Multi-trip Pickup and Delivery Problem, with Split Loads, Profits and Multiple Time Windows to Model a Real Case Problem in the Construction Industry

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Abstract: This paper presents the first optimization study of multi-site transportation in the construction industry, which allows mutualizing building material delivery and construction waste removal. This study is inspired by a real-world problem encountered in the framework of the French R&D project DILC, in which a pooling platform must centralize the delivery of building materials to the construction sites and the pickup of their waste, using a limited and heterogeneous fleet that is allowed to perform multiple trips, under time and capacity limitation constraints. The problem under study, called the Multi-Trip Pickup and Delivery Problem, with Split loads, Profits and Multiple Time Windows is a new extension of the vehicle routing problem with pickup and delivery, that considers new realistic constraints specific to the construction industry such as each construction site may have a priority on its delivery request or its pickup request or both, with a higher priority level for delivery request, and each construction site may have several time windows. To solve this problem, we propose new insertion criteria that takes into consideration several aspects of our problem, which we have embedded in a construction heuristic. Experiments performed on new instances have shown the efficiency of our method.

1 INTRODUCTION

The problem addressed in this paper is a multi-site simultaneous optimization of building material delivery and waste pickup through a pooling platform in the construction sector. This issue is the result of a collaboration that we are conducting within the French framework of the R&D project DILC, whose aim is to design an innovative platform for optimizing construction site logistics, that is adapted to multi-site eco-city construction projects. The optimization lever studied in the DILC project is the consolidation of the transportation flows and human resources through a physical platform that is modular, removable and mobile, and the development of decision support tools to help the platform managers to optimize their logistics.

Unlike direct transportation from suppliers to construction sites, the pooling platform aims grouping many delivery building materials from different suppliers, receiving them in pallets according to a schedule corresponding to the progress of construction activities on the construction sites. From the received building materials, ready-to-use kits are prepared on the platform, stored and delivered in pallets to the construction sites. The kit represents the site supply unit, that is, a kit must be delivered in full. It is not possible to split the kit into several deliveries. Each kit is characterized by its ID, the number of pallets it contains, and its weight. The delivery request from the construction sites may involve different kits, and the quantities of material delivery demands are known to sometimes exceed the truck's capacity, which requires to supply the construction sites several times, so splitting the delivery demand is allowed in our case. The quantity of waste is relatively inferior to the quantity of material to be delivered, but can also be split.

The platform must also manage the removal of waste from construction sites to the platform. It should be noted that there are two types of waste: Big-bag waste and tipper waste. Big-bag wastes are packed on pallets and concern wastes that are produced with small and medium quantities such as soft plastic, hard plastic, and cardboard. Tipper waste concerned the wastes that are produced with high quan-

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tities like wood and metals. In this study, we focus only on Big-bag wastes because their removal can be pooled with the delivery of building materials using a limited and heterogeneous tail-lift truck fleet, whose capacity is given in pallets. The vehicles perform multiple trips between the platform and the construction sites to load the kits at the platform, deliver them to the construction sites, collect waste from the construction sites and unload these wastes in the recycling center located just next to the platform.

It should also be noted that the planning of operations within the platform does not concern this study. The problem addressed here is the routing optimization between the platform and the construction sites to mutualize the materiel delivery and the waste removal, and more specifically we present a new variant of the well-known pickup and delivery problem, named MTPDPSPMTW for the Multi-Trip Pickup and Delivery Problem, with Split loads, Profits and Multiple Time Windows.

