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A Novel Adaptive Genetic Algorithm for Dynamic Vehicle Routing Problem With Backhaul and Two-Dimensional Loading Constraints:

A Case in Tunisian Posta

Ines Sbai, Institut Supérieur de Gestion de Tunis, LARODEC Laboratory, Université de Tunis, Tunis, Tunisia*
Saoussen Krichen, Institut Supérieur de Gestion de Tunis, LARODEC Laboratory, Université de Tunis, Tunis, Tunisia

ABSTRACT

In this paper, the authors consider an extension of the dynamic vehicle routing problem with backhauls integrated with two-dimensional loading problem called DVRPB with 2D loading constraints (2L-DVRPB). In the VRPB, a vehicle can deliver (linehaul) then collect goods from customers (backhaul) and bring back to the depot. Once customer demand is formed by a set of two-dimensional items, the problem will be treated as a 2L-VRPB. The 2L-VRPB has been studied on the static case. However, in most real-life applications, new customer requests can happen over time of backhaul and thus perturb the optimal routing schedule that was originally invented. This problem has not been analysed so far in the literature. The 2L-DVRPB is an NP-Hard problem, so the authors propose to use a genetic algorithm for routing and packing problems. They applied their approach in a real case study of the regional post office of the city of Jendouba in the North of Tunisia. Results indicate that the AGA approach is considered as the best approach in terms of solution quality for a real-world routing system.

KEYWORDS

2L-DVRP, Backhaul, Dynamic Vehicle Routing Problem, Genetic Algorithm, Packing, Post Office

1. INTRODUCTION

Vehicle Routing Problem (VRP) is a key component of distribution and logistics management. It consists in finding an optimal set of trips for a fleet of vehicles which must serve a predefined set of customers. The most studied variant in transportation logistics is capacitated VRP (CVRP) (Sbai et al. (2020)).

The CVRP can be extended to the VRP with time windows (VRPTW) by adding time windows in which deliveries need to take place. Another variant is the VRP with pickups and deliveries (VRPPD) in which orders may be picked up and delivered. More recently, a VRP with backhauls (VRPB) or the linehaul-backhaul problem has been studied, when VRP involving both delivery (linehaul) and pickup (backhaul) points. In contrast to the classical VRP, a practical important variant of this problem is the dynamic VRP (DVRP) where new customer demands change during operation reference.

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In real life, companies are faced with a large number of additional constraints which increase the com- plexity of the problem. For example, the capacitated vehicle routing problem with two-dimensional loading constraints (2L-CVRP) includes the routing and loading aspects simultaneously.

The 2L-CVRP is defined as giving a central depot of a homogenous fleet of vehicles driving between two customers, or from the depot to a customer, to deliver requested product. Products to be de- livered are thought to be rectangular shaped items. The objective of the 2L-CVRP is to find the routes of the vehicles of the fleet, minimizing the delivery costs, and determining, for a given route, the feasible two-dimensional orthogonal loading arrangement of the transported items into the vehicle loading surface.

Planning the distribution and pick-up of goods as a VRP with Backhauls (VRPB) in an efficient manner is an appropriate way to reduce logistic cost and improve the quality of service. Therefore, we consider the 2L-CVRP with backhaul, in which a set of customers can be divided in two distinct sets: the set of linehaul (deliver) and the set of backhaul (pickup) customers. For each route two packing plans have to be provided that stow all boxes of all visited linehaul and backhaul customers, respectively, taking into account the additional packing constraints.

All the existing research has been studied the 2L-VRPB as a static case in which all information and problem parameters are assumed to be known in advance, and the related decisions are made prior to the start of plan execution. However, in real-life applications, a new arrived order such as a courier, money-transfer and repair-maintenance services can be happen over time and thus trouble the optimal routing schedule that was originally invented.

Therefore, we address a Dynamic Vehicle Routing Problem with Backhaul and 2-dimensional loading constraints (2L-DVRPB) in which new customer orders with two-dimension and order cancellations continually happen over time of backhaul.

This problem is a combination of two most important NP-hard optimization problems in distribution logistics, the Dynamic Vehicle Routing Problem with Backhaul constraint (DVRPB) and the Two-dimensional Bin Packing Problem (2BPP).

To solve the 2L-DVRPB, we propose an Adaptive Genetic Algorithm (AGA) and a new packing heuristic named Min lost area heuristic (MILAH).

Moreover, the 2L-DVRPB has many industrial applications in different fields of real life, such as shipping and transportation industry. So, we applied our approach in a real case study of the dis- tribution of two dimension parcels in Regional Post Office of the region of Jendouba in the North of Tunisia.

The remainder of this paper is structured as follows. The related literature review is provided in Sec- tion 2. Section 3 and 4 present a brief description and a Mathematical formulation of the 2L-DVRPB problem. Section 5 describes the proposed Genetic Algorithm for solving the 2L-DVRPB. In Section 6, a set of heuristics for the loading subproblem are given. In section 7 and 8, the efficiency of the proposed approach is investigated with experimental results and a real case study. In Section 7, we end with some concluding remarks and future works.

2. LITERATURE REVIEW

Several works have been developed to address numerous variants of the CVRP while considering additional features such as dynamic aspect, backhaul and loading (packing) aspects. The dynamic vehicle routing problem is well-known as an *NP-H*ard combinatorial optimization problem that at- tract significant attention over the past few years (Abdallah et al. (2017) and Chen et al. (2018)). Backhauling has been proven to be an efficient way to achieving significant savings. In the Vehicle Routing Problem with Backhauls (VRPB), the set of customers is divided into delivery locations (linehaul) or pickup points (backhaul), a recent survey paper with interesting conclusions and research perspectives on the VRP with backhaul, including models, exact and heuristic algorithms, variants, industrial applications and case studies, are identified in Koc and Laporte (2018). Since new requests appear during the routing service, the problem will be considered as dynamic. To solve the DVRPB, Ninikas and Minis (2014) employed the heuristic Branch-and-Price algorithm. Also, Wang and Cao (1997) used a local search (LS) algorithm. Ninikas et Minis (2018) solved a variant of DVRP with Multi Backhauls that allows orders to be transferred between vehicles during plan implementation using Branch-and-Price algorithm.

Regarding a brief outline of the literature on the 2BPP which is the term of defining a loading problem which choose to use the problem in 2D only. To solve the 2BPP, exact algorithms and lower bounds was used by Pisinger and Sigurd (2007) and Fekete and Schepers (2006). Also, metaheuristic methods have also been proposed to solve this problem, Lodi et al. (2017) presented a heuristic algorithm based on partial enumeration to solve the 2BPP with guillotine constraints. Then, Dahmani et al. (2015) proposed a variable neighborhood descent (VND) algorithm. In the same way, Khebbache et al. (2008) used the Iterated LS. Whereas, Polyakovskiy and M'Hallah (2018) proposed both exact and approximate approaches to solve the 2BPP with due dates.

In recent years, new research studies combining the CVRP and 2BPP have appeared. The 2L-CVRP was studied first by Iori et al. (2007) using an exact algorithm based on branch-and-cut technique, they tested their approach with only small scale instances (60 instances). To tackle large size problem, the first meta-heuristic approach for the is the Tabu Search (TS) proposed by Gendreau et al. (2008) for the routing and the packing problems. Then, Zachariadis et al. (2009) proposed a Guided TS which is a combination between a TS and a Guided LS. Fuellerer et al. (2009) presented an Ant Colony Optimization (ACO). After that, an Extended Guided TS algorithm (EGTS+LBFH) is developed by Leung et al. (2011). Duhamel et al. (2011) combined the Greedy Randomized Adaptive Search (GRASP) Procedure with Evolutionary LS algorithm to obtain a RCPSP-CVRP solution (GRASP-ELS) and to transform it into 2L-CVRP solution. In addition, Leung et al. (2013) developed a Simulated Annealing (SA) with heuristic LS. In the same way, Zachariadis et al. (2013) proposed a Promise Routing-Memory Packing (PRMP). Wei et al. (2015) proposed a Variable Neighborhood Search(VNS) approach. For the same problem, Sbai et al. (2017) presented an adaptive GA for solving the 2L-CVRP with time windows, results showed that the proposed GA is competitive in terms of the quality of the solutions founded. In the same way, Sbai et al. (2020) used an effective GA for solving the 2L-CVRP, the algorithm is tested with 150 benchmark instances, experimental results show the effectiveness of the proposed algorithm. In addition, Wei et al. (2018) proposed A SA algorithm with a mechanism of repeatedly cooling and rising the temperature to solve the four ver- sions of this problem, with or without the LIFO constraint, and allowing rotation of goods or not. More recently, Guimarans et al. (2018) proposed a hybrid simheuristic algorithm to solve a version of the 2L-CVRP with stochastic travel times.

The combination of VRP whith backhauls and loading constraints is a recent studied problem, Bort- feldt et al. (2015) proposed a LNS and a VNS (LNS-VNS) for solving the three dimension VRP with backhaul and a Tree Search heuristic (TSH) is proposed for packing boxes. Reil et al. (2018) extended the last approach for the VRPBTW with 3D loading constraints by considering various types of backhauls. Pinto et al. (2015) studied the VRP with mixed Backhaul using an insert heuristic and a Bottom-Left heuristic (BLH) for packing aspect. Also, Dominguez et al. (2016) proposed a hybrid algorithm that integrates biased-randomised versions of vehicle routing and packing heuristics within a LNS metaheuristic framework. Moreover, Zachariadis (2017) described a LS approach for solving the 2L-VRPSDP and the 2L-VRPCB. Pinto et al. (2017) proposed a VNS algorithm. Likewise, the VRP

with pickup and delivery (PD) and 2D or 3D loading constraints is only addressed in four works. The first one is proposed by Malapert et al. (2008) for solving the 2L-VRPPD. The second one is presented by Bartok and Imreh (2011) for solving the 3L-VRPPD using a simple LS method. The third one is described by Mannel and Bortfeldt, they discussed several 3L-VRPPD variants and a hybrid approaches based on LNS and tree search heuristics are proposed for packing boxes. The last one is introduced by Zachariadis et al. (2016) the VRP with Simultaneous (2L-SPD) with LIFO constraints using a Local Search algorithm. The previous papers studied the 2L-VRPB in the static case, while,

Table 1. Comparative study of the existing VRP with Backhaul and loading constraints in the literature

	Reference	Problem	TW	Environ-Ment	Packing algorithm	Routing algorithm	Bench-mark	Case study
VRP With Backhaul	Bortfeldt et al.(2015) [3]	3L-VRPB	-	Static	TSH	LNS/VNS	✓	
	Reil et al (2018) [38]	3L-VRPB	✓	Static	TS	TS	✓	
	Pinto et al.(2015) [33]	2L-VRPMB	-	Static	BLH	Insert-heu	✓	
	Zachariadis et al.(2017) [49]	2L-VRPB	-	Static	LS	LS	✓	
	Pinto et al. (2017) [35]	2L-VRPB	-	Static	VNS	VNS	✓	
	This Paper	2L-DVRPB	-	Dynamic	GA	GA	✓	✓
Pickup And Delivery Problem	Bartok and Imreh (2011)[2]	Pickup 3L-VRPPD	✓	Static	LS	LS	✓	
	Mannel and Bortfeldt(2016) [26]	3L-VRPD	-	Static	TSH	LNS	✓	
	Zachariadis et al (2016) [48]	2L-SPD	-	Static	LS	LS	✓	
	Malapert et al.(2008)[25]	2L-VRPPD	-	Static	based-model heuristics	Bottom-Left scheduling	✓	

in this work, we choose to use a new combination of two combinatorial optimisation problems: the Two- dimensional Vehicle Routing Problem (2L-VRP) and the Vehicle Routing Problem with Backhauls (VRPB) and dynamic request(DVRPB). Table 1 presents a comparative State-of-the art study of the existing VRP with Backhaul and loading constraints.

3. PROBLEM DEFINITION

In this paper, we consider a realistic variant of the CVRP that combines vehicle routing and loading (packing) aspects as well as backhauls:

- **Routing** : A route R is a sequence $(0,c_1,\ldots,c_n,0)$ that starts and ends with the depot and includes $n \geq 1$ pairwise different customers ($c_i > 0$). A route is feasible if it includes at least one linehaul customer ($1 \leq c_i \leq$ l) and all linehaul customers precede the first backhaul customer (l+1 $\leq c_i \leq$ l+b) if any. A solution is called feasible if the following conditions are satisfied:
- Each route should choose the central depot as the starting and the ending point;
- All customers should be visited once and only once;
- Each customer appears exactly in one route;
- The number of routes does not exceed the given number of vehicles
- **Loading** : each route consists of two legs. Along the first leg, linehaul orders are served. This implies that the vehicle leaves the depot fully loaded and delivers items to the customer locations. When the last linehaul of the route has been served, the vehicle space is empty and the vehicle proceeds to the second route leg along which backhaul customers are visited. This means that the loading constraints must be checked for the two depot-adjacent arcs: for the depot leaving arc, a feasible loading pattern must be identified for all delivery items assigned to the vehicle, while for the depot returning arc, a feasible loading pattern must be identified for all pick-up items shipped to the depot.
- **Backhaul** : a customer may require either delivery or pick-up service. Thus, the customer set N is composed by two customer types: the linehaul customers *l* which require only delivery service and the backhaul customers *b* which require only pick-up service.

The 2L-VRPB is aimed at identifying the minimum cost set of routes such that:
The total number of routes does not exceed Q (at most one route per vehicle).

- Within any route, linehaul customers are visited before backhaul ones (precedence constraint).
- There exists a feasible loading pattern for both the delivery and pickup items assigned to a route.

In this paper, we investigate a 2L-DVRPB model similar to the DVRP that was first introduced by Kilby et al. (1998) and then refined by Montemanni et al. (2003) with respecting the packing and the backhaul constraints. A general description of the static 2L-VRPB is first given in order to introduce our 2L-DVRPB model. In the static 2L-VRPB all the routing information is known in advance before the optimization has begun. Hence, no new information relevant to routing is obtained during the optimization. On the other hand, in the dynamic 2L-DVRPB, some information may exist to the planner in the backhaul case before the optimization begins but, generally, information can change or new information can be added during optimization.

