Heterogeneous Vehicle Routing Problem with Vehicle Dependent Travel Time for Urban Freight Transportation

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Abstract

According to United Nations, in 2018, 55% of the world's inhabitans lives in urban areas and it is predicted that this figure will increase to 68% by 2050. This resulted that urban freight transportation has become an essential problem in urban planning. Often, congestion in the city make a short distance is traveled in long time. Because of the congestion, the difference in type of vehicle can differ the speed that can be achieved and the travel time. Moreover, since different vehicle has the different in size, then small vehicle can use different route which can result in shorter travel time. Therefore, it is important for hetergoneous vehicle routing problem (HVRP) to consider the difference of travel times between the various types of vehicles in urban context. The travel time of small vehicle is shorter than large vehicle due to congestion. We call this problem as heterogenous vehicle routing problem with vehicle dependent travel time (HVRPVDTT). This paper reveals that it is important to consider the difference in travel time between difference type of vehicles in urban freigh transportation because it can lead to the to different routing and vehicle assignment decision.

Keywords
Urban Logistics, Congestion, Heterogeneous Vehicle Routing Problem, Vehicle Dependent Travel Times

1. Introduction
Logistics is defined as all activities related to the movement and coordination of products from their origin to the final point of delivery, including production and distribution (Bektas 2017). The primary activites in logistics are transportation, warehousing, order processing and inventory management. Distribution channels and transportation make product possible to move from the location they are produced to the end customer location which usually separated by distance. Factors which is important to be considered in logistics is transportation cost since it is the highest cost in total logistics cost which occupies 29.4% followed by inventory cost, warehousing cost, packing cost, management cost, material handling cost and ordering cost (Tseng et al. 2005).

Transportation cost cost can be reduced by optimizing the assignment of vehicle and the sequence of the route. This optimization task is called routing problem. According to Bektas (2017), there are two main problems in routing problem, traveling salesman problem (TSP) and vehicle routing problem (VRP). Vehicle routing problem is defined as a task of designing delivery routes to service scattered located customers in a supply chain (Sharma et al. 2018). The objective of VRP is to minimize the cost of routes of given vehicle fleet (Toth and Vigo, 2014). Since the first introduction by Dantzig and Ramzer in 1959, hundreds of papers have formulated many variants of VRP and have proposed the exact and approximation solution to VRP (Baldacci et al., 2007). In addition, VRP is one of the most studied and challenging problems in the field of combinatorial optimization. There are many of literature surveys on the VRP and its variants, which are conducted by Cordeau et al. (2007); Laporte (2009); Braekers et al. (2015); Sharma et al. (2018); and the books by Golden, Raghavan, and Wasil (2008) and Toth and Vigo (2014).

According to Snyder and Shen (2019), the basic variant development of VRP are time windows (time period which fleet must arrive at each customer); multiple depots (the customer may be served from two or more depots); backhauls (there are some customers require product to be delivered while others require products to be picked up and brought back to the depot; the delivery customers must come before backhaul customers on a given route); pickup and deliveries (customers require their orders to be picked up at one location and delivered to another, both using the same vehicle); and periodic (where given customers must be visited a fixed number of times per period (can be week, month, etc)).

The basic VRP and some of its variants assume that all the fleet vehicle are homogeneous vehicles (all vehicles have the same capacity) while in most practical distribution, customers are delivered using heterogenous vehicles (Koc et al. 2016). There are two major type of HVRP. First, the problem with an unlimited number of hetetogenous fleet (fleet size and mix vehicle routing problem (FSM) which introduced by Golden et al (1984). Second is the problem in which the number of fleets is predetermined (heterogeneous fixed fleet vehicle routing problem (HF) which introduced by Taillard (1999). Based on this two major categories, then they can be distinguish further as five important variants, which are the FSM with fixed and variable vehicle costs (FSM(F,V)), FSM with fixed vehicle cost only (FSM(F)), the HF with fixed and variable vehicle costs (HF(F,V)) and the HF with variable vehicle costs only denoted by HF(V).

Like classcial VRP with homogeneous vehicle, many variants are also developed for HVRP. Accroding to Koc et al. (2016), the variants of HVRP which have been developed are time windows, multiple depots, stochastic demand, pickup and deliveries, multi-trips, the use of external carriers, backhauls, open routes, overloads, site-dependencies, multi-vehicle task assignment, green routing, single and double container loads, two-dimensional loading, time-dependencies, multi-compartments, multiple stacks and collection depot. Over the years, most of research efforts has tendency towards the study of rich extensions of the standard HVRP and there still exist numerous resarch opportunities on these rich extension (Koc et al. 2016).

