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The new formulation for the Integrated Dial-a-Ride Problem with Timetabled fixed route service

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***Abstract*— In designing the mobility of modern cities it has become important to take into account the concept of flexible transport services. Traditional public transportation has shown its limitations to satisfy the changes in growing cities and particularly unable to adapt to particular events or particular people such as transportation of unable or elderly people that concerns significantly user's transportation. Moreover, the door-to-door transportation is sometimes too expensive. For that, this paper considers the Integrated Dial-A-Ride Problem (IDARP) which is a special case of the Dial-A-Ride Problem (DARP). It deals with the scheduling of vehicles to insure the transportation of the passengers, with the integration of the fixed route service to the DARP. We have proposed a new formulation for the Integrated Dial-A-Ride Problem with timetabled fixed route service (IDARP-TT) with the objective of minimizing the combined operational costs and the waiting time.**

Keywords— Integrated Dial-A-Ride Problem with timetabled fixed route service, satisfaction of the passengers, waiting time, transportation of disabled persons.

I. Introduction

Demography changes continuously, every day the population density raises and every aging population entails an increasing demand for specialized transportation systems to improve the traditional public transportation. So, individuals are always needing more flexible transport that can increase their satisfaction. In the literature, problems concerning the transportation of passenger or patient are usually called dial-a-ride problems (DARP). Public transportation systems are progressing to meet more flexible solution for two reasons: to satisfy the mobility needs and to reduce the cost of transportation. Individual can use his vehicle to avoid the public transportation and its drawbacks, but it is at the same time non-ecological, and costly. However, the public transportation has many benefits compared to individual transportation. A bus, train or other public transportation vehicle transporting a group of people, so it costs less, produces less CO_2 and takes up less road space than the case where individuals would transport themselves, each in their own car. The public transportation problem belongs to the vehicle routing problem (VRP) or named also pickup and delivery problem (PDP).

In the past, the public transportation contains buses or taxies, but now days there are also metros and the subways. So, finding the best schedule is becoming more difficult to insure more flexible service for the passengers.
The use of the metros or the subways means crossing a fixed route, because these modes of transportation have specific ways and different stations. For that reason, appears the Integrated Dial-a-Ride Problem (IDARP) which is a generalization of the Dial-A-Ride Problem (DARP).

II. The Integrated Dial-a-Ride Problem (IDARP)

A. Definition

First, we will start with the definition of the DAR which concerns the management of a fleet of vehicles used for public transport. This system carries people from the desired pickup point to the desired delivery point, during a pre-specified time interval. The customers demand the service by calling a central unit and specifying: the pickup point, the delivery point (respectively, origin and destination), the number of passengers and some limitations on the service time (for example the earliest departure time). Such transportation system is called demand-responsive [1].

DARP is the name of many different problems in the literature. Hence, the DARP is used in several applications:

- Door-to-door transportation of elderly;
- Door-to-door transportation of physically disabled;
- Public transport in areas with low population density;
- patient transportation to/from hospitals and other medical facilities;
- Parcel pickup and delivery service in urban areas….

The Integrated Dial-a-Ride Problem is a generalization of the Dial-a-Ride problem. The IDARP is to schedule dial-a-ride requests, where some part of each journey may be carried out by a fixed route service. The plan of the fixed routes is given

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but the target is how to use the existing fixed route in an optimal way [2].

B. Terminology

There are some important terms used in the DARP so we have to defined them

- The Dispatcher: he is the decision making, which is not necessarily a human being.
- The request: the dispatcher has to decide which requests have to be served and schedule the accepted requests. In this problem the request is the order made by the customer.
- The vehicle: some problems are treated with only one vehicle (single vehicle problem) where others need more (multiple vehicle problem). The vehicles can be homogeneous (identical characteristics) or heterogeneous (different characteristics). The difference between vehicles can be in capacity or in persons that have to be carried (for example transporting ordinary people needs seats different from those used to transport handicapped persons)
- The route is a series of stations associated with services that are to be performed. In the first case all requests can be handled in one station, only one service is performed at a time. But in the second case, some of the requests needs to be transported between stations, in this case more services can be performed at the same time.
- Transfer points: are the bus or train or subway stations which are used in case of changing between a demand responsive vehicle and a fixed route, and vice versa.
- Maximum ride time: is the total time spent to carry the user from the pickup point to the delivery point.

By choosing the best way of integrating the fixed route and demand responsive service, an operator of public transport can benefit from both the cost-efficiency of fixed route services and the flexibility of a demand responsive service. This can reduce operating costs and increase the level of service to passengers, since a door-to-door service can be provided.