3.1 Static 2L-VRPB

The 2L-VRPB is defined on a complete graph $G = (V, E)$, where $V = D \cup L \cup B$ is the vertex set of $1 + l + b$ vertices composed of the disjoint subsets $D = \{0\}$, $L = \{1, \ldots, l\}$ and B={l+1,. . . ,l+b}, that represent the depot, the linehaul customers and the backhaul customers, respectively. $E = \{(i, j) | i, j \in$ V, i $\neq j\}$ is the set of edges that connect the customers with each other and with ttthe depot. A nonnegative cost, c_{ij}, is associated with each edge $\{i,j\} \in E$ and represents the travel cost spent to go from customer i to customer j.

In the depot, there are m identical vehicles, each vehicle has the same weight capacity Q and a rectangular loading surface that is accessible from a single side for loading and unloading operations, whose width and length are W and H, respectively. We also denote by $A = W \times H$ the total area of the loading surface. It is also assumed that $m \geq max(m_L, m_B)$, where m_L and m_B are the minimum numbers of vehicles needed to separately serve all linehaul and backhaul customers, respectively.

Each vehicle starts its tour from the depot, deliver (Linehaul) its designated customers, then collect goods from customers (backhaul) and turns back to the depot.

An amount of demands q_i with a total weight equal to d_i is associated with every customer $i \in L \cup B$ that represents the amount requested from or delivered to the depot, depending on whether the customer is linehaul ($i \in$ L) or backhaul ($i \in$ B). Each demand has a specific width w_{ilt} and length h_{ilt}, $lt = \{1, \ldots, |q_i|\}$.

Each item lt will be denoted by a pair of indices (i, lt). We denote by $a_i = \sum_{t=1}^{|qi|} w_{it} \times h_{it}$ the total area of the items of each customer i, depending on whether the customer is linehaul (i $\in$ L) or backhaul (i $\in$ B).

The demand must be placed on the loading surfaces without being rotated: their l- and w-edges must be parallel to the L- and W-edges of the vehicle surfaces, respectively. This constraint models the practical cases of automated, fixed orientation palette loading. Considering the convenience of unloading of items, in our case of backhaul we consider the sequential version of loading (also referred as last in first out (LIFO)) for both loading and unloading operators, which is a more practical constraint: when a customer i is visited, all items of customer i must be unloaded by employing straight movements, parallel to the length of the vehicle, without moving items of other customers.

In addition, to take into account the packing feasibility in every route, we start by defining the loading surface of a vehicle as a W*H matrix with indexes x ϵ {1,2,…W} and y ϵ {1,2,…,H}. Hence, the position of the bottom-left corner of item lt from customer i, loaded on vehicle k, is denoted by coordinates $({}_{Xilt}{}^{k}, y_{ilt}^{k})$. We also define a route R as a subset of customers forming a route or partial route ($R \subseteq V$). Finally, we define the variable Ω_{ilt} to indicate if item lt of customer i has been rotated ($\Omega_{ilt} = 1$) or not ($\Omega_{ilt} = 0$).

The decision variables of the problem are, x_{ij}^{k}

defined as:

1 if the vehicle k travels from customers i to j
$x_{ij}^{k} = 0$ otherwise

Ω_{ilt}= 1 if item lt of customer i has been rotated
0 otherwise

In our case, the static 2L-VRPB aims to minimize the overall cost of each solution that uses m vehicles under the following constraints:

(a) All orders related to a customer should be loaded on the same vehicle;
(b) Each route should choose the central depot as the starting and the ending point;
(c) All customers should be visited once and only once;
(d) The total weight of all items in a route should not exceed the capacity Q of the vehicle;
(e) All items of each customer should be completely loaded on the surface of the vehicle; (f) No two items can overlap in the same route;
(g) The transportation requests of customers are exhaustively satisfied;
(h) Within any route, linehaul customers are visited before backhaul ones (precedence constraint). As shown, Figure 1 presents the static case (at t=0) where customer orders are known in advance

and two initial routes schedules (linked with solid line) are generated to service these static customers (presented with white nodes). At route 1, the sequence of linehaul customer visited is [0,1,2,3], while the sequence of backhaul customer visited is [3^*,2^*,1^*,0]. For each route (linehaul and backhaul) two feasible loading vehicles are associated. The first one involves all items to be delivered to linehaul customers where customer 1 requires two items (1-1 and 1-2), customer 2 requires one item (2-1) and customer 3 requires three items (3-1, 3-2 and 3-3).

The second loading vehicle is associated with items to be picked-up from backhaul customers and sent to the depot customer 3* sends one item (3*,1), customer 2^* sends one item (2^*,1) and customer 1^* sends two items (1^*,1 and 1^*,2).

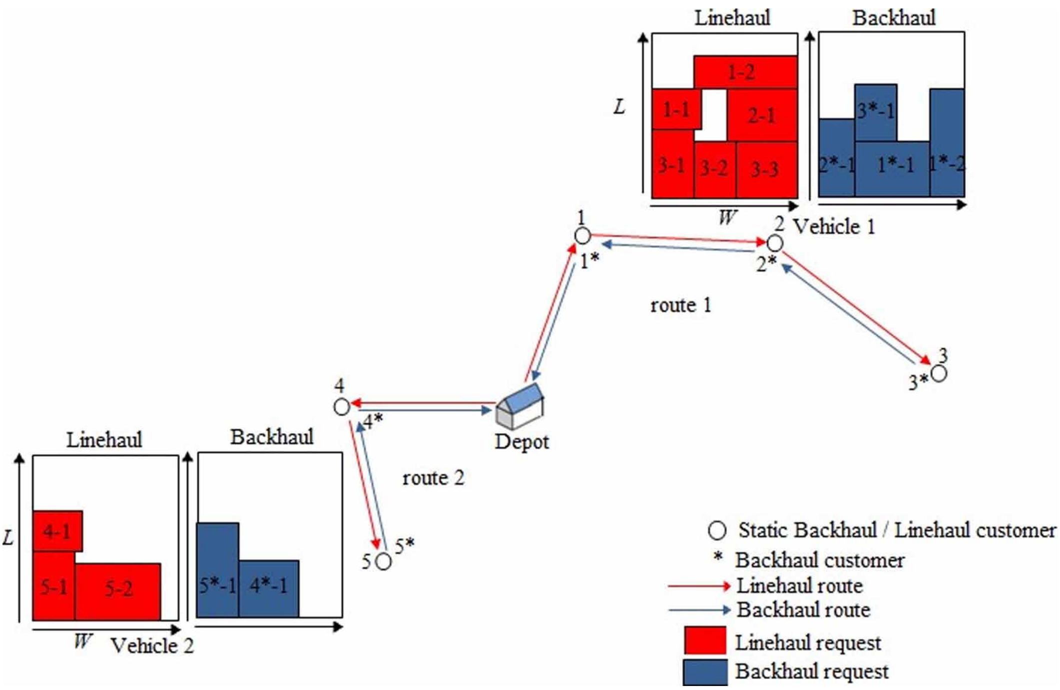
At route 2, the sequence of linehaul customers visited is [0,4,5] while the sequence of backhaul cus- tomers visits is [5^*,4^*,0]. Two loading vehicles are associated for linehaul and backhaul customers. For the case of linehaul order, customer 4 requires one item (4-1) and customer 5 requires two items (5-1 and 5-2), while for the backhaul order, customer 4^* sends one item (4^*-1) and customer 5^* sends one item (5^*-1) to the depot.

3.2 Dynamic 2L-VRPB

In contrast to a static 2L-VRPB (Dominguez et al. (2016)), the performance of the dynamic counterpart is assumed to be dependent not only on the number of customers and their spatial distribution, but also the number of dynamic events and the time *(t)* when these events actually take place with respecting the packing and the backhaul constraints.

Therefore, to measure the dynamism problem (Lund (1996)), the degree of dynamism is defined as follows:

Figure 1. An example of a static 2L-VRPB solution (at t=0)



$$\delta\left(\delta = \frac{\eta_d}{\eta_{tot}}\right)$$

.While, δ the ratio between the number of dynamic requests n_d and the total number of requests n_{tot}.

if (δ=1) all requests are known in advance (the problem is completely static)
if (δ=0) No requests are known in advance (the problem is completely dynamic)

As proposed by Montemanni et al. (2003), we decompose the 2L-DVRPB into a sequence of static 2L-VRPBs.

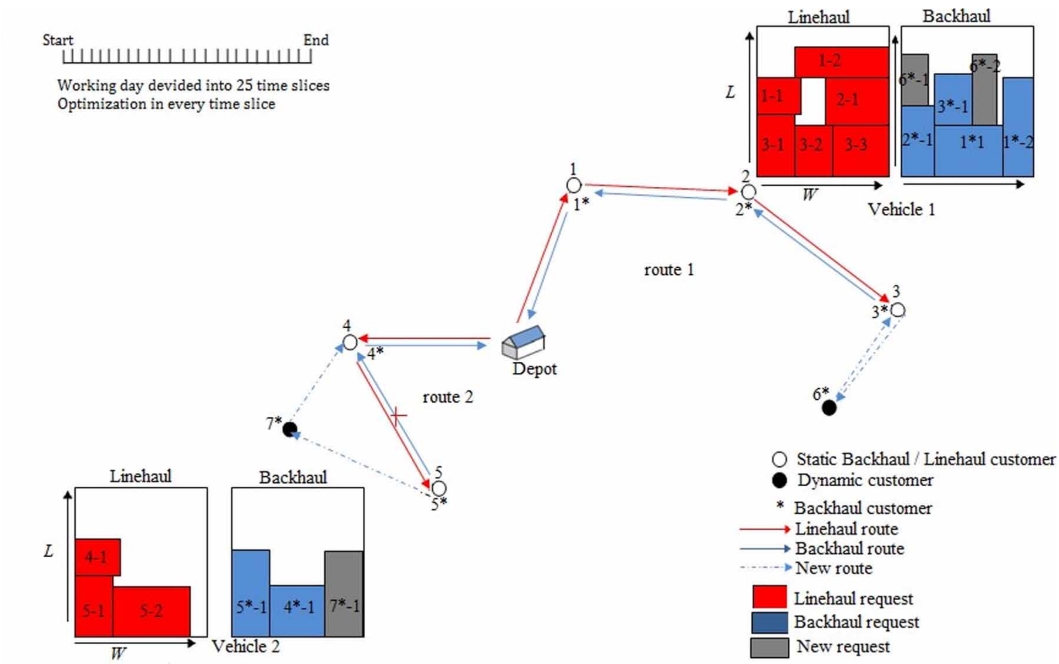
Therefore, to solve the 2L-DVRPB, the working day, T, is divided into *t*.

If any new customers order $q_i(t)$ arrives during a time *t* the solutions are re-adapted.

Once the calculations allotted for a given time t are completed the best-fitted chromosome is selected, decoded and the vehicle routes it represents are examined. In the DVRP, the solution(s) obtained from the previous time t can be reused as an initial population for the next time t. Figure 2presents an example of a 2L-DVRPB solution.

Figure 2 presents the dynamic case, where new backhaul customers (presented with black node) are considered. Therefore, new route segments (presented with dashed line) are created. For route 1, a new backhaul customer 6* arrived. So, the sequence of backhaul customer visited is updated to [6^*, 3^*, 2^*, 1^*, 0]. The new customer 6^* sends two items (6^*-1 and 6^*-2) within the loading backhaul vehicle to the depot. Regarding route 2, a new customer 7^* arrived and the sequence of backhaul customer visited is updated to [5^*,7^*,4^*,0]. The new customer 7^* sends one item (7^*,1) within the loading backhaul pattern to the depot. Figure 2 presents a framework of the suggested solution.

Figure 2. An example of a Dynamic 2L-VRPB solution (at t>0)



4. MATHEMATICAL FORMULATION OF THE 2L-DVRPB PROBLEM

In this section, we present the mathematical formulation of the 2L-DVRPB:

$$Min\ Z(x) = \sum_{k=1}^{m} \sum_{i=0}^{n} \sum_{j=0,j\neq i}^{n} C_{ij}(t)\ x_{ij}^{k}(t) \tag{1}$$

$$\sum_{j=1}^{n} x_{0j}^{k}(t) = \sum_{i=1}^{n} x_{0i}^{k}(t) = 1, k \in \{1,\ldots,m\} \tag{2}$$

$$\sum_{j=0,j\neq i}^{n} \sum_{k=1}^{m} x_{ij}^{k}(t) = 1, i \in \{1,\ldots,n\} \tag{3}$$

$$\sum_{i\in b;j\in l} x_{ij}^{k}(t) = 0, k \in m \tag{4}$$

$$\sum_{i\in l;j\in b} x_{ij}^{k}(t) \leq 1, k \in m \tag{5}$$

$$\sum_{i=1}^{n}\sum_{j=0,j\neq i}^{n} x_{ij}^{k}\left(t\right)q_{i}\left(t\right) \leq Q, k \in \left\{1,\ldots,m\right\} \tag{6}$$

$$\sum_{i,j\,\epsilon V, i\neq j} a_{i}\, x_{ij}^{k}\,(\mathrm{t}) \leq \mathrm{A},\ \mathrm{k}\ \epsilon\ \{1,\ldots \mathrm{K}\} \tag{7}$$

$$0 \leq x_{ilt}(t) \leq (W-w_{ilt})(1-\Omega_{ilt})+(W-h_{ilt}\,\Omega_{ilt}) \tag{8}$$

$$0 \leq y_{ilt}(t) \leq (H-h_{ilt})(1-\Omega_{ilt})+(H-w_{ilt}\,\Omega_{ilt})$$
$$\forall\ i\ \epsilon R,\ \forall\ lt\ \epsilon\ \{1,2,\ldots m_{i}\}$$

$$x_{ilt}(t)_{+}\ w_{ilt}(1-\Omega_{ilt})+h_{ilt}\,\Omega_{ilt} \leq x_{jl't} \tag{9}$$

$$x_{jl't}(t)_{+}\ w_{jl't}(1-\Omega_{jl't})+h_{jl't}\,\Omega_{il't} \leq x_{ilt}$$
$$y_{ilt}(t)_{+}\ h_{ilt}(1-\Omega_{ilt})+w_{ilt}\,\Omega_{ilt} \leq y_{jl't}$$
$$_{yjl't}(t)_{+}\ h_{jl't}(1-\Omega_{jl't})+w_{jl't}\,\Omega_{jl't} \leq y_{ilt}$$
$$\forall\ i,j\ \epsilon R,\ \forall lt\epsilon\{1,2,\ldots,q_{i}\},\ \forall\ l't\epsilon\{1,2\ldots q_{j}\},\ (i,lt) \neq (j,l't)$$

$$x_{ij}^{k}\left(t\right), y_{j}^{k}\left(t\right) \in \left\{0,1\right\} i, \in \left\{1,\ldots,n\right\}, j \in \left\{0,\ldots,n\right\}, i \neq j, k \in \left\{1,\ldots,m\right\} \tag{10}$$