According to United Nations, in 2018, 55% of the world’s inhabitans lives in urban areas and it is predicted that this figure will increase to 68% by 2050. The city population of the world has increase rapidly from 751 million in 1950 to 4.2 billion in 2018. As the result of ths growth, many business opportunities and potential market are open. This resulted that urban freight transportation has become an essential problem in urban planning. Many classical VRP and HVRP has been developed in the city environment. One of the prominent variants of VRP in city environment are time-dependecies which considers congestion and peak hours in the city (Koc et al. 2016 and Cataruzza et al. 2017). This kind of VRP is called time-dependent vehicle routing problem. In this problem, planners consider the strong relationship between time of the day and travel times in urban areas (Cataruzza et al. 2017). Some authors had included time-dependency in their VRP model (Cataruzza et al. 2017).

There are a set of objectives in routing problems, which are to minimize the total travel time, to minimize the number of vehicle, to minimize a cost function, to minimize total distance traveled, to minimize any penalty for late visit, to maximize profit function and to minimize any risks or harzard associated with shipments (Bektas 2017). The objective of VRP and HVRP in city environment is more appropriate to minimize the total travel time rather than to minimize total distance traveled or cost which based on the distance because of the level of congestion. Many of HVRP studies is to minimize total traveling cost and distance. There are few literatures about the heterogeneous vehicle routing problem to minimize travel time. Boschetti and Maniezzo (2015) studied HVRP for urban logistics problem in mid-sized town which consider multi-trip, time windows and pickup and deliveries. They used matheuristics based on dual ascent procedure applied to an extended set covering model and on a randomized constructive heuristic to solve the problem. In this research, travel time could be indexed over the time of the day to include congestion (time-dependent). For every kind of vehicles, they used the same travel time (travel time is associated with arc i,j). Masmoudi and Cheikhrouhou (2018) studied HVRP in application to homecare to services the patients by considering a lunch break during the working day of caregivers. In this paper travel time is assumed the same for each kinds of vehicles. They assumed that travel speed is constant over a link.

Often, congestion in the city make a short distance is traveled in long time. Moreover, because of the congestion, the difference in type of vehicle can differ the speed that can be achived and the travel time. According to Walton and Buchanan (2012), motorcycle have the average speed 10% faster than other vehicles (including car). Putra (2017), took an example in Jakarta city, Indonesia, he said there was a driver stuck in the city center of jakarta using pick-up car with the average speed only 5 km/hour along with hundreds of other cars crammed. According to Hanifan (2017), if we avaraged out all vehicle’s movement in Jakarta, each route requires an extra 48 minutes per day. He also did an experiment to find out how long it would take to pass a route in Jakarta (Mampang route) and it was found that in the morning by motorcycle it took 32 minutes, while by car it took 1 hour 23 minutes. Moreover, since different vehicle has the different in size, then small vehicle can use different route from large vehicle. Small vehicle may pass the narrow road if there is a traffic jam which can result in different travel time.

Therefore, it is important for HVRP to consider the difference of travel times between the various kind of vehicles in urban context. The travel time of small vehicle is shorter than large vehicle due to congestion. Some previous research using average velocity to differentiate the traveling cost between various kinds of vehicles used and using the same travel time matrix between various kinds of vehicle (Hanum et al. 2017, Setiawan et al. 2019). However, using the average values is not a good choice since plans based on assumptions about average values usually go wrong (Savage, 2002). In this paper, we use the different traveling time between nodes for each kinds of vehicles. To the best of our knowledge, there is no research on HVRP which consider the travel time differentiation between different kind of vehicle. We call this problem Heterogeneous Vehicle Routing Problem with Vehicle Dependent Travel Times (HVRPVDTT). The objective function of this model is to minimize the travel time which is more appropriate to be used in urban/city context where congestion is exist. In addition to that, the model can be useful to distribute a time sensitive product (i.e: perishable product like ready food, fruit, meat, vegetable, etc).

1.1 Objectives

The objectives of this study are: (1) develop the heterogeneous vehicle routing problem with vehicle dependent travel time for urban freight transportation and (2) to examine the influence of having different travel time for different vehicle on the decision because of the congestion in city

2. Methods

In this paper, we examine the influence of travel time differentiation between different kind of vehicles in urban freight transportation/urban logistics context. We call this as Heterogeneous Vehicle Routing Problem with Vehicle Dependent Travel Times (HVRPVDTT). This problem is appropriate to be used in urban freight transportation context which travel times between nodes is different for small vehicles and large vehicle because of congestion. The formulation of HVRPVDTT is developed based on the formulation of HVRP from Suthikarnnarunai (2008). The formulation is based on three index formulation of HVRP which travel cost is altered to travel time so that travel time between nodes can be different for each of vehicle.