The MTPDPSPMTW belongs to the class of Vehicle Routing Problem with Pickup and Delivery (VRPPD), which has been studied for more than 30 years (Parragh et al., 2007; Parragh et al., 2008), and consists of transporting objects or people between origins and destinations. More precisely, the problem studied in this paper is included in the class VRP with Backhauls (VRPB) where objects or individuals are transported from a depot to linehaul customers and from backhaul customers to a depot (Parragh et al., 2008), and the most adequate VRPB subclass with our problem is the VRP with Divisible Deliveries and Pickups (VRPDDP), which is a special case of the VRPPD, where each customer may have delivery and/or pickup requests that must be served with capacitated vehicles, and the pickup and the delivery quantities can be served, if helpful, in two separate visits(Nagy et al., 2015). Many variants of VRPPD with several constraints have been proposed in the literature to model real transportation problems. In some cases, the available resources are insufficient to service all customers. Thus, a known profit is associated with each customer, the goal is to find the subset of customers to be serviced and to determine vehicle routes that: maximize the total acquired profit, minimize the total traveling cost, and satisfy temporal and capacity constraints (Chentli et al., 2018). Several variants of VRPPD introduced the concept of time windows where the service at each customer must start within one given time windows (Sun et al., 2020). The most relevant extension of the VRPPD is the VRPPD with split loads (VRPDPSL) where customer demands can be split between several vehicles (Nowak et al., 2008). Other variants of VRPPD which combines split and multi-trip are available in the literature such as (Haddad et al., 2018) and (Yin et al., 2013).

Despite the abundant literature on the pickup and delivery problem, the problem that we present here is a novel one and allows us to model constraints that are specific to the construction sector. Our contribution can be summarized in the two following issues:

- The MTPDPSPMTW allows to simultaneously consider constraints that have never been previously combined in the pickup and delivery variants studied in the literature. More specifically, these are the constraints on heterogeneous fleet of vehicles, multi-trips, splitting demands, profit and time windows. Note that in our problem, profit is associated with a pickup request and/or a delivery request, while in most studies in the literature profit is associated with a customer and includes both pickup and delivery requests.

- The MTPDPSPMTW is an NP-hard problem, and to resolve it we propose new score criteria to deal with the complexity of our problem, and we embed these criteria in a constructive polynomial heuristic, named SBH (Score Based Heuristic). Experiments on new instances show the effectiveness of this approach.

The remainder of the paper is organized as follows. Section 2 describes the problem. A constructive heuristic is proposed in Section 3. Experimental results with the definition of benchmarks are given in Section 4. Finally, concluding remarks and guidelines for future research are given in Section 5.

2 PROBLEM DEFINITION AND NOTATION

The Multi-Trip Pickup and Delivery Problem, with Split loads, Profits and Multiple Time Windows, named MTPDPSPMTW can be defined on a complete, undirected graph $G = (E,V)$, where $V = \{0,\dots,n\}$ is the set of vertices and $E = \{(i,j) : i,j \in V, i \neq j\}$ is the set of edges. Vertex 0 is the pooling platform while the other vertices are the construction sites. A travel time t_{ij} and cost $c_{i,j}$ are assigned to each edge (i,j). A fleet of heterogeneous tail lift vehicles is located on the platform. The vehicle fleet is composed by m vehicles with different capacities and time availability. We noted Q_k the capacity in pallets of the k^{th} vehicle $k \in \{1,\dots,m\}$,W_k its volume capacity in tons, and by D_k its maximum working time.

Each site $i \in V$ has a pickup demand $\overrightarrow{p_i}$ a delivery demand $\overrightarrow{d_i}$. Note that, all demands are integer vectors.$\overrightarrow{p_i}$ is in this form $(big-bag_1,\dots,big-bag_z)$ which expresses the pickup demand of each type of

Big-bag waste. $\overrightarrow{d_i}$ is represented as $(kit_1,\ldots,kit_{z'})$ that describes the delivery demand of each type of kits. A kit can contain one or more pallets and the Big-bag waste unit is the pallet. Thus, all demands of site delivery and pickup are expressed in pallets. In the rest of the paper we denote by $qt(\overrightarrow{vect})$ the size of demand in pallets ($\overrightarrow{vect}$ can be $\overrightarrow{p_i}$ or $\overrightarrow{d_i}$). Sometimes, the demands of sites (delivery and/ or pickup) are greater than the vehicle capacity (for example $qt(\overrightarrow{d_i}) > Q_k$), then the site can be served by the same vehicle with several trips or by several vehicles. Each site can have a priority on its delivery demands or its pickup demands or both. To satisfy these requirements, two real values pp_i and pd_i are associated with each site i and correspond to the pickup profit and delivery profit, respectively. Unlike the literature approaches where the profit is associated with customers, in our model, the profit is associated with each demand.

