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► **To cite this version:**

Samuel Deleplanque, Jean-Pierre Derutin, Alain Quilliot. Anticipation in the Dial-a-Ride Problem: an introduction to the robustness. FEDERATED CONFERENCE ON COMPUTER SCIENCE AND INFORMATION SYSTEMS - WCO, Sep 2013, Kraków, Poland. pp.299 - 305. hal-00918302

HAL Id: hal-00918302

<https://hal.science/hal-00918302v1>

Submitted on 13 Dec 2013

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Anticipation in the Dial-a-Ride Problem: an introduction to the robustness

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Abstract—The Dial-a-Ride Problems (DARP) models an operation research problem related to the on demand transport. This paper introduces one of the fundamental features of this type of transport: the robustness. This paper solves the Dial-a-Ride Problem by integrating an *Inserability* measurement. The technique used is a greedy insertion algorithm based on time constraint propagation (time windows, maximum ride time and maximum route time). In the present work, we integrate a new way to measure the impact of each insertion on the other not inserted demands. We propose its calculation, study its behavior, discuss the transition to dynamic context and present a way to make the system more robust.

I. INTRODUCTION

Today, the Dial-a-Ride Problems are used in transportation services for elderly or disabled people. Also, the recent evolution in the transport field such as connected cars, autonomous transportation, and the emergence of the shared service might need to use this type of problem at much larger scales. But this type of transport is expensive and the management of the vehicles requires as much efficiency as possible, however the number of requests included in the vehicles planning can vary depending on the resolution used.

In [1] we solve the DARP by using constraint propagation in a greedy insertion heuristic. This technique obtains good results, especially in a reactive context, and is easily adaptable to a dynamic context. But, each demand is inserted one after another and the process doesn't take into account the impact of each insertion on the other not inserted demands, and so, in a dynamic context, the future demands. In this work, we present a measure of an insertion capacity named *Inserability*. We introduce its calculation by integrating the impact of an insertion on the time constraints (time windows, maximum route time and maximum ride time).

This measurement may be used in different ways: selection of the demand to insert, selection of the insertion parameters, and exclusion of a demand. These three uses may be related to static as well as dynamic contexts by anticipating the future demands. The goal is to insert the current demand in order to build flexible routes for the future ones.

This paper is organized in the following manner: after a literature review, the next section will propose a model of the classic DARP. Then, we will review how to handle

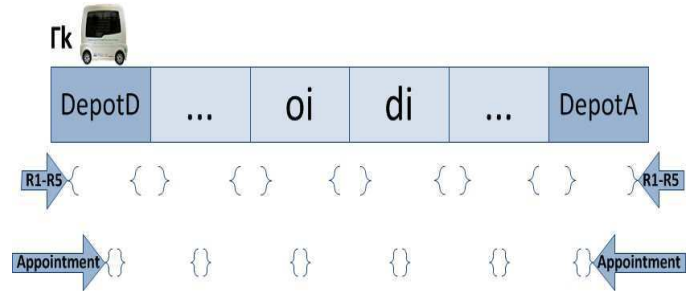


Fig. 1. Times windows' contraction

the temporal constraints with a heuristic solution based on insertion techniques using propagation constraints. We will continue by explaining the way to measure the *Inserability*, a calculation based on the evolution of the time windows after an insertion. Then, we will give some uses of this measurement including making an appointment which minimize the time windows (cf. Figure 1). In the last part of the paper, the computational results will show the efficiency of our *Inserability*'s measurement and we will report the evolution of the number of demands inserted in a resolution of some instances' sets.

II. LITERATURE REVIEW

The first works of the transportation optimization problem are related to the Traveling Salesman Problem ([2]). Since that time, other transportation problems have emerged as the vehicle routing and scheduling problems, and the Pick-up and Delivery Problem (PDP). The PDP is the ancestor of the problem of the Dial-a-ride problem which has been studied since the 1970's. DARP can be modeled in different ways. There are a number of integer linear programmings [3], but the problem complexity is too high to use, most of which are NP-Hard because it also generalizes the Traveling Salesman Problem with Time Windows (TSPTW). Therefore, the problem must be handled through heuristic techniques. [4] is an important work on the subject and uses the Tabu search to solve it. Other techniques work well like dynamic programming (e.g. [5] and [6]) or variable neighborhood searches (VNS) (e.g. [7] and [8]). Moreover, a basic feature of DARP is that it usually

integration, but only the effect on the demands already inserted. In this section, we introduce a *Inserability* calculation by integrating this impact of an insertion related to the time constraints (time windows, maximum ride time and maximum route time).