We compare the result of HVRP without considering the time differentiation between different kind of vehicles (we will call this HVRP) to HVRP considering the time differentiation between different kind of vehicles (we will call this HVRPVDTT). In this research, we will use two type of vehicle (motorcycle and car). Motorcycle is used to represent small vehicle in urban environment while car is used to represent the large vehicle in urban environment. We use the real travel time data between nodes in Jakarta (Indonesia's capital) using Google Maps. We collect travel time between using motorcycle and car in Jakarta using Google Maps. Then, this different travel time is used in HVRPVDTT. In HVRP we use the same travel time between motorcycle and car (using either motorcyle travel time or car travel time time). For HVRP we use the formulation from Suthikarnnarunai (2008) while for HVRPVDTT we use the formulation in the next session. We use A Mathematical Programming Language (AMPL) to solve the HVRP dan HVRPVDTT. The research methodology of this research can be seen in Figure 1.

The problem studied in this research is distribution problem in congested urban environment using heterogeneous vehicles which different in types and capacities. Each vehicle has its own limited capacity. The vehicles, if assigned, must visit all the customer assigned to it once. All customer demand is delivered in full supply and no time windows on each customer. Because of the congestion, the travel time between nodes are different depending on the vehicle used. The objective is to minimize total travel time since it is more appropriate than to minimize the total distance in congested urban environment. In congested urban environment, close distance can be achieved in a long time.

In graph, HVRPVDTT is represented with arc and nodes. Let G = (N,A), where N = {0, 1, …, n} is the node set, where node 0 correspond to depot, while V\{0} are customers. $A = \{(i,j): i,j \in N$ and $i \neq j$ is the set of arcs. Every customer has a demand d_i unit. Tijk represented travel time between node i and node j using vehicle k. There is K vehicles which can be different in types and capacity. Uk is a capacity of vehicle k. Variable xijk will be 1 if vehicle k is used to move from i to j, 0 otherwise. Variable Yik will be 1 if vehicle k serves node i, 0 otherwise. The formulation of HVRPVDTT is as follow:

Objective Function:
Minimize:

$$\min \sum_{(i,j)\in A} \sum_{k=1}^{K} T_{ijk} x_{ijk}$$

Subject to:

$$\sum_{k=1}^{K} y_{ik} = 1 \qquad \forall i \in V\backslash\{0\}$$

$$\sum_{k=1}^{K} y_{0k} \leq K$$

$$\sum_{j\in V\backslash\{i\}} x_{ijk} = y_{ik} \qquad \forall i \in V, k = 1, \ldots, K$$

$$\sum_{j\in V\backslash\{i\}} x_{jik} = y_{ik} \qquad \forall i \in V, k = 1, \ldots, K$$

$$\sum_{i\in V\backslash\{0\}} d_i y_{ik} \leq U_k \qquad \forall k = 1, \ldots, K$$

$$u_{0k} = 1 \qquad \forall k = 1, \ldots, K$$

$$u_{ik} \leq n \qquad \forall i \in \{1, 2, \ldots, n\}, k = 1, \ldots, K$$

$$u_{ik} \leq 2 \qquad \forall i \in \{1, 2, \ldots, n\}, k = 1, \ldots, K$$

$$u_{ik} - u_{jk} + 1 \leq (n-1)(1 - x_{ijk}) \qquad \forall i, j \in \{1, 2, \ldots, n\}, k = 1, \ldots, K$$

$$y_{ik} \in \{0,1\} \qquad \forall i \in V, k = 1, \ldots, K$$

$$x_{ijk} \in \{0,1\} \qquad \forall (i,j) \in A, k = 1, \ldots, K$$

Objective function (1) is to minimize total travel time. Constraints (2) ensure every customer will be visited once and only one vehicle. Constraints (3) ensure that only K vehicles leave the depot. Constraints (4) and (5) ensure that the same vehicle enters and leaves a given customer node respectively. Constraints (6) ensure that capacity of every vehicle is not violated. Constraint (7) – (10) are sub-tour elimination constraints. Constraints (11) and (12) ensure the value of decision variable is binary (1 or 0).

3. Data Collection

We use hypothetical data for the number of nodes. In this numeerical experiment we use 4 various numbers of customers (6, 10, 12 and 15). There are 2 kinds of vehicle, motorcycle and car for distribution. There are 5 motorcycles and 5 cars available. For maximum capacity of motorcyle and car, we use maximum load that can be carried by the motorcycle which is 120 kg according to Iman (2017) while the maximum load that can be carried by car which is 600 kg according to Teknisimobil (2020). For the demand data, we generate three various demand (small, normal and large) for each of customers as follows which can be seen in Table 1.

