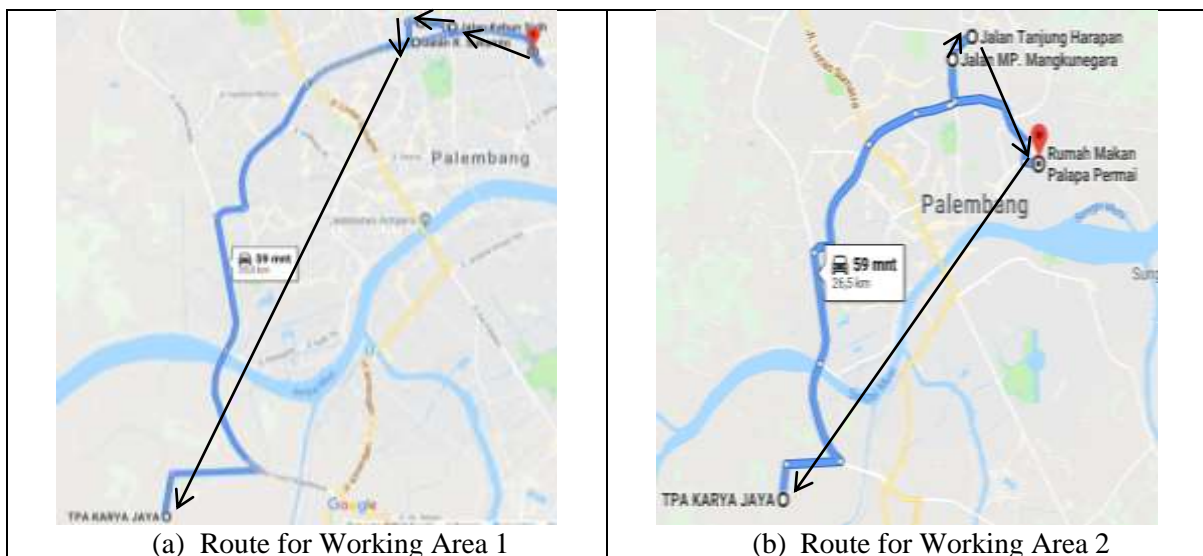

| (a) Route for Working Area 1 | (b) Route for Working Area 2 |

Figure 3. Optimal Routes for (a) Working Area 1 and (b) Working Area 2 of Waste transportation

4. Conclusion

From the calculation of RC-OCVRPTWD using LINGO 13.0 application, the minimum distance of waste transportation routes and the time needed to complete waste transportation in the 3 working areas of the Kalidoni Sub-District, Palembang were obtained. For Working Area 1 the route is TS 1-TS 2-TS 4-TS 3-FS with a distance of 28.6 km and a deadline of 2 hours 51 minutes. For Working Area 2, the route is TS 1-TS 2-TS 3-FS with a distance of 23.6 km and a deadline of 1 hour 42 minutes, and for Working Area 3, the route is TS 1-TS2-TS 3-FS with a distance of 38 km and a deadline of 3 hours 16 minutes. Therefore, it can be concluded that the longer the distance between TS to TS, FS to TS and vice versa and the more volume of waste transported, the longer the time needed to complete the transport of waste.

For further investigation, it is a necessity to also include the condition of traffics especially in busy hour. The recent results is intended to show the bigger picture how transportation problem of waste collection in one of sub-district in Palembang that can be considered as latest achievement in

designing optimal routes. In the future works, some limitations mentioned earlier could be also first priorities to be investigated into the model.

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