Combination of VRP and Traffic Assignment to determine the location of Logistics Distribution Centers

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Abstract. The choice of location for a distribution center is one of the most critical management decisions in a supply chain system. Both the cost of a distribution system and the level of customer service provided by the system are significantly affected by the number, size, and location of distribution centers. In this paper, taking into account the benefits of the customer and the logistics planning department, a two-level programming model is presented for finding the optimal location for the logistics distribution center. The upper-level model is to determine the optimal location by minimizing planner costs, and the lower one which is a combination of VRP and traffic assignment providing an equilibrium demand distribution with minimized courier costs. with certain limitations, a simple algorithm is proposed.

1) Background

More than 25 years ago, Ogden (1992) already needed a policy of sustainable goods transportation (urban logistics) to minimize the negative impacts of urbanization. Currently, logistics is very important as a driver of the economy and development in urban areas. Therefore, a sustainable solution is needed to reduce traffic congestion in the city center and reduce the environmental impact of the transportation of goods (Thompson, 2001).

According to Dablanc (2011), the definition of urban goods transportation is "all the movement of goods in urban areas generated by economic activity and the fulfillment of needs which includes all deliveries of materials, spare parts, consumables, letters and others so that economic activity continues". This definition also includes home delivery through commercial transactions. This includes personal transportation taken by individuals to obtain goods for themselves (i.e. shopping trips), or continuous traffic (i.e. trucks passing through a city on their way to other destinations without serving businesses or households in that city) or service trips (i.e. travel where the primary purpose is to perform on-site service activities, not merely delivering or picking up goods) (Allen et al., 2000).

According to some researchers, the characteristics of the transportation of goods in urban areas are: (1) most of them consist of frequent shipments and in smaller quantities which is a direct result of the high fragmentation of recipients, with many small entities that are geographically dispersed

(Taniguchi et al. ., 2004; Danielis et al., 2010); (2) urban freight transport is characterized by a lower utilization of vehicle capacity than intercity transport (Taniguchi et al., 2004). Allen and Browne (2010) have collected data for 16 UK cities and found that the load factor is 58.4% for travel to and from urban areas and 39.3% for travel within urban areas; (3) Delivery operations usually occur on roads with most of the transport vehicles parked illegally causing congestion (Aiura and Taniguchi, 2006).

Vehicle Routing Problem (VRP) is an optimization problem for determining routes with limited vehicle capacity. In this case, there is an initial depot and a number of n places to visit with varying demand. A vehicle is expected to meet the demands of each of these places from the depot.

The rest of the paper is organized as follows. In Section 2, we perform a literature review to summarize the existing researches, in particular to discover their shortcomings. In Section 3, we state our contributions. In Section 4, we present the structure of model. In Section 5, we explain the Structure Model and Calculation Procedure. In Section 6, we summarize the study.

2) Literature Review

2.1 Logistics Center Location Selection Method

In the literature there is no general name or definition for the term "logistics center". Various terms have been used, such as: distribution center, urban consolidation center (UCC), freight village, dry port, inland port, load center, logistics node, gateway, central warehouse, freight/transport terminal, transport node, logistics platform, logistics UCC , distripark (Higgins and Ferguson, 2011; Rimiené and Grundey, 2007).

Many classical and heuristic methods have been proposed to solve logistic center location problems, including linear, non-linear programming, simple algorithm, Lagrangian relaxation, branch & cut methods, branch and bound (Mayer and Wagner, 2002), local beam search, tabu search. (Glover, 1993), artificial neural network, fuzzy control, AHP (Janic and Reggiani, 2001), generic algorithms, expert systems, multi-agent systems and so on. But conventional site selection methods have limitations related to their inability to add all indicators to the site selection model. These models usually consist of several basic elements, such as; objective functions, potential locations, requirements, distances or timescales, and some rules for allocation (Chi and Kuo, 2001).