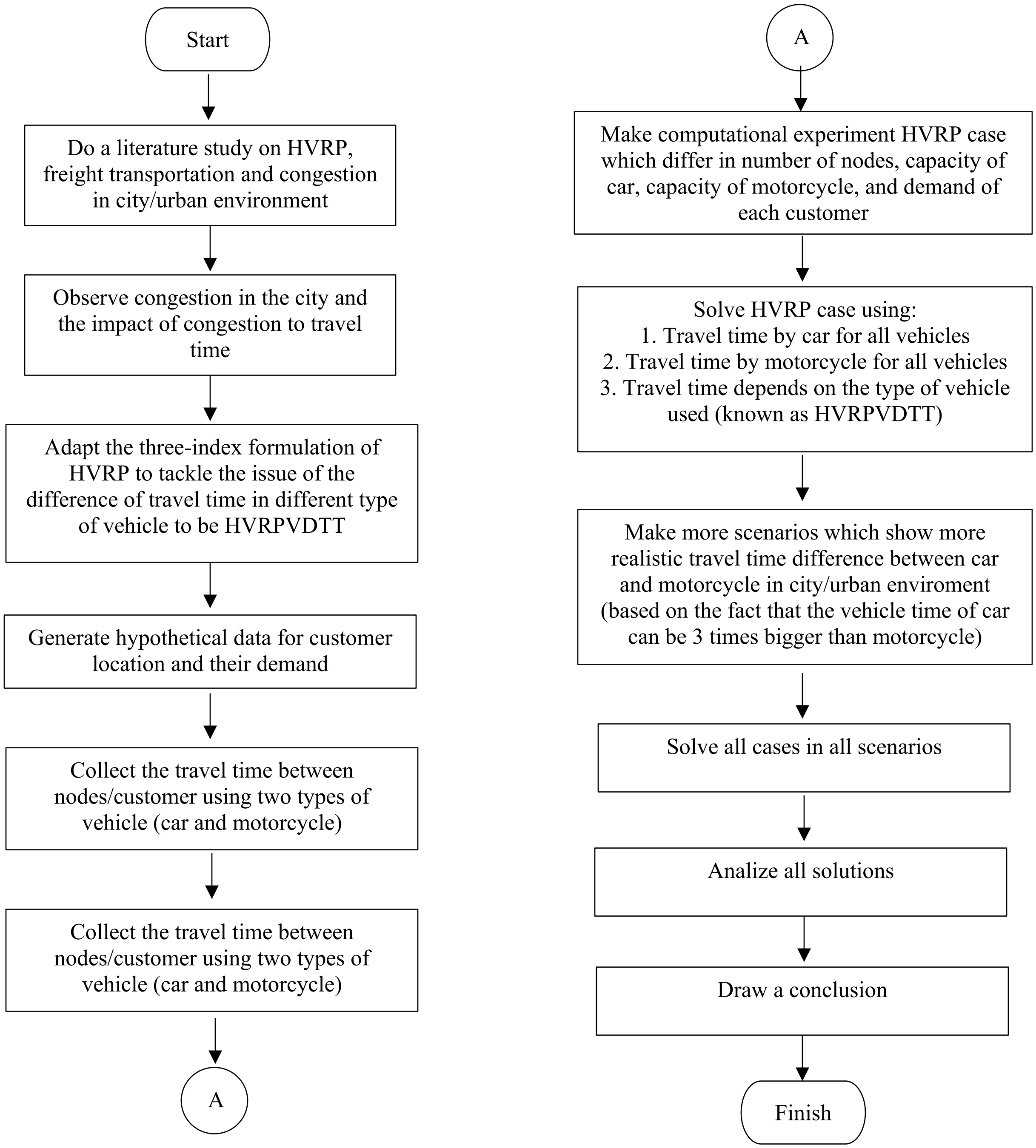

Figure 1. Research Methodology

Table 2. Hypothetical demand data of customers

Customers	Demand (Normal)	Demand (Small)	Demand (Large)
1	23	53	17
2	28	33	19
3	32	40	25
4	37	62	28
5	31	37	18
6	57	23	27
7	46	53	24
8	41	31	14
9	26	24	15
10	45	40	24
11	29	38	23
12	28	50	21
13	43	-	-
14	30	-	-
15	47	-	-

For location of each customers (node 1-15) and depot (node 1), we choose any location in Jakarta arbitrarily. After we choose the location of depot and customers than we spot that nodes in Google Maps. The location of all nodes is given in Table 2 below.

Table 2. Location of each nodes

Nodes	Area in Jakarta	Points in Google Maps
0	Glodok	Glodok Plaza
1	Jelambar Baru	Komplek Duta Mas
2	Kelapa Gading	Perumahan Kelapa Gading Pratama
3	Pluit	Pantai Mutiara
4	Kebayoran Lama	Permata Hijau Residences
5	Pancoran	Kalibata City Tower Apartment Kemuning
6	Matraman	Jl. Pisangan Baru I
7	Karet Tengsin	Sahid Sudirman Residence
8	Pantai Indah Kapuk	Pantai Indah Kapuk Hospital
9	Kemang	Kemang Village
10	Menteng	Apartemen Taman Rasuna Tower 12
11	Pondok Indah	Pondok Indah Hospital
12	Ancol	Ancol Mansion
13	Puri Indah	Puri Mansion Apartment
14	Kosambi	Kosambi Baru
15	Senopati	Senopati Suites

After location of nodes is determined, then the travel time between nodes is obtained using Google Maps. In Google Maps, we can choose either motorcycle or car to travel between nodes. If there are some alternative routes, we choose the route which is recommended by Google Maps. We collect the travel time between nodes for motorcycle and car. Table 3 and 4 shows the travel time of using car and motorcycle respectively.