Each vertex $i \in V \setminus \{0\}$ has a service time s_i which corresponds to the loading/unloading time on site, and a set of time windows $TW_i = \{[e_i^1,l_i^1],[e_i^2,l_i^2],\ldots,[e_i^t,l_i^t]\}$ where e_i^p $p \in \{1,\ldots,t\}$ is the earliest time to begin service at the vertex i and l_i^p is the latest time to finish service at the vertex i . Some time windows are flexible, so, time delays allow arrival before e_i^p and departure after l_i^p. These time delays are noted me_i^p (ml_i^p respectively) for the upstream delay (the downstream delay respectively),so each time window of a site i can be enlarged to $[e_i^p - me_i^p, l_i^p + ml_i^p] = [e_i^*, l_i^*]$. If a delay time of a time window is null, the time window is called hard time window, otherwise the time window is flexible, the flexibility of a given time window is more important if the delay time is larger. In fact, this time delay can be used mainly by the platform managers to help them to negotiate more effectively the time window constraints with the construction sites.

Furthermore, we defined $[e_0,l_0]$ as the single time window of the platform that designates the earliest possible departure from the platform and the latest possible arrival at the platform. The service time s_0 at the platform is given by the sum of the loading time of kits and unloading time of Big-bag waste. This service time is not considered for the first trip of each vehicle since the first vehicle loading can be done independently of its tour. If a vehicle travels directly from site i to site j. The service of site j starts at $b_j = max\{e_j^c, b_i + s_i + t_{i,j}\}$ where $e_j^c = min_{1\leq k\leq |TW_j|}\{e_j^k - me_j^k \mid l_j^k + ml_j^k - (b_i + s_i + t_{i,j} + s_j) \geq 0\}$ designated the lower bound of the most adequate time window. If the vehicle arrives too early at j, the service can start at $b_j = max\{e_j^c - me_j^c, b_i + s_i + t_{i,j}\}$ if $me_j^c \neq 0$. Note that waiting is not allowed because construction site activities do not allow access to the sites beyond the imposed time constraints.

A feasible solution to our problem is composed of a set of feasible trips assigned to adequate vehicles. A feasible trip is a sequence of nodes that satisfies the following set of constraints:

- Each trip must start and end at the pooling platform.
- Each kit must be delivered in full, no possibility to split the kit into several trips.
- The overall amount of materials delivered and wastes picked along the route must not exceed the vehicle capacity (Q_k, W_k).
- The total duration of each trip calculated as the sum of all travel duration required to visit all the construction sites of the trip sequence, and service time needed for each visit to a construction site during the tour could not exceed D_k ;
- Each site can be visited at most once during the trip while respecting one of its time windows.

We seek to construct a feasible solution of a minimum number of trips, and affecting one or several trips to the available vehicles such that:

- The total duration of each vehicle's route, calculated as the sum of all its trips duration, and the sum of the platform's service times don't exceed D_k
- Each vehicle must start at the pooling platform no earlier than e_0 and finish at the pooling platform no later than l_0.
- No more than m vehicles are used;
- Each construction site may be visited several times with the same or different vehicles, so splitting is allowed for delivery requests and pickup requests, and some sites may not be visited at all.
- The sum of the quantities delivered to a given construction site must be less than or equal to its delivery request and the sum of the quantities collected from a given construction site must be less than or equal to its pickup request. This means that the customer can be delivered and/or collected partially.

The objective function is a weighting of three objectives: time, profit, and the number of priority customers fully served. Our goal is to minimize the first objective and maximize others.

3 SCORE BASED HEURISTIC

The MTPDPSPMTW is an NP-hard problem. Hence, the use of exact optimization methods is not able to solve this problem in polynomial time, when the problem concerns the very large real-world data sets. However, heuristics are more suitable for this problem. Accordingly, we proposed a new construction heuristic called SBH (Score Based Heuristic) and new score criteria adapted to our problem such as distance, time, customer service urgency, the deadline to serve a customer, priority (profit delivery and profile pickup).In this section, we describe this heuristic.

