

Using Insertion Heuristic to Solve Dynamic Multi-Depot Vehicle Routing Problem

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Abstract-For any dynamic vehicle routing problem, if new routes are planned in response to a new dynamic request, and the new routes are very different from the original ones, the whole process becomes more complicated. In order to reduce the changes in the routes, this research proposes an insertion heuristic for solving a dynamic multi-depot vehicle routing problem where pick-up and delivery requests are both considered. The insertion heuristic can also take the current positions of vehicles into account. Five instances provided by a specialist webpage were tested to analyze the difference between solutions that do or do not consider the current positions of vehicles. The results show that considering the vehicles' current positions reduces the completion time by 11.79%, but increases the number of rejected requests by 10.23% on average.

Keywords- *Dynamic Vehicle Routing; Multi-depot; Pick-up and Delivery*

I. INTRODUCTION

The vehicle routing problem (VRP) has been studied extensively because of its wide applicability to many real-world situations [1]. Based on the structure of the VRP, several variant types of solutions have been developed, one of which is multi-depot VRP (MDVRP) [2]. In MDVRP, there is more than one depot. Each vehicle departs from a depot to serve customers whose requests are given at the beginning and the vehicle finally returns to that same depot. The routes of all vehicles are planned before they depart from the depots in the first time period. When new customer requests are received, the original vehicle routes have to be changed to satisfy the new requests. The MDVRP then becomes the dynamic MDVRP (DMDVRP).

This research deals with a DMDVRP in which two types of dynamic customer requests, pick-up and delivery, are taken into consideration. As illustrated in Fig. 1, each depot has one vehicle. In the beginning, before vehicles leave their respective depots, the route of each vehicle is planned, based on the existing customer requests. After the vehicles leave the depots, new customer requests are received dynamically. Each new dynamic request can be served by any vehicle. If the dynamic request is a pick-up, any vehicle can change its current destination (planned next customer) to serve the new request. Thus, the current positions of all vehicles must be taken into consideration. If the dynamic request is a delivery, no vehicle can serve it immediately, because the product for the new request has not yet been loaded onto a vehicle. The dynamic request can be served only after a vehicle has completed its route and returned to the depot to load the product requested. Thus, the presented DMDVRP is extended and becomes a DMDVRP with requests of pick-ups and deliveries (DMDVRPPD).

For the proposed DMDVRPPD, a simple heuristic is proposed for re-planning the original routing when a new customer request is received. It was assumed in this research that the known requests are sorted immediately in the depot once all routes have been planned and that all drivers have previewed their routes for the day. Any change in the original routes complicates the whole process. Therefore, unlike general heuristics, which have been adopted for the DVRP, the proposed simple heuristic changes the planned routings as little as possible.

Finding the optimal solution for the DVRP was not the main objective of this research; instead, based on a simple heuristic, the aim of this research was to compare the results between when current vehicle positions are taken into consideration and when they are not. If the current positions of vehicles are taken into consideration, vehicles can change their current destinations and provide service to the new pick-up dynamic request. Otherwise, vehicles can only provide the service for the new pick-up dynamic request after the delivery customers have been serviced. Whether the current positions of vehicles are taken into consideration or not, the results of new routing will not influence the dynamic delivery request, as the package has not yet been loaded onto a vehicle. The dynamic delivery request can only be serviced after the vehicle returns to the depot.

The remainder of this paper is organized as follows. In Section 2, the literature relating to the DVRP is reviewed. Then, in Section 3, an insertion heuristic is proposed for solving the DMDVRP with requests for pick-ups and deliveries. Computational results are reported in Section 4, followed by a summary and some concluding remarks in Section 5.