In the next figure “fig. 1”, the different ways of travelling with the IDARP are presented.

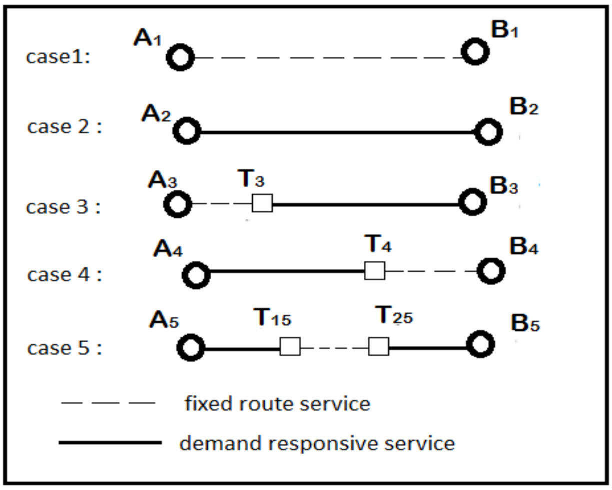

Fig. 1. Various manner of traveling with the IDARP

III. LITERATURE REVIEW

The integrated dial-a-ride problem is a new variant of the DARP in which passengers can use both the demand responsive vehicle and the public transport one, the change is made at particular stations, called transfer points. The particularity of this problem is the combination of the fixed route service and the demand responsive service, and the objective is to minimise costs.

The two earliest papers discussing this problem are [3] and [4]. [3] a real case is treated from Ann Arbor, Michigan where 45 dial-a-ride vehicles and 36 express buses are operated. The demand responsive vehicles are allocated to the zones, and act as stockbreeder to the fixed route service, as well as they can serve inter-zone travel requests. In time periods with low demand, connections between different dial-a-ride vehicles are also made. The paper of [4] focused on algorithms for scheduling the vehicles’ journeys. The main objective of this model was to maximizes the passenger utility, subject to a series of service constraints. A trip insertion heuristic is used to schedule simultaneously passenger and vehicle trips.

The next paper [5] has focused on minimizing the operator’s costs, for that a heuristic is used to schedule the integrated trips, subject to passenger level of service constraints. Both the operators’ and the customers’ perspectives are considered also in [6]. Two measures of performance were considered in the objective function; total travel distance of demand responsive vehicles and total travel time of passengers. Using a real case, they tested the proposed heuristic.

Some other authors focused in their researches on the actual design of the integrated services.

[7] and [8] tried to apply a dial-a-ride system in long distance transportation systems. Then he used the procedures for planning journeys combining fixed route services and demand responsive vehicles.

Since the Pickup and delivery problem with transfers (PDPT) is a special case of the Dial-a-Ride Problem with

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Transfers without the maximum ride time constraints, it has been the subject of little research. Some of these works concerning the PDPT come from Dial-A-Ride applications, without considering quality of service constraints.

[9] presented a heuristic for a PDPT in which every node can be considered as transfer node. In this work, the transfer operation can be viewed as a recourse policy, as transfers are used only if the insertion of a request into the solution requires the use of an additional vehicle. The dynamic version with the adaption of the same heuristic was later applied in [10].

[11] proposed heuristics for a PDPT. In this work, a new constraint is considered concerning the capacitated and the incapacitated vehicles. The objective was to minimize the makes pan.

[12] presented an ALNS for a pickup and delivery problem, but in this paper a single transfer point is taken into account; he considers a real case from the Denmark city treated the transportation of flowers. The algorithm was evaluated on real instances going up to 982 orders.

Recently, [13] introduced an adaptive large neighbourhood search (ALNS) to solve the PDPT. But this time the objective was focused on minimizing the total travel time. A competitive result was proven and the travel time was saved of up to 9% by using intermediate transfers.

[14] proposed an ALNS for the dial-a-ride problem with transfers (DARPT). Always the main objective is to minimize cost, for that new variants and new constraints are always discussed. So, we have the insertion of the transfers which are specific points in which users are transferred from one vehicle to another. For that, they argued that using transfers between vehicles may lead to significant savings in terms of operating costs. This study proposed that as long as the capacity of the vehicle is not exceeded, passengers can share the same vehicle even if they are associated with separate requests. Here appears the importance of transfers, in which vehicles are located and changes of passengers are made.

[15] part B. consider the Pickup and Delivery Problem with Time Windows, Scheduled Lines and Stochastic Demands (PDPTW-SLSD) in which a set of requests has to be transported from pick-up to delivery destinations in two possible ways, demand responsive vehicle or using the fixed route services. In this paper, they added new set of constraints taking in account the time windows of the passengers which mustn't be exceeded.

