Immediate Parcel to Vehicle Assignment for Cross Docking in City Logistics: A Dynamic Assignment Vehicle Routing Problem

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Abstract: In this paper we present the Dynamic Assignment Vehicle Routing Problem. This problem arises in parcel to vehicle assignment where the destination of the parcels is not known up to the assignment of the parcel to a delivering vehicle. The assignment has to be done immediately without the possibility of re-assignment afterwards. The problem is defined and various methods are proposed to come to an efficient solution method. Three cases are presented to test this efficiency. An approach using minimum cost insertion with penalty performs best.

1 INTRODUCTION

City logistics focuses on the efficient and effective transportation of goods in urban areas while taking into account the negative effects on congestion, safety, and environment (Savelsbergh and Van Woensel, 2016). In city logistics two main transport strategies are used: full truckload or less-than-truckload (Cattaruzza et al., 2017). Less-than-truckload examples are found typically in parcel delivery services, express services and supermarkets distribution. Here, consolidation and transshipment ask for satellite locations with cross docking, redistributing the incoming freight into other, possibly smaller vehicles to serve customers. This results in 2 echelon distribution and vehicle routing problems (2E-VRP), which are described in the survey of (Cuda et al., 2015). The authors of this survey consider strategic planning decisions, including decisions concerning the infrastructure of the network, and tactical planning decisions, including the routing of freight through the network and the allocation of customers to the intermediate facilities. At the tactical level, the customer locations are considered known.

In the case the customer locations are not known before operations, we come in the range of dynamic vehicle routing problems. The review of (Pillac et al., 2013) gives a separation of those problems between static and dynamic on one axis and deterministic and stochastic on the other axis. In 'static and deterministic' problems, all input is known beforehand and vehicle routes do not change once they are in execution, see for an overview of these classic vehicle routing problems (VRP) (Baldacci et al., 2007). 'Static and stochastic' problems are characterised by input partially known as random variables, which realisations are only revealed during the execution of the routes, see for example (Bertsimas and Simchi-Levi, 1996). Here also clustering techniques for stochastic data can be used (Ngai et al., 2006).

In 'dynamic and deterministic' problems, part or all of the input is unknown and revealed dynamically during the design or execution of the routes. These are also called online VRP problems (Bjelde et al., 2017; Jaillet and Wagner, 2008). Similarly, 'dynamic and stochastic' problems have part or all of their input unknown. This input is revealed dynamically during the execution of the routes, but in contrast with the latter category, exploitable stochastic knowledge is available on the dynamically revealed information. See for a survey (Ritzinger et al., 2016). In addition, methods based on anticipation can be used (Ulmer et al., 2015).

In this paper, we look at a satellite location where the incoming parcels have to be distributed over a number of vehicles to deliver them to the customers. The satellite location has no, or a rather small, space for storage. This means that the parcels have to be assigned directly, after unloading and scanning, to an outgoing vehicle. There is no possibility to reassign on a later moment in time. The parcels are delivered to the assigned vehicle instantaneously. The destination of the parcels is not known beforehand and is re-

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vealed only at arrival at the satellite location. This gives a problem that is, to the author's knowledge, not studied earlier. We call it the Dynamic Assignment Vehicle Routing Problem (DA-VRP). This looks like a 'dynamic deterministic' VRP, however, the assignment of the parcels is done at the same time the destination is revealed. This means that the planning is done dynamically, but in contrast to the common dynamic case, it is done in upfront, where the route is not being executed yet, giving the possibility to change the order per vehicle, but not to interchange between the vehicles. We will present and compare approaches for this problem.

Furthermore, we will extend this problem with the possibility to reveal the destination of a certain percentage (x%) of the parcels beforehand. This can be revealed by using an information system or by the possibility to store a certain percentage after revealing the destination, before the assignment has to be fixed. Also for this extension we will compare various approaches.

The remaining of this paper is organised as follows. First, in Section 2 the problem will be defined. Next, in Section 3, we will present approaches to come to a dynamic assignment of the parcels to the vehicle and we will discuss the assumptions underlying the model. In Section 4, we will elaborate on the cases we use to show the performance of the various approaches, followed by the results in Section 5. Conclusions and recommendations can be found in Section 6.