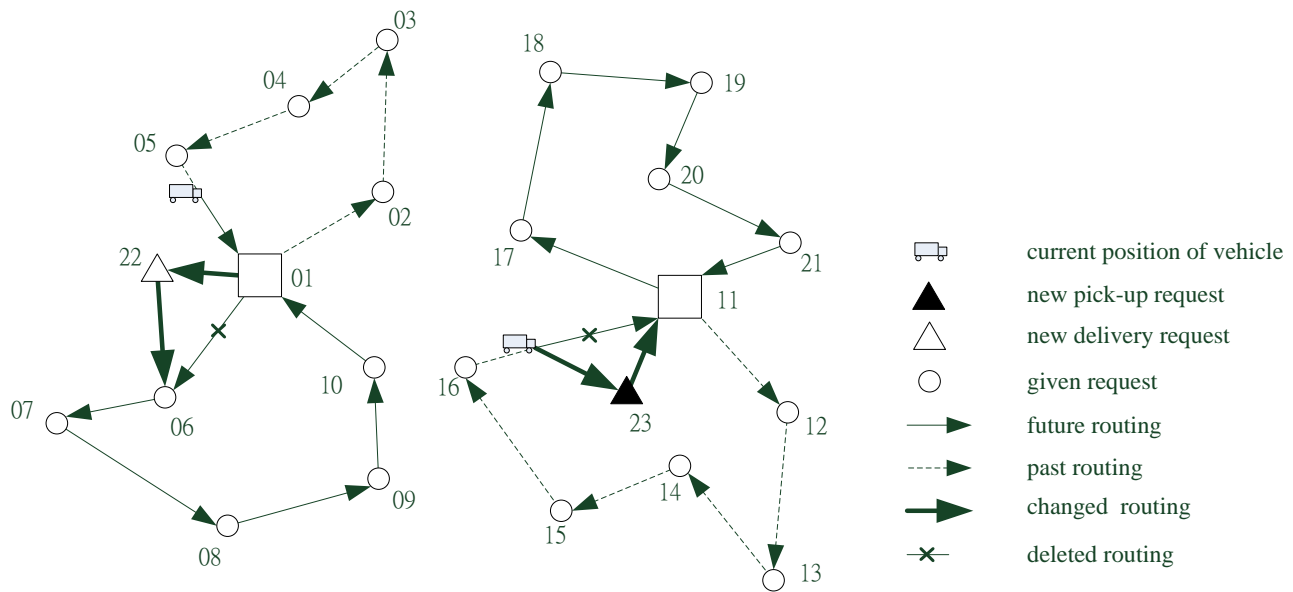


Fig. 1 Example of DMDVRPPD

II. LITERATURE REVIEW

The aim of this research was to solve the dynamic vehicle routing problem that involves multiple depots. Each depot has one vehicle to pick-up and deliver the goods between customers and the depot. New requests can be pick-ups or deliveries, and are generated dynamically. The locations of the vehicles are taken into consideration when re-planning the routing. Berbeglia et al. [3] stated that the main issue regarding the dynamic vehicle routing problem with pickups and deliveries is the online dial-a-ride problem (OIDARD). However, this particular problem is different from the DMDVRP. For example, the depot is not taken into consideration in OIDARD. There are few studies related to DVRP in which the depot is taken into consideration. Some recent related researches are introduced as follows.

Branchini et al. [4] proposed a constructive heuristic to maximize the expected profit of a Brazilian transportation company using a single depot and a fleet of vehicles. The capacity of each vehicle was limited. For any requests that could not be satisfied under the policy of the company, the company hired additional vehicles from small companies. Moreover, if the request could not be satisfied within the time window, lateness penalties were incurred.

Wen [5] introduced a problem based on a large distributor operating in Sweden. This was a dynamic vehicle routing problem which dealt with the distribution of orders from a depot to a set of customers over a multi-period time horizon. Customer orders and their feasible service periods were dynamically revealed over time. The problem was modelled as a mixed integer programming problem and solved by a three-phase heuristic to minimize total travel costs and customer waiting times and to balance the daily workload over the planning horizon.