In addition, there are various studies related to location selection decisions that have been commonly carried out using multi-criteria decision-making (MCDM) techniques, such as the selection of distribution centers with a weighted fuzzy factor rating system (Ou and Chou, 2009), selection of distribution centers with three-stage hierarchy of selection (Vinh Van and Devinder, 2005), distribution location problems with QFD (Chuang, 2002), location problems with fuzzy-AHP (Kaboli, et al., 2007), logistics center selection with dynamic dual- diamond model (Wang et al., 2005), location of logistics distribution based on genetic algorithms and fuzzy comprehensive evolution (Ren and Wang, 2006), decision on the location of intermodal freight transport with multi-objective evaluation model (Sirikijpanichkul and Ferreira, 2006), the selection of the location of the logistics center based on the fuzzy-analytical hierarchy process (Fuzzy-AHP) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) (Wang and Liu, 2007),

The selection of the location of the logistics center using fuzzy MCDM based on entropy weight (Chen and Lili, 2006), the selection of the location of the facility or factory with multiple objective decision making (Farahani and Asgari, 2007), the selection of the location of the facility using AHP (Yang and Lee, 1997), store location with fuzzy-AHP (Kuo et al., 2001), port selection with AHP

(Ugboma et al., 2006), reverse logistics location selection (Kannan et al., 2008), selecting a location for the logistics center on factors and methods (Chen and Liu, 2006), selection of logistics centers with fuzzy-AHP and Electre (Elimination et Choice Translating Reality) Method (Ghoseiri and Lessan, 2008) and multi-modal hub location (Ashayeri and Kampstra, 2002).

2.2 Publications on Vehicle Routing Problem (VRP)

Based on searches in several journals, it was found that various forms of VRP have been studied by several researchers (R. Lahyani et al, 2015). These publications add to the treasury of knowledge about VRP and its use in transportation science, especially the supply chain of goods distribution.

In his research, Montoya - Torres (2015) and M. Figliozzi (2010) describes the various variants that exist in VRP, including: the VRP considering maximum route length, (DVRP); the VRP with time windows constrains (VRPTW); the VRP considering backhauls (VRPB); periodic VRP (PVRP); VRP with multiple trips (VPRMT); split delivery vehicle routing problem (SDVRP) and others.

At present, solution of VRP is not only vital in the design of distribution systems in supply chain management, but also important in urban solid waste collection, street cleaning, school bus routing, routing of salespeople, and courier services. Researches can be roughly divided into theoretical papers providing mathematical formulations and exact or approximate solution methods for academic problems and case-oriented papers. More recently, attention has been devoted to more complex variants of the VRP (usually called “rich” VRPs) that are closer to the practical distribution problems than classic VRP models.

Taniguchi and Yamada (2003) studied the vehicle routing and scheduling procedures using advanced information systems and freight transport systems in urban areas. (Ando and Taniguchi, 2006) studied travel time reliability in vehicle routing based on the data obtained by probe vehicles. Conrad and Figliozzi (2010) proposed Traffic Queuing Algorithm and Arrival and Departure Time Algorithms to quantify the impacts of congestion on time-dependent real-world urban freight distribution networks; Deflorio et al. (2012) applied the performance indicators to compare different service settings and introduced a simulation approach to build the demand; Mu˜nuzuri et al. (2012) believed that modelling urban freight transport is difficult and highly data-demanding and proposed a trip generation model to achieve the estimation of an origin-destination matrix for freight transport in a city.

In real-world applications, static design is more important when VRP is between the layers of depots and facilities. In a small period of time (e.g., a quarter or a month), spatial distribution of depots/facilities, demand flows between depots and facilities of the urban solid waste collection, street cleaning, school bus routing, routing of salespeople, and courier services may hardly change. Thus one delivery scheme may be used for the whole quarter or month. This is similar to bus transit service, where daily personal travel demand is relatively stable and the redesign of bus routes day by day and the dynamic scheduling of buses hour by hour are not necessary.

2.3 Research on Interactions Between Delivery Vehicles and Other Vehicles

In several studies that have been carried out, in general, the value of traffic only looks at distribution vehicles, when in fact there are many other vehicles on the highway. The interaction between distribution vehicles and other vehicles will certainly affect the performance of distribution vehicles, especially in choosing the route to be taken from one point to another.

However several studies have also looked at the relationship and interaction between distribution vehicles and other vehicles in the same traffic, for example Taniguchi et al. (1999) considered the interactions between the background traffic and the service trucks of the logistics terminals when locating the terminals. They used a bilevel programming model, and the upper-level problem describes the behavior of the planner for minimizing the total cost. The lower level problem describes the behavior of each company and each truck in choosing optimal logistics terminals and transportation routes. The model explicitly takes into account traffic conditions in the network and was successfully applied to an actual road network in the Kyoto-Osaka area in Japan. They only dealt with the location problem not VRP problem because each service truck runs between a terminal and only one depot.