Table 3. Travel time using car (in minutes)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	-	17	35	22	34	38	31	22	28	33	27	41	18	38	44	23
1	23	-	53	24	33	55	47	33	20	50	43	47	31	24	29	40
2	41	54	-	58	58	50	29	42	67	30	65	62	30	65	69	43
3	23	22	50	-	55	58	50	40	15	54	45	70	22	45	48	42
4	39	44	51	48	-	30	32	17	57	16	29	15	54	35	44	12
5	47	58	44	65	35	-	25	25	62	24	26	39	56	62	68	25
6	39	49	30	58	42	31	-	33	66	42	32	56	31	63	71	35
7	27	38	37	41	24	25	17	-	43	20	12	31	31	39	48	10
8	31	24	60	12	54	70	60	45	-	65	56	64	31	31	31	53
9	48	55	35	60	26	23	35	25	56	-	28	16	56	56	63	14
10	36	55	64	50	29	22	17	14	51	21	-	32	36	48	58	18
11	52	58	65	63	22	40	47	32	61	19	42	-	56	48	57	25
12	18	31	36	32	57	54	42	42	38	53	43	62	-	57	62	44
13	52	33	64	35	37	61	59	47	31	49	54	53	57	-	11	46
14	60	41	72	44	45	68	66	51	34	65	63	56	66	19	-	55
15	36	40	45	45	16	20	26	10	45	13	20	23	44	42	50	-

Table 4. Travel time using motorcycle (in minutes)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	-	14	32	19	30	31	26	19	24	28	22	35	15	33	37	20
1	18	-	44	17	25	43	39	26	18	38	34	37	26	21	24	33
2	31	42	-	54	47	38	25	37	51	32	54	56	32	54	58	38
3	20	15	42	-	39	46	41	29	13	45	39	48	19	35	38	37
4	30	32	41	38	-	25	28	14	43	14	24	14	42	29	36	10
5	38	40	37	49	31	-	21	25	55	17	25	30	44	49	57	21
6	28	37	21	43	36	22	-	25	50	35	24	45	35	53	55	27
7	22	29	31	33	19	21	17	-	37	19	12	26	30	38	41	10
8	28	20	51	11	37	58	49	38	-	48	44	49	28	26	27	46
9	38	39	30	45	21	20	31	21	49	-	26	14	46	42	47	12
10	29	38	54	45	27	18	15	16	50	18	-	28	35	47	55	17
11	39	39	51	46	18	30	38	25	51	18	36	-	50	37	44	19
12	16	25	30	25	45	43	35	34	32	47	36	51	-	45	48	35
13	37	25	53	32	26	49	50	36	26	39	43	39	45	-	7	36
14	42	30	60	37	32	52	57	41	26	46	51	46	51	8	-	43
15	31	30	39	37	13	17	24	12	42	10	18	19	38	35	42	-

As we can see in Table 3 and 4, in the city the distance is asymmetric and the choice of car or motorcycle give the difference travel time between nodes. The travel time data between motorcycle and car is not much different, since it is obtained in February 2021 which global pandemic is ongoing. Because of pandemic situation, society is encouraged to work and study at home and to minimize trip out of the house. This situation made a road condition in Jakarta is not congested as usual. In normal condition, the difference of travel time between motorcycle and car is much more different. According to experiment which was conducted by Hanifan (2017), it was found that in the morning by motorcycle it took 32 minutes, while by car it took 1 hour 23 minutes to pass a route in Jakarta (Mampang route). From this experiment, we can see that the difference between travel time using motorcycle compare to car is approximately three times. Based on our experience, frequently in Jakarta, it only took 15 minutes if we use motorcycle, but if we use a car, it can took 1 hour with the same route. Based on this situation, we also make scenarios which the travel time using car is 50% higher than motorcycle, 100% higher than motorcycle and 150% higher than motorcycle. All of scenarios used can be seen in Table 5 below.