During the insertion process, the state of the system is given by:

- A set of demands $D-D1$ already integrated in the routes, and $D1$ is the set of demands not inserted,
- a collection $\Gamma = \cup_{k \in K} \Gamma_k$ of routes including a list of nodes related the *Depot*, *origin* and *destination* nodes,
- a exhaustive list of insertion's parameters sets. Each set gathers 5 elements : k the vehicle, i the demand, (x, y) the pair of insertion nodes (locating respectively o_i between x and the successor of x , and d_i between y and the successor of y), and v the evolution of the collection $\Gamma = \cup_{k \in K} \Gamma_k$'s cost.

B. Insertion's parameters

Given that the difficulty of the instances' problem is linked to the time constraints, we introduce an *Inserability* calculation related to the times windows contractions. During an insertion's assessment, these reductions appear once the inference rules are propagated. Here, we try to find a good 3-uple (k, x, y) , the vehicle and the location of the *origin/destination* nodes, in order to give enough space to the future demands (which have to be integrated in $\Gamma = \cup_{k \in K} \Gamma_k$).

We set $INSER(i, \Gamma)$ the *Inserability* measurement of the demand I . The quantity $U_n^k(z)$ denotes the vehicle k time windows' amplitude of the node n once it has been inserted to the right of node z . $INSER$ is calculated as follows:

- $INSER(i, \Gamma) = \sum_{k \in K} INSER1(i, \Gamma_k)$;
- $INSER1(i, \gamma) = Max_{(x,y)} INSER2(i, \gamma, x, y)$, γ a tour of Γ ;
- $INSER2(i, \gamma, x, y) = U_{o_d}^\gamma(x) \cdot U_{d_d}^\gamma(y)$.

We set $Inserted(\Gamma, i_0, k, x, y)$ the updated collection of tours Γ with the insertion of the selected demand i_0 at the locations x and y in the vehicle k . The $INSER(i, \Gamma)$ measurement allows us to write the *Optimization Inserability Problem* which consists to find the best insertion parameters in order to keep the vehicles' scheduling more flexible:

Optimization Inserability Problem. Find the optimal parameters (k, x, y) inserting i_0 and maximizing the value $Min_{i \in D1-i_0} INSER(i, Inserted(\Gamma, i_0, k, x, y))$.

For instance, the value $Min_{i \in D1-i_0} INSER(i, Inserted(\Gamma, i_0, k, x, y))$ may be used if all the demands have to be inserted. Another

optimization may be process as the maximization of the sum $\sum_{i \in D1-i_0} INSER(i, Inserted(\Gamma, i_0, k, x, y))$. The choice is made according to the homogeneity of the demands and if the problem requires to insert all the set D .

This problem only optimizes the variation of the *Inserability* values and doesn't include other performance criteria like the minimization of the ride times, waiting times or distances. The *Inserability* criterion can be integrate in a mix of economical cost (point of view of the fleet manager) and of QoS criteria (point of view of the users). Then, the process maximizes the function $Perf = \mu \cdot \sum_{i \in D1-i_0} INSER(i, Inserted(\Gamma, i_0, k, x, y)) - v(Inserted(\Gamma, i_0, k, x, y))$ with μ a criterion coefficient and v the performance value function mixing the costs related to the both points of view.

C. Other uses of the Inserability measurement

So far, we select the demand i_0 according to the number of vehicles available (taking in account all the time and load constraints). The *Inserability* measurement $INSER(i_0, \Gamma)$ may be also used in order to select the next request i_1 to insert. This application could be used in a context where all the demands of D have to be integrated. The selection is based on the smallest *Inserability* measurement. Once a demand is selected, the problem may solve the *Optimization Inserability Problem*. Here, the two steps may be written in a non-deterministic way. The demand may be selected randomly through a set of $N1$ elements with the smallest $INSER$ value. The same scheme may be applied on a set of a insertion parameters of $N2$ elements with a best (k, x, y) elements maximizing the quantity $Min_{i \in D1-i_0} INSER(i, Inserted(\Gamma, i_0, k, x, y))$.