Lorini et al. [6] dealt with vehicles picking up goods at customer locations and bringing them back to a central depot. Two elements related to travel time were taken into consideration: time-dependent travel time and unknown dynamic perturbations, in addition to new customer requests. Moreover, when the routes were modified to account for the occurrence of new customer requests, the positions of the vehicles were taken into consideration. The planned routes might require diverting a vehicle away from its current destination.

Mu et al. [7] assumed that when a vehicle breaks down during the delivery, a new routing solution must be quickly generated to minimize costs. The two Tabu Search algorithms developed to solve the problem were assessed in relation to an exact algorithm.

Azi et al. [8], basing their research on a static version of the vehicle routing problem proposed by Azi et al. [9], developed a dynamic version of the problem where each vehicle delivers goods to customers by multiple routes. When a vehicle leaves the depot, the current route cannot be changed; therefore, if a new customer request arrives after the vehicle left the depot, the delivery of the new request can only be included in some future routes. The objective was to maximize the total profit. If a new request for service has a higher cost but less revenue, that request will be rejected.

Hong [10] proposed an improved large neighborhood search (LNS) for a dynamic vehicle routing problem with a rigid time window. If possible, all new requests would be served by vehicles that had already left the depot. If the number of new requests was too great to be served by active vehicles, then a new vehicle was added to satisfy all requests. Like Lorini et al.

[6], the current positions of vehicles were taken into consideration, but only when the new request was urgent; in this way, costs could be minimized and the need to assign a new vehicle eliminated.

Pillac et al. [11] proposed a dynamic vehicle routing problem with stochastic demand (DVRPSD). They considered the single-vehicle case with discrete and uniformly distributed demand distributions. Because the demand from customers is uncertain, it is possible that a request will exceed the remaining vehicle capacity. In this case, the vehicle delivers the quantity up to its remaining capacity and returns to the depot to restore its capacity. Afterward, a subsequent visit to the customer is planned to serve the remaining demand.

Ferrucci et al. [12] dealt with the relationship between the response time and customer inconvenience in a dynamic vehicle routing problem with soft time-window constraints. They assumed that after a request arrives, customer inconvenience increases gradually. However, if the response time exceeds the maximum allowed response time, customer inconvenience increases rapidly and incurs a high penalty. A Tabu Search (TS) algorithm was proposed for solving the problem.

Yu et al. [13] introduced a distance-based clustering approach to simplify the dynamic multi-depot vehicle routing problem by allocating each customer to its nearest depot. Thus, DMDVRP was decomposed to a sequence of DVRPs. An improved ant colony optimization (IACO) with an ant-weight strategy and mutation operation was presented to optimize the vehicle routing problem (VRP).

Albareda-Sambola et al. [14] introduced a dynamic multi-period vehicle routing problem with probabilistic information in which, at each time period, the set of customers requiring a service in later time periods was unknown, but its probability distribution was available. Requests for service must be satisfied within a given time window that comprises several time periods of the planning horizon. An adaptive service policy was proposed, which estimates the best time period to serve each request within its associated time window in order to reduce distribution costs.

With the exception of the literature cited above, no reports have dealt with the dynamic vehicle problem taking into account multiple depots, positions of the vehicles, pick-ups and deliveries.

III. INSERTION HEURISTIC

As mentioned in the first section, the aim of this research was to serve a new customer request with a new route in which the change to the previous route would be as small as possible. Therefore, an insertion heuristic was proposed, by which new customer requests would be inserted into the current solution. Each customer is inserted at the most feasible insertion place over every future route. In this research, the best insertion place corresponds to the lowest completion time. The completion time is the time until the last vehicle serves all its customer requests and returns to its depot. If two or more insertion places result in the lowest completion time, these insertion places will be selected to ensure the least detour time. The total completion time is the sum of the completion time of all vehicles. If all possible insertion places result in completion time longer than a given accepted completion time, the new request is rejected.