This paper proposed a large neighbourhood search heuristic embedded into sample average approximation (SAA) method. To solve this problem, some instances containing 40 requests are used, the operational costs were reduced compared with the results corresponding to the PDPTW stochastic routing solutions.

In [16], the main objective is to provide customer satisfaction (safety, mobility, minimum travel time...) with minimum costs. Recently, most of the agency encourages the use of the public transport in order to minimize the use of the private cars, all that leads to the development of the system.

The purpose of this study is to permit to the user to make a choice between the routes without transfers and routes with transfers. When making choice, the user has to specify which objective to optimise, either reducing time or minimizing cost.

In this study, and using the Statistical Package for the Social Sciences (SPSS), the results show that the users are more sensitive to minimize travel cost than to travel time.

Areas with low demand density are considered in this paper [17], where passengers usually find problem with public transportation accessibility. This leads to longer waiting time and the not satisfaction of the users from these areas. This study analysed the performance of a system when fixed and flexible public transport systems co-exist while offering competing services. As explained in this paper there is a difference between the fixed and the flexible public transportation:

-The term fixed public transport means that there is a conventional public transport system with pre-determined line and schedules.

- The term flexible public transport refers to demand responsive transport systems comprising of a fleet of services serving real time requests.

In [18] the elderly and/or persons with disabilities need a more flexible transportation than the rest of the population to get to and from the fixed route public transport systems. For that, flexible door-to-door transport is offered as a complement. This paper tries to introduce a richer version of the IDARP than previous version, significantly more applicable to real world planning situations. For that, the IDARP is extended and timetables for fixed route services are included so we have the IDARP-TT. This extension will force the fleet of vehicles to schedule the arrival at transfer locations at the time before the departure of the public transport vehicle to avoid the delay which could minimize passenger satisfaction.

In [2], each transfer location is modelled by one node for each request. This makes the number of nodes too large because every request adds (2+g) nodes to the network, where g is the number of physical transfer locations. This paper tries to minimize the number of nodes used in the model which is based on the one presented in [2]. Thus, in this article two mixed integer linear programming formulations of the integrated dial a ride problem with timetables are presented and analysed. The difference between the two models is the way the transfer locations are modelled:

- In the first model: for each physical transfer location $\bar{r}$ artificial transfer nodes are created, where $\bar{r}$, is the number of requests.

- In the second model: each node has two indices, the first represents the physical location and the second the visit number. This opens up for a location being visited multiple times.

Also, in this article, some restrictions have been relaxed for both costs minimizing and user inconvenience:

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- Allow to some requests to begin or end their journeys at transfer nodes if they are close to their pick up or drop off nodes.
- Not every pick up or drops off nodes have to be visited.

We were interested to study the literature of the IDARP to know the most important researches made in this context and we found that a great number of studies were made about these problems in their different form and provide different methods to improve the satisfaction of whether the customer (the passenger) or the dispatcher.

IV. THE IDARP-TT : NEW FORMULATION AND RESOLUTION

In the proposed research, we consider the IDARP as defined in [17]. The problem treated is called the Integrated Dial-A-Ride Problem with timetables (IDARP-TT) includes timetables for the fixed route service. For the passengers whose trips are integrated with the public transport system, the level of service diminishes because there is a discomfort associated with transfers. The importance of customer satisfaction was identified by many industries as a key factor of competitive advantage.

So, based on this idea, we have been attracted to this article. In reality, we have to involve the customer when making the decision to reach a highest level of satisfaction. The objective of the company is to optimize the cost of the proposed routes while preserving a reasonable quality in the service offered to its customers.

A. problem description

A set of $\bar{r}$ customer requests for vehicles where each customer specifies a pickup and drop-off location pair. Passengers also specify their preferred time windows during which they have to be served. All vehicles start from the start depot node 0 and return to the end depot node 2 $\bar{r}$ +1 once routing is complete. The model for static IDARP-TT is formulated on the assumption that the transportation requests are previously known.