Table 5. All scenarios use in computational experiment

Scenarios	Number of nodes	Car capacity	Motorcycle capacity	Travel time using car	Travel time using motorcycle	Demand data
1	6	600	120	Table 3	Table 4	Normal
2	10	600	120	Table 3	Table 4	Normal
3	12	600	120	Table 3	Table 4	Normal
4	15	600	120	Table 3	Table 4	Normal
5	12	480	120	Table 3	Table 4	Normal
6	12	720	120	Table 3	Table 4	Normal
7	12	600	240	Table 3	Table 4	Normal
8	12	600	60	Table 3	Table 4	Normal
9	12	300	60	Table 3	Table 4	Normal
10	12	120	60	Table 3	Table 4	Normal
11	6	600	120	(Table 4) * (1,5)	Table 4	Normal
12	10	600	120	(Table 4) * (1,5)	Table 4	Normal
13	12	600	120	(Table 4) * (1,5)	Table 4	Normal
14	15	600	120	(Table 4) * (1,5)	Table 4	Normal
15	12	480	120	(Table 4) * (1,5)	Table 4	Normal
16	12	720	120	(Table 4) * (1,5)	Table 4	Normal
17	12	600	240	(Table 4) * (1,5)	Table 4	Normal
18	12	600	60	(Table 4) * (1,5)	Table 4	Normal
19	12	300	60	(Table 4) * (1,5)	Table 4	Normal
20	12	120	60	(Table 4) * (1,5)	Table 4	Normal
21	6	600	120	(Table 4) * (2)	Table 4	Normal
22	10	600	120	(Table 4) * (2)	Table 4	Normal
23	12	600	120	(Table 4) * (2)	Table 4	Normal
24	15	600	120	(Table 4) * (2)	Table 4	Normal
25	12	480	120	(Table 4) * (2)	Table 4	Normal
26	12	720	120	(Table 4) * (2)	Table 4	Normal
27	12	600	240	(Table 4) * (2)	Table 4	Normal
28	12	600	60	(Table 4) * (2)	Table 4	Normal
29	12	300	60	(Table 4) * (2)	Table 4	Normal
30	12	120	60	(Table 4) * (2)	Table 4	Normal
31	6	600	120	(Table 4) * (2,5)	Table 4	Normal
32	10	600	120	(Table 4) * (2,5)	Table 4	Normal
33	12	600	120	(Table 4) * (2,5)	Table 4	Normal
34	15	600	120	(Table 4) * (2,5)	Table 4	Normal
35	12	480	120	(Table 4) * (2,5)	Table 4	Normal
36	12	720	120	(Table 4) * (2,5)	Table 4	Normal
37	12	600	240	(Table 4) * (2,5)	Table 4	Normal
38	12	600	60	(Table 4) * (2,5)	Table 4	Normal
39	12	300	60	(Table 4) * (2,5)	Table 4	Normal
40	12	120	60	(Table 4) * (2,5)	Table 4	Normal
41	12	600	120	Table 3	Table 4	Large
42	12	120	60	Table 3	Table 4	Large
43	12	600	120	Table 3	Table 4	Small
44	12	120	60	Table 3	Table 4	Small
45	12	600	120	(Table 4) * (1,5)	Table 4	Large
46	12	120	60	(Table 4) * (1,5)	Table 4	Large
47	12	600	120	(Table 4) * (1,5)	Table 4	Small
48	12	120	60	(Table 4) * (1,5)	Table 4	Small
49	12	600	120	(Table 4) * (2)	Table 4	Large
50	12	120	60	(Table 4) * (2)	Table 4	Large

Scenarios	Number of nodes	Car capacity	Motorcycle capacity	Travel time using car	Travel time using motorcycle	Demand data
51	12	600	120	(Table 4) * (2)	Table 4	Small
52	12	120	60	(Table 4) * (2)	Table 4	Small
53	12	600	120	(Table 4) * (2,5)	Table 4	Large
54	12	120	60	(Table 4) * (2,5)	Table 4	Large
55	12	600	120	(Table 4) * (2,5)	Table 4	Small
56	12	120	60	(Table 4) * (2,5)	Table 4	Small

In every scenario of Table 5, we make 3 compare of problem. First, travel time data uses travel time data from car for all kind of vehicles (we called this HVRP car. Second, travel time data uses travel time data from motorcycle for all kind of vehicles (we called this HVRP motorcycle). Third, travel time data uses travel time data from car or motorcycle depend on which vehicle is used.

4. Results and Discussion

4.1 Computational Results

After all scenarios are generated, then they are solved using A Mathematical Programming Language (AMPL). If the variable is big enough then we use NEOS Server Optimization (https://neos-server.org/neos/) to help in solving the problem. For simplicity. we only show the result of scenario 1- 10 out of 56 scenarios which can be seen in Table 6.