Also, $INSER(i_0, \Gamma)$ may be useful for a larger set D . If the instance doesn't have any solution integrating all the set D , it is preferable to identify requests to exclude as soon as possible. The exclusion of a demand i_0 may be set up if its insertion results in Γ not enough flexible to include the other elements of $D1$. In other words, the demands excluded will be those that will have the most impact of future insertions. The difference $\sum_{i \in D1-i_0} (INSER(i, \Gamma) - INSER(i, Inserted(\Gamma, i_0, k, x, y)))$ of the inequality (4) takes in account the *Inserability* measurement of $D1 - i_0$ before and after the insertion of i_0 in the routes of Γ . If this difference is larger than the threshold ξ , the demand is excluded. In the experimentation' section, we will discuss the fact this threshold should be dynamic and decreases over the execution.

$$\sum_{i \in D1-i_0} (INSER(i, \Gamma) - INSER(i, Inserted(\Gamma, i_0, k, x, y))) > \xi \quad (1)$$

D. The Inserability optimization suited to the greedy insertion algorithm

The calculation of $INSER(i, \Gamma)$, $i \in D$, begins to be time consuming starting from a medium size of D once

the *INSER2* value is based on the time windows' amplitude obtained after the propagation of the time constraints. So, this is important to spot each step of the process where the *Inserability* measurement doesn't have to be updated. When i_0 is selected, $INSER2(i, \Gamma_k, x, y)$, $INSER1(i, \Gamma_k)$ and $INSER(i, \Gamma)$ are known for all demand in $D1 - i_0$ and all $k = 1..K$. Once i_0 is about to be inserted, the process computed the value $H(i), i \in D1 - i_0$ (cf. formulation (2)). Then, the algorithm tries the insertion of each i from $D1 - i_0$ in $Inserted(\Gamma, i_0, k, x, y)$ and deduce the value $K(i)$ given in formula (3) for all $i \in D1 - i_0$ and ultimately the quantity $Val(k, x, y) = Min_{i \in D1 - i_0}(K(i) + H(i))$.

$$H(i) = INSER(i, \Gamma) - INSER1(i, \Gamma_k) \quad (2)$$

$$\begin{aligned} K(i) &= INSER(i, Inserted(\Gamma, i_0, k, x, y)) \\ &= H(i) + INSER1(i, Inserted(\Gamma, i_0, k, x, y)_k) \end{aligned} \quad (3)$$

Other calculation may be avoided. We set W_1 such that $W_1 = Min_{i \in D1 - i_0} INSER(i, \Gamma)$. If the quantity $INSER(i, \Gamma) - INSER1(i, \Gamma_k)$ is larger than W_1 , there is no need to test the impact of the insertion of i_0 on i .

Finally, we're able to use $INSER(i, \Gamma)$ once we integrate the future demands presented in the next section. In a dynamic context, the *Inserability* measurement helps the routes to be enough flexible for the next insertion process. Moreover, the making an appointment have to be set with the same purpose and $INSER(i, \Gamma)$ is able to help to do it.

V. INTRODUCTION TO THE ROBUSTNESS IN THE DARP: ANTICIPATION OF THE FUTURE DEMANDS AND *Inserability* MEASUREMENT INTEGRATION

The problem may have to be handled according to a *dynamic* context and the greedy insertion algorithm is easily adaptable to this context. Once the *Inserability* measurement is included in the performance criteria, the system may increase its robustness. In order to accomplish this, we need to exploit knowledge about future demands. In our case, this knowledge is related to the type of on demand transportation service. In this paper, we will use a simple extrapolation of this probable demands based on the demand already broadcasted.

We won't take into account the way the system supervises its various communication components with the users. In reality, there are eventual divergences between the data which were used during the planning phases and the situation the system.

We set $D - V$ the virtual demands, $D - R$ the real demands, and $D - Rejet$ the set of the ones excluded from the insertion algorithm such that $D - Rejet = DV - Rejet \cup DR - Rejet$. The $D - V$ formulation is given in (4). p_i gives us the number of times the demand $i \in D$ will appear for each period of each discrete planning horizon.

$$D - V = \sum_{i \in D} i \cdot p_i \quad (4)$$

Then, we're able to update the formula (5) the performance function *Perf*.

$$\begin{aligned} Perf &= \\ &\alpha \cdot \sum_i p_i INSER(i, Inserted(\Gamma, i_0, k, x, y)) \\ &+ \mu \cdot \sum_{i \in D1 - i_0} INSER(i, Inserted(\Gamma, i_0, k, x, y)) \\ &\quad - v(Inserted(\Gamma, i_0, k, x, y)) \end{aligned} \quad (5)$$