3) Contribution of This Research

In previous studies, when the location of the depot is on a network with stable traffic flow (not changing), then the influence of traffic flow can be carried out statically, not influenced by other traffic. However, in reality the performance of traffic flow (especially distribution vehicles) is strongly influenced by the interaction between distribution vehicles and other vehicles, so the influence of other vehicles on this network must be considered.

When the number of delivery vehicles is large in the road network, this will affect the performance of other vehicles in the network and will affect the movement of the origin-destination matrix. so it is necessary to combine and interact between delivery vehicles and other vehicles on the road network.

Under the total traffic equilibrium, transforming the multidepot VRP to GEA (the problem of Grouping Customers + Estimating OD Traffic + Assigning traffic) to take the interactions between delivery trucks and other vehicles into account to obtain delivery schemes under "the total traffic equilibrium." Solving GEA with bilevel model. Based on the feedback loop of "the problem of Grouping Customers determining the delivery routes - updating OD traffic assigning OD traffic – re-grouping...," firstly the customers are divided into several groups and secondly the delivery loops/paths for the groups are obtained and the initial OD matrix is updated, and thirdly links' traffic flows are calculated by user equilibrium traffic assignment model.

4) The Structure of Model

4.1 Model Assumptions

The model described here aims to obtain the most optimum depot location based on the shortest route length traversed by distribution vehicles and other vehicles as a result of the interaction between the two types of vehicles. The assumptions in this model include: (1) Study area consists of continuous but nonover-lapping traffic zones, the OD trips of vehicles other than delivery trucks do not change, but the paths between origins and destinations are not fixed, which will be determined based on UE Theory; (2) Demand of each costumer is given; (3) Depots' supply amounts are big enough; (4) Length of delivery loop is shorter than the truck's maximum range (5) All delivery trucks are the same type, with the loading capacity given (6) Loading and discharging times during the delivery are ignored (7) One truck is equivalent to 3 per car units; (8) Drivers know the travel times of all roadways and try to choose the shortest path

4.2 Upper Level Model

Z^n_i = the total delivery time of all delivery trucks in nth round of grouping, which is the objective value of theupper model

X_{ijk}^{n} = Variable 0 – 1, X_{ijk}^{n} = means vehicle k via path i-j in nth round of grouping; it is the decision variable to determine the route of a delivery truck, and further the entire delivery network; X_{ijk}^{n} is decision variable, which determines the OD trips of delivery trucks, the path between two customers will be determined R: the set of origins of other vehicles; through UE in the lower model

$\bar{R}$ = the set of origins of other vehicles
$\hat{R}$ = the set of origins of delivery trucks (depots or customers)
R = the set of origins of all vehicles, $R = \bar{R} + \hat{R}$
K = the set of delivery trucks;
T_{ijk}^{n} = the travel time of truck k from i to j in nth round of grouping;
q_j = the demand of costumer j;
Q = loadcapacityoftruck$k$;
d_{ij} = length of delivery path from site i to site j;
D = maximum travel range of a truck;
M_r = the number of delivery trucks in depot r;
K_{aij}^{n} = (0 – 1) variable, where K_{aij}^{n} = 1 means path i – j via link a in nth round of grouping

The mathematical equations used in the Upper model are as follows:

$$Min\, Z_1^n = \sum_{i\in\bar{R}}\sum_{k\in K}\sum_{j\in\bar{S}}\left(X_{ijk}^n T_{ijk}^n + X_{jik}^n T_{jik}^n\right) + \sum_{i\in\hat{S}}\sum_{k\in K}\sum_{j\in\hat{S}} X_{ijk}^n T_{ijk}^n \quad (2)$$

Where :

$$\sum_{r\in\hat{R}}\sum_{j\in\hat{S}} x_{rjk}^n q_j + \sum_{i\in\hat{S}}\sum_{j\in\hat{S}} x_{ijk}^n q_j \le Q, \quad \forall k \in K \quad (3)$$

$$\sum_{\forall r\in\hat{R}}\sum_{j\in\hat{S}} x_{rjk}^n d_{rj} + \sum_{j\in\hat{S}}\sum_{\forall r\in\hat{R}} x_{jrk}^n d_{jr} + \sum_{i\in\hat{S}}\sum_{j\in\hat{S}} x_{ijk}^n d_{ij} \le D, \quad \forall k \in K \quad (4)$$