2 DYNAMIC ASSIGNMENT VEHICLE ROUTING PROBLEM

We assume a situation where parcels have to be delivered, called 'the demand', to customers in a certain region. In the methodology and the example cases, we assume a homogeneous distribution of the demand over all potential customers, characterised by a group of houses, for example a postal code area. Parcels are delivered at a satellite location from various directions, where the destination of each parcel is revealed at arrival by scanning the parcel. In the base case, the parcel is, simultaneously with revealing its destination, assigned to an outgoing vehicle.

Definition: DA-VRP - In a Dynamic Assignment Vehicle Routing Problem (DA-VRP) k parcels arrive at a location in a specific order. In that specific order, each of the parcels reveal their destination and have to be assigned immediately to one of the m vehicles, that will deliver the parcel to its destination. In the basic version of this problem, each parcel requires one capacity unit of the vehicles and all vehicles have capacity C. When assigning the jth parcel, vehicle i can only be regarded iff $n_i < C$, where n_i equals the load of vehicle i at that current moment.

In the extended case, a certain percentage, randomly drawn from all parcels, reveals its destination earlier, for example coming from an other distribution point, or can be stored some time, after which the stored parcels can be assigned in one step to the empty vehicles.

3 METHOD

In this section we indicate some approaches that can be used to assign the parcels to the vehicles. We distinguish two steps in our approach:

1. Initial assignment of direction to vehicles;
2. Dynamic assignment of arriving parcels;

The first step gives a potential direction to each of the vehicles, or none if empty vehicles are used, by assigning a base load, a certain region or some initial direction. The second step assigns directly the incoming parcels to the vehicles. Both the initial assignment and the dynamic assignment will be discussed in the next section in more detail. In Section 3.2 the mathematical solution techniques that are used in the assignment steps are presented. After these two steps the load of all vehicles is known and for each vehicle a regular TSP can be solved.

3.1 Detailed Steps

It might be helpful to give an initial load or assignment of a certain area to each of the available vehicles. This is done in step 1 of the approach, the *initial assignment of direction to vehicles*. Here we distinguish four basic methods:

1. No load – the vehicles stay empty until the first dynamic assignment.
2. Basic load – In the case that a certain percentage (x%) of the parcels reveal their destination before assignment, we will assign these parcels to the available vehicles evenly using a VRP solution method. We assume that the revealed parcels are randomly distributed over all potential customers.
3. Separation by dummy location - We perform a k-Means clustering over all potential customers

and assign a dummy parcel with one of the cluster means to each vehicle. K-means clustering (James et al., 2013) aims to partition observations into k clusters, in which each observation belongs to the cluster with the nearest mean.

4. Total geographical separation - Again we perform a (k-Means) clustering over all potential customers (postal codes) and assign each of those (postal codes) clusters to a vehicle.

Next, three methods for the second step, *the dynamic assignment of arriving parcels*, are proposed:

1. Based on smallest distance to cluster mean – for all vehicles we can calculate the geographical mean of all assigned parcel destinations. We assign the arriving parcel to that vehicle for which the distance from the parcel destination to the geographical mean is minimal.
2. Based on minimal insertion costs – for all vehicles we calculate the minimal cost of inserting the arriving parcel destination to the route. As we assume that the assigned parcels are ordered in the routing of the vehicle, we can calculate the cost by trying to insert the parcel between each pair of consecutive parcels in the vehicle. The insertion that is cheapest will be selected.
3. Based on fixed clusters – here the parcel is simply assigned to the cluster it belongs to, using the total geographical separation of the initial stage, based on customer or postal code of the customer.

When, by one of these methods, the assignment is determined, the parcel is inserted on the right place in the route of the selected vehicle, meeting the assumption of ordering.

If the vehicles have a fixed capacity, there are two aspects we have to consider. First is what to do when a vehicle is loaded to its capacity. In assignment strategy one and two, this means that this vehicle cannot be selected anymore for assignment. The cost of assignment to a fully loaded vehicle will be set to infinity. For the third assignment strategy, we propose to switch to the second strategy if the vehicle that was selected is full.