This research deals with two types of new customer requests, pick-up requests and delivery requests. For pick-up requests, if the current positions of vehicles are taken into consideration, a vehicle can change its current path to serve the new request immediately if it will result in the lowest completion time. An example of a possible insertion for this type of pick-up request is illustrated in Fig. 2(a). If the current positions of vehicles are not taken into consideration, the insertion between the current position of the vehicle and its current destination is not permitted. An example of a possible insertion of this type of pick-up request is illustrated in Fig. 2(b).

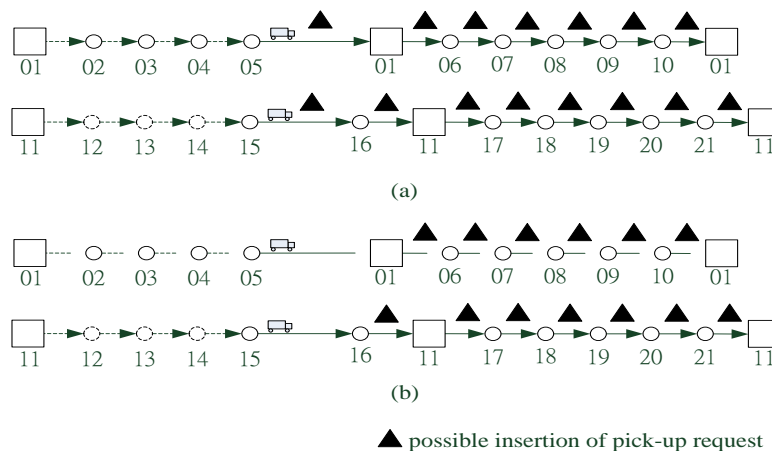


Fig. 2 Examples of possible insertions of a pick-up request

Delivery requests can only be served after a vehicle returns to its depot. Therefore, the possible insertion places are in future routes that begin from the depots of all vehicles. An example of a possible insertion of a delivery request is illustrated in Fig. 3.

Moreover, for both types of requests, it is possible to serve them after a vehicle has served all requests and returned to the depot. Therefore, the new request can be inserted after the last stop (depot), but a new stop (depot) must then be added. This means that a new route is added for a vehicle. An example of this kind of insertion is illustrated in Fig. 4.