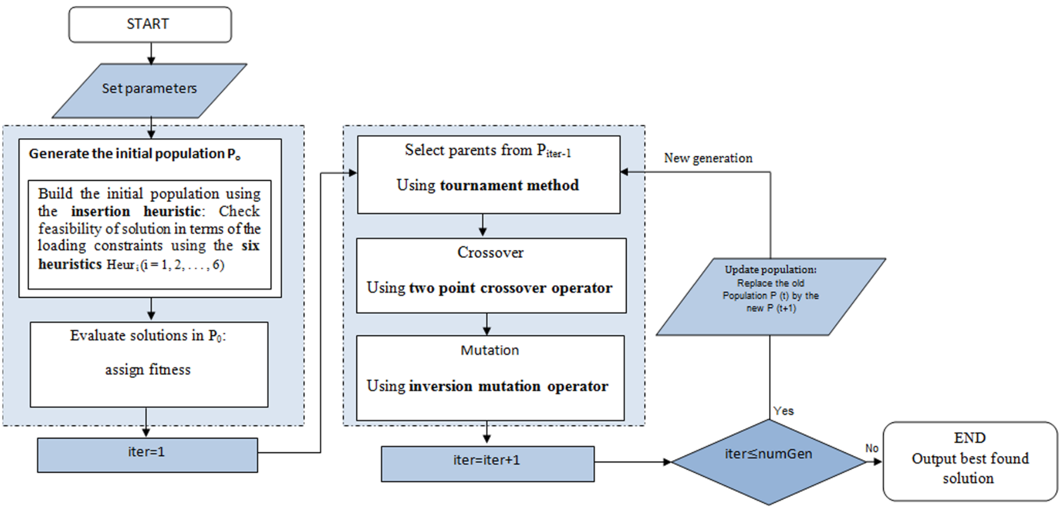
- The objective function (1) consists of minimizing the total cost of a fleet of vehicles at time t.
- Constraints (2) express that each travel should begin and end at the depot and routes are only allowed to start with a linehaul customer.
- Constraints (3) provide that a single vehicle leaves each customer *at time t.*
- Constraints (4) and (5) enforce that no linehaul customers are visited with vehicle *k* after servicing any backhaul customer.
- Constraints (6) guarantee that the vehicle weight is not exceeded.
    - Constraints (7) guarantee that the vehicle surface is not exceeded.
    - Constraints (8)ensures that items are loaded within the vehicle's loading surface
    - Constraints (9) permit to avoid any two items (lt and lt') overlapping on the surface of the vehicle.
    - Constraints (10) are the integrality conditions on the x-variables.

5. AN ADAPTIVE GENETIC ALGORITHM FOR THE 2L-DVRPB

The 2L-DVRPB is a combination of two NP-hard problems: the dynamic VRPB and the two-dimensional bin packing problem (2BPP). Genetic Algorithms (GAs) proved to be able to solve many NP-hard problems reaching near optimum solutions. In addition, GAs are good at solving dy- namic problems AbdAllah et al. (2017). An adaptive GA is developed to solve the proposed 2L-DVRPB. A flowchart illustrating the sequence of applying improvements to the AGA is given in Fig. 3. In our case, our AGA starts by generated an initial population using the insertion

heuristic, to determine whether a route-sequence of customers-is feasible in terms of the loading con- straints of the examined problem, we designed a bundle of six packing heuristics $Heur_{i}$ (i = 1, 2, . . . , 6). A set of parameters are initialised in this step which are (maximum number of generations (Max- Gen), population size (PS), crossover rate (CR) and mutation rate (MR)). Then, a fitness function

Figure 3. Flowchart of the proposed AGA



using the objective function is used to evaluate each individual. Two solutions are selected randomly from the population using the tournament selection. After that, a two point crossover is used in order to maintain the feasibility of the random moves. Then, an inversion mutation operation is defined as a perturbation of the structure with a random element that may effect the next generation. At each generation, the fitness is then selected to enhance an improved population for the subsequent steps. Finally, the old population is replaced by the new population of offspring solutions. This process is repeated until a number of generations are reached (1000 generations). Algorithm 1 describes the main steps of our AGA. In the following subsections, we describe our proposed AGA in more details.

Algorithm 1. The Adaptive GA approach for the 2L-DVRPB

```
Input: :
   N: set of customer ; Q: vehicle capacity; i_l, i_b: linhaul and backhaul requests,
   population P(t), t: number of generation                          # GA parameters
Begin
t=0                                                                  # generation counter
Create an Initial Population Insertionheuristic
Evaluate each chromosome in P(t)        # Evaluate P (t): Population of chromosomes using fitness function
while Stopping criterion is not satisfted        # Stopping criterion: no more feasible moves can be made do
If Environmental change then
  Re-adapt solutions
  else Initialize P^t                                                # P^t: a temporary population
for i=1 to P(t)| do |
      Select two parents from P(t)
      Apply Crossover (offspring)                   # Using the Two point Crossover operator
      if the offspring and parents are identical then
          Improve each offspring by the Mutation operator             # Using the inversion operator
      end if
end for
   t = t + 1;                                                        # Update generation counter
Replace the old Population P (t) by the new P^t;
end if
end while
Output: Best found solution    # routes with shortest total travelled distance for serving linhaul and backhaul customer
   nodes
End
```

5.1 Initial Population

First, a randomly initial population is generated.

An insertion heuristic is used to dispatch requests to vehicle routes. First we start with opening R empty routes. A starting region is chosen randomly from the depot. After that, iteratively insert one customer at a time. Since the definition of the VRPB requires that every vehicle visits at least one linehaul customer the heuristic insert a randomly selected linehaul customer at the beginning of each route as an initialization step. At each iteration, one customer is randomly selected and inserted in a randomly chosen route. If the selected customer is a linehaul customer, it is inserted at the beginning of the route. If it is a backhaul customer, it is inserted at the end of the route. The customers are inserted in the solution with considering the capacity and the packing constraints of the problem. Then, linehaul and static backhaul customers are sequentially inserted in increasing order of the angle formed by each region and their locations and Customers are inserted into the position service with minimum routing cost with respecting the packing and the following linehaul and backhaul customers constraints:

A linehaul customer can only be inserted between two linehauls or between the depot and the first linehaul or between the last linehaul and the first backhaul or if there is not a backhaul in the route, the insertion will be between the last linehaul and the depot. The same constraints are applied to the insertion of a backhaul customers.

Once the initial static routes are generated, the simulation of the operations day can start. A new customer request is inserted at minimum additional cost into one of the planned routes. The solution is updated.

The above process is repeated until a feasible 2L-DVRPB solution is obtained and will be updated automatically with the arrival of a new customers.

5.2 Solution Encoding

Each 2L-DVRPB solution encoding is based on indexed array to present the chromosomes. Each chromosome includes a set of linehauls customers and backhaul customers, to be visited by an assigned vehicle. The 2L-DVRPB solution is represented by a set of chromosomes, it can be considered as a valid solution if all constraints for the loading and routing problems are satisfied.

In our AGA representation, the solution is a set of n where $n = L + B$ customers. Each 2L-DVRPB solution is a string entities of an artificial chromosome.

Algorithm 2. Insertion heuristic

```
Input: :
   n: set of unassigned customers ; R: set of empty routes; K set of used vehicles
Begin
R_i=0                                                    #Initialize an empty route R
k=0                                                      # Initialize an empty vehicle k
repeat
    Among all unassigned customers, select the customer closest to the depot
      IF packingheur=TRUE # Check the feasibility of the solution in terms of the loading constraints using the six
    heuristics Heur_i (i = 1, 2,..., 6)
    R ← R_i   n_i                                        # Assigned a customer n_i to the route R_i
    n ← n\  n_i                      #Remove customer n_i from the list of unassigned customer
    ELSE
     R ← R_i+1                                           # Start a new route
     k ← k+1                                             # Start a new vehicle
     ENDIF
until n= {Ø}                                             # all customers are inserted

Output: Feasible obtained solutions
End
```

The solution is represented as an integer string. In our approach, a chromosome representation has the form of a vector of length (L+B+m+1), where L is the number of Linehaul customers, B is the number of backhaul customers and m is a set of identical vehicles. There are also the depot 0 in the vector representing the start and the end of each vehicle route. The sequence between two 0 is the sequence of nodes to be visited by a vehicle.

Each gene in the string or chromosome is the integer node number assigned to that customer originally. Figure 4 presents an example of a chromosome of 2 routes with 12 customers (5 linehaul customers and 6 backhaul customers) where the node 0 indicates the center Depot. The positive nodes represent the static customers and the negative ones represent the dynamic customers (when a new customer is newly added).

The two routes are presented as follows: Route 1: [0 1 3 -6 3* 2* 1* 0]

Route 2: [0 4 5 5* -7 4* 0]

5.3 Fitness Function

Each individual is evaluated using the fitness value $F(x)$. The fitness function of our 2L-DVRPB problem is to find the shortest routes. So, the fitness value is calculated as follows that is the total

$$Min\ Z(x) = \sum_{k=1}^{m} \sum_{i=0}^{n} \sum_{j=0,j\neq i}^{n} C_{ij}(t)\ x_{ij}^{k}(t)$$

distance travelled: $F(x)= z(x)$

where,

- c_{ij} designates the cost of traveling from customers i, j

^{k} designates the distance traveled by the vehicle k from customers i to j.

5.4 Selection Operator

In this paper, we choose to use Tournament method as a selection operator that requires the following steps:

Step 1: Select randomly two individuals from the population.
Step 2: Compares their fitness values.

Figure 4. A Chromosome representation

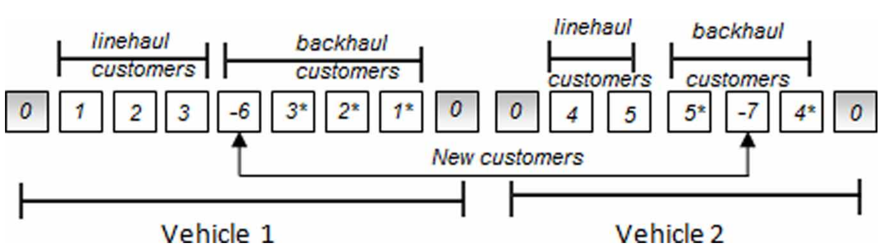
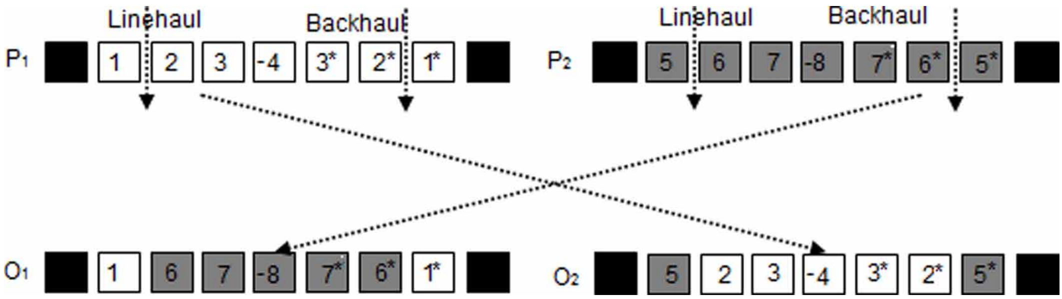


Figure 5. An example of the two point crossover operator



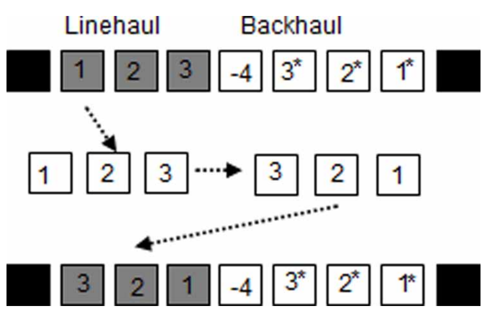
Step 3: Select parents with the better fitness value as P_1 and P_2.

5.5 Crossover and Mutation Operators

In this paper, we use the two point crossover operator. The two point Crossover operator selects two parents for crossover and then randomly selects two crossover points. Two offspring are created by combining the parents at crossover point. it requires three steps:

Step 1: Select two parents used for crossover.
Step 2: Randomly select crossover linehaul point p_i ($i = 0$ to l-1) and crossover backhaul point p_i ($i = 0$ to b-1) called mapping section.
Step 3: Two offspring are created by combining the parents at crossover linehaul and backhaul point. In Figure 5 an example is given to illustrate the two point crossover operator. In each solution, the first segment presents the linehaul customers and the second one presents the backhaul customers. Apply the elitism operator, insert the new offspring into the initial population to always substitute the worst individual. For the mutation operator, we use the inversion which generates two cut-points from the linehaul customers or from the backhaul customers of the chromosome, and then reverses a part of customers between these two cut-points. Figure 6 describes an example of the inversion mutation operator.

Figure 6. Example of the inversion mutation operator



5.6 Stopping Criterion

This above process are repeated until a number of 1000 generation is reached.

6. HEURISTICS FOR THE LOADING SUBPROBLEM

In this section, we described whether a route-sequence of customers-is feasible in terms of the loading constraints of the examined problem.

In our case of sequential version, first, the rectangles are sorted by the reverse visiting order of customers. Then, the rectangles demanded by the same customer are sorted in decreasing order of the area of the rectangle.

Furthermore, the feasibility of loading an item into the vehicle loading space is checked using six packing heuristics. The first five heuristics $Heur_i$ (i = 1, 2, . . . , 6) are based on the work by Zachariadis et al. (2009).