As in the previous sections, the process may exclude some demands taking in account the future requests. We updated the inequality (1) by the (6). α is a coefficient based on the importance of the future demands.

$$\begin{aligned} \alpha \cdot \sum_i p_i \cdot (INSER(i, Inserted(\Gamma, i_0, k, x, y)) \\ - INSER(i, \Gamma)) \\ + \sum_{i \in D1 - i_0} (INSER(i, \Gamma) \\ - INSER(i, Inserted(\Gamma, i_0, k, x, y))) \\ > \xi \end{aligned} \quad (6)$$

VI. DISCUSSION ABOUT THE MAKING AN APPOINTMENT AND THE DYNAMIC CONTEXT

Most work on vehicle scheduling problems including time window studies how to integrate a set of demands in the vehicle planning. Making an appointment anticipating the future is especially rare. Previous sections explained how to select and integrate user's request while keeping enough space for the next set of demands.

Once routes are built and integrated a first set D , the users expect the date when the vehicle selected will pick them up. In the lists forming the K routes, each node has a time window. After the appointment's date is set, each time window becomes tight with zero amplitude or equals a very small delay. How the appointments' dates are made is very important for the next insertion's process. For instance, we consider a fleet of 2 vehicles with two plannings including 5 demands while the distances are minimized (cf. Figure VI). The time windows are relatively wide so, while the distance traveled is minimized, the difference of each appointment's time between two nodes is the exact time to join them. The vehicle $k=2$ from the Figure VI may integrated the node o_7 between its depot node and o_5 even if its time windows have a zero amplitude (the vehicle will only have to leave the depot earlier). On the other hand, if the difference on the appointment' times given to the users related to the nodes d_5 and o_3 equals to $DIST(d_5, o_3)$, the insertion of d_7 will be forbidden. In the same way, there will be a violation of some constraint once nodes o_6 and d_6 will be inserted in the vehicle $k = 1$.

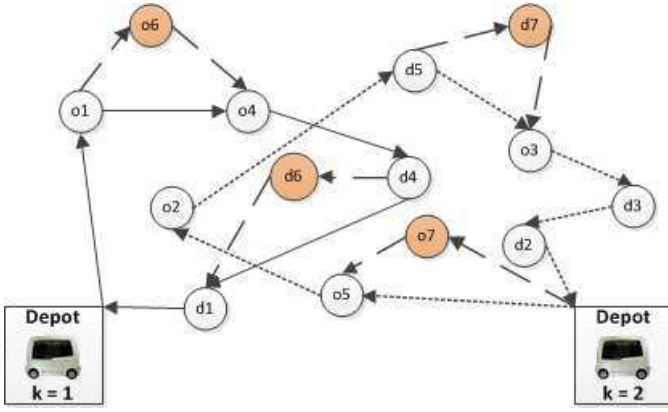


Fig. 2. New insertions after the making an appointment

One more time, the $INSER(i, \Gamma)$ values may be used in order to set the appointment dates without to have the problem above. The appointment's dates may be calculated once the process have inserted the virtual demands $D - V$ and the real demands $D - R$.

The previous section shows the way to anticipate the future demands $D - V$. These demands are related to a dynamic context. Note again that our greedy algorithm is easily adaptable to this context. More specifically, the technique doesn't change unlike the state of each route. The first node isn't a depot node anymore but a dynamic node related to the vehicle's location. The entire constraint propagation process is applied on these new routes. A simulation will be necessary to evaluate the anticipation of the future demands including in the dynamic context.

VII. COMPUTATIONAL EXPERIMENTS

In this section, we study the behavior of our *Inserability* measurement used in the resolution of Dial-a-Ride instances. The algorithms were implemented in C++ and compiled with GCC 4.2. In [1], we solve the [4]'s instances by our greedy insertion algorithm based on constraint propagation. We obtained good results in the majority of instances, but, only 1% of the replications gave us a of feasible solution on the *R10a* instance. The CPU time was smallest or equal to the best times in the literature; we don't work on this feature for this experiment.

A. First experimentation: the optimization of the selection of the demand to insert

1) *INSER's measurement used in the selection of a demand:* We note by T^{DARP} the rate of 100 replications which give us a feasible solution obtained by using the solution of [1]. Here, the selection of the demand is based on the lowest number of cars which are able to accept it. T_{Rob}^{DARP} is the rate obtained with the same process except that each demand is selected at each iteration by the lowest *Inserability* value $INSER$.

