Urban Truck Scheduling and Routing Problem

Zefeng Lyu, Zeyu Liu, Rui Zhou

1. Introduction and literature review

Nowadays, electronic commerce offer us a new way for shopping and play an increasingly important role in people's daily life. Many electronic commerce companies, such as Alibaba, Amazon have become famous all around the world. In order to satisfy customers and reduce the transportation cost, building an efficient and economic logistic system is significantly crucial.

The Urban truck scheduling and routing problem talked in this article is a classic vehicle routing problem (VRP), which seeks to find routs to deliver goods from a central depot to a set of geographically dispersed customers(Coelho et al., 2016). There exists a wide variety of VRPs and a broad literature on this class of problems (see, for example, the invited review of Gilbert Laporte, 1991). We could get a new VRP if only we change the side conditions, such as capacity restrictions, time windows, etc. It is notable that electric vehicles become more and more popular because of their property of environment-friendly and economic. When electric vehicles are involved, problem will become more complicated because we need to determine whether a vehicle should get charging and move further or just turn back. Besides, some researchers pay more attention to our environment protection. Bektas and Laporte (2011) are the first to propose the Pollution-Routing Problem (PRP) to offer insights into environment-friendly vehicle routing.

In this article, we study a real CVRPTW problem derived from a distribution center of a Chinese electronic commerce company that serves around 1000 customers. In this case, fixed, variable (transportation) and waiting cost need to be considered as objective function. The constraints of this version VRP are as follows.

1. Capacity: Each vehicle has an identical volume and weight limitation.
2. Time Window: Vehicles are supposed to arrive in the time windows. But early arrival is allowed at the cost of waiting.

We solve this problem by using heuristic algorithm and simulation. Heuristic algorithms for the VRP can often be derived from procedures derived from the TSP(Laporte, 1992). There are lots of heuristic algorithms, such as Clarke and Wright algorithm, Tabu search algorithm, Genetic algorithm, Particle swarm algorithm, etc. However, when applying these methods to VRPS care must be taken to ensure that only feasible vehicle routs are created(Laporte, 1992). Simulation software is another helpful tool for VRP problem. AnyLogic, one of the most popular simulation software, can be used in to strengthen the model by introducing random traffic flow to simulate practical traffic conditions(Fan, Xu, & Xu, 2009). Besides, AnyLogic could visualize the result and make it readable for non-technical personnel.

The rest of this article is organized as follows. Section 2 defined the problem to be solved and put up the relative sample data. Section 3 propose a mathematic model. Then, we describe how we solve this problem by using algorithm and simulation software "AnyLogic" in section 4. After that, we display the result in section 5. Finally, we draw a conclusion and give out some future research we may do in section 6.

2. Problem definition

A distribution center of JD is associated to city A. This center provides distribution services to over a thousand customers of this city needing bulk commodities daily. It is assumed that there is no constraint on how many trucks can be used every day. It is also assumed that JD's comprehensive costs cannot be reduced. Each customer have a time window for receiving goods but it is a soft constraint, which means that track may arrival before than the time window. If vehicle arrives early, a waiting cost of 24 yuan per hour should be counted. Later arrival is not allowable. Each truck can serve multiply customers but each customer could only be served by one truck at one time. Besides, the capacity of truck should be taken into consideration when it serve multiply customers. The task is determining the quantity of truck to be used and designing their routing and scheduling plans. The final target is to optimize the total cost, which include fixed cost of using a truck, transportation cost and waiting cost if the truck arrive before the earliest time of that customer.

2.1 Input Data

Table 1

Customer Sample Data

Node ID	Longitude	Latitude	Package Weight (tons)	Package Volume (cubic meters)	Earliest Time	Latest Time
1	116.242043	40.072630	0.20760	0.3666	09:00	12:00
2	116.403595	39.872945	0.05863	0.1687	13:30	14:00
3	116.186289	40.016361	0.03645	0.0745	13:00	15:00
4	116.508011	39.826296	0.02595	0.0542	09:00	10:00
5	116.130997	39.825921	0.0198	0.1117	11:00	13:30
…	…	…	…	…	…	…
50	116.214509	40.122890	0.01697	0.0260	11:00	12:00

The distribution center was located at (116.571614, 39.792844). This distribution center is responsible for 1000 customers nearby. However, computing 1000 customer is really complicated. In order to simplify our model and reduce the computing time, we only pick up the first 50 customers for analyzing. The data needed include the customer's longitude, latitude, package weight, package volume, and time window for receiving the cargo. Part of these data are displayed in Table 1.

Table 2

Tuck Capacity Sample Data

Type	Max Volume (cubic meters)	Max Weight (tons)	Driving Range (kilometers)	Unit Trans Cost (Yuan per kilo.)	Fixed Cost (Yuan)
TRUCK	16	2.5	120	14	300

Each truck will leave from the distribution center after 8:00 AM and must return before 12:00 PM. There are two types of vehicle available. Type 1, named "IVECO", could carry 2 tons of cargo while its volume is no more than 12 cubic meters. It can driving up to 100 kilometers. Its transport cost and fixed cost are 12 yuan per kilometer and 200 yuan per day. Type 2 named "TRUCK". TRUCK is more powerful that IVECO, but also more expensive. Its capacity of volume, weight and driving range are 16 cubic meters, 2.5 tons and 120 kilometers, respectively. Its transport cost and fixed cost are 14 yuan per kilometer and 300 yuan per day. Both of these two kind of vehicle are chargeable. But we do not take charging into consideration in this article. It is notable that we only use the type 2 vehicle “TRUCK” and its quantity is unlimited. The capacity information is shown in Table 2.