Let *Load pos* denote a list of available loading positions for the items. So, the first available loading position lies in the front left corner (0,0) of the vehicle and the *Load pos*=0*,* 0. When an item is successfully inserted, four new positions are added onto the list and the *Load pos* is updated. Each heuristic loads an item in the most suitable position selected from the feasible ones according to the individual criterion as follows:

```
Algorithm 3 bundle of packing heuristics
Input: :
HeurheurInd= Heur1, Heur2, Heur3, Heur4,Heur5,Heur6
Begin
int HeurheurInd=1
Empty Vehicle, Load pos= 0, 0
for each Item it do
Determine Position pos     Load pos for it, according to HeurheurInd
IF (no feasible pos exists)
heurInd = heurInd + 1
If (heurInd = 6)
heurInd = 1
  ENDIF
  go to
  ENDIF
  Place it in pos
  Remove pos from posList, add new loading positions in Load pos
end for
Output: Produce feasible loading
End
```

6.1 Heur1: Bottom-Left ftll (W-axis)

The selected position is the one with the minimum W-axis coordinate, breaking ties by minimum Laxis coordinate.

6.2 Heur2: Bottom-Left ftll (L-axis)

The selected position is the one with the minimum L-axis coordinate, breaking ties by minimum Waxis coordinate.

6.3 Heur3: Max Touching Perimeter Heuristic

The selected position is the one with the maximum sum of the common edges between the inserted item, the loaded items in the vehicle, and the loading surface of the vehicle.

6.4 Heur4: Max Touching Perimeter No Walls Heuristic.

The selected position is the one with the maximum sum of the common edges between the inserted item and the loaded items in the vehicle.

6.5 Heur5: Min Area Heuristic

The selected position is the one with the minimum rectangular surface. The rectangular surface corresponding to the position at the circle point is shown on the left in Figure.

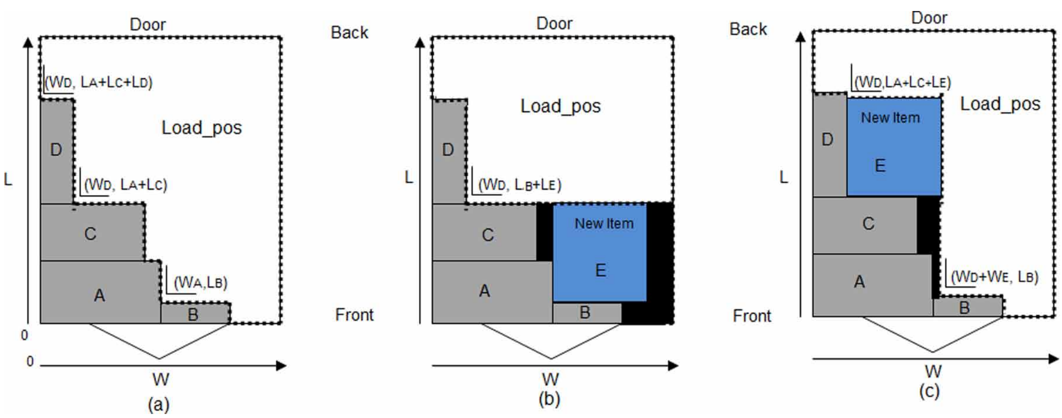
More details of these five heuristics can be found in Zachariadis et al. (2009) and Leung et al. (2011). Heur6: Min lost area heuristic:(MILAH)

The selection position of loading an item in list of available loading positions *Load pos* is the one with the minimum lost area.

When the height of the region between the upper edge of the new item and the border of the bin or the edges of the already inserted items is less than the smallest edge-length of the remaining items and none of the remaining items can be fitted into this area. Such regions are called lost area. Figure 6 schematically describes the mechanism of an item insertion. Where Figure 7 (b) presents the first insertion position of the item E, the region between the items C, A and the new inserted item E (see dark region in figure 7 (b) is less than the smallest edge-length of the remaining items and none of the remaining items can be fitted into this area. Such regions are called lost area. Figure 7 (c) presents the selected loading position of the new item E with the minimum surface of lost area. This heuristic aims at achieving a high degree of utilisation of the available surfaces. The position for the placement of an item is selected from the list of available positions *pos List* and must not lead to any loading constraint violation (overlapping or sequential constraint).

This bundle of heuristics are employed for the linehaul and the backhaul cases.

Figure 7. The process of inserting an item. (a) The list of available loading positions Load pos, (b) The first insertion position of item E, (c) The second position of item E with the minimum lost area.



7. COMPUTATIONAL EXPERIMENTS

7.1 Parameters Setting

All the tests were performed with the same configuration of the AGA. The algorithm was run 10 times on each instance. Table 2 reports the parameters of our AGA algorithm.

Table 2. A Meta-tuning of the GA

Parameters	Values
Population Size (N)	100
Selection	The tournament selection
Crossover rate	0,65
Mutation rate	0,20
Replacement strategy	The elitism operator
Maximum number of generation	1000

We take one problem version, depending on the loading constraint configuration under consideration: 2|*SO*|L version (sequence constraint, fixed orientation).

This section presents the computational results based on a set of benchmark instances used by Gendreau et al. (2008), but with a different types of 2L-VRP constraints (2L-VRP with backhaul and dynamic 2L-VRP with backhaul).

The proposed AGA approach is implemented using Java Language version 7. All experiments were performed on a PC equipped Intel (R) Core (TM) i3-4005U CPU with 4 GB(Gigabytes) of RAM under Microsoft Windows 7.

In order to demonstrate the performance of our proposed AGA, we design and solved it with the following steps: Computations are carried out in three phases:

1. We start our experiments by solving a set of classical 2L-CVRP benchmark instances (introduced by Iori et al. (2007) and Gendreau et al. (2008)) without dynamic and without backhauls constraints and considered the sequential oriented loading (2|*SO*|L) in order to prove the efficiency of our approach. As a result, our results are compared with the best-known solution (BKS) found in the literature (among SA, EGTS + LBFH, ACO, GRASPELS, and PRMP). Our AGA generates new best solutions when compared to the BKS.

In addition, the obtained solutions of our algorithm is perfectly comparable to other state-of-the- art approaches that deal with the 2L-CVRP for the 2|*SO*|L.

2. Then, we generate a new set of instances for the static 2L-VRP whith backhaul from the classical 2L-CVRP using the method described by Toth and Vigo (1997) to generate VRPB instances from classic Euclidean VRP ones.

Performance comparison between proposed algorithm and other algorithms in the literature that deal with the 2L-CVRPB is given as well.

3. Once the efficiency of our AGA approach has been proved for the static 2L-VRPB case, we use the effective degree of dynamism to define a framework classifying 2L-DVRP among weakly, moderately and strongly dynamic problems proposed by Larsen et al. (2002, 2007). Accordingly, we generate a new set of instances for the dynamic 2L-VRPB. We have also inves- tigated the impact of the degree of dynamism (dod) on strategy effectiveness [29], [30]. To do so, for all backhaul instances we examined cases of low dod (25% Dynamic requests), moderate dod (50% Dynamic requests) and high dod (75% Dyamic requests).

In this work, we deal with pickup problems. The driver of the vehicle is not concerned with what he is transporting, but only the quantity that he will pick from the customer. We fix the above mentioned parameters that can affect the final travel distances as follows:

The optimization begins to plan routes with the known static customers at time $t = 0$. To the best of our knowledge, no test instances are available in the literature for the version of the dynamic 2L-VRPB studied in this article. Therefore, we cannot compare them against other state-of-the- art approaches for the problem. However, to ensure the validity of our approach we calculate the value of information.

7.2 Computational Results for the 2L-VRP

In this section, in order to evaluate the quality of the solutions obtained with our algorithm, we tested its performance on several 2L-VRP benchmark sets introduced by [15] and [12]. These instances were derived from 36 CVRP instances, described by [31], by expressing the customer demand as a set of two-dimensional, weighted and rectangular items. To generate the aforementioned item sets, five classes of the item demand characteristics are used [15]. These instances can be downloaded at http://www.or.deis.unibo.it/research.html.

Five classes are created for each of the 36 CVRP problems. So, 180 instances are generated from the five classes. Some details of instances are reported as follows: The dimensions values of loading

Class 1: In class 1, each customer is associated a single item of width and length equal to nil. The problems of Class 1 are in fact pure CVRP instances, as every customer sequence is feasible in terms of the loading constraints of the problem examined. They are used to test the algorithmic effectiveness in terms of the routing aspects of the problem examined.

Classes 2-5: For classes 2 to 5, each customer i, a set of m_i items is generated. m_i is uniformly distributed within a given range. Each item is classified into one of the three shape categories, namely vertical, homogeneous and horizontal, with equal probability. The dimensions (width and length) of an item are uniformly distributed into the ranges determined by this items shape category. The m_i and the dimension ranges are provided in Table 3. surface of each vehicle are $L = 40$ and $W = 20$ for all instances. Table 3 shows the characteristics of items in Classes 2-5 instances.

Table 3. The item's characteristics of classes 2 to 5 instances

Class	M	Ver	tical	Homogenous		Horizontal	
		Length	width	Length	width	Length	width
2	[1, 2]	[0.4L, 0.9L]	[0.1W, 0.2W]	[0.2L, 0.5L]	[0.2W, 0.5W]	[0.1L, 0.2L]	[0.4W, 0.9W]
3	[1, 3]	[0.3L, 0.8L]	[0.1W, 0.2W]	[0.2L, 0.4L]	[0.2W, 0.4W]	[0.1L, 0.2L]	[0.3W, 0.8W]
4	[1, 4]	[0.2L, 0.7L]	[0.1W, 0.2W]	[0.1L, 0.4L]	[0.1W, 0.4W]	[0.1L, 0.2L]	[0.2W, 0.7W]
5	[1, 5]	[0.1L, 0.6L]	[0.1W, 0.2W]	[0.1L, 0.3L]	[0.1W, 0.3W]	[0.1L, 0.2L]	[0.1W, 0.6W]

7.2.1 Computational Environments for 2L-VRP

We executed our AGA ten times for each instance by setting the random seed from 1 to 10. We compare our AGA with some of the most efficient approaches for 2L-CVRP, including PRMP [48], VNS [45] and SA [46]. The computational environments for these approaches are summarized in Table 4. All these approaches were also executed 10 times for each instance. In the following tables, the cost listed is the best cost achieved over 10 runs. We list the details of only the best-known solution

Table 4. Computational environments of different methods

Methods	CPU	RAM
SA	Intel 2.4 GHz Core Duo	-
ACO	Pentium IV 3.2 GHz	2
GRASP-ELS	Opteroun 2.1 GHz	-
EGTS+LBFH	Intel Core 2 Duo 2.0 GHz	2
PRMP	Intel Core 2 Duo E6600 2.4 GHz	-
VNS	IntelXeon E5430 with a 2.66 GHz (QuadCore)	8GB
SA	IntelXeon E5430 with a 2.66 GHz (QuadCore)	8GB
AGA	Intel(R) Core(TM) i3 CPU170 GHz	4GB

(BKS) among all previous approaches and the two methods with excellent performance: PRMP, VNS and SA for the 2|*SO*|L versions.

Results for the sequential oriented variant of the 2L-VRP (2|*SO*|L) are summarised in Table 5 for classes 1 to 5. The proposed method was applied ten times on each of the pure CVRP instances of Class 1. For the Class 1 instances, the first column of Table 4 compares the best cost of each test problem against BKS on the pure CVRP (Class 1) instances. Our AGA finds better solutions for 9 instances (in bold) and matches the BKS for 21 instances. Moreover, the average cost of AGA is smaller than the BKS. Thus, the AGA is very effective in respect of the routing aspect.

Column 2 to 5 include the best solution found for each instance from class 2 to 5 by means of our AGA approach and its corresponding %gap to the best-known solution (BKS) found in the literature. In all cases, we present the best found solution over 10 executions of our algorithm per instance, allowing a maximum running time of 500 seconds. Among the 144 instances, the AGA finds better solutions for 64 instances (in bold) and reaches the best solutions for 71 instances. The improvement on the single instance reaches up to -2.364%. On average, the greatest improvement is obtained on the class 3 with -0.873%, and the least improvement is for the class 4 with -0.437%.

Table 14 (in Appendix) compare the best solution scores averaged over the four instances (Classes 2-5) of each test problem (instances 1-36) against previous solution approaches proposed for the 2|*SO*|L version of 2L-CVRP. These approaches are the PRMP algorithm [47], the VNS metaheuristic [44] and SA [45]. We observe that the proposed method consistently improves or matches the best algorithmic scores for 26 out of the 36 problems. More specifically, for 26 instances (in bold), AGA improves the average solution scores obtained by PRMP, VNS and SA, whereas for 10 instances, it matches their solution values. The average improvement is equal to 0.24%. In terms of the computational effort, the CPU time required by AGA method is comparable.

BKS: Best known solution(among SA, EGTS + LBFH, ACO,GRASPELS, and PRMP).
The column Average (*Avg*) : gives the average cost of different versions for each class.

The *%gap* is the percentage difference between the best solution found by our method and the reference solution.