To formulate the IDARP-TT, we use the same notations of [17] as follows:

In IDARP-TT, we assume that the fleet of heterogeneous vehicles is divided into homogeneous vehicles classes. The set of vehicles classes is denoted V and the set of vehicles of class $v \in V$ is denoted K_v which have to serve $\bar{r}$ customer requests. A set of resources is defined as S. Each vehicle class v has a capacity Q_{vs} of resource $s \in S$ and each request r has a demand L_{rs} of resource s. The customer requests lead to $\bar{r}$ pick up and $\bar{r}$ drop off nodes. The nodes form a directed graph G = (N, A) where N is the set of all nodes and A is the set of all arcs connecting those nodes. For each arc (i, j) is associated a travel cost C_{ijv} and a travel time T_{ijv} when using vehicle class v. The node set includes the vehicle depot, pick-up nodes, drop-off nodes, and transfer nodes. The pick-up nodes are denoted N^p which are identical to the set of requests R. The drop-off nodes are denoted N^d.Thus, each pick-up node $i \in N^p$ is associated with a drop off node $i + \bar{r} \in N^d$. Each node i has a starting service time $t_i \in \left[\underline{T_i}, \overline{T_i} \right]$ which are successively the earliest start of service and the latest service time at this node. The transfer nodes are modelled in the same way as in Hall et al. (2009); for each physical transfer location (e.g. a bus stop) $\bar{r}$ artificial transfer nodes are created. The set of artificial transfer nodes is denoted N^G where g is the number of transfer locations in the fixed route transportation system. The sets $N_r^G \subset N^G$ contain the transfer nodes corresponding to request r . The set of arcs connecting artificial transfer nodes is denoted A^G. The set of timetabled departures between the nodes i and j connected by arcs in A^G is denoted D_{ij}. Each departure $d \in D_{ij}$ has a departure time T_{ijd}^D from node i and an arrival time T_{ijd}^A at node j. The cost C_{ijd} is associated with departure d between transfer nodes i and j.

For the model proposed in [17] the requests are allowed to end or begin their trip at a fixed route stop. For that they introduced the set N_{PD}^G which constitutes a set of pick-up and drop-off nodes which are associated with a public transport stop.

B. Research contribution

As mentioned before, we aim to maximize the satisfaction of the customer and involve service quality in the objective of the dispatcher. To increase the level of satisfaction of the passenger we propose to introduce three extensions to the model:

1) The first extension introduced in this model is that the set R (the requests) is divided into two sets:

- R_H : The set of the healthy customers how don't need a special service. They can use demand responsive vehicle or public transport vehicles or both.
- R_D : The set of the disabled customers, they can't use the public transport vehicles. They need the door to door transportation. We can't ask them to use the demand responsive vehicle then to change vehicle in transfer node to use the public transport vehicles. The dispatcher has to find the best schedule to allow them to reach their drop-off node directly without changing vehicle.

2) The second is the waiting time which is introduced as the third part of the objective function. The introduction of timetable to the model insures that the public transport vehicle cannot be delayed due to late demand responsive vehicles, but in the same time the customer sometimes can wait for the

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public transport vehicle which diminishes the level of service. For that, we introduce the waiting time WT and we try to find the appropriate formula which permits to the customer, when arriving at the transfer node, to minimize his waiting time until the public transport vehicle arrives.

3) The third is the limitation of the number of changing vehicles. Due to transfers and changing the vehicles between the public transport vehicle and the demand responsive vehicle can decrease the satisfaction level, we introduced a constraint which ensures that the maximum number of changing a vehicle for the same healthy customer is 2. The first time when arriving at the transfer node to use the public transport vehicle (if needed). The second time is when arriving at the last transfer node to return to the demand responsive vehicle (if needed) to continue the journey to the corresponding drop off node.

C. *Test Instances*

We use two instances to evaluate the new formulation, which are a real-world instance from the town of Norrkoping, Sweden, as used in [17] depending on the number of requests and vehicles. The first instance has 2 requests (1 healthy and 1 disabled) and 2 heterogeneous vehicles (different capacities). The second instance has 4 requests (3 healthy and 1 disabled) and 2 heterogeneous vehicles (different capacities). They contain the original travelling times, costs, time windows, time service and the timetable of the fixed route.

We consider that these arcs are invalid:

- From to the same node
- To the node representing the start depot
- From the node representing the end depot
- From start depot to any drop-off node
- From any pick-up node to end depot
- From drop-off node to the pick-up node for the same request.