$$\sum_{j\in\hat{S}} x_{rjk}^n = \sum_{j\in\hat{S}} x_{jrk}^n \le 1, \quad \forall r \in \hat{R},\ \forall k \in K \quad (5)$$

$$\sum_{i\in\hat{R}}\sum_{k\in K} x_{ijk}^n + \sum_{i\in\hat{S}}\sum_{k\in K} x_{ijk}^n = 1, \quad \forall j \in \hat{S} \quad (6)$$

$$\sum_{k\in K}\sum_{j\in\hat{S}} x_{rjk}^n \le M_r, \quad r \in R \quad (7)$$

$$\sum_{i\in\hat{R}}\sum_{j\in\hat{R}} x_{ijk}^n = 0, \quad k \in K \quad (8)$$

$$T_{ijk}^n = \sum_a t_a^n \times \kappa_{aij}^n. \quad (9)$$

Equation (2) is an objective function that aims to minimize the total travel time of distribution vehicles, equation (3) is to ensure that the total number of goods carried by distribution vehicles is not greater than the total maximum capacity of distribution vehicles, equation (4) for limiting that the total distribution vehicle trips are smaller than the maximum distribution vehicle mileage limit, then equation (5) to ensure that distribution vehicles depart and return at the same depot.

The next constraint is equation (6) to ensure that each depot is only served by one truck whose movement originates from the depot or other customers, equation (7) limits that the travel time traversed by the distribution vehicle is the shortest from the depot to the customer or between two customers, and equation (8) is to ensure that the distribution vehicle does not move from one depot to another.

4.3 Lower Level Model

Variables in the Lower Model are defined as follows:
Z_2 = objective value, i.e. the total travel time on all segments
t_a^n = Travel time on segment a which is loaded on the nth iteration
X_a^n = Traffic flow on section a resulting from the loading on the nth iteration
f_{rsk}^n = Traffic flow on path between OD(r,s) resulting from loading on the nth iteration
q_{rs}^n = Traffic flow between OD(r,s) resulting from loading on the nth iteration
δ_{arsk}^n = Variable (0-1), if link is on path from to of the load on the nth iteration, is 1, otherwise 0
$t_a(0)$ = Free flow travel time of link a

The lower model is as follows:

$$\min: \quad Z_2 = \sum_a \int_0^{x_a^n} t_a^n(w)\, dw \tag{9}$$

Flow limitation, which ensures that traffic flow cannot be negative and meets flow conservation:

$$\sum_k f_{rsk}^n = q_{rs}^n, \quad \forall r, s \tag{10}$$

$$f_{rsk}^n \geq 0, \quad \forall r, s \tag{11}$$

$$x_a^n = \sum_r \sum_s \sum_k f_{rsk}^n \delta_{arsk}^n, \quad \forall a \tag{12}$$

The link performance function is as follows:

$$t_a^n = t_a(0)\left[1 + \alpha\left(\frac{x_a^n}{C_a}\right)^{\beta}\right] \tag{13}$$

Equation (9) is the objective function; (10), (11), and (12) are flow constraints, which ensure that the traffic flow should not be negativity and satisfy the flow conservation. Equation (13) is the link performance function;

5) Structure Model and Calculation Procedure

5.1 Structure Model

The structure of the proposed model as shown in Figure 1, begins by creating scenarios that include: potential LDC locations, and variations in LDC locations, and variations in LDC sizes. In this scenario, determine the vehicle distribution route using the Vehicle Routing Problem (VRP) approach to get the shortest route. From the results of the shortest route, then the flow of distribution vehicles is combined with other vehicles, a traffic assignment is carried out using a user equilibrium approach. The results of the traffic assignment are then carried out by VRP to get a new route, then a traffic assignment is carried out again and so on, looping is carried out until it reaches equilibrium and does not change.

After the above procedure has been carried out for each scenario, it is then possible to determine the best location using the Pareto method. The best location pattern and number of LDCs is the one with the smallest total travel time from distribution vehicles and other vehicles.