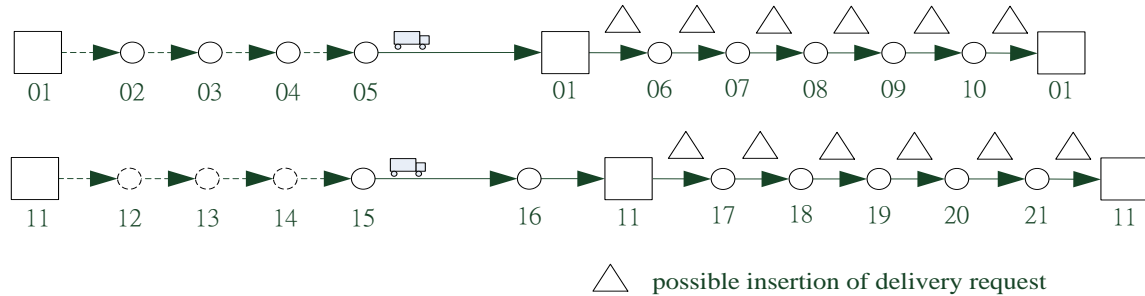


Fig. 3 Example of a possible insertion of a delivery request

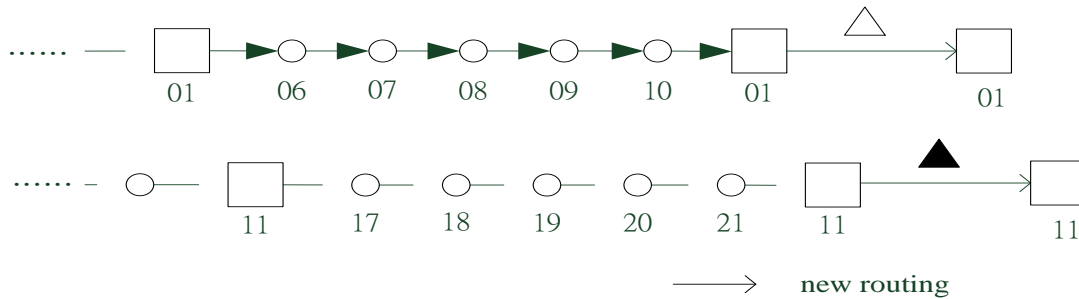


Fig. 4 Example of an insertion to add a new route

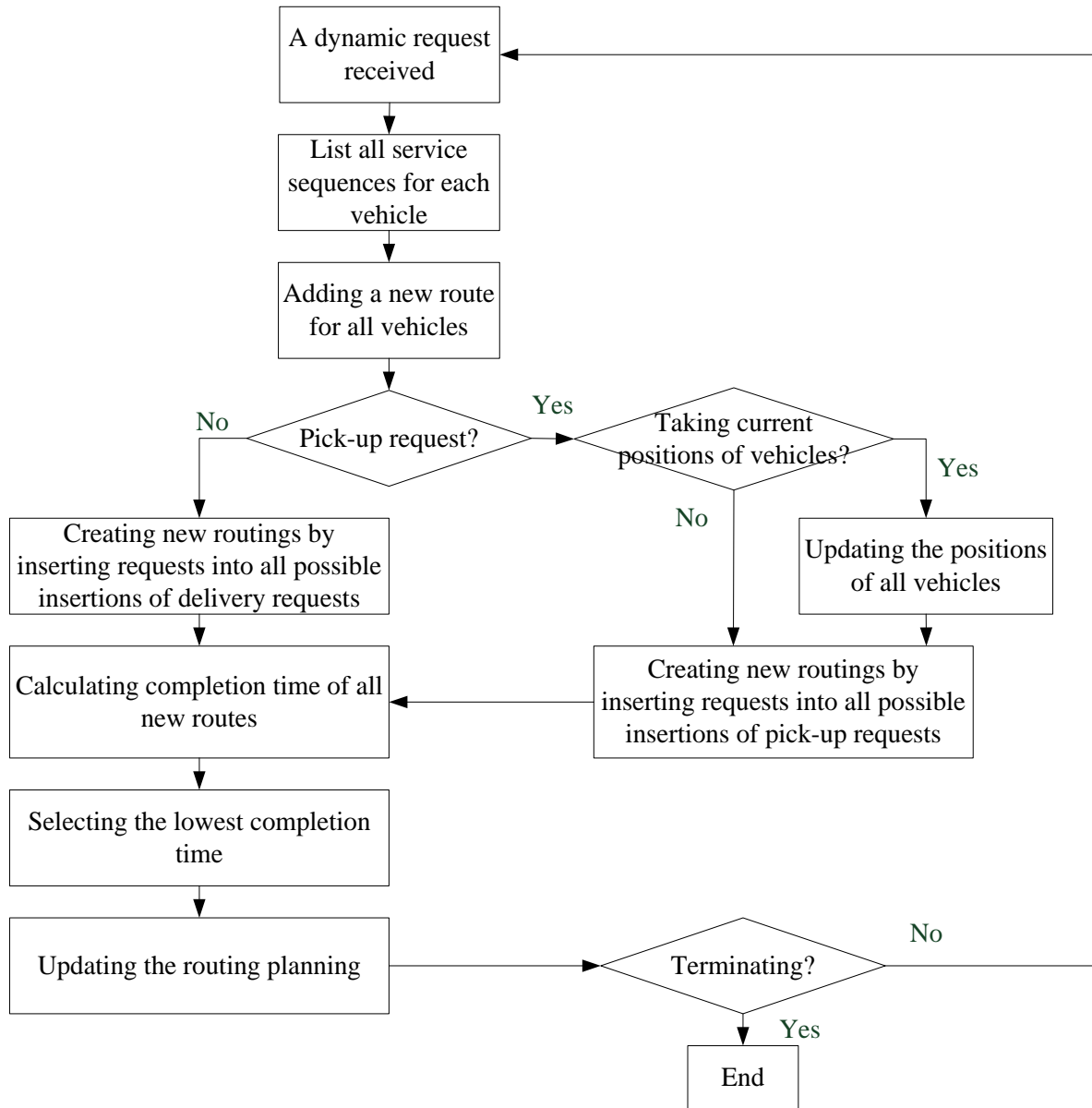


Fig. 5 Procedure of proposed insertion heuristic

The entire proposed insertion heuristic is illustrated in Fig. 5. The service sequence of each vehicle by which customers are to be serviced when a dynamic request is received is listed. Then, new routings are added for each vehicle, as illustrated in Fig. 4. If the new request is a pick-up request then all possible new routings are created, as illustrated in Fig. 2(a) and 2(b), respectively, depending on whether the vehicles' current positions are being taken into consideration. If the new request is a delivery request, then all possible new routings are created, as illustrated in Fig. 3. After all possible new routings are created, the completion time is calculated and the new routing plan with the lowest completion time is selected and updated.

The completion time of a new routing is a simple calculation. When customer k is inserted between two customers, i and j , who are to be serviced sequentially in the original route, the completion time of the new routing, CT' , can be calculated by Eq. (1). In this equation, CT indicates the completion time of the original routing, T_{ij} indicates the transportation time between customers i and j , T_{ik} indicates the transportation time between customers i and k , and T_{kj} indicates the transportation time between customers k and j .

$$CT' = CT - T_{ij} + T_{ik} + T_{kj} \quad (1)$$

IV. COMPUTATIONAL EXPERIMENTS

In this section, the performance of the proposed insertion heuristic in solving the DMDVRPPD is examined. The webpage <http://neo.lcc.uma.es/radi-aeb/WebVRP/> presents a range of VRP related instances, including a capacity-limited vehicle