$\%gap = 100\ ((\mathrm{BKS} - C_{P\ V\ NS})/BKS)$

Table 5. Results for the 2L-VRP from class 1 to 5

Ist	Class 1			Class 2			Class 3			Class 4		Class 5		
	BKS	**GA**	**%Gap**	**BKS**	**GA**	**%Gap**	**BKS**	**GA**	**%Gap**	**BKS GA**	**%Gap**	**BKS**	**GA**	**%Gap**
1	278.73	278.73	0.00	290.84	290.84	0.00	284.52	284.55	0.01	294.25 294.25	0.00	278.73	278.73	0.00
2	334.96	334.96	0.00	347.73	347.73	0.00	352.16	352.16	0.00	342.00 342.00	0.00	334.96	334.96	0.00
3	358.40	358.40	0.00	403.93	403.93	0.00	394.72	394.72	0.00	368.56 368.56	0.00	358.40	358.40	0.00
4	430.88	**430.86**	-0.005	440.94	440.94	0.00	440.68	440.68	0.00	447.37 450.37	0.670	430.88	430.88	0.00
5	375.28	375.28	0.00	388.72	388.72	0.00	381.69	**372.71**	-2.35	383.87 383.87	0.00	375.28	375.28	0.00
6	495.85	495.85	0.00	499.08	499.08	0.00	504.68	504.68	0.00	498.32 **495.30**	-0.606	495.85	497.02	0.24
7	568.56	568.56	0.00	734.65	734.65	0.00	709.72	709.72	0.00	703.49 703.49	0.00	658.64	**658.63**	-0.002
8	568.56	568.56	0.00	725.91	725.91	0.00	741.12	**741.08**	-0.005	697.92 697.92	0.00	621.85	621.85	0.00
9	607.65	**607.60**	-0.008	611.49	611.49	0.00	613.90	613.90	0.00	625.10 625.10	0.00	607.65	607.65	0.00
10	535.74	535.74	0.00	700.20	**700.10**	-0.01	628.93	628.93	0.00	715.82 715.82	0.00	690.96	690.96	0.00
11	505.01	505.98	0.19	721.54	721.54	0.00	717.37	717.37	0.00	815.68 815.68	0.00	636.77	**622.99**	-2.16
12	610.00	610.05	0.008	619.63	619.63	0.00	610.00	610.00	0.00	618.23 618.23	0.00	610.23	**608.95**	-0.002
13	2006.34	2006.34	0.00	2669.39	**2669.30**	-0.003	2486.44	**2438.41**	-1.93	2609.36 2609.36	0.00	2421.88	**2414.82**	-0.29
14	837.67	837.67	0.00	1101.61	**1089.16**	-1.13	1085.42	1085.42	0.00	983.20 **981.78**	-0.14	924.27	924.27	0.00
15	837.67	**837.58**	-0.01	1041.75	1041.75	0.00	1181.68	1181.68	0.00	1246.49 1246.49	0.00	1230.40	1231.40	0.081
16	698.61	698.61	0.00	698.61	**697.55**	-0.15	698.61	698.61	0.003	708.20 708.22	0.002	698.61	698.61	0.00
17	861.79	861.81	0.002	870.86	870.86	0.00	861.79	861.79	0.00	861.79 861.79	0.00	861.79	**842.77**	-2.207
18	723.54	723.54	0.00	1053.09	**1051.00**	-0.2	1103.45	**1100.96**	-0.22	1134.11 1134.11	0.00	926.53	926.53	0.00
19	524.61	524.61	0.00	792.42	**791.24**	-0.15	801.13	801.13	0.00	801.21 **801.17**	-0.005	652.58	**650.61**	-0.30
20	241.97	241.97	0.00	547.82	**544.28**	-0.65	541.58	541.58	0.00	552.91 **550.99**	0.00	478.73	**476.73**	-0.417
21	687.60	687.62	0.002	1060.72	**1060.69**	-0.003	1150.85	**1144.88**	-0.52	1006.21 **1000.19**	-0.002	893.18	**893.11**	-0.017
22	740.66	740.66	0.00	1081.44	1081.44	0.00	1094.66	1094.66	0.00	1089.27 1089.27	0.00	948.60	948.71	0.012
23	835.26	**835.22**	-0.005	1093.27	1093.27	0.00	1117.54	1117.54	0.00	1095.08 **1093.01**	-0.19	950.25	**932.72**	-1.84
24	1024.69	1024.69	0.00	1222.40	1222.40	0.00	1118.44	1118.44	0.00	1141.97 1141.97	0.00	1048.69	1048.69	0.00
25	826.14	826.14	0.00	1458.83	1458.83	0.00	1436.57	1436.57	0.00	1435.18 1435.18	0.00	1183.63	**1182.61**	-0.086
26	819.56	**817.56**	-0.24	1327.47	**1327.45**	-0.002	1396.52	**1391.57**	-0.35	1447.03 1447.03	0.00	1252.65	**1251.66**	-0.08
27	1082.65	1082.65	0.00	1367.85	1367.85	0.00	1423.74	1412.47	0.00	1357.75 **1348.57**	-0.67	1270.34	**1254.94**	-1.21
28	1040.70	**1040.68**	-0.002	2699.21	**2699.16**	-0.002	2787.24	**2688.71**	-3.53	2700.66 2700.66	0.00	2399.25	2400.55	0.05
29	1162.96	**1162.92**	-0.003	2289.84	2289.84	0.00	2172.69	**2148.99**	-1.09	2312.37 **2295.89**	-0.71	2191.69	**2175.96**	-0.71
30	1028.42	1028.42	0.00	1875.38	**1875.36**	-0.001	1915.42	**1911.44**	-0.20	1910.54 **1900.94**	-0.50	1575.64	**1562.46**	-0.84
31	1299.56	1299.48	0.00	2369.07	**2339.89**	-1.23	2360.63	**2352.33**	-0.35	2469.40 **2457.74**	-0.47	2072.19	**2051.32**	-1.00
32	1294.91	1294.98	0.006	2384.29	**2360.91**	-0.98	2325.74	**2318.77**	-0.30	2357.57 **2341.75**	-0.67	2031.92	**2013.99**	-0.882
33	1298.02	1298.02	0.00	2376.58	**2335.83**	-1.71	2469.85	**2445.58**	-0.98	2470.76 **2439.89**	-1.25	2054.29	**2034.92**	-0.942
34	708.39	**708.34**	-0.007	1226.98	**1216.99**	-0.81	1253.88	**1247.85**	-0.48	1242.26 **1240.62**	-0.13	1062.18	1062.22	0.14
35	865.39	865.39	0.00	1447.30	**1422.95**	-1.68	1529.77	**1509.79**	-1.30	1558.69 1548.99	-0.62	1281.90	**1275.99**	-0.461
36	585.46	**583.94**	-0.26	1784.57	1784.57	0.00	1869.38	**1829.35**	-2.14	1740.64 **1710.75**	-1.71	1549.51	**1540.99**	-0.55
Av	769.505	**769.428**	-0.02	1175.70	**1171.45**	-0.51	1182.29	**1173.58**	-0.873	1187.312 **1183.38**	-0.437	1057.24	1052.13	-0.544

7.3 Computational Results for the static 2L-VRP with backhaul

Notice that the 2L-VRPB can be seen as an extension of the 2L-VRP, i.e. every 2L-VRP instance may be considered as a especial case of 2L-VRPB.

In class 1, each customer is associated a single item of width and length equal to nil. For this reason, our algorithm does not need to be modified to solve 2L-VRP instances. We tested our GA approach contemplating sequential oriented loading (2|*SO*|L).

We generate a new set of instances for the static 2L-VRP whith backhaul from the classical 2L-CVRP using the method described by Toth and Vigo [42] to generate VRPB instances from classic Euclidean VRP ones. The 2L-VRP instances have been extended to generate new instances for the 2L-VRPB. Thus, we have generated three new 2L-VRPB instances for each 2L-VRP one. These new instances contain 50%, 60%, and 80% linehaul customers. To obtain such linehaul-backhaul distributions, we select a customer every two, three, or five customers, respectively, to be a backhaul location. These linehaul/backhaul configurations are represented in Table 6, 7, and

8 respectively. Accordingly, we produced a total of 540 2L-VRPB instances derived from the 180 2L-VRP instances introduced by [15] and [12]. Then, our results are compared to BR-LNS of [6], to the best of our knowledge, only this work have investigated the 2L-VRPB for the sequential oriented loading (2|*SO*|L). Table 6 presents our results for instances with a one linehaul every two backhaul configurations. In particular, the performance of our algorithm is improved by compared our results with the BR-LNS one presented by [6]. Therefore, on 180 instances with 50% Linehaul and %50 backhaul of the Sequential 2L-VRPB, our AGA could find better value for 105 (in bold) instances (58%) and matches the same value for 50 (28%) instances from class 1 to 5. In addition, we noticed that our AGA matches the best AVG equal to (-0.17, -0.13, -0.13, -0.24 and -0.019) from class 1 to 5 respectively. Moreover, Table 7 presents our results for instances with 60% linehaul and 40% backhaul configuration. In particular, the performance of our algorithm are improved by compared our results with the BR-LNS results presented by [6]. Therefore, at most 180 instances with 60% linehaul and %40 backhaul of the sequential 2L-VRPB, Our AGA could find better value for 123 (in bold) instances (68%) and matches the same value for 31 (17%) instances from class 1 to 5. In addition, we noticed that our AGA matches the best Avg equal to (-0.24, -0.33, -0.30, -0.26 and -0.18) from class 1 to 5 respectively. In addition, Table 8 presents our results for instances with 80% linehaul and 20% backhaul configuration. In particular, the performance of our algorithm are improved by compared our results with the BR-LNS one presented by [6]. Therefore, on 180 instances with 60% Linehaul and %40 backhaul of the Sequential 2L-VRPB, Our AGA could find better value for 111 (in bold) instances (62%) and matches the same value for 28 (16%) instances from class 1 to 5. In addition, we noticed that our AGA matches the best Avg equal to (-0.56, -0.48, -0.19, -0.43 and -0.15) from class 1 to 5 respectively.

In summary, the proposed AGA performs quite well on large-scale instances, in which al most the BR-LNS for Classes 1 to 5 . Therefore, our proposed AGA is an effective algorithm for 2L-VRPB. In terms of computational time, it is difficult to compare the running times of different algorithms fairly because different algorithms were coded in different programming languages and tested on different machines.

The Value of Information

The Value of Information aims to measure the performance of a dynamic optimization problem. It was discussed in [27], [32] , and [29] .

In this study, we report the performance of the proposed AGA method based on the so-called value of information, which was originally introduced by Mitrovic-Minic et al. [27].

Consider the 2L-DVRPB instance R and the related static problem R_s, in which all dynamic requests are known prior to the dispatching of the vehicles (i.e., at time $t = 0$). Then the value of information metric $V_{«}$ corresponding to algorithm s while solving dynamic problem R is defined by the following expression:

$$V_{\Im}\Re = \frac{Z_{\Im}\Re - Z_{\Im}\Re_s}{Z_{\Im}\Re} * 100 \tag{7}$$

where $Z_{«}(R)$ and $Z_{«}(R_s)$ are the values of the objective function for dynamic problem R and for the related static problem R_s, both solved by algorithm s. Note that s is used at each reoptimization step for R , while s is used once to solve R_s. In our case, to define the value of information, in terms of the interaction of the re-optimization strategies with the value of degree of dynamism (dod) and the customer positions (for the case of 50% L, 50% B, the case of 60%L, 40% B and the case of 80% L and 20% B) Table 9 presents the performance of each class with respect to dod for 25%, 50% and 75% respectively. Note that this is the average performance over all related instances. The value of information is always positive as it may be expected. In the case of routing costs, it is smaller for

Table 6. Results for the 2L-VRPB from class 1 to 5 with 50% linehaul customers and 50% backhaul customers

Ist	Class 1			Class 2			Class 3			Class 4			Class 5		
	BR-LNS	**Our AGA**	**%gap**	**BR-LNS**	**Our AGA**	**%gap**	**BR-LNS**	**Our AGA**	**%gap**	**BR-LNS**	**Our AGA**	**%gap**	**BR-LNS**	**Our AGA**	**%gap**
1	301.99	**300.74**	-0.41	308.76	**308.75**	-0.003	308.76	**301.33**	-2.40	312.12	**310.20**	-0.61	307.63	307.63	0.00
2	308.76	308.76	0	308.76	308.76	0	308.76	**305.66**	-1.004	308.76	308.76	0	308.76	308.76	0.00
3	335.54	**335.47**	-0.02	336.40	**334.37**	-0.6	345.66	**344.33**	-0.39	335.54	335.54	0.00	335.54	336.31	0.22
4	375.12	**373.10**	-0.54	375.12	**373.10**	-0.53	375.12	**373.44**	-0.45	375.12	**374.25**	-0.23	375.12	375.12	0.00
5	372.12	**368.98**	-0.84	376.84	**375.72**	-0.3	373.71	**373.27**	-0.12	372.12	**370.63**	-0.4	372.12	373.78	0.47
6	432.30	**430.61**	-0.40	428.88	429.97	0.25	432.30	**429.89**	-0.55	432.30	**427.31**	-1.15	432.30	429.30	0.69
7	689.32	**686.44**	-0.42	692.26	**690.25**	-0.69	691.85	695.85	0.57	699.27	**698.99**	-0.04	689.32	**687.83**	-1.52
8	689.32	**688.75**	-0.08	698.87	**697.89**	-0.14	718.89	**717.79**	-0.15	692.26	**691.96**	-0.04	677.52	**676.91**	-0.21
9	494.03	**494.11**	-0.01	501.48	**499.98**	-0.29	494.03	**493.69**	-0.07	500.57	**499.97**	-0.12	494.03	**494.01**	-0.004
10	502.77	**501.86**	-0.18	610.45	**609.54**	-0.15	536.29	**535.92**	-0.069	589.43	**588.34**	-0.18	571.68	**568.98**	-0.472
11	502.77	502.77	0.00	603.37	**602.85**	-0.08	581.42	**581.37**	-0.008	644.27	**644.21**	-0.01	573.31	573.57	0.04
12	471.46	471.46	0.00	482.63	482.63	0.00	471.46	471.46	0.00	475.76	**475.46**	-0.06	471.46	471.46	0.00
13	2276.57	2276.57	0.00	2399.98	2399.98	0.00	2384.40	2384.40	0.00	2354.57	2354.57	0.00	2326.80	2356.80	1.28
14	751.69	751.69	0	870.04	870.04	0.00	878.23	878.23	0.00	777.60	777.60	0.00	771.31	771.31	0.00
15	751.69	**750.78**	-0.12	850.73	**848.99**	-0.20	853.62	853.62	0.00	909.02	909.23	0.21	907.13	**906.55**	-0.63
16	543.09	**542.98**	-0.20	549.86	549.86	0	544.24	**544.21**	-0.005	543.39	**543.21**	-0.03	542.60	**542.46**	-0.025
17	638.14	**637.95**	-0.03	635.94	**634.89**	-0.16	635.94	**634.96**	-0.15	638.14	638.14	0	635.94	635.98	0.006
18	834.86	**834.82**	-0.005	937.03	**936.92**	-0.11	919.65	**919.56**	-0.01	918.57	918.57	0	845.35	845.38	0.003
19	562.83	562.83	0.00	655.44	655.44	0.00	655.97	655.97	0.00	637.33	637.33	0.00	617.50	617.50	0.00
20	319.72	**319.27**	-0.14	419.92	**419.29**	-0.15	397.05	**396.83**	-0.05	398.26	398.26	0.00	375.20	375.23	0.008
21	721.78	**720.87**	-0.13	876.37	**876.33**	-0.004	892.75	**892.68**	-0.08	844.89	**844.81**	-0.01	783.33	**783.15**	-0.03
22	721.68	**721.35**	-0.045	872.10	**872.06**	-0.004	862.65	862.67	0.002	899.02	899.08	0.006	805.17	805.17	0.00
23	746.90	**746.55**	-0.05	880.09	**879.99**	-0.01	860.55	**860.05**	-0.06	862.22	862.25	0.003	802.86	802.86	0.00
24	838.96	**838.69**	-0.03	920.51	**919.98**	-0.06	890.40	**890.28**	-0.013	896.58	**896.24**	-0.037	844.15	844.15	0
25	889.59	889.59	0	1144.05	1144.07	0.002	1102.54	1102.54	0	1091.96	1091.96	0	984.61	984.61	0.00
26	779.21	**778.99**	-0.09	1031.22	**1031.08**	-0.01	1039.09	1039.09	0.00	1096.63	1096.63	0.00	903.86	903.88	0.002
27	964.88	**962.89**	-0.20	1073.48	1073.48	0	1089.58	**1085.85**	-0.34	1058.67	**1057.76**	-0.09	1012.70	**1011.70**	-0.09
28	1022.91	**1022.90**	-0.09	1780.33	**1779.33**	-0.05	1801.48	**1800.84**	-0.03	1813.13	1813.17	0.002	1616.89	1616.89	0.00
29	1217.36	1217.36	0.00	1727.00	1727.00	0.00	1638.68	1638.68	0.00	1667.36	1667.36	0.00	1625.58	1625.58	0.00
30	1050.11	**1050.09**	-0.002	1415.14	**1415.08**	-0.004	1396.25	**1395.52**	-0.09	1385.71	1385.71	0	1236.57	1236.59	0.002
31	1216.24	**1215.85**	-0.03	1686.66	**1684.95**	-0.10	1698.68	**1697.89**	-0.04	1730.54	**1728.86**	-0.09	1545.89	**1542.98**	-0.18
32	1202.83	**1201.38**	-0.12	1700.82	**1700.52**	-0.017	1679.53	**1679.35**	-0.01	1687.62	**1686.86**	-0.04	1521.70	**1515.61**	-0.40
33	1213.71	1213.71	0.00	1716.05	**1716.00**	-0.003	1715.24	**1715.14**	-0.006	1732.86	**1730.68**	-0.12	1505.30	1505.30	0.00
34	702.84	**701.48**	-0.2	890.10	**890.07**	-0.003	908.90	**906.85**	-0.22	877.18	**875.96**	-0.14	808.02	808.32	0.37
35	747.01	747.01	0	1006.72	**1005.27**	-0.14	1020.11	**1018.96**	-0.11	1027.38	**1026.83**	-0.05	893.69	**892.71**	-0.11
36	488.96	**488.66**	-0.06	1090.58	1090.58	0.00	1126.35	1126.35	0	1052.64	**1052.60**	-0.003	946.13	947.31	0.12
Avg	741.085	**740.48**	-0.17	912.61	**912.08**	-0.13	906.39	**905.68**	-0.13	884.13	**859.23**	-0.24	846.30	**839.21**	-0.019