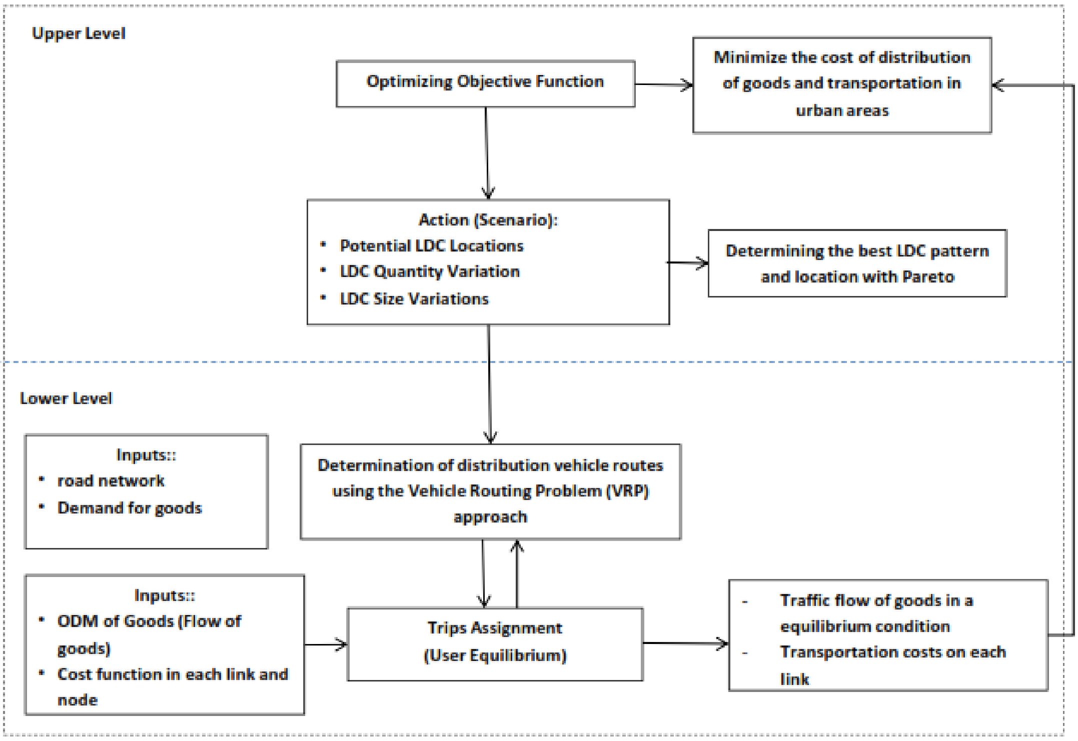

Figure 1. Structure Model

5.2 Calculation Procedure

5.2.1 Calculation Flow at Lower Level

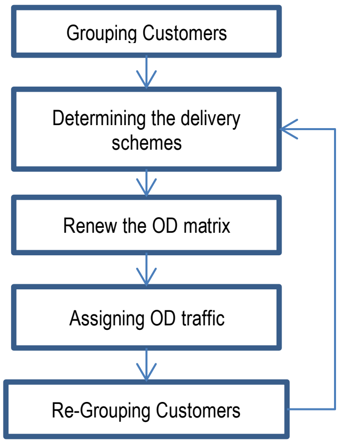

Figure 2. Calculation Flow Chart at Lower Level

The flow chart of the calculation procedure as presented in Figure 2. The first stage is customer grouping, in this process each customer will be grouped into the nearest LDC. This process is very important because the grouping of customers to the LDC that is not proper will cause an increase in the total distance of the vehicle route. The next stage is Determining the delivery schemes, at this stage the vehicle route is carried out separately for each LDC using the VRP settlement method for one LDC using the insertion heuristic method. The approach used in the VRP program is to use the Genetic Algorithm method.

The next step is Estimate Demand (Renew the OD Matrix), Determine the OD trips of the delivery trucks based on the optimal grouping pattern, and then add the OD trips of the delivery trucks to the former OD matrix. after Renew the OD Matrix, the next step is traffic assignment, Frank-Wolfe (FW) approach is used to solve the lower model, which is a normal user equilibrium traffic assignment model.