The *Inserability* measurement is already efficient once it's used in the selection of the demands to insert. The rate

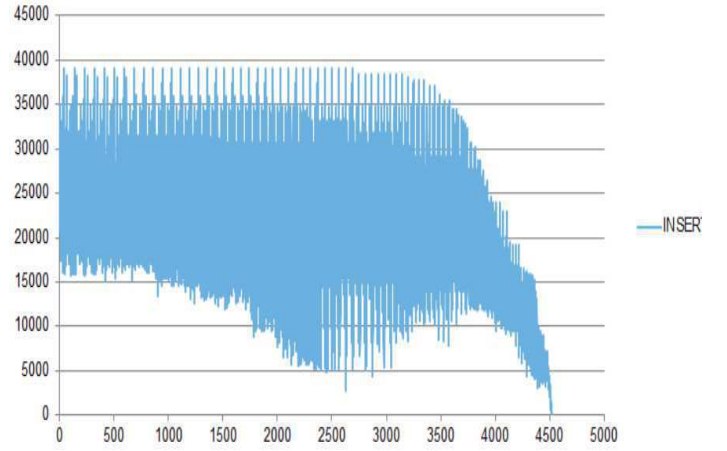


Fig. 3. $INSER$ values on the not inserted demands

obtained for the pr08, pr09, pr10 and pr19 are clearly more interesting (for the instance pr08, the rate increases by 56% to 91% of success).

Inst.	$Taux_{Success}^{DARP}$	$Taux_{Success}^{DARPRob}$
pr01	99	100
pr02	100	100
pr03	97	100
pr04	100	100
pr05	100	100
pr06	100	100
pr07	90	96
pr08	56	91
pr09	18	21
pr10	1	7
pr11	100	100
pr12	100	100
pr13	99	100
pr14	100	100
pr15	100	100
pr16	100	100
pr17	98	100
pr18	99	100
pr19	64	99
pr20	43	56
Av.	83,2	88,5

TABLE I
 $Taux_{Success}^{DARP}$ Vs $Taux_{Success}^{DARPRob}$

2) *The INSER's measurement behaviour:* Each time a replication can't integrate all the request, the $INSER$ value of the demands not inserted has to be null. In Figure VII-A2, throughout resolution process applied to the R10a instance, we note the evolution of more than 4500 $INSER$'s demands not inserted. The technique used is the second approach selecting the demand by the smallest *Inserability*. The values noted are from a failed replication.

One can observe big gaps between some $INSER$'s until the 4000 first values. After that, for the remaining requests, the *Inserability* values decrease strongly because the routes begin to be not flexible. Between the 2500th and the 3500th, for some demands, the $INSER$ are very low at the beginning just

before to increase strongly. This is explained by the fact the process inserts the demand with the lowest *INSER* but their insertion don't make a big impact on the other demands not inserted. This impact is related to the *Optimization Inserability Problem* studied below.

B. Second experimentation: the optimization of the insertion parameters

In a second experimentation, we compare the [1]'s approach and another algorithm based on the optimization of the parameters (x,y,k) . The selection of the request to insert is the same for both solutions. For the second one, once a demand i_0 is selected, we maximize the sum $\sum_{i \in D1-i_0} INSER(i, Inserted(\Gamma, i_0, k, x, y))$ in order to find the best parameter (x,y,k) which will integrate i_0 in the route k . We don't optimize $Min_{i \in D1-i_0} INSER(i, Inserted(\Gamma, i_0, k, x, y))$ because we create instances especially with a set D too large for inserting all the requests. So, the demand with the smallest value *INSER* for a given parameters (x,y,k) could never be integrated into the routes.

The two algorithms were applied to five sets of 5 randomly generated instances. All the instances have their time constraints related to the interval $[0;400]$ and all the load was unit. We set by $e_{F(o)}$ and $e_{F(d)}$ the amplitude of the time windows at the *origin* and the *destination* given by the users, respectively. The other parameters are given in table II.

K	$e_{F(o)}$	$e_{F(d)}$	Δ	CAP
10	35	10	∞	10

TABLE II
PARAMETERS' INSTANCES

We generate 5 different sets of 5 instances with a variation of the number of demands $|D|$. We set by T_{Insert} and by T_{Insert} the demand inserted's rate the first resolution and the second technique, respectively. Finally Gap_{Insert} in the gap in percentage between each rate. Its calculation is given by $Gap_{Insert} = 100 \cdot (T_{Insert_{Rob}} - T_{Insert}) / T_{Insert}$. We launched 100 replications of each technique on the 5 sets. The results are provided by the table III.