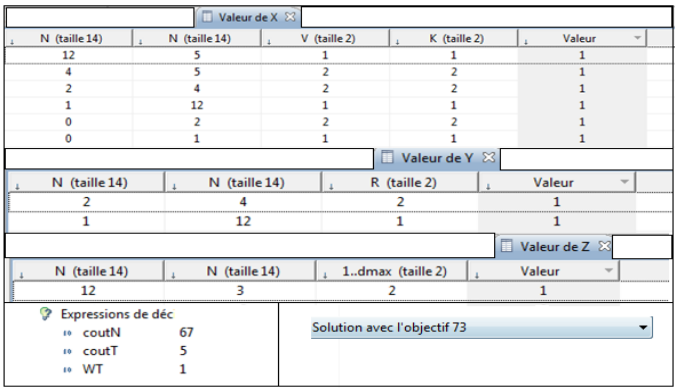
Remark: For the costs and the times it has the same measuring scale

1 unit of cost = 1 unit of time

D. *Numerical experiments*

The purpose of the numerical tests is to test the new model and the usefulness of including the new constraints explicitly in the model. We solve the problem using IBM CPLEX Optimization Studio version 12.5 encoded under the Microsoft Visual Studio 2010 Ultimate software and run on PC with windows 7 platform, Intel® Core (TM)® i 7 -2670 QM CPU @ 2.20 GHZ and 4 Go RAM available.

The optimal solutions are presented here after “Fig. 2,” and “Fig. 3,”, then we used a table “TABLE I,” to show the CPU for the 2 instances.



Valeur de X

N (taille 14)	N (taille 14)	V (taille 2)	K (taille 2)	Valeur
12	5	1	1	1
4	5	2	2	1
2	4	2	2	1
1	12	1	1	1
0	2	2	2	1
0	1	1	1	1

Valeur de Y

N (taille 14)	N (taille 14)	R (taille 2)	Valeur
2	4	2	1
1	12	1	1

Valeur de Z

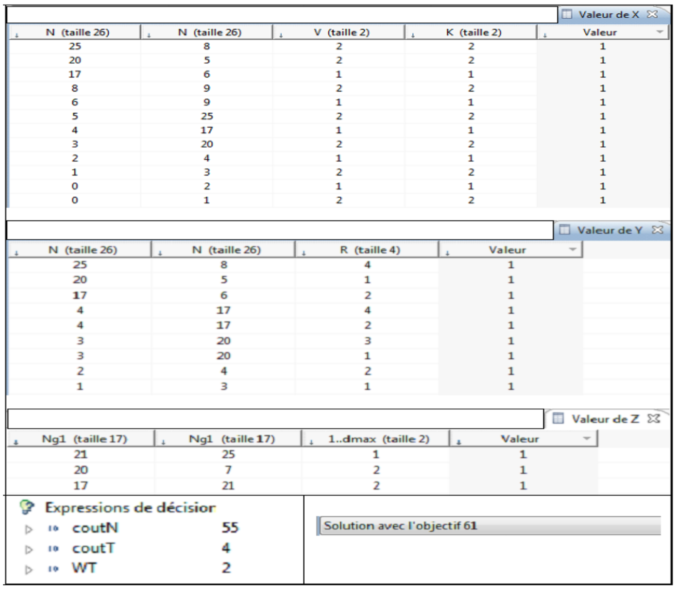
N (taille 14)	N (taille 14)	1..dmax (taille 2)	Valeur
12	3	2	1

Expressions de déc

coutN	67
coutT	5
WT	1

Solution avec l'objectif 73

Fig. 2. *The optimal Solution for the instance of 2 requests*



Valeur de X

N (taille 26)	N (taille 26)	V (taille 2)	K (taille 2)	Valeur
25	8	2	2	1
20	5	2	2	1
17	6	1	1	1
8	9	2	2	1
6	9	1	1	1
5	25	2	2	1
4	17	1	1	1
3	20	2	2	1
2	4	1	1	1
1	3	2	2	1
0	2	1	1	1
0	1	2	2	1

Valeur de Y

N (taille 26)	N (taille 26)	R (taille 4)	Valeur
25	8	4	1
20	5	1	1
17	6	2	1
4	17	4	1
4	17	2	1
3	20	3	1
3	20	1	1
2	4	2	1
1	3	1	1

Valeur de Z

Ng1 (taille 17)	Ng1 (taille 17)	1..dmax (taille 2)	Valeur
21	25	1	1
20	7	2	1
17	21	2	1

Expressions de décision

coutN	55
coutT	4
WT	2

Solution avec l'objectif 61

Fig. 3. *The optimal Solution for the instance of 4 requests*

TABLE I. CPU TIME FOR INSTANCE 1 AND 2

Data	N	K	SOL	CPU
Instance 1	2	2	73	0.61
Instance 2	4	2	61	1.04

V. CONCLUSION

In this study, our occupation aimed to give a new formulation of the IDARP-TT and to solve it. The IDARP-TT was formulated to determine the vehicles’ tours and to improve the requests’ satisfaction with the objective function which aims to minimize the total combined costs and the waiting time. Satisfactory results have been obtained but we could further extend the IDARP-TT to consider bigger instances and to solve it with a heuristics.

As a future work, we aim to apply the model on larger instances.

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