5.2.2 Traffic Assignment

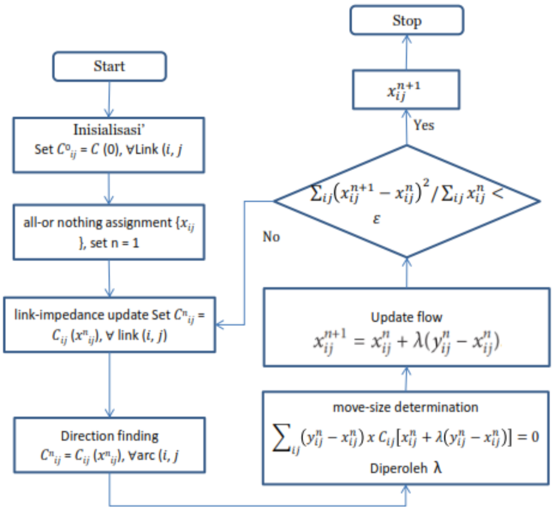

Figure 3. Algoritma traffic assignment model with user equilibrium

Frank-Wolfe (FW) approach is used to solve the lower model, which is a normal user equilibrium traffic assignment model,as follows:

Step 1 (initialization). Set $0ij$ = (0), Link (i,), do an all-or nothing assignment to get a set of feasible currents $\{xij\}$, and set = 1

Step 2 (link-impedance update). Set $C^{n}_{ij} = C_{ij}(x^{n}_{ij})$, ∀ link (i, j).

Step 3 (direction finding). Repeat the all-or nothing assignment with = $C^{n}_{ij} = C_{ij}(x^{n}_{ij})$, ∀arc (i, j) to the additional stream link $\{y^{n}_{ij}\}$

Step 4 (move-size determination). Solve $\sum_{ij}(y_{ij}^{n} - x_{ij}^{n})\, x\, C_{ij}[x_{ij}^{n} + \lambda(y_{ij}^{n} - x_{ij}^{n})] = 0$ to obtain λ.

Step 5 (flow update). One has
$x_{ij}^{n+1} = x_{ij}^{n} + \lambda(y_{ij}^{n} - x_{ij}^{n})$

Step 6 (convergence judgment), If $\sum_{ij}(x_{ij}^{n+1} - x_{ij}^{n})^2 / \sum_{ij} x_{ij}^{n} < \varepsilon$ (ε = a given threshold). stop calculation and output x_{ij}^{n+1} . Otherwise set n=n+1,and go to Step 2

6) Case Study and Discussion

6.1 Case Study

The retailing delivery of mineral water products called Tripanca in Bandar Lampung, Lampung Province (Indonesia) is used to do the case study. There are consist of four depots, 27 retailers (customers). The daily demands of the 27 customers are listed in Table 1. The study area is divided into 31 traffic zones (Figure 4) and the road network is shown in Figure 5. Other vehicle OD trip matrices during time 7.30-8.30 come from the personal trip survey of Bandar Lampung in 2019.

Assigning the initial OD matrix on the road network, we can get the initial link flow X_a^0 and travel time t_a^0.

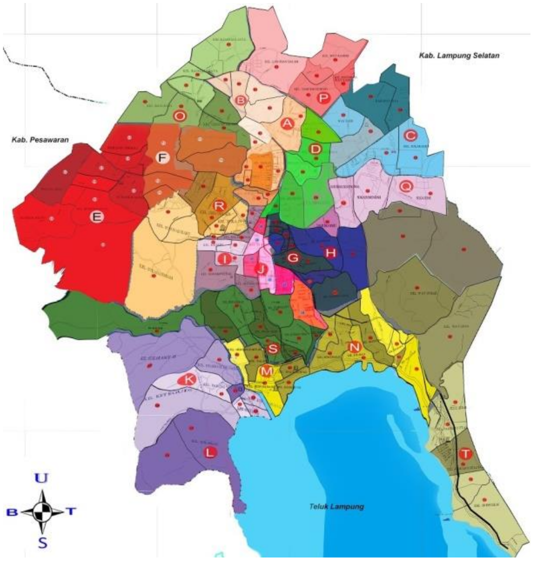

Figure 4. Study area and Zones

Figure 5. Road network

Table 1. The demands of the customers (Ton/Day)

Customer	Amount	Customer	Amount	Customer	Amount
1	0.31	10	0.12	19	0.27
2	0.18	11	0.15	20	0.12
3	0.09	12	0.23	21	0.09
4	0.16	13	0.21	22	0.15
5	0.11	14	0.18	23	0.17
6	0.08	15	0.20	24	0.26
7	0.22	16	0.07	25	0.09
8	0.15	17	0.16	26	0.14
9	0.21	18	0.24	27	0.16

6.2 Result and Discussion

The solution of the optimization model, which is the delivery schemes under total traffic equilibrium, The distance travelled by all delivery trucks is 69.6 km and the corresponding travelling time is 218.3 minutes. The delivery schemes when the interactions between the delivery trucks and other vehicles are not considered, namely, the delivery schemes under partial traffic equilibrium. In this case, the total travel distance of the delivery trucks is 72.6 km and the total travel time is 323.5 minutes. Although the distance of the schemes under total traffic equilibrium is 13.6% longer, its travel time is 30.2% shorter. Therefore, we cannot say that the schemes obtained under partial traffic equilibrium are the real optimal ones and should not be adopted for the real work.