routing problem (CVRP), MDVRP, periodic vehicle routing problem (PVRP), split delivery vehicle routing problem (SDVRP), and a vehicle routing problem with pick-up and delivery (VRPPD). For all instances, the corresponding best known solutions are provided on the webpage. The present research has taken the best known solutions of the first 5 MDVRP instances as the initial routes and assumed that the vehicle speed is 1, which means the distances are equal to the transportation time between any pair of customers.

A. Experimental Structure

In this research, the performances of the insertion heuristic are affected by the degree of dynamism and the accepted completion time. The degree of dynamism depends on the number of new customer requests and the arrival time of the new requests [15]. The more new customer requests and the later they arrive, the higher the degree of dynamism. Therefore, when the degree of dynamism is higher, more new customer requests could be rejected. As regards the accepted completion time, all vehicles have to serve all their requests and return to their depot before that time. Thus, the shorter the accepted completion time, the greater the likelihood a new customer could be rejected.

In relation to the concepts of degree of dynamism and accepted completion time, two parameters, N_{ratio} and T_{range} , were proposed in this research for the design of the experiment. N_{ratio} was used to determine the number of new customer requests, which can be calculated by Eq. (2), in which N_{static} is the number of known requests in the instance presented by the webpage. When N_{ratio} is larger, it indicates that the number of new customer requests is greater.

$$\text{Number of new customer requests} = N_{static} \times (1 + N_{ratio}) \quad (2)$$

