DIAL-A-RIDE ROUTING SYSTEM: THE STUDY OF MATHEMATICAL APPROACHES USED IN PUBLIC TRANSPORT OF PEOPLE WITH PHYSICAL DISABILITIES

Adriano de Faria, Universidade Federal do ABC, drndfr1987@yahoo.com.br

Marcio Yamashita, Faculdade de Tecnologia de São José dos Campos

Luiz Antonio Tozi, Instituto Tecnológico da Aeronáutica (ITA), tozi@ita.br

Valter João de Souza, Faculdade de Tecnologia de São José dos Campos

Irineu de Brito Junior, Universidade de São Paulo (USP), ibritojr@yahoo.com.br

ABSTRACT

In this paper we present a model to dial-a-ride transportation for people with disabilities in the city of São José dos Campos, a technological center located 91 km from São Paulo, and implement an algorithm for routing. It was used as a method, the study of transport and the Problem Dial-a-ride (DARP) and the implementation of Parallel Insertion Heuristic. We developed a program in Excel and Visual Basic to simulate real applications, resulting in the insertion of 56% of them. Thus, we intend to cooperate with the case study of the mathematical approaches used in routing the transport of persons with disabilities by providing a better service and thereby improving the quality of their lives.

DIAL-A-RIDE TRANSPORTATION

Transport is essential as it serves the needs and social support to economic activities. If, on the one hand, people can use any form of transport tend to only notice its importance when something goes wrong, there are others for whom a step represents an insurmountable barrier. The performance of an accessible public transport service impacts in simple activities for people with reduced mobility, which are usually assisted by companions and have a social life shortened. (European Conference of Ministers of Transport, 1991)

Definition

The term dial-a-ride, initially covering the transportation of elderly, ambulances used in regular services, minibus and mini-buses to the fixed routes, taxi and courier service (Madsen et al., 1995). Bergvinsdottir (2004) expands the transport of animals and goods highly time-sensitive transport. Also added is the transportation of students, who are considered, for example, changes in school and turns to ad hoc adjustment in cases such as illness or part of the journey is performed by a family member (Haidemann, 2007).
However, the most common use of literature, including Pfliegl (2007) and this work, considers the Dial-a-ride as the transportation of persons with reduced mobility.

Transport system

The Dial-a-ride is a form of mass transit that would respond to areas of low demand for travel or people of special needs (Jaw, 1984). According to classification of Vuchic (1981), corresponds to a public transportation, urban route for parades, special time for mass and vehicle tire, driven, propulsion generated and manual control.
In this system, a user requests by phone (dial) a transport (ride) to the planning team, informing the source and geographic destination and times of entry and exit. The operator, in turn, inform the final hours, allowing the user to cancel, modify or accept the service. In cases where requests are not concentrated in time or near geographic locations are scattered, the use of large vehicles is disadvantaged. Therefore, it is common to use small vehicles like van and minibus.

Implementation

The Dial-a-ride came in the United States in the 70s to supply, at a reasonable cost, new demands of groups that had no access to a vehicle, appropriate public transport, be made available to low-frequency, transport away from the region of interest user or when the passenger had some feat characteristic would hinder that it to conventional public transport. Wilson et al. (1976) had already identified more than sixty Dial-a-ride in the United States and Canada. In Barcelona, a shuttle service door-to-door for people with disabilities was established in 1978 (European Conference of Ministers of Transport, 2006).
Many cities in the world have this system of transport in an advanced stage, as Bologna, Kopenhagem, Stockholm, Helsinki, Hong Kong, London, Los Angeles, Montreal, New York, Paris, São Paulo and Toronto. In other regions, this service is being created or expanded, including in most cities in Latin America. (Rickert et al., 2004).

Characteristics influencing the service

The demand for this service, understood as the total of people with special needs registered, depends on the characteristics of the service, which have as influences (Kanafani, 1983):

Technology: characteristics of the vehicle and planning systems and communication;

Operational Strategy: policy of delimitation of the timetable and size of the fleet;

User Behavior: associated with the type of trip and geographical grouping of the requests, as classified by Hutchinson (1974);

Requests and operational constraints: a consequence of the three items above.

The capacity of the vehicle depends on the type of device. Inside, according Everling et al. (1997), the vehicle must consider the physical aspects of cost, space requirements and environmental requirements sensory-formal and ergonomic requirements.

Quality

The quality of service at Dial-a-ride is complex because it has different behavior for specific groups. The search for Pagano and McKnight (1983) conducted with 659 users of Dial-a-ride has shown that old people tend to prefer safety while younger people tend to focus on aspects such as cordiality and waiting time. A more systematic assessment was undertaken by Paquette et al. (2009).
A method to measure the level of service concept in transport (LOS, Levels of Service) originated in the Highway Capacity Manual (1965). Urban transport in fixed lines, are adopted six stages assessed by a (high quality) to F (low quality) to identify the users' perception. The Dial-a-ride, however, differs in key aspects such as management in particular and the proportion of spontaneous trips, as well as flexibility in the choice of origins and destinations. The increase in this complexity is reflected in the increase in the number of stages for assessment: a numerical scale from 1 (high quality) to 8 (low quality). (Transit Cooperative Research Program, 2003)

THE DIAL-A-RIDE ROUTING PROBLEM

Many versions of the Dial-a-ride problem were studied since the consultancy work of Wilson et al. (1971). This problem is also known as the Handicapped Persons Transportation Problem (Toth, Vigo, 1997, Wong, Bell, 2006), door-to-door handicapped transportation (Ioachim et al., 1995), paratransit vehicle shceduling problem (Karabuk, 2009). This also comes from the multiple classifications, as proposed by Bodin et al. (1983), Savelsbergh and Sol (1995), Toth and Vigo (2002) and Belfiore (2006).