To demonstrate the validity of the proposed model, we set some scenarios by changing ODmatrices and the numbers of delivery trucks, respectively and then do sensitivity analysis. For building the scenarios, we adjust vehicle OD trip matrix of Bandar Lampung in 2019 with η_1 ($\eta_1 \in [0.2, 2]$ by step = 0.2) and multiply the number of delivery vehicles by η_1 ($\eta_2 \in [0.2, 2]$ by step 0.2). Then, we use the 0.2, 0.4, . . . , 2.0 times of the initial OD traffic and the 0.2, 0.4, ...,2.0 times of the delivery trucks to test the model and give some findings,respectively. The comparing indices are the overlapping ratio ρ_1 of the delivery loops/paths, which means the sensitivities of traffic volumes to the delivery loops, and the ratio of customers not changing service depot ρ_2, which means the sensitivities of traffic volumes to the groupings, and the total travel time (T_d) of the delivery trucks.

$$\rho_1 = \frac{\text{length of overlapping routes in different scenarios}}{total\ lenght\ of\ routes\ under\ the\ situation\ of\ free\ flow\ traffic}$$

$$\rho_1 = \frac{\text{number of the customers not changeing cervice depot}}{number\ of\ customers}$$

The indices are shown in Figure 6. When η_1 = 0.2 or η_1 = 0.4, ρ_1=1 and ρ_2=1. It can be seen that the delivery schemes under the total traffic equilibrium and the situation of free flow traffic are the same. In this three case (namely, η_1= 0.0, 0.2, 0.4), the total travel times (Td) of the delivery trucks hardly change, and the loops/paths of the delivery truck sare totally the same.

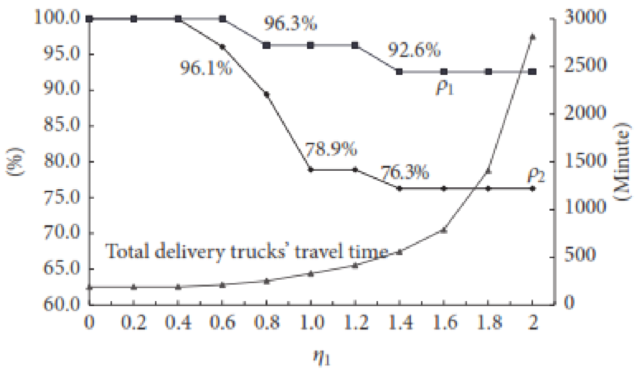

Figure 6. ρ_1=1 and ρ_2=1 and T_d in different schenario

When η_1= 0.6, ρ_1<1, ρ_2=1. It means that the delivery loops/paths under the total traffic equilibrium and the situation of free flow traffic are not the same any more. The length of the path of the total traffic equilibrium is longer (2.58 km), while the length of the path of the shortest road distance (same as the path of the shortest travel time because the network is in free flow situation) is shorter (2.34 km); however, the travelling times are 13.6 minutes and 15.3 minutes, respectively.

7) Conclusions

In this paper, we change multidepot VRP into GEA, which is an alternative way of designing routes for a multidepot VRP and then modelling urban goods transport. A bilevel programming is proposed to model the GEA, and the interaction among the path choice behaviors of all vehicles and the interaction between delivery schemes and OD trip matrix can be simulated. Then the solution for multidepot VRP is obtained by hybrid grouping method, genetic algorithm, and Frank-Wolf algorithm. The delivery schemes outputs from the model are those under total traffic equilibrium and thus are realistic, which can make full use of road capacity and balance the traffic flow in the entire network.

This paper has also proposed a method for determining the location of a logistics center on a freight distribution network in urban areas by considering routes through a combination of vehicle routing problem (VRP) and traffic assignment methods. Traffic flow performance conditions are also considered in this method, along with the traffic flow of goods delivery vehicles and other vehicle traffic flows.

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