The second aspect is asymmetry in loading. If the vehicles start empty, it is likely that the first two vehicles will be loaded until one reaches its maximum capacity. Then a new vehicle is started. This strategy does not account for a more even distribution of the parcels over the vehicles, giving the possibility to each get a (relatively) restricted area and it does not account for the possibility that parcels will show up that clearly should have been assigned to a vehicle, but cannot, due to capacity restrictions. For these reasons we add a fourth dynamic assignment strategy, as alternative to the second, where the price of insertion increases when the vehicle has more load. Precise details follow in the next section.

4. Based on minimal insertion costs – for all vehicles we calculate the minimal cost of inserting the arriving parcel destination to the route. As we assume that the assigned parcels are ordered in the routing of the vehicle, we can calculate the cost by trying to insert the parcel between each pair of consecutive parcels in the vehicle. The cost is multiplied by a penalty factor, depending on the load of the vehicle. The insertion that is cheapest will be selected.

If we assume no initial load, this leads to 12 combination of methods, of which 7 are sound and will be discussed:

1. Empty trucks (1) – filled by cluster approach (1)
2. Separation (3) – filled by cluster approach (1)
3. Empty trucks (1) – filled by insertion approach (2)
4. Separation (3) – filled by insertion approach (2)
5. Empty trucks (1) – filled by insertion approach with penalty (4)
6. Separation (3) – filled by insertion approach with penalty (4)
7. Total Separation (4) – filled based on fixed clusters (3)

If there is initial load, in the extended case, we use the second method for the initial assignment (2. Basic load) and we could use methods 2-4 at the dynamic assignment phase. Next to these scenarios we use for comparison a 'full information solution'. Here all information is known beforehand and a VRP method can be used for solving this.

3.2 Solution Techniques

We use four mathematical solution techniques within our approaches: VRP solution method, k-Means clustering method, Insertion method and a Dynamic clustering method. The two former are used from other sources, the two latter are described in more detail.

For the VRP method, which will be used for 'Basic load' and for the 'Full information' solution we used a VRP solver, based on a Simulated Annealing method, implemented in Matlab by Yarpiz (www.yarpiz.com). We use this implementation with the following parameters: number of iterations 2500; number of inner iterations: 250. For the k-Means clustering method in the Separation methods we use the basic Matlab implementation, 'kmeans(X,k)'

The Insertion method works as follows. We assume that already each vehicle i has a tour indicated by the (x,y) coordinates of the destination of the parcels, starting and ending at the satellite location with coordinates $(x_{i,0},y_{i,0}) = (x_0,y_0)$:

$$(x_{i,0},y_{i,0}),(x_{i,1},y_{i,1}),\ldots,(x_{i,n_i},y_{i,n_i}),(x_{i,0},y_{i,0})$$

Now, a parcel with coordinates (x,y) has to be assigned to a cluster. For each vehicle i, determine the pair of consecutive points k,l such that

$$d_i = \min_{k,l} d((x_{i,k},y_{i,k}),(x,y)) + d((x,y),(x_{i,l},y_{i,l}))$$

$$-d((x_{i,k},y_{i,k}),(x_{i,l},y_{i,l}))$$

is minimal for all pairs k,l, where $d((x_1,y_1),(x_2,y_2))$ denotes the distance between two destinations, noted by their (x,y) coordinates. The parcel will now be inserted, on the spot between k_i^* and l_i^*, in the tour i that minimises d_i for all i. In case of the Insertion method with penalty, this distance is multiplied by a penalty factor $(1+p_i)$ where

$$p_i = P \cdot n_i / C,$$

where P is the chosen penalty value, n_i the current load of vehicle i and C the capacity of the vehicle. The value of P is case dependent. In all cases used later, we use the first 10 problem instances for learning the optimal value of P for that case.

The Dynamic Clustering methods works as follows. Again a parcel with coordinates (x,y) has to be assigned to a cluster. Cluster i consists of parcels with coordinates $(x_{i,1},y_{i,1}),\ldots,(x_{i,n_i},y_{i,n_i})$ and a cluster point $(\overline{x_i},\overline{y_i})$, where $\overline{x_i} = \frac{1}{n_i}\sum_{k=1}^{n_i} x_{i,k}$ and $y_i = \frac{1}{n_i}\sum_{k=1}^{n_i} y_{i,k}$. Now assign the parcel to cluster i such that $d((x,y),(\overline{x_i},\overline{y_i}))$ is minimised.