TABLE 1 COMPLETION TIME WHEN THE ACCEPTED COMPLETION TIME IS UNLIMITED

Problems	Dynamic parameters		Completion time	
	N_{ratio}	T_{range}	Without considering current positions of vehicles	Considering current positions of vehicles
P01	0.1	0.5	344.31	284.97
		0.7	343.01	294.72
	0.2	0.5	388.23	308.51
		0.7	386.54	333.24
P02	0.1	0.5	281.71	278.70
		0.7	272.57	283.83
	0.2	0.5	334.34	294.84
		0.7	297.61	312.03
P03	0.1	0.5	363.26	323.79
		0.7	354.53	342.09
	0.2	0.5	402.30	380.12
		0.7	368.61	364.50
P04	0.1	0.5	895.02	776.34
		0.7	903.15	782.70
	0.2	0.5	1036.58	940.58
		0.7	1030.19	923.93

P05	0.1	0.5	849.22	716.73
		0.7	817.57	675.82
	0.2	0.5	1035.30	884.64
		0.7	1027.21	860.93
Average			586.56	518.15

T_{range} was used to decide the arrival time of new customer requests. In this research, all new customer requests were assumed to arrive randomly in a range between time 0 and T_e . T_e can be calculated by Eq. (2). When T_{range} is larger, it indicates that a new customer request could arrive later.

$$T_e = \text{Accepted completing time} \times T_{range} \quad (3)$$

The whole experimental structure, which included insert heuristic, problem generation and a completion time calculation, was coded via C# programming language. The whole experimental structure is shown in the second and third columns of Table 1.

Moreover, the probabilities of new pick-up and delivery requests are the same. This research tested each instance in two situations. The first situation assumed that the accepted completion time was unlimited; therefore, all new customer requests were accepted. The second situation assumed that the accepted completion time was 1.1 times the completion time of the original instances when N_{ratio} was 0.1, and 1.2 times the completion time of the original instances when N_{ratio} was 0.2.

B. Analysis of Experimental Results

Table 1 shows the completion time in the first situation. It was found that considering the current positions of vehicles resulted in shorter completion time in most cases. However, for some cases, this was not guaranteed. Table 2 shows the percentage of new customer requests accepted in the second situation. It was found that considering the current positions of vehicles led to the rejection of more requests in most cases. The results, as shown in Tables 1 and 2, indicated that taking the current positions of vehicles into account did not guarantee a better performance.

TABLE 2 PERCENTAGE OF NEW CUSTOMER REQUESTS ACCEPTED WHEN ACCEPTED COMPLETION TIME IS LIMITED

Problems	Dynamic parameters		Percentage of new customer requests accepted	
	N_{ratio}	T_{range}	Without considering current positions of vehicles	Considering current positions of vehicles
P01	0.1	0.5	20%	28%
		0.7	20%	24%
	0.2	0.5	24%	34%
		0.7	28%	32%
P02	0.1	0.5	52%	60%
		0.7	52%	60%
	0.2	0.5	48%	60%
		0.7	54%	62%
P03	0.1	0.5	37%	42%
		0.7	40%	45%
	0.2	0.5	44%	49%

		0.7	46%	53%
P04	0.1	0.5	76%	76%
		0.7	76%	74%
	0.2	0.5	82%	81%
		0.7	82%	76%
P05	0.1	0.5	78%	88%
		0.7	78%	90%
	0.2	0.5	89%	88%
		0.7	89%	89%
Average			55.81%	60.61%

V. CONCLUSIONS

This research aimed to solve a DMDVRP in which pick-up and delivery requests were considered. In order to minimize the change of routes, an insertion heuristic, which took the current positions of vehicles into consideration, was proposed. Five examples of the MDVRP, as provided by a specialist webpage, were tested in order to analyze the difference between scenarios where the current positions of vehicles were or were not considered. The results showed that taking the current positions of vehicles into account did not guarantee a better performance.

The literature survey conducted for the present study indicated that the proposed DMDVRPPD is new and there has not been a previous formulation. If the proposed DMDVRPPD was formulated as an optimization problem, then it would be possible to adopt more solution methods, as well as take more factors into account. This would provide an opportunity for future research; however, the result would be new routes very different from the original routes and thus depart from the motivation for our use of the insertion heuristic.