larger instances, implying that less distance would be gained by knowing all requests in advance for the larger instances. The reverse relation is observed for the number of vehicles.

8 TUNISIAN CASE STUDY

In order to evaluate the performance of the proposed approach, we choose to apply our approach in a real case study provided by a Regional Post Office of the city of Jendouba (RPOJ) in the North West of Tunisia. The latter ensures the distribution of parcels and letters in different countries' offices and postal cells that cover the governorate of Jendouba.

There are 41 post offices located in different districts in the Jendouba including the distribution center JDB, as shown in Figure 8. Their names are listed in Table 10.

Table 7. Results for the 2L-VRPB from class 1 to 5 with 60% linehaul customers and 40% backhaul customers

Ist	Class 1			Class 2			Class 3			Class 4			Class 5		
	BR-LNS	**Our AGA**	**%gap**	**BR-LNS**	**Our AGA**	**%gap**	**BR-LNS**	**Our AGA**	**%gap**	**BR-LNS**	**Our AGA**	**%gap**	**BR-LNS**	**Our AGA**	**%gap**
1	274.25	**272.52**	-0.63	275.25	275.25	0	274.25	274.25	0	274.25	274.52	0.10	284.22	284.22	0.00
2	323.52	**321.01**	-0.77	323.52	**323.28**	-0.07	323.52	**321.86**	-0.5	323.52	**323.23**	-0.09	323.52	**318.98**	-1.4
3	352.70	**350.98**	-0.49	380.89	**378.98**	-0.5	355.02	355.02	0	352.83	352.87	0.011	352.70	352.70	0.00
4	396.11	**394.89**	-0.31	397.66	**395.87**	-0.45	396.11	**393.96**	-0.54	396.11	**395.98**	-0.03	396.11	396.27	0.04
5	365.55	**365.47**	-0.02	378.70	**375.98**	-0.71	365.55	365.55	0.00	373.66	**371.96**	-0.45	365.55	**364.75**	-0.22
6	405.66	405.99	0.08	408.53	408.53	0.00	405.99	405.99	0.00	425.35	425.35	0.00	405.99	405.99	0.00
7	678.88	**676.98**	-0.28	703.67	**702.75**	-0.13	693.58	**691.85**	-0.25	703.67	**702.76**	-0.13	693.58	693.58	0.00
8	692.49	**689.94**	-0.36	693.58	693.58	0	703.67	703.76	0.013	703.67	**700.67**	-0.43	693.58	695.58	0.00
9	526.48	526.48	0	531.24	**530.42**	-0.15	530.35	**528.53**	-0.32	526.48	**524.66**	-0.34	526.48	**521.84**	-0.82
10	550.62	**548.59**	-0.37	611.94	**610.49**	-0.23	576.50	**574.86**	-0.28	637.45	**634.78**	-0.42	590.46	590.64	0.03
11	550.62	**550.28**	-0.06	626.35	626.59	0.03	565.46	565.64	0.31	638.45	638.45	0.00	565.82	**563.28**	-0.45
12	497.63	**495.36**	-0.47	515.80	**515.66**	-0.027	497.63	**495.36**	-0.45	498.25	498.25	0	497.63	**497.39**	-0.05
13	725.95	**725.59**	-0.05	894.55	894.55	0	886.27	**882.78**	-0.4	871.59	**868.95**	-0.30	767.04	767.17	0.017
14	725.95	**720.59**	-0.05	894.55	**893.98**	-0.06	886.27	**868.89**	-1.96	871.59	**871.57**	-0.002	767.04	767.04	0.00
15	725.95	**725.33**	-0.08	834.07	**832.00**	-0.25	886.93	**886.71**	-0.02	899.68	899.86	0.020	892.28	**884.98**	-0.81
16	582.64	**582.60**	-0.007	578.20	578.20	0	578.20	**576.89**	-0.22	599.82	**597.87**	-0.33	578.20	**576.88**	-0.23
17	697.42	**696.23**	-0.17	681.87	689.88	1.17	680.30	680.30	0	680.30	**675.69**	-0.63	680.30	**678.28**	-0.3
18	814.27	**811.27**	-0.37	956.22	**956.02**	-0.43	918.54	920.45	0.20	963.98	963.98	0	880.82	**868.78**	-1.37
19	878.70	**876.96**	-0.19	694.60	**668.99**	-3.7	712.12	**708.12**	-0.56	678.47	**666.74**	-1.72	625.08	628.11	0.49
20	304.45	**301.54**	-0.96	427.23	**425.36**	-0.44	424.19	**423.89**	-0.07	467.63	**463.85**	-0.80	392.19	**390.98**	-0.30
21	715.42	**713.89**	-0.21	927.84	**919.89**	-0.85	973.94	**970.89**	-0.31	860.51	**859.21**	-0.15	815.47	815.96	0.06
22	742.14	**742.06**	-0.01	883.66	883.66	0	935.45	**934.54**	-0.93	875.77	875.77	0	843.17	843.17	0
23	773.12	**768.97**	-0.53	931.68	**929.87**	-0.19	955.00	955.00	0.00	913.78	913.87	0.01	841.20	**838.89**	-0.27
24	873.83	874.83	0.11	1007.87	**1007.78**	-0.009	948.72	**948.65**	-0.007	948.54	**943.85**	-0.5	884.62	**882.82**	-0.20
25	830.07	**825.70**	-0.52	1219.02	**1214.89**	-0.33	1141.33	**1140.39**	-0.08	1178.43	**1171.95**	-0.54	1021.60	1021.60	0
26	773.24	773.24	0	1095.65	**1090.56**	-0.46	1086.15	**1080.95**	-0.47	1107.94	**1107.22**	-0.06	952.00	**951.98**	-0.002
27	974.54	**974.45**	-0.009	1173.29	**1170.98**	-0.19	1180.91	**1180.13**	-0.06	1091.93	1091.98	0.05	1074.09	1074.09	0
28	1039.50	**1037.63**	-0.18	1925.05	**1922.36**	-0.14	2029.48	**2026.52**	-0.14	1974.14	**1971.41**	-0.14	1827.23	1828.83	0.88
29	1342.38	**1340.83**	-0.11	1846.64	1846.46	0	1722.74	1722.74	0	1881.43	**1881.34**	-0.05	1798.12	1795.88	0.12
30	1059.28	**1055.82**	-0.32	1560.45	**1558.54**	-0.12	1554.94	1554.94	0	1566.45	**1561.54**	-0.13	1326.03	**1325.33**	-0.05
31	1278.37	**1275.73**	-0.20	1904.79	**1900.97**	-0.20	1866.44	**1863.75**	-0.14	1934.79	**1931.92**	-0.15	1719.53	1717.850	0.10
32	1291.09	**1282.96**	-0.63	1894.47	**1891.74**	-0.14	1846.20	**1844.95**	-0.07	1875.74	**1875.47**	-0.014	1662.50	**1658.89**	-0.21
33	1305.80	1305.37	0.03	1905.83	1901.38	-0.23	1947.88	1945.98	-0.09	1950.56	1950.65	0.005	1663.11	1660.69	0.14
34	633.81	**631.38**	-0.01	953.01	**953.01**	-0.43	988.73	**981.37**	-0.38	953.31	**953.31**	-0.56	867.07	869.70	0.30
35	793.11	**793.01**	-0.01	1133.30	**1128.38**	-0.43	1156.39	**1151.93**	-0.38	1205.36	**1198.63**	-0.56	1026.55	**1024.55**	-0.19
36	550.55	**549.58**	-0.17	1267.03	**1266.91**	-0.001	1315.68	**1315.52**	-0.1	1230.27	**1230.22**	-0.004	1109.22	**1109.10**	-0.01
Avg 723.50		**721.77**	-0.24	917.79	**928.83**	-0.33	925.28	**923.4**	-0.30	928.76	**927.70**	-0.26	853.06	**851.85**	-0.18

Three vehicles are used to distribute letters and parcels between the existing path-way of the RPOJ which are illustrated as follows:

Path 1: Tabarka {JDN-MLJBLJ-SJM-FRN-JTR-BBC-BMT-ABY-ADH-BBM-HMB-JBL-TBN-AES- TBK-MMB-TBA-EMJ}
Path 2: Ghardimaou {CTT-HKM-HDL-ESD-SMK-EDK-OLH-OMZ-OGC-GDM-OMD}
Path 3: Bousalem {SSB-MRJ-BSL-BDR-SMR-RMN-BAN-BBR-BLT-ESB}

The vehicles has a fixed height(H), width(W) and capacity weight(Q) equal to 2 meters, 2.5 meters and 550 kg respectively. Each one must starts with the distribution center of Jendouba JND (depot) for two positions;

Table 8. Results for the 2L-VRPB from class 1 to 5 with 80% linehaul customers and 20% backhaul customers