Initially, the heuristic selects a vehicle available from a heterogeneous fleet. Throughout this work, the vehicle selection has undergone the following rules: If the total demand of the sites not yet served is greater than the maximum capacity in this fleet, then the vehicle available with the maximum capacity is selected. Otherwise, the vehicle with the minimum capacity that meets all demands is selected. In the next step, the heuristic creates an empty trip and associate it with the selected vehicle. This trip is extended by appending the feasible site j that has the minimum score based on $Cr_{i,j}$ Eq(7) to the sites i (the latest routed site). A free client j is said feasible if it can be added to the current route without violating time window constraint TW_j, vehicle capacity constraint Q_k (pallet capacity), W_k (tons capacity), and vehicle time availability D_k. During the loading of a vehicle at the platform, two cases are possible: either that the site demand d_j is less than the vehicle's capacity, in this case, all customer delivery will be loaded into this vehicle (the customer is fully delivered). otherwise, the customer is partially delivered on the current trip. Two sites or more will probably be delivered partially on the same trip due to atomic deliveries of kits. For example, if we consider a vehicle k with $Q_k = 16$ and two sites where $\overrightarrow{d_1} = (4\,kit_1, 3\,kit_3)$ and $\overrightarrow{d_2} = (2\,kit_2, 1\,kit_3)$. Knowing that kit_1, kit_2 and kit_3 are composed by $3, 2$ and 5 palettes, respectively. Thus 4 kit_1 will be delivered to site 1 and 2 kit_1 to site 2. As soon as the limit vehicle capacity is reached or no site can be inserted to the current trip, the vehicle returns to the platform and a new route is initialized. If the vehicle availability time has expired a new vehicle is selected. The algorithm converges when all customers are satisfied or all resources are used. The main structure of this heuristic is given by algorithm 1.

In this part of our paper, we describe the selection criteria of the SBH heuristic proposed to the MTPDPSPMTW. Firstly, we consider the distance $d_{i,j}$ Eq(1) which allows to select the closest sites to the current vehicle location. The second criterion is the travel time $T_{i,j}$ Eq(2). In addition, we consider the customer service urgency using all time windows and their margins Ur_{ij} Eq(3) which favors the selection of sites where their remaining time service is very short. The fourth criterion is the deadline to serve the site Ds_j Eq(5) this promotes the selection of sites whose deadlines will expire as soon as possible.

The last are the profit related to delivery Pd_i and pickup Pp_i which are represented by Eq(5) and Eq(6), respectively. The values of Pd_i and Pp_i are fixed according to real cases. The goal of these criteria is to foster the serving of the sites with priority. To ensure continuity of deliveries service for a site, we multiply the delivery profile Pd_i by progress rate delivery as shown in Eq(7). For example, if a site i has a demand d_i such as $qt(\overrightarrow{d_j})$=15 palettes and only 10 palettes are delivered on the current trip.It will have a more chance than the other sites where the service has not yet started to be selected on the next trip because the progress rate delivery of i is $\sum \frac{cd_j}{qt(\overrightarrow{d_j})} = \frac{10}{15} = 0.75$, but, the progress rate delivery of other sites is null. This to avoid multiplying partial services.

- $$d_{ij} \tag{1}$$
  the distance between the last site visited i and a site j not yet satisfied either in delivery or in collection
- $$T_{ij} = b_j - (b_i + s_i) \tag{2}$$
  the time difference between the end of service at i and the start of service at j
- $$Ur_{ij} = l_j^c - (b_i + s_i + t_{ij}) + \sum_{\substack{1 \le k \le |TW_j| \\ k \ne c \\ e_j^k \ge b_i + s_i + t_{ij}}} l_j^k - e_j^k + \beta \left(ml_j^c + \sum_{\substack{1 \le k \le |TW_j| \\ k \ne c \\ e_j^k \ge b_i + s_i + t_{ij}}} me_j^k + ml_j^k \right) \tag{3}$$
  the site service urgency when we consider all time windows and their margins. $\beta = 1$ if we allow the use of time windows margins 0 otherwise.
- $$Ds_j = \max_{1 \le k \le |TW_j|} (l_k) - (b_i + s_i + t_{ij}) \tag{4}$$
  deadline to serve the site j.
- $$Pd_i = \begin{cases} 5 & \text{if site } i \text{ has priority in deliveries} \\ 2 & \text{if site } i \text{ has non-priority in deliveries} \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