Moreover, when taking the current positions of vehicles into consideration, the ‘current positions’ change continuously. When a new customer request arrives, the routing planners need to know the positions of vehicles for re-planning the new routes in order to accept or reject that request. When the new request is accepted, the new routes are transmitted to the drivers, but there is a time delay between routing planners receiving the positions of all vehicles and drivers receiving their new routes. Sometimes it is difficult for drivers to follow their new routes. For example, the vehicle may have just passed an intersection or moved onto a highway.

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REFERENCES

- [1] W. Ho, G. T. S. Ho, P. Ji, and H. C. W. Lau, “A hybrid genetic algorithm for the multi-depot vehicle routing problem,” *Engineering Applications of Artificial Intelligence*, vol. 21, pp. 548–557, 2008.
- [2] Y. Kuo and C. C. Wang, “A variable neighborhood search for the multi-depot vehicle routing problem with loading cost,” *Expert Systems with Applications*, vol. 39, pp. 6946–6954, 2013.
- [3] G. Berbeglia, J. F. Cordeau, and G. Laporte, “Dynamic pickup and delivery problems,” *European Journal of Operational Research*, vol. 202, pp. 8–15, 2010.
- [4] R. M. Branchini, V. A. Armentano, and A. Løkketangen, “Adaptive granular local search heuristic for a dynamic vehicle routing problem,” *Computers and Operations Research*, vol. 36, pp. 2955–2968, 2009.
- [5] M. Wen, J. F. Cordeau, G. Laporte, and J. Larsen, “The dynamic multi-period vehicle routing problem,” *Computers and Operations Research*, vol. 37, pp. 1615–1623, 2010.
- [6] S. Lorini, J. Y. Potvin, and N. Zufferey, “Online vehicle routing and scheduling with dynamic travel times,” *Computers and Operations Research*, vol. 38, pp. 1086–1090, 2011.
- [7] Q. Mu, Z. Fu, L. Lysgaard, and R. Eglese, “Disruption management of the vehicle routing problem with vehicle breakdown,” *Journal of the Operational Research Society*, vol. 62, pp. 742–749, 2011.

- [8] N. Azi, M. Gendreau, and J. Y. Potvin, "A dynamic vehicle routing problem with multiple delivery routes," *Annals of Operations Research*, vol. 199, pp. 103-112, 2012.
- [9] N. Azi, M. Gendreau, and J. Y. Potvin, "An exact algorithm for a vehicle routing problem with time windows and multiple use of vehicles," *European Journal of Operational Research*, vol. 202, pp. 756-763, 2010.
- [10] L. Hong, "An improved LNS algorithm for real-time vehicle routing problem with time window," *Computers and Operations Research*, vol. 39, pp. 151-163, 2012.
- [11] V. Pillac, C. Guéret, and A. L. Medaglia, "An event-driven optimization framework for dynamic vehicle routing," *Decision Support Systems*, vol. 54, pp. 414-423, 2012.
- [12] F. Ferrucci, S. Bock, and M. Gendreau, "A pro-active real-time control approach for dynamic vehicle routing problems dealing with the delivery of urgent goods," *European Journal of Operational Research*, vol. 225, pp. 130-141, 2013.
- [13] B. Yu, N. Ma, W. Cai, T. Li, and X. Yuan, "Improved ant colony optimization for the dynamic multi-depot vehicle routing problem," *International Journal of Logistics Research and Applications: A Leading Journal of Supply Chain Management*, vol. 16, pp. 144-157, 2013.
- [14] M. Albareda-Sambola, E. Fernández, and D. Laporte, "The dynamic multiperiod vehicle routing problem with probabilistic information," *Computers and Operations Research*, vol. 48, pp. 31-39, 2014.
- [15] A. Larsen, O. B. G. Madsen, and M. M. Solomon, "Partially dynamic vehicle routing - models and algorithms," *Journal of the Operational Research Society*, vol. 53, pp. 637-646, 2002.