Table 6. Computational result

Scenarios	Problems	Travel time	The number of Cars used	The number of motorcycles used	Total number of vehicles used
1	HVRP Car	221	2	0	2
	HVRP Motorcycle	176	1	1	2
	HVRPVDTT	193	0	2	2
2	HVRP Car	270	1	1	2
	HVRP Motorcycle	224	1	1	2
	HVRPVDTT	261	1	1	2
3	HVRP Car	295	2	0	2
	HVRP Motorcycle	250	2	0	2
	HVRPVDTT	286	1	1	2
4	HVRP Car	347	2	0	2
	HVRP Motorcycle	293	2	0	2
	HVRPVDTT	347	2	0	2
5	HVRP Car	295	2	0	2
	HVRP Motorcycle	250	2	0	2
	HVRPVDTT	286	1	1	2
6	HVRP Car	295	2	0	2
	HVRP Motorcycle	250	2	0	2
	HVRPVDTT	286	1	1	2
7	HVRP Car	295	2	0	2
	HVRP Motorcycle	250	1	1	2
	HVRPVDTT	270	0	2	2
8	HVRP Car	295	2	0	2
	HVRP Motorcycle	250	2	0	2
	HVRPVDTT	295	2	0	2
9	HVRP Car	305	2	0	2
	HVRP Motorcycle	250	2	0	2
	HVRPVDTT	305	2	0	2
10	HVRP Car	394	4	0	4
	HVRP Motorcycle	339	4	0	4

	HVRPVDTT	394	4	0	4

4.2 Analysis and Discussion

For analysis, we compare the result between HVRP Car, HVRP Motorcycle and HVRPVDTT in terms of total travel time, the number and types of vehicles used, and the routing.

In terms of total travel time, total travel time of HVRPVDTT is always between total travel time HVRP car and total travel time HVRP motorcycle, because if mix type of vehicle is used, then HVRPVDTT will use the appropriate travel time according to the type of vehicle used. It can be seen that if we are not differentiating the travel time based on the vehicle type, then the total travel time we proposed as the solution is not right. For HVRP car, from 56 scenarios, it is obtained that the right total travel time is 47 scenarios out of 56 (89%) when the routing decision on HVRP car is only using car. While in HVRP motorcycle, there is right travel time of all 56 scenarios because in every scenario, car is used in the routing decision.

In terms of the number and type of vehicles used; HVRP car, HVRP motorcycle and HVRPVDTT gives the different number and type of vehicles used. In terms of routing decision, the routing decision is the same if the vehicle used and the route is the same. For example, in scenario 2 gives in Table 7 below

Table 7. Computational result of scenario 2

Problem	Route	Types of vehicle used	Total traveltime
HVRP car	0-7-10-4-9-5-6-2-0	Car	270
	0-1-8-3-0	Motorcycle	
HVRP Motorcyclecycle	0-10-5-9-4-7-6-2-0	Car	224
	0-1-8-3-0	Motorcycle	
HVRPVDTT	0-7-10-4-9-5-6-2-0	Car	261
	0-1-8-3-0	Motorcycle	

As we can see from Table 6, HVRP car has the same decision for both types of vehicle used and the route while HVRP motorcycle has different route. Although HVRP car and HVRPVDTT has the same decision, the total travel time is different because in HVRP car, time travel between nodes is using the travel time of using car, so it is obvious that the total travel time is different. HVRP car has 44 out of 56 scenarios (83%) which are different from HVRPVDTT in terms of routing decision, while HVRP motorcycle has only 1 out of 56 scenarios (98%) which are different from HVRPVDTT in terms of routing decision.

Therefore, based on this computational result, it is important to differ travel times based on the type of vehicle in the congested city environment since it can give the different result (travel time, number and types of vehicle used and the routing decision).

5. Conclusion

In this paper, we examine the heterogenous vehicle routing problem (HVRP) in urban environment. Because of congestion, the different type of vehicles gives the different travel time between nodes. It can lead to different routing and vehicle assignment decision. So, it is important for HVRP model to differentiate travel time between types of vehicle in urban logistics context. We call this problem as Heterogeneous Vehicle Routing Problem with Vehicle Dependent Travel Time (HVRPVDTT). Although this problem can be seen as HVRP formulation with three index formulation, but there is no previous research about the HVRP which concern with the issue of the different of travel time between types of vehicle in urban environment. This problem can enrich the routing problem literature in urban logistics context. For further research, the HVRP with time dependent and vehicle dependent travel time or HVRP with dynamic vehicle dependent travel time can be developed. It also interested to develop the heuristics/metaheuristics solution for more complex HVRPVDTT problem.

References

Baldacci, R., Battara, M., and Vigo, D., Routing a heterogeneous fleet of vehicles, in *The Vehicle Routing Problem: Latest Advances and New Challenges*, pp. 1-25, 2008.

Bektas, T., *Freight Transport and Distribution: Concepts and Optimisation Models*, 1st Edition, CRC Press, Florida, 2017.

Boschetti, M., and Maniezzo, V., A set covering based metaheuristic for a real-world logistics problem, *International Transactions in Operational Research*, vol. 22, no.1, pp. 169-195, 2015.