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- $$Pp_i = \begin{cases} 2 & \text{if site } i \text{ has priority in pickup} \\ 1 & \text{if site } i \text{ has non-priority in pickup} \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

$$\begin{aligned} Cr_{ij} = {} & \gamma_1 \frac{d_{ij}}{\max_j(d_{ij})} + \gamma_2 \frac{T_{ij}}{\max_j(T_{ij})} + \gamma_3 \frac{Ur_{ij}}{\max_j(Ur_{i,j})} \\ & + \gamma_4 \frac{Ds_j}{\max_j(Ds_j)} - \gamma_5 \sum \frac{cd_j}{qt(\overrightarrow{d_j})} \times \frac{Pd_j}{\max_j(Pd_j)} \\ & - \gamma_6 \frac{Pp_j}{\max_j(Pp_j)} \end{aligned} \tag{7}$$

where:
cd_j is the number of pallets delivered to site j so far.
$\sum_{i=1}^{6} \gamma_i = 1 \qquad \gamma_i \geq 0 \; \forall i \in 1,\ldots,6$

4 COMPUTATIONAL STUDY

In this section, we describe our experimental results. Section 4.1 presents the characteristics of the MTPDPSPMTW test instances. Section 4.2 the configurations for the values of the parameters of our algorithm using the irace package. The results of detailed and comprehensive computational studies are summarized in Section 4.3.

4.1 Instance Generation

To evaluate the performance of our heuristic, we designed two groups of MTPDPSPMTW instances based on DILC real scenarios. The distance between two sites or between a site and the platform is chosen randomly between 1 and 150 km. For each instance, 20% of sites have a load of a delivery request in $[Q, 3Q]$, 60% in $[\frac{1}{3}Q, Q]$ and 20% lower than $\frac{1}{3}Q$. The load of a pickup request is lower than $\frac{1}{3}Q$ for all sites, where $Q = 16$ is the pallet capacity of the largest vehicles. The percentage of priority requests waste collection is always fixed at 50%. Each site can have one, two, or three time windows. The set of site time windows can be fixed chosen from a list $\{[06:00-08:00 \quad 0-30], [11:00-14:00 \quad 30-0], [17:00-20:00 \quad 30-0]\}$ of predefined or chosen randomly respecting platform time windows, where the notation $[e_i\text{–}l_i \quad me_i - ml_i]$ correspond to the time window $[e_i, l_i]$ of site i with upstream delay me_i and downstream delay ml_i.

To evaluate the effectiveness of our heuristics on several real cases, we create the first group of instances named G1 which contains three basic instances DILC10, DILC20, and DILC100 or 10,20 and 100 designating the number of sites. The number of vehicles is 3, 5, and 10 for instances DILC10, DILC20, and DILC100, respectively. In all instances, 70% of vehicles have a large capacity, $Q = 16$ and the leftovers have a small capacity of $Q = 4$. In each instance, we vary the percentage of priority requests deliveries from 0%, 30%, 60%, and 100%. Then we obtain 4 subgroups. For each subgroup described above, we vary the percentage of random time windows from 0%, 30%, 70%, and 100%. So we have 16 instances

Algorithm 1: Score Based Heuristic.

Input: A MTPDPSPMTW instance;
A list L_{uns} of unsatisfied sites ;
$L_{uns} \leftarrow \emptyset$;
A list L_{feas} of feasible sites ;
$L_{feas} \leftarrow V$;
Output: A feasible solution
$Total\_D \leftarrow Calculate\_Total\_delivery()$;
$Total\_P \leftarrow Calculate\_Total\_pick\_up()$;
$k \leftarrow Select\_vehicle()$;
$vehicleLoad \leftarrow 0$;
$Availability\_k \leftarrow D_k$;
Create an empty route r for this vehicle and initialize it with the platform ;
$vehCount \leftarrow 1$;
while $(vehCount \leq m)$ *AND* $(L_{uns_i} \neq \emptyset)$ **do**
    while $(vehicleLoad < Q_k)$ *AND* $(Availability\_k < D_k)$ **do**
        Update L_{feas_i};
        if $L_{feas_i} \neq \emptyset$ **then**
            Let $j \in L_{feas_i}$ such that $Cr_{i,j} = \min_{j \in L_{feas_i}} (Cr_{i,j})$ referring to Eq. (7) ;
            Update($\overrightarrow{d_j}, \overrightarrow{p_j}$);
            Update($Total\_D, Total\_P$);
            Connect j to last visited site i ;
            Update($vehicleLoad$);
            Update($Availability\_k$);
            Update L_{uns_i};
        else
            break;
        end
    end
    Connect the last site of the route r to the platform ;
    if $Availability\_k < D_k$ **then**
        Create an empty route and initialize it with the platform;
        Associate this route to the current vehicle;
    else
        $k \leftarrow Select\_vehicle()$;
        $vehicleLoad \leftarrow 0$;
        $Availability\_k \leftarrow D_k$;
        Create an empty route for this vehicle ;
        $vehCount \leftarrow vehCount + 1$;
    end
end