Ist	Class 1			Class 2			Class 3			Class 4			Class 5		
	BR-LNS	Our AGA	%gap	BR-LNS	Our AGA	%gap	BR-LNS	Our AGA	%gap	BR-LNS	Our AGA	%gap	BR-LNS	Our AGA	%gap
1	259.97	**255.79**	-1.60	259.97	**255.79**	-1.60	260.22	**258.58**	-0.63	275.25	**272.36**	-1.04	259.97	260.01	0.015
2	299.64	**285.77**	-4.62	314.14	**302.52**	-3.69	322.42	**321.39**	-0.31	299.64	**297.46**	-0.72	299.64	**295.68**	-1.32
3	349.12	**342.66**	-1.85	350.83	**346.38**	-1.26	367.86	**364.68**	-0.86	356.76	**351.98**	-1.33	349.12	**347.89**	-0.003
4	415.83	**411.38**	-1.07	395.42	**389.10**	-1.59	395.42	397.85	0.61	410.20	**405.66**	-1.10	395.42	**391.99**	-0.87
5	376.68	**372.97**	-0.98	376.68	**374.89**	-0.47	376.68	**371.58**	-1.35	385.74	385.95	0.05	376.68	378.68	0.53
6	432.83	**428.38**	-1.02	432.85	**430.58**	-0.52	432.83	**429.38**	-0.79	432.83	**431.96**	-0.20	432.83	**429.38**	-0.8
7	598.68	600.86	0.36	723.39	**721.89**	-0.2	674.70	**673.04**	-0.24	674.28	**671.25**	-0.44	631.28	**630.21**	-0.17
8	598.68	**595.86**	-0.47	683.64	**681.69**	-0.28	713.49	**712.35**	-0.15	660.95	661.97	0.15	603.43	**601.34**	-0.35
9	571.75	**569.57**	-0.38	573.06	**558.60**	-2.52	573.06	579.66	1.15	571.75	**569.24**	-0.43	571.75	**569.57**	-0.4
10	512.06	**507.98**	-0.79	642.58	643.85	0.19	613.95	**608.59**	-0.87	663.73	666.37	0.39	609.63	**604.89**	-0.77
11	512.06	512.06	0	662.43	662.43	0.00	663.37	663.37	0.00	737.89	737.89	0.00	614.38	615.98	0.26
12	523.41	523.41	0.00	546.33	546.33	0.00	524.53	524.53	0.00	534.87	534.87	0.00	522.56	522.56	0.00
13	1997.84	**1991.98**	-0.29	2489.25	2490.96	0.06	2468.80	**2459.98**	-0.35	2518.66	**2514.63**	-0.16	2286.38	2283.83	0.11
14	746.28	**744.82**	-0.19	1017.55	**1015.96**	-0.15	879.84	**877.48**	-0.26	900.65	**899.56**	-0.12	863.12	863.12	0.00
15	746.28	**743.82**	-0.32	963.49	**961.98**	-0.15	1024.84	**1024.48**	-0.03	1085.14	1085.14	0	1002.07	1002.00	0.007
16	613.19	**611.96**	-0.20	614.67	**613.23**	-0.23	610.99	**610.55**	-0.07	622.18	**620.81**	-0.22	610.99	611.01	0.003
17	725.83	727.84	0.27	734.15	**731.33**	-0.38	723.17	724.71	0.21	724.47	**721.74**	-0.37	722.62	722.96	0.05
18	791.40	**790.22**	-0.14	1000.84	**1000.25**	-0.05	971.94	**970.98**	-0.09	989.86	**987.68**	-0.22	909.63	**907.06**	-0.28
19	567.89	**565.98**	-0.33	698.50	**692.69**	-0.83	742.96	**739.48**	-0.46	722.10	**720.98**	-0.15	637.06	638.60	0.24
20	288.90	**283.99**	-1.69	460.16	461.18	0.22	466.63	**464.36**	-0.48	500.80	501.89	0.21	445.67	445.67	0.00
21	703.81	703.81	0.00	965.26	965.62	0.03	1035.99	**1032.45**	-0.34	906.63	906.66	0.003	848.91	848.91	0.00
22	733.42	733.42	0.00	990.59	990.59	0.00	968.10	968.10	0.00	996.26	996.26	0.00	886.16	888.16	0.22
23	794.85	**794.58**	-0.03	958.56	**955.65**	-0.30	986.13	**984.31**	-0.18	956.42	**951.24**	-0.54	873.26	**867.62**	-0.6
24	904.53	904.98	0.04	1061.97	1062.95	0.09	999.72	**997.69**	-0.20	1002.35	1002.37	0.001	922.58	922.58	0.00
25	859.97	**857.69**	-0.26	1312.22	1314.01	0.13	1255.11	**1253.98**	-0.09	1271.21	**1270.12**	-0.08	1088.57	**1085.75**	-0.02
26	833.59	**831.95**	-0.19	1259.05	**1257.98**	-0.08	1229.65	1230.56	0.07	1283.55	**1282.95**	-0.05	1125.75	**1125.57**	-0.015
27	1004.20	**1000.99**	-0.31	1245.97	**1244.79**	-0.09	1283.22	1286.99	0.29	1207.54	1207.54	0	1149.52	1149.52	0
28	1059.68	**1057.86**	-0.17	2303.88	2303.88	0	2334.18	**2328.98**	-0.22	2186.90	**2175.03**	-0.54	2047.11	**2041.02**	-0.29
29	1210.77	**1205.69**	-0.41	2009.95	**2001.59**	-0.41	1986.48	**1984.84**	-0.08	1905.98	**1902.89**	-3.97	1935.20	**1934.58**	-0.032
30	1067.26	1068.62	0.12	1687.05	**1685.05**	-0.11	1663.83	**1661.38**	-0.14	1642.08	1642.08	0	1445.86	1445.86	0.00
31	1260.15	**1258.51**	-0.13	2048.22	**2046.89**	-0.06	2029.25	2030.52	0.06	2141.65	2153.56	0.55	1864.63	1865.36	0.4
32	1260.15	1260.15	0	2038.96	**2036.69**	-0.11	2026.01	**2023.10**	-0.14	2005.18	**2003.81**	-0.88	1795.95	**1792.23**	-0.20
33	1295.28	**1293.82**	-0.11	2081.76	**2080.67**	-0.05	2191.51	2192.15	0.02	2147.33	2147.33	0.00	1880.20	**1878.89**	-0.07
34	654.71	655.17	0.07	1066.72	**1063.79**	-0.27	1087.44	1089.89	0.22	1078.34	**1075.78**	-1.06	946.10	**946.88**	-0.08
35	839.02	**837.20**	-0.21	1253.38	**1251.38**	-0.19	1308.31	**1303.13**	-0.39	1318.93	1315.39	1.2	1146.00	1147.89	0.16
36	584.62	584.62	0	1500.73	1500.73	0	1494.50	1494.50	0	1448.06	1447.96	0.06	1309.89	**1301.98**	-0.6
Avg 722.064 **725.416** -0.56				1047.894 **1045.663**-0.48			1046.88	**1039.99**	-0.19	1043.504 **970.28**		-0.43	955.80	**954.58**	-0.15

Computational Results for the dynamic 2L-VRP with backhaul

The first one is to deliver (linehaul) parcels to different deliver post office, the second one is to pickup (backhaul) parcels from the post office and return to the distribution center of Jendouba.

The geographical locations of a set of the post offices to be serviced (deliver or collect) are already known by the dispatcher before the server leaves the depot. All linehaul (deliver) must be done be- fore the backhaul (collect). The customer demand is formed by a set of two-dimensional, rectangular, weighted items.

During the execution of the distribution plan, new customers call-in, requesting (pickup) services. These arriving requests (here after denoted as Dynamic Requests, DRs) have to be collected and returned back to depot.

A new requests can be happen over time of backhaul. Therefore, the new request must be served with respect to the constraints of capacity and time limited. Otherwise, the new demand will be shifted

Table 9. The value of information for the 2L-DVRPB solved by the AGA with 540 instances for static and dynamic aspects

			Class 1	Dynami		Aspect	Class 2-5		Static Class 1	Aspect Class 2-5	Value of i Class 1			formation Class 2-5	
		25%	50%	75%		25%	50%	75%			25%	50% 75%		25% 50%	75%
2L-DVRPB (50% L 50%B)		912.40	1223.99	2044.44		1097.34	1385.18	2113.12	740.48	879.05	19%	40% 64%		20% 36%	58%
2L-DVRPB (60% L 40%B)		857.16	1125.26	1899.57		1123.73	1231.67	2061.08	721.77	907.94	16%	36% 62%		19% 26%	56%
2L-DVRPB (80% L 20%B)		899.67	1150.09	1163.59		1150.71	1371.97	1371.14	725.41	1002.62	19%	37% 37%		13% 27%	27%

Table 10. Post offices in Jenbouba(Tunis)

Post office	Post office	Post office
1. Ain Draham (ADH)	15. El Morjne (EMJ)	29. Melloula Maabar (MMB)
2. Ain El Beya (ABY)	16. Essaada (ESD)	30. Oued El Maaden (OMD)
3. Ain Essobh (AES)	17. Essanabel (ESB)	31. Oued Mliz (OMZ)
4. Babouch (BBC)	18. Fernana (FRN)	32. Ouerguech (OGC)
5. Badrouna (BDR)	19. Ghardimaou (GDM)	33. Ouled Hlel (OLH)
6. Balta (BLT)	20. Hakim (HKM)	34. Roumani (RMN)
7. Bellarijia (BLJ)	21. Hammam Bourguiba (HMB)	35. Sidi Meskine (SMK)
8. Ben Bechir (BBR)	22. Hdhil (HDL)	36. Souk Essebt (SSB)
9. Beni Mtir (BMT)	23. Jaballah (JBL)	37. Souk Jemaa (SJM)
10. Bou Salem (BSL)	24. Jantoura (JTR)	38. Soumrane (SMR)
11. Bouaouene (BAN)	25. Jendouba (JDB)	39. Tabarka (TBK)
12. Brirem (BRM)	26. Jendouba Nord (JDN)	40. Tabarka Aroport (TBA)
13. Cit Ettataouer (CTT)	27. Marja (MRJ)	41. Tbainia (TBN)
14. Eddkhailia (EDK)	28. Malga (MLG)	

to the next day and it will be included within the static service planning. The operation is carried out on a daily basis Monday through Friday. The service period is 8h, the service area is 3102 km^2, and vehicle speed is 60 km/h. Requests occur during the static service period according to a continuous uniform distribution, except static requests are known and no new request is known in advance.

Our objective is to distribute parcels safely within the given time restrictions while minimising the costs as possible. Table 11 detailed Vehicle's expenses in the post office of Jendouba for a year suchas fuel, expenses, driver's salary/year and Conveyor's salary/year.

In the RPOJ, the degree of dynamism increases with the demands during the period of events. Therefore, we handled the 27-day transportation problems of the RPOJ and we ranked the problems according to their percentage of linehaul, backhaul and value of dynamism as follow:

Case1: 50% Linehaul and 50% Backhaul(where the value of dynamism are 25%,50% and 85% respectively)
Case2: 60% Linehaul and 40% Backhaul(where the value of dynamism are 25%,50% and 85% respectively)
Case3: 80% Linehaul and 20% Backhaul(where the value of dynamism are 25%,50% and 85% respectively).

To assess the performance improvement, we run our present algorithm against the same data of the RPOJ. Then, our solutions are compared with RDPJ previous solutions. The comparisons are pre- sented in tables 12, in which the first column indicates the value of dynamism (25%,50% and 85%), the second column shows selected day, the third one presents the RPOJ results, the forth column gives the results of our AGA and the last one describes the %gap of the results. Table 14 indicates that the proposed method provides an improvement over the current solution designed manually by the dispatcher since it reduces the overall costs for all the data sets. Our solutions minimize the total cost with an improvement of up to 17%.

Figure 8. Existing Post Office in Jendouba

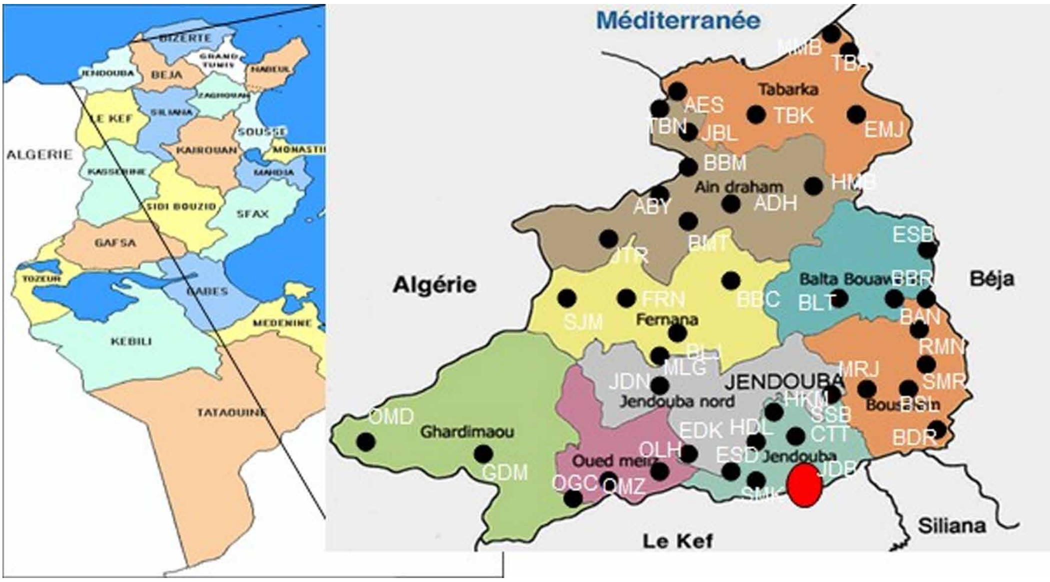


Table 11. Vehicle's Expenses in the post office of Tunisia

Fuel	Expenses/year					Driver's salary /year	Conveyor's salary /year
	Insurance	Wheels	Battery	Vehicle's tour	vehicle's maintenance		
0.500 DT/km	400 DT	440 DT	150 DT	30 DT	450 DT	20000 DT	17000 DT

We can conclude that our AGA produces best solutions using both benchmark and real data instances. Table 13 presents an example of instance with (50% Linehaul, 50% Backhaul and a value of dynamism equal to 25%). Figure 9 shows a cartographic format of the solution using Google Maps.

The new path obtained when adding the new nodes of "Tabarka Airport" and "OMD" is shown in Figure 9(c) it is described as follow:

Linehaul :

Distrib-center $\rightarrow Fernana \rightarrow BeniMtir \rightarrow AinDrahem \rightarrow Babbouch \rightarrow H.Borghuiba \rightarrow Tabarka \rightarrow$
$Jaballah \rightarrow El-Morjen$

Backhaul :

$El{-}Morjen \rightarrow Jaballah \rightarrow TabarkaAirport \rightarrow Tabarka \rightarrow H.Borghuiba \rightarrow babbouch \rightarrow$
$AinDrahem \rightarrow$
$BeniMtir \rightarrow Fernana \rightarrow Distrib-center.$

Table 12. Post offices in Jenbouba(Tunis)

DOD	Days	Post office Results	Our AGA results	%gap
For 50% Linehaul and 50% Backhaul				
	Day1	687.68	622.63	-10.44
25%	Day2	896.42	790.23	-13.44
	Day3	789.52	620.85	-27.17
	Day1	520.23	498.02	-4.46
50%	Day2	625.25	589.55	-6.05
	Day3	595.63	520.12	-14.51
	Day1	720.13	678.02	-6.21
75%	Day2	440.25	407.14	-8.13
	Day3	797.63	550.26	-44.95
For 60% Linehaul and 40% Backhaul				
	Day1	487.68	322.63	-51.15
25%	Day2	896.46	750.23	-19.49
	Day3	778.25	689.85	-12.81
	Day1	427.23	390.85	-9.30
50%	Day2	525.78	512.58	-2.57
	Day3	487.36	377.22	-29.20
	Day1	320.74	204.53	-56.81
75%	Day2	347.52	237.66	-46.22
	Day3	640.66	560.32	-14.39
For 80% Linehaul and 20% Backhaul				
	Day1	587.68	422.63	-39.05
25%	Day2	796.45	785.23	-1.42
	Day3	782.62	620.25	-26.18
	Day1	331.32	289.23	-14.55
50%	Day2	235.51	178.75	-31.75
	Day3	595.63	520.12	-14.51
	Day1	520.13	448.02	-16.09
75%	Day2	740.25	698.14	-6.03
	Day3	578.63	540.22	-7.11
Avg	-	598.24	512.04	-16.83

9. CONCLUSION AND FUTURE WORK

A Dynamic Vehicle Routing Problem with Backhauls and two-dimensional loading problem (2L-DVRPB) has been studied in this article. This problem is important both in research and industrial domains due to its many real world applications. We present an adaptive genetic algorithm for solving the 2L-DVRPB. In addition, a new heuristic MILAH is used to minimize the non-used area in the vehicle.