Braekers, K., Ramaekers, K., and Nieuwenhuyse, I., The vehicle routing problem: state of the art classification and review, *Computers & Industrial Engineering*, vol. 99, pp. 300-313, 2016.

Cataruzza, D., Absi, N., Feillet, D., and Gonzalez-Feliu, J., Vehicle routing problems for city logistics, *EURO Journal on Transportation and Logistics*, vol. 6, no. 1, pp. 51-79, 2017.

Cordeau, J.-F., Laporte, G., Savelsbergh, M.W.P., Vigo, D., Barnhart, C., and Laporte, G., Vehicle Routing, *Handbook in Operational Research and Management Science*, 14, pp. 367-428, 2007.

Dantzig, G.B., and Ramser, J.H., The truck dispatching problem, *Management Science*, vol. 6, pp. 80-91, 1959.

Golden, B., Assad, A., Levy, L., and Gheysens, F., The Fleet Size and Mix Vehicle Routing*, Computers & Operations Research*, vol. 11, no. 1, pp. 49-66, 1984.

Golden, B.L., Raghavan, S., and Wasil, E.A., *The Vehicle Routing Problem: Latest Advances and New Challenges,* Springer, 2008.

Hanifan, A.F., *Di Jakarta, Orang Buang Umur Seminggu di Jalanan Tiap Tahun*, Available: https://tirto.id/di-jakarta-orang-buang-umur-seminggu-di-jalanan-tiap-tahun-cw3D, February 17, 2021.

Hanum, F., Hartono, A.P., and Bahktiar, T., On the multiple depots vehicle routing problem with heterogeneous fleet capacity and velocity, IOP Conference Series: Materials Science and Engineering, 332, doi 10.1088/1757-899X/332/1/012052.

Iman, M., *Batas Angkut Barang Untuk Motor*, Available: https://beritagar.id/artikel/otogen/batas-angkut-barang-untuk-motor, February 9, 2021.

Koc, C., Bektas, T., Jabali, O., and Laporte, G., Thirty years of heterogeneous vehicle routing, *European Journal of Operational Research*, vol. 249, pp. 1-21, 2016.

Laporte, G., Fifty years of vehicle routing, *Transportation Science*, vol 43, no. 4, 2009.

Masmoudi, M.A., and Cheikhrouhou, N., Heterogeneous vehicle routing problems with synchronization: application to homecare scheduling routing problem, *9th Conference on Engineering and Management of Healthcare Systems GISEH 2018*, 2018.

Putra, Y.D., *Kerugian Akibat Macet Jakarta pada 2020 diprediksi Mencapai Rp 87.7 Triliun*, Available: https://megapolitan.okezone.com/read/2017/11/22/338/1818879/kerugian-akibat-macet-jakarta-pada-2020-diprediksi-mencapai-rp-87-7-triliun#:~:text=Intelligent%20Transport%20System%20(ITS)%20Indonesia,5%20triliun%20pada%20tahun%202010., February 17, 2021.

Setiawan, F., Masruroh, N.A., and Pramuditha, Z.I., On modelling and solving heterogeneous vehicle routing problem with multi-trips and multi-products*, Jurnal Teknik Industri*, vol. 21, no.2, pp. 91-104., 2019.

Sharma, S.K., Routroy, S., and Yadav, U., Vehicle routing problem: recent literature review of its variants, *International Journal of Operational Research*, vol. 33, no. 1, pp. 1-31., 2018.

Snyder, L.V., and Shen, Z-J.M., *Fundamentals of Supply Chain Theory*, John Wiley&Sons, Hoboken, 2019.

Suthikarnnarunai, N., A sweep algorithm for the mix fleet vehicle routing problem, *Proceedings of the International Multiconference of Engineers and Computer Scientist*, Vol.2., 2008.

Taillard, E.D., A heuristics column generation method for the heterogeneous fleet vehicle routing problem, *RAIRO (Recherche Operationalle)*, vol. 33, pp. 1-14., 1999.

Teknisimobil., 20+ Daftar Kapasitas Muatan Maksimal Mobil, Available: https://teknisimobil.com/berita/20-daftar-kapasitas-muatan-maksimal-mobil-15737/, February 9, 2021.

Toth, D., and Vigo, D., *Vehicle Routing: Problems, Methods, and Applications*, Mathematical Optimization Society and Society for Industrial and Applied Mathematics (MOS-SIAM) series in optimization, Philadelphia, 2014.

Tseng, Y.-y., Yue, W.L., and Taylor, M.A., The role of transportation in logistics chain, *Eastern Asia Society for Transportation Studied*, vol. 5, pp. 1657-1028, 2005.

Walton, D., and Buchanan, J., Motorcycle and scooter speeds approaching urban intersections, *Accident Analysis & Prevention*, vol. 48, pp. 335-340, 2012.

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