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per group, resulting in a total of 48 instances in our test group G1.

The most representative cases are the instances DILC100. Consequently, we create a second group of instances noted G2-100-70-50 where 100 is the number of clients of which 70 are priority and 50 is the percentage of sites who have random time windows. 10 instances are generated in this group to assess the impact of each criterion studied in section 3 on the behavior of SBH.

4.2 Training SBH Parameters

Our heuristics use a score to select the most suitable site. This score utilizes a set of criteria. To weigh these criteria in the most effective way, we have chosen automatic tuning using Iterated Racing for Automatic Algorithm Configuration (IRACE). IRACE is a tool based on machine learning methods to tune optimization algorithms, i.e. automatically finding good configurations for the parameter values of a target algorithm. (López-Ibáñez et al., 2016). We set to 2000 the maximum number of algorithms runs during the tuning for the algorithm runs for all instances. The chosen parameters space for this racing are $\gamma_i \in [0,1]$ and $\sum_{i=1}^{6} \gamma_i = 1$. Table 1 shows the best setting parameters found by irace. These results show that all parameters are not null, hence the importance of all proposed criteria to calculate the score.

Table 1: Best configurations found by irace for the SBH heuristic.

Parameter	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6
Value	0.14	0.32	0.1	0.16	0.25	0.012

4.3 Resultats Analysis

The SBH heuristic was coded in python. All tests were carried out on a personal computer with Intel Core(TM) i7-7920HQ processor at 3.10 GHz and the Microsoft Windows 10 operating system using 32.00 GB RAM.

Table 2 shows the results obtained by our heuristic to solve the instance DILC 10, 20, and 100 described above. These results reveal that the heuristic can completely satisfy a high percentage of priority requests (for example, for the DILC20 group of instances, we have 93.49% of priority delivery requests completely satisfied, and 98.12% of priority pickup requests). The heuristic adds a lower percentage of partially satisfying requests to complete routes. It can be observed that the rate of partially satisfying requests is higher for priority delivery requests compared to non-priority delivery requests (18.84% for partially fulfilled priority delivery requests versus 6.9% for partially fulfilled non-priority pickup requests for DILC10 instances). The quantities of pickup requests are much lower than the delivery quantities, which explains the low percentage of partially fulfilled requests.

For instances DILC10 we observe that 78.2% of priority delivery requests are fully satisfied and 18.8% are partially satisfied. The pallets delivered correspond to 66.6% of the total number of pallets requested. For non-priority delivery requests, 77.1% are totally satisfied, and 6.9% partially satisfied. The percentage of totally satisfied pickup requests is also high 77.1% for the priority and 98.4% for the non-priority. The collected pallets represent 66.6% of the total.

For instances DILC20, we note that the percentage of priority and non-priority delivery requests completely satisfied is very high 93.4% and 94.3%, respectively. The percentages of pickup requests totally satisfied are very lofty 98.12% for both priority and non-priority requests. This explains the high rate of pallets delivered 94.9% and collected 98.5%.