Table 3
Distance Sample Data

From Node	To Node	Distance (kilometers)	Transport Time (minutes)
0	1	63536	77
0	2	27489	33
0	3	62041	75
0	4	13365	17
0	5	45570	55
...	...	...	...

In order to calculate the transportation cost, we need to know the distance between distribution center and customer, customer and customer. Besides, we need the transport time to determine if the arrival time is in the time window. Part of the sample data are shown in Table 3.

2.2 Constrains

1) All customers should be served exactly once by one truck.
2) Capacity limitation: the whole weight and volume could not exceed the capacity of trucks.
3) Time window: package should be delivered within the specified time window. (Soft Constrains)
4) Each truck should return before sustainable mileage reaches 0.
5) Demand of customers must be satisfied.

2.3 Assumptions

1) The trucks begin at the distribution center and need to return to the distribution center once the goods have been delivered.
2) There is an infinite number of trucks available.
3) The unloading time for each customer is constant at 0.5h.
4) The coefficient of waiting cost described is 24 yuan/h. Later arrival is not allowable.

3. Theoretical model

Table 4
Parameters

Constant variable	Description	Value
C_f	Per-unit TRUCK fixed cost (yuan)	300
C_d	Per-unit travel cost for TRUCK (yuan/per kilometer)	14
C_w	Per-unit waiting cost (yuan/per hour)	24
V_{max}	Vehicle volume capacity (m^3)	16
V_j	Unloading volume at node j (m^3)	Table 1
W_{max}	Vehicle load capacity (t)	2.5
W_j	Unloading weight at node j (t)	Table 1
D_{max}	Maximum driving range for vehicle B (kilometer)	120
D_{ij}	Distance between node i and node j	Table 3
T_s	Unloading time (hour)	0.5
T_i^{early}	Earliest arrive time of customer i	Table 1
T_i^{last}	Latest arrive time of customer i	Table 1
T_{ij}	Travel time between node i and node j	Table 3
T_{depart}	Earliest departing time of vehicle k	8:00
T_{back}	Latest backing time of vehicle k	24:00

This problem is a classic capacity vehicle routing problem with time window (CVRPTW). This instance pf the CVRPTW consists of a set of customers C, a distribution center O. C_O denotes the set of nodes with the distribution center O. There are K trucks for transportation and the upper bound of K is equal to 50. A binary variable x_{ij}^k is used for indicating whether the k^th truck visits customer j after visiting customer i.

The maximum volume and weigh of truck k is defined in V_{max} and W_{max}, respectively. V_j and W_j represents the volume and weight of goods needed by customer j, respectively. Similar to the load capacity, D_{max} is the maximum driving range and d_j^k represents the driving capacity remain. It is notable that the value of d_j^k should keep positive. Besides, T_{ij} represents the traveling time from node i to node j and T_s is the unloading time in each customer. The start time of unloading for customer i is saved in t_j^k . For each customer i, a range [T_i^{early}, T_i^{last}] is defined representing the time windows. The value of t_j^k should smaller than or equal to T_i^{last}. The parameters mentioned above are shown in Table 4.

Then, this problem can be modeled as follows:

Minimize
$$C_{total} = C_{fixed} + C_{travel} + C_{wait}$$
$$C_{fixed} = \sum_{k \in K} \sum_{j \in N} C_f x_{Oj}^k$$
$$C_{travel} = \sum_{k \in K} \sum_{i \in N_O} \sum_{j \in N_O} C_t d_{ij} x_{ij}^k \qquad i \neq j$$
$$C_{wait} = \sum_{i \in C} C_w \max\{0, T_i^{early} - T_i^k\}$$

Subject to
$$\sum_{j \in C} x_{Oj}^k = 1 \qquad \forall k \in K \tag{1}$$
$$\sum_{k \in K} \sum_{i \in C_O} x_{ij}^k = 1 \qquad \forall j \in C \tag{2}$$

$$\sum_{i \in C_O} x_{ij}^k = \sum_{m \in C_O} x_{jm}^k \qquad \forall k \in K, \forall j \in C, i \neq j \neq m \qquad (3)$$

$$t_j^k = \max\{T_j^{early}, t_i + T_{ij} x_{ij}^k\} + T_s \leq T_j^{last} \qquad \forall i \in C_o, \forall j \in C_o \qquad (4)$$

$$t_O^k \geq T_{depart} \qquad \forall k \in K \qquad (5)$$

$$t_{back}^k \leq T_{back} \qquad \forall k \in K \qquad (6)$$

$$d_j^k = d_i^k - D_{ij} x_{ij}^k \geq 0 \qquad \forall k \in K, \forall i \in C_o, \forall j \in C_o \qquad (7)$$

$$\sum_{i \in C_O} \sum_{j \in C} W_j x_{ij}^k \leq W_{\max} \qquad \forall k \in K \qquad (8)$$

$$\sum_{i \in C_O} \sum_{j \in C} V_j x_{ij}^k \leq V_{\max} \qquad \forall k \in K \qquad (9)$$

$$x_{ij}^k = \{0,1\} \qquad \forall k \in K, \forall i \in C_o, \forall j \in C_o, i \neq j \qquad (10)$$

The problem is a minimization problem with an objective function consisting of three parts: travel cost, fixed cost and waiting cost. Equation (1) ensures that each truck get started form distribution center O. Equation (2) and (3) force that all customers should be served exactly once by one truck. The timing constraints are covered by Eq. (4) – (6). Equation (7) ensures that each truck should return before sustainable mileage reaches 0. Equation (8) and (9) are the capacity constraints. The last equation (10) forces the value of the decision variable x_{ij}^k to be either zero or one.

4. Algorithm and simulation

5. Results

5.1 model validation

6. Conclusion and discussions