4 CASES

The cases are all situated in the city of The Hague, The Netherlands. The city has circa 530,000 inhabitants and circa 255,000 houses. The total area of the city consists of 98 square kilometres. The houses are divided into 13,297 postal code areas. For each case we draw a number of destination, uniformly over all postal codes and assume that a parcel has to be delivered to that location. The number of parcels and the available number of trucks vary in the three cases:

- Case 1: 350 parcels, 10 vehicles;
- Case 2: 350 parcels, 5 vehicles;
- Case 3: 200 parcels 5 vehicles.

For each case we sampled 100 days or instances, independently. We assume that the only costs are the variable costs based on the total distance driven by the vehicles. A parcel is assumed to have capacity 1 and the capacity of the vehicles is in number of parcels.

5 RESULTS

As defined earlier we have seven scenarios if there is no initial load assigned to the vehicles. These scenarios are used on the three cases. A 'full information solution' is used as reference point, where all parcels are known and the tours are constructed using the VRP solver. This is not a guaranteed optimal solution, where the used method is a meta-heuristic. We see in Table 1 that methods 1, 2 and 3 give an overall bad solution. The average scores over all 100 instances are all more than double the VRP solution. These are both the clustering approaches and the insertion approach without penalty using empty vehicles. Methods 4 and 7 work reasonably on the two cases with 5 vehicles. These are the insertion approaches without penalty and an initial separation and the method with strict separation, fixed areas of delivery. Best performing are the methods 5 and 6 based on the insertion approach with penalty. Resulting in a 14-17% higher cost that the VRP solution.

Table 1: Performance of the 7 combinations of methods compared to the VRP solution.

	Case 1	Case 2	Case 3
1	282%	229%	230%
2	286%	231%	233%
3	283%	229%	230%
4	237%	146%	146%
5	115%	117%	115%
6	117%	115%	114%
7	224%	130%	127%
VRP	100%	100%	100%

If we assume the possibility to reveal the destination of a certain percentage, e.g., 50%, of the parcels beforehand, we can compare this with the situation where there is no information about the destination of the parcels, and with the situation with full information. We use case 2 in this example. For the situation with no information we use methods 6 and 7 as reference, for the full information situation we use the VRP solution. The information can be revealed by the use of an information system or by the possibility to store a certain percentage after revealing the destination and before the assignment. We assume here that for this part the VRP approach can be used, using the number of vehicles (here 5) and 50% of the capacity.

Now an evenly distributed base load for all vehicles is known. Next the insertion method with penalty is used for the dynamic assignment of the next 50% of the parcels. Starting with the average solution of the VRP approach over all 100 instances and calling this 100%, we see that the fixed areas of delivery gives a 30% increase in costs and the insertion with penalty 15%. Revealing 50% of the destinations leads to decrease of costs of 9%-point, compared to the 0% solution, and is 6% higher that the 100% information VRP solution. The results are summarised in Table 2.

Table 2: Results.

Method	Score
Fixed clusters 0%	130%
Insertion 0%	115%
Insertion 50%	106%
VRP 100%	100%

6 CONCLUSIONS AND RECOMMENDATIONS

In this paper we discussed a problem in parcel distribution where the destination of the parcels is revealed only after arrival at the satellite location: the Dynamic Assignment Vehicle Routing Problem. In the case that there is no, or limited, space for storage, the parcels have to be assigned directly and moved to one of the available distribution vehicles. We showed that use of an insertion method, with an increasing penalty function with the occupancy rate, gives the best results. The initial assignment to trucks has no or low effect on this result.

If an initial load is assumed, which is distributed equally over the vehicles using the VRP solver, further assigning using the insertion method leads to a decrease in cost. From this we can conclude that assigning incoming parcels dynamically, using the insertion method is preferable to fixed clusters. Using information for even a part of the parcels improves the solution even more in the direction of a full information based solution.

For further research we propose to look at the effect of higher capacities, more dense demand distributions and variable demand, leading to an unknown number of required vehicles per day. Also a more detailed definition of capacity, in volume, and time restrictions at customers side can be added.

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