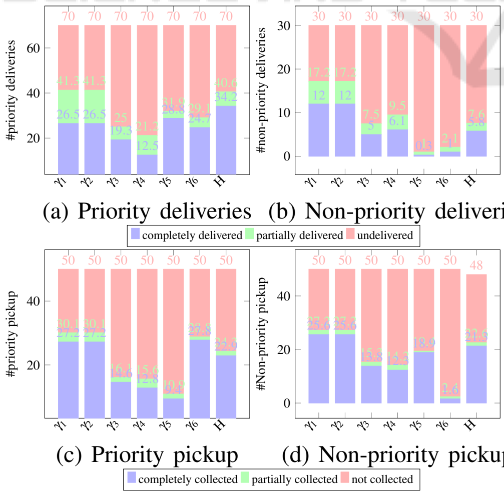
Finally, for large instances DILC100, the results indicate that 53.4% of priority delivery requests are entirely satisfied and 7.9% are incompletely satisfied. The percentage of non-priority delivery requests completely satisfied is 25.6% and 6.3 for the requests partially satisfied. The percentage of pickup requests fully satisfied is 46.2% for the priority requests and 41.2% for non-priority requests. The rates of pallets delivered and collected are proportional to the percentage of requests served. According to these results, we conclude that the SBH is effective for all instances in terms of all metrics. Consequently, our heuristic algorithm can be used to solve real industrial cases.

4.4 Impacts of the Criteria on SBH's Behavior

Referring to table 2 we show that instances DILC100 are the most difficult, so we decided to evaluate the impact of each criterion discussed in Section 3 on the behavior of our heuristic using instances of G2-100-70-50 group. To reach these goals, we used the following metrics: The priority deliveries (Figure 1a) and non-priority deliveries (Figure 1b) metrics are statistics on the average number of priority and non-priority delivery sites, respectively. Priority pickup (Figure 1c) and non-priority pickup (Figure 1d) represent statistics on the average number of priority and non-priority sites in pickup. The total distance and total time are exposed by Figure 2a and 2b, respectively.

The number of material pallets delivered (Figure 2c) represents the average of the pallets delivered on all sites priority or non-priority. The number of Big-bag pallets collected (Figure 2d) designates the average of pallets collected from all sites.

Figures1 illustrates these statistics which represent the result of the evaluation of each criterion separately, i.e. $\gamma_i = 1$ for the i^{th} criterion, and the other cities are not taken into account. If we consider the distance criterion only $d_{i,j}$ Eq(1), we notice that the average of priority delivery requests totally satisfied is quite important 26.5 among 70 (see Figure 1a), as well as the average of non-priority delivery requests totally satisfied which is equal to 12 (see Figure 1b). The same goes for the average of priority and non-priority pickup requests. We also note that the average of delivery requests (priority or not) partially satisfied is high, which contradicts our objective, which aims to satisfy completely all sites. This can be explained by the fact that when we use this criterion, the heuristic aims to minimize the total distance traveled by the fleets of vehicles 5059 km which increases the number of tours and consequently the number of requests served in terms of deliveries and pickup without taking into account priority and complete request fulfillment. Thus, the average of the amount of pallet delivery and pallet pickup is important that corresponding to 575.8 and 289.6, respectively. As time is proportional at the distance, we obtain the same results for both criteria.

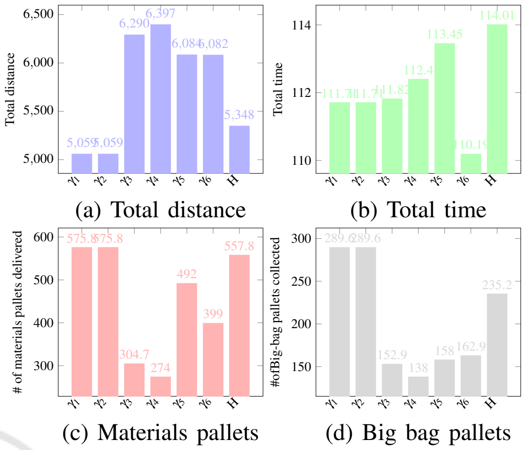


(a) Priority deliveries (b) Non-priority deliveries

(c) Priority pickup (d) Non-priority pickup

Figure 1: Comparisons between the impact of each criterion on deliveries and pickup.

If we consider only the site service urgency Ur_{ij} Eq(3), we observe that the average of delivery requests totally satisfied (priority or not) and the average of pickup requests totally satisfied is very low compared to the other criteria. This is explained by the fact that our heuristic selects the site which has the minimum service time such a site can be far from the current vehicle position which increases routes and reduces the number of trips. Consequently, the number of sites served and the average of pallets delivered and collected decreases as shown in Figure 1.