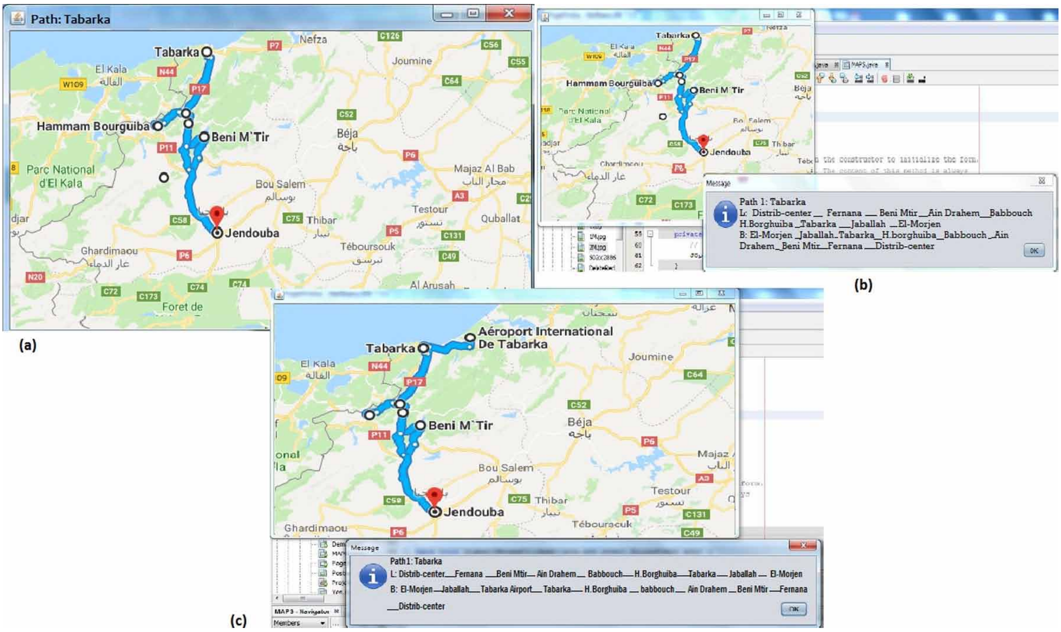
Table 13. An example of instance with 50% Linehaul, 50% Backhaul and a value of dynamism equal to 25%

		Nbre of Items	Item1			Item2			Item3			Item4			Item5			Item6		
			h	*w*	*q*	*h*	*w*	*q*	*h*	*w*	*q*	*h*	*w*	*q*	*h*	*w*	*q*	*h*	*w*	*q*
Path1:	Distrib-Centre	**28**																		
Tabarka	Fernana	3	5	10	8	7	7	20	10	2	50									
	Beni Mtir	2	7	7	20	4	7	35												
	Ain Drahem	5	4	8	45	5	9	20	5	6	51	5	12	15	12	2	11			
	Babbouch	3	4	9	10	4	18	21	2	18	23									
Linehaul	H.Borghuiba	3	7	3	24	4	3	31	8	2	26									
	Tabarka	6	6	10	17	8	8	15	5	4	22	5	4	27	17	3	28	4	16	21
	Jaballah	2	12	5	30	4	8	17												
	El-morjen	4	5	9	14	9	2	25	3	7	31	5	9	38						
	El-morjen	4	5	9	14	9	2	25	3	7	31	5	9	38						
	Jaballah	1	2	9	35															
New	**Tabarka airport**	5	8	9	34	5	6	27	8	6	14	6	6	25	7	8	32			
	Tabarka	4	5	4	19	7	7	25	6	8	21	6	3	28						
	H.Borghuiba	2	8	3	34	8	8	31												
Backhaul	Babbouch	1	9	9	15															
	Ain Drahem	3	5	7	35	9	9	27	6	8	18									
	Beni Mtir	2	5	4	29	7	4	36												
	Fernana	1	8	10	12															
	Distrib-Center	**23**																		
Path2:	Distrib-Centre	**23**																		
Ghardi	Ettataouer	5	7	8	44	6	8	22	7	7	32	9	3	35	4	6	25			
-maou	West Jendouba	6	8	9	12	17	2	45	7	8	16	11	3	16	6	7	44	2	9	18
	Oued Mliz	3	4	8	16	7	3	21	12	11	55									
	Ghardimaou	2	9	7	22	8	6	33												
Linehaul	Eddkhailia	1	5	9	26															
	Ouerghech	2	7	9	21	4	5	16												
	Hakim	1	8	9	42															
	Oued Mliz	3	11	2	38	7	7	28	8	3	36									
	Oued Mliz	2	8	2	37	4	9	25												
	Hakim	1	9	7	47															
	Ouerghech	2	5	6	28	8	7	36												
	Eddkhailia	1	8	6	29															
Backhaul	Ghardimaou	2	5	7	32	9	5	30												
New	OMD	5	9	4	18	7	15	33	5	9	35	4	11	37	8	4	28			
	Ettataouer	1	5	9	45															
	Distrib-Center	**14**																		

To the best of our knowledge, the problem has not been analysed so far in the literature. Therefore, our approach is tested on an extensive set of instances which have been adapted from existing benchmarks for the 2L-VRP.

Since there has been no other algorithm in the literature for solving such problems, we could not compare the performances of different algorithms. To test the effectiveness of our solution approach, we have conducted a series of runs on the 2L-CVRP and static 2L-VRPB models. Fine quality results are obtained, improving and matching several best known solution scores. In addition, our algorithm was applied to a series of newly constructed 2L-DVRPB benchmark instances. The obtained results indicate that our method is stable and capable of achieving very high utilization of the vehicle loading spaces.

Figure 9. Geographical solution (a) Tabarka path before the simulation (b) Tabarka path after the simulation (c) Insertion of the node "Tabarka aerport" in the path Tabarka.



Then, to measure the performance of our solutions, we calculated the Value of Information. The proposed algorithm generated good solutions.

Moreover, we applied our approach in a real case study of the regional Post Office of the city of Jendouba in the North of Tunisia. The results are then highlighted in a cartographic format using Google Maps. Results indicates that the proposed method provides an improvement over the current solution designed manually by the dispatcher since it reduces the overall costs for all the data sets. For future work, we can apply our method of AGA for the Two dimensional Dynamic Vehicle Routing Problem with Backhaul and Time windows constraints.

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APPENDIX

Table 14. Results for the 2L-DVRPB from class 1 to 5 with 50% linehaul customers and 50% backhaul customers for a DoD= 25%, 50% and 75% respectively

DoD= 25%					DoD=50%					DoD=75%				
Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5
375.83	393.25	385.63	389.34	398.36	550.74	549.75	559.25	572.26	572.32	950.74	952.33	960.35	965.23	962.35
384.76	394.52	392.53	392.35	393.68	508.76	508.79	507.99	508.77	508.94	959.01	960.00	957.98	959.98	959.98
435.47	427.69	428.61	439.85	441.36	585.47	585.02	601.35	587.52	588.92	980.79	982.36	985.63	987.96	988.99
448.1	448.65	448.32	448.35	457.29	623.73	639.86	629.75	620.55	625.69	1043.28	1043.28	1043.48	1044.09	1044.96
442.98	442.32	442.89	441.15	444.65	619.06	635.36	635.27	623.85	637.28	1049.93	1078.36	1075.63	1072.86	1084.36
508.01	510.02	509.16	509.63	510.96	700.94	700.89	700.89	700.26	700.97	1151.00	1157.36	1157.65	1158.36	1159.78
776.44	792.36	786.35	777.63	794.39	1187.07	1194.35	1199.75	1187.09	1189.45	1887.09	690.25	695.85	698.99	687.83
838.75	858.97	963.75	851.36	967.98	1209.00	1229.92	1337.98	1298.36	1255.96	2054.64	2066.14	2068.56	2076.98	2078.23
594.11	594.36	597.13	596.38	599.18	794.37	846.98	843.96	846.97	443.96	1344.74	499.98	493.69	499.97	494.01
601.86	710.98	636.02	698.48	698.51	852.22	966.86	910.36	896.32	886.95	1465.28	1586.32	1496.52	1498.56	1499.36
622.77	732.39	689.35	697.52	698.96	941.81	602.85	581.37	644.21	573.57	1453.13	1568.32	1589.23	1592.36	1594.65
571.69	582.67	571.26	577.64	578.62	797.15	797.22	803.96	797.15	799.36	1373.81	1389.52	1390.12	1391.55	1391.64
2976.57	3018.94	3020.96	3019.35	3014.36	3633.26	3789.32	3779.36	3780.96	3789.36	5676.57	5778.63	5875.32	5876.32	5878.32
911.69	1024.39	1098.36	982.36	998.36	1307.05	1458.32	1459.22	1359.67	1359.98	1977.60	2025.36	2060.32	2058.32	2048.32
911.18	1001.99	1024.64	1128.39	1121.16	1291.76	1398.35	1398.75	1485.39	1488.35	2489.59	2598.25	2598.52	2679.55	2696.45
663.21	678.86	684.36	689.31	697.85	893.63	893.77	894.52	896.84	897.85	1343.21	1349.63	1349.77	1350.52	1351.23
788.28	798.25	782.69	798.36	798.88	1040.31	1042.36	1047.66	1052.96	1055.63	990.11	990.22	990.23	991.36	991.38
1015.18	1245.36	1203.97	1198.36	1101.39	1347.18	1452.36	1457.63	1458.36	1347.22	2220.87	2338.56	2339.62	2342.55	2343.56
686.61	789.36	786.39	789.64	791.38	913.19	1028.33	1024.36	1032.69	915.26	1426.08	1532.16	1532.17	1534.26	1531.23
399.52	501.39	501.87	499.86	501.97	569.51	672.85	673.95	678.25	688.65	1009.62	1110.22	1111.23	1110.55	1111.32
871.10	998.37	997.85	998.73	999.18	1177.22	1278.55	1298.55	1278.96	1299.36	2021.19	2142.36	2156.32	2151.33	2101.22
872.21	984.37	992.37	992.72	994.87	1172.04	1284.36	1298.55	1299.52	1299.89	2081.70	872.06	862.67	899.08	805.17
906.77	1008.96	1008.95	1007.85	1009.18	1186.00	1296.32	1294.56	1298.63	1295.86	2275.78	2383.63	2384.22	2387.52	2387.57
1019.44	1192.25	1193.68	1124.39	1194.85	1299.67	1399.36	1399.25	1399.54	1399.75	2259.05	2386.55	2386.57	2386.67	2386.69
1079.95	1279.73	1307.98	1279.35	1298.95	1412.95	1725.36	1739.35	1798.23	1798.66	2469.89	2773.66	2773.89	2784.36	2784.38
969.91	1398.36	1397.84	1397.84	1399.87	1345.44	1665.36	1668.96	1678.25	1687.56	2471.55	2778.55	2778.65	2778.66	2778.67
1073.13	1173.48	1187.97	1188.94	1197.98	1595.54	1695.86	1695.84	1696.85	1698.55	2471.55	2578.56	2588.65	2578.65	2578.96
1243.33	1992.38	1994.87	1918.37	1997.86	1693.70	2396.52	2396.36	2396.85	2398.77	2672.39	3378.55	3455.32	3455.36	3356.78
1567.94	2057.98	2078.94	2126.38	2132.98	1967.61	2417.52	2418.25	2427.25	2455.36	3483.57	3986.35	3889.23	3910.23	3970.85
1350.09	1415.08	1395.52	1385.71	1236.59	1700.50	2102.36	2109.26	2121.3	2123.63	3221.83	3663.25	3668.26	3689.27	3691.23
1536.16	1978.84	2009.38	2197.38	2009.87	1968.21	2365.32	2356.36	2365.32	2365.78	3478.87	3887.55	3889.54	3921.32	3898.65
1521.86	1978.58	2009.87	2158.96	2007.89	1960.92	2469.32	2478.23	2485.22	2485.86	3451.33	3965.23	3866.78	3879.25	3879.82
1534.66	2001.32	2278.96	2287.94	1978.89	1974.56	2470.23	2484	2484.32	2488.63	3486.84	3988.23	3988.36	3988.48	3856.23
851.84	990.28	1101.39	998.87	998.91	1158.30	1286.45	1352.63	1286.85	1289.63	1289.95	1977.60	906.85	875.96	808.32
907.67	1209.96	1291.69	1297.82	1198.34	1227.33	1526.27	1532.16	1592.36	1584.96	2130.44	2489.32	2489.96	2487.96	2496.83
587.34	1590.58	1663.53	1552.67	1449.87	857.51	1486.36	1487.25	1426.77	1488.56	1486.84	2008.32	2009.63	2009.87	2012.15

Ines Sbai is a Ph.D in Computer Sciences , in the higher institute of management of Tunis, ISG University of Tunis, Tunisia. She is currently a Member of the Larodec laboratory (ISG). Her current research interests include optimization algorithms (metaheuristics), especially genetic algorithms, and their application to real-parameter benchmarking and real-world problems in the domain of road-traffic optimization. Because of this work, she has published several papers in referred international and national conferences.

Saoussen Krichen is an Associate Professor in the higher institute of management of Tunis, ISG University of Tunis, Tunisia, and Member of the Larodec laboratory (ISG). She works on single and multiobjective, optimisation, dynamic optimization, coalition formation and supply chain management. She has published several papers on real-world problems using bio-inspired algorithms. Her research activity has resulted in several scientific publications consisting of 15 articles in journals indexed by DBLP and Scopus, and more than 16 refereed conferences. Besides that, Pr. Krichen has published 3 books and several book chapters.