$ D $	50	75	100	150	200
T_{Insert}	100	93.2	78.9	64.2	52.6
$T_{Insert_{Rob}}$	100	96.8	85.3	66.4	54.1
Gap_{Insert}	0	3.86	8.11	3.43	2.81

TABLE III
GAP BETWEEN THE *INSERT* RATES

In future experiments, we need to optimize the value $Perf = \mu \cdot \sum_{i \in D1-i_0} INSER(i, Inserted(\Gamma, i_0, k, x, y)) -$

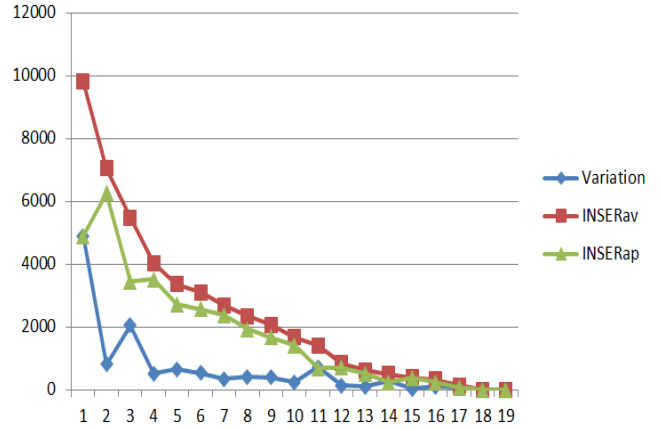


Fig. 4. Variation of the Inserability values between each insertion

$v(Inserted(\Gamma, i_0, k, x, y))$ to calculate each best insertion parameters. Here, we're just taken in account the *INSER* values in order to integrate the most requests possible. The results show us that the larger of $|D|$ defines if the system needs to optimize the *Inserability* measurement. For $|D| = 50$, all the requests are able to be inserted easily, so, the *INSER* values doesn't have any interest. When the set is composed of 100 demands, we obtained a Gap_{Insert} of 8,11% meaning there are more than 8% more requests inserted by the second approach.

For this set of instance, we also tried to integrated a new feature in our algorithm: we've added the ability to exclude a request if the impact of one insertion involving a significant drop of the general *Inserability's* demands from $D1 - i_0$. Before that, we study the threshold which limits the variation of *Inserability*.

We exclude a demand selected i_0 if $\sum_{i \in D1-i_0} (INSER(i, \Gamma) - INSER(i, Inserted(\Gamma, i_0, k, x, y))) > \xi$ is true with ξ a threshold. The calculation of the threshold is a difficult problem. In the figure VII-B, we report the $\sum_{i \in D1-i_0} (INSER(i, \Gamma) - INSER(i, Inserted(\Gamma, i_0, k, x, y)))$ Variation with *INSERav* and *INSERap* the values $\sum_{i \in D1-i_0} INSER(i, \Gamma)$ and $\sum_{i \in D1-i_0} INSER(i, Inserted(\Gamma, i_0, k, x, y))$, respectively. This figure shows us that the threshold ξ have to be dynamic and calculate according to the average of *INSER*.

We used this type of dynamic threshold for the third set of instances with 100 demands. We exclude an request if the current ξ is exceeded, and only this feature is added in the second approach. We obtained a gain of 1,3% in average (from 85,3% to 86,6%) meaning approximately one more demand is able to be inserted.

VIII. CONCLUSION

The Dial-a-Ride Problem is one of the transport problems with the highest number of hard constraints like time windows.

The insertion techniques are able to obtain a good solution in a reasonable time. Its adaptability to a dynamic context is easy but a lack of robustness could appear once the goal is to integrate requests as much as possible.

We have introduced a way to measure the impact of each insertion on the other demands not inserted. This *Inserability* measurement could be used in order to exclude a demand, to select a demand to insert and also to calculate the best insertion parameters. This value, named *INSER*, leads to a large amount of work opportunities. We have introduced a simple way to make the model of the future demands, and how to adapt our greedy insertion algorithm based on the constraint propagation to the dynamic context. In future work, we will develop a simulation which is necessary to show the efficiency of the demands anticipation. The final goal will be to develop the most robust algorithm possible in order to adapt it to a real context.

ACKNOWLEDGMENT

This work was founded by the French National Research Agency, the European Commission (Feder funds) and the Region Auvergne in the Framework of the LabEx IMobS3.

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