(a) Total distance (b) Total time

(c) Materials pallets (d) Big bag pallets

Figure 2: Comparisons between the impact of each criterion on distance, time, and pallets delivered and collected.

When we assess the deadline to serve the site Ds_j Eq(4). We note that the average of priority delivery requests totally satisfied and the average of material delivered pallets are the smallest 12.5 and 274, respectively. However, the distance traveled by the fleet of vehicles is the longest 6397 km . This is due to the behavior of our heuristic that chose the site with the time service that will expire the earliest. These sites are often distributed in distant geographical areas, which proves the results obtained.

Table 2: Results of the score based heuristic for solving instance DILC 10, 20, and 100.

			DILC10	DILC20	DILC100
Priority	**Delivery**	**% of sites 100% satisfied**	78.2	93.4	53.4
		% of partially satisfied sites	18.8	5.2	7.9
	Pickup	**% of sites 100% satisfied**	77.5	98.1	46.2
		% of partially satisfied sites	98.9	0	3.3
Non-Priority	**Delivery**	**% of sites 100% satisfied**	77.1	94.3	25.6
		% of partially satisfied sites	6.9	4.8	6.3
	Pickup	**% of sites 100% satisfied**	98.4	98.1	41.2
		% of partially satisfied sites	0	0	2.3
Distance			1236.4	2522.7	5188.6
Number of hours			31.2	54.3	111.1
Number of trucks			3	4.9	10
% pallet served in deliveries			66.6	94.9	42.2
% pallet served in pickup			85.1	98.5	45.6

When we test the influence of delivery profit Pd_j Eq(5) on heuristic behavior, we notice that the maximum of the average of priority delivery requests totally satisfied 28.8 is reached for this criterion and the average of priority delivery requests partially satisfied is the smallest 3.1 thanks to the progress rate delivery which encourages the continuity of site service. The average of non-priority delivery requests totally or partially satisfied tends towards zero. The average of non-priority pickup requests is greater than the average of priority pickup requests since the majority of sites served are the priority in the delivery and not in the collection. The total time is the biggest despite the distance is no longer this is due to the bigger service time.

We find that the pickup profit Pp_j Eq(6) allows us to serve a large number of pickup priority sites as well as delivery priority sites, since, most of the sites served, in this case, are the priority in pickup and deliveries. For all the criteria we notice that the average number of partially satisfying pickup requests is very small since the quantity of Big-bag waste generated by construction sites is low below 3/4 vehicle capacity, which allows them to be collected easily.

Our heuristic SBH combines all the criteria described previously in a weighted manner according to Table 1. This combination noted H in Figures 1 and 2 allows obtaining good results on all comparative metrics. Indeed, our heuristic satisfies the highest number of priority delivery requests 34.2, and a significant number of non-priority delivery requests 5.8. The average pickup requests totally satisfied is also important compared to the other criteria. The average amount of pallet delivery and pallet pickup are comparable to the ones obtained by $d_{i,j}$ and $T_{i,j}$. The total time duration taken by our heuristic is highest because the priority sites are not necessarily nearby in addition to the time of loading and unloading of vehicles.

5 CONCLUSION

In the present paper, we described a new variant of the vehicle routing problem with pickup and delivery, named MTPDSPMTW for multi-trip pickup and delivery problem, with split loads, profits, and multiple time windows. This new variant allows modelling a real-world problem encountered in the construction industry and combines for the first time characteristics that have been studied separately in the literature on vehicle routing problems. These are multi-trip, split loads, profit, time window and the use of heterogeneous vehicles. The issue is that not all customers can be served because the number of vehicles is limited, and partial service is allowed, so the difficulty arises in selecting the customers to be included in the tour while prioritizing service satisfaction for customers with a high priority (maximizing profit), and allowing non-priority customers to be included to to fill the residual capacity and/or time of the vehicles. We proposed a new insertion score based on six criterai, that is embedded in a construction heuristic (SBH). Numerical results on new instances show that all proposed criteria have a non-zero weight in the score and that the combination of all criteria gives the most significant results in relation to the objective of maximizing the number of priority customers completely satisfied. The effectiveness of these results has been validated by our industrial partners, and have been retained for further experimentation. The next step is to develop metaheuristic approaches to improve obtained results.

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