Classification

There is a common division of Problem Dial-a-ride in the cases static and dynamic. The static nature allows a decision-making, planning and long-term strategy, and different scenarios can be created and solved in a simulation process (Savelsbergh, Sol, 1995). In this case, the computational time is less important, since the request is made in advance of at least one day. The dynamic nature, however, the method of solution should be very fast for users to have a return of your application while waiting on the phone (Bergvinsdottir, 2004). Some studies of the dynamic version are of studies from Xiang et al. (2008) and Colorni and Righini (2001).
Another classification considers the division or not the geographical region into areas based in the level of service policy, grouping in regions that possess the same time window. In the study to the case of Los Angeles, where the system's Dial-a-ride serves 3.8 million annual requests for people with physical disabilities, the conversion of a Dial-a-ride centralized with an only value of time window for the Dial-a-ride decentralized represent a savings of 10 thousand miles. (Dessouky et al., 2005; Quadrifoglio et al., 2008)

Algorithms

Dynamic Programming

According Haidemann (2007), the dynamic programming aims to solve problems that require many calculations of sub problems to be redone, which allows the division into stages. At each stage, there is a decision policy associated building a sequence of interrelated decisions. An accurate algorithm of dynamic programming was developed by Psaraftis (1983) for Dial-a-ride with a single deposit, without restriction of time window and capacity of the vehicle in the cases static and dynamic. The objective function pondered the total time of operation of the vehicle and an indicator of satisfaction according to the sum of waiting time and travel of each user. The solutions identified are improved by Desrosiers et al. (1986), also using dynamic programming with the advantage of using criteria for the elimination of impracticable states. From the adaptation algorithm Psaraftis (1983), with the junction of the equivalents stop points Haidemann (2007) applied to the Dial-a-ride the static on a case study of school transportation in the city of Curitiba, a city of southern Brazil.

Branch-and-Bound

The branch-and-Bound is a systematic way of finding solutions to combinatorial problems. Presented by Horiwitz and Sahni (1978), also called enumeration implicit algorithm, limited bifurcation or search tree, because it takes a tree whose branches represent possible values of decision variables and the nodes containing partial solutions. The strategy focuses on eliminating branches of solutions are not viable or more disadvantageous when compared with some solution found at that moment t in a strategy categorized as "divide and conquer". (Znamensky, 2000)

Application of Branch-and-Bound in Dial-a-ride comes from the reduction of the search tree, from the use of small capacity vehicles. A method of programming Branch-and-Bound was applied by Suticliffe and Board (1990) in the Dial-a-ride Problem.

Branch-and-Cut

The performance of the Branch-And-Cut, according Naddef and Rinaldi (2002) is restricted if the performance of the algorithm of phase-cutting plan is not good, the number of iterations of the cutting phase of plans is too high, the linear program does not present solution due to the size and the tree generated by use of the bifurcation has become very large.
A branch-and-Cut is applied by Ropke et al. (2007) to the Problem of Dial-a-ride with multiple vehicles.

Simulated Annealing

Simulated Annealing (SA) refers to a variant of the technique of local search, where a set of feasible solutions is explored by repeated movement of a current solution to another, accepting worsening moves to escape from local optimums (Mauri, 2006). An application in Dial-a-ride was accomplished through the work of Baugh et al. (1998), Bergvinsdottir et al. (2004) and Mauri (2006).

Tabu Search (TS)

The word tabu (or taboo) was originally used in an island in Polynesia to indicate things that could not be touched because they are sacred. Similarly, one of the characteristics of tabu search is the exclusion of regions considered to be prohibited in order to avoid repeating the same set. However, as the taboos of society are broken, the Tabu Search taboos should be violated if it is clear that there is a better alternative. (Cunha, 2006)
Attanasio et al. (2003) describes the implementation of Tabu Search heuristic using parallel computing for the static version of the Problem of Dial-a-ride. An application of Tabu Search in a Problem of Dial-a-ride dynamic was carried out by Beaudry et al. (2006) in a real case in Germany in which 250 patients are transported daily in eleven ambulances. The problem is the transport of patients in the campus of a large hospital, considering specific features of the hospital environment. Other applications were made by Aldaihani and Dessouky (2003), Cordeau and Laporte (2003b) and Melachrinoudis et al. (2007).

Scatter Search

The Scatter Search heuristic is based on principles started in the 60s, being applied more avidly from the 90's. Scatter Search works with a set of reference around 10 to 20 elements, which are diversified by deterministic strategies in search of better solutions (Belfiore, 2006).
An application of Scatter Search Problem in Dial-a-ride is presented by Chan (2004).

Genetic Algorithms

Genetic Algorithms (GA) are based on the principles of natural selection and evolution reported by Charles Darwin in 1859, and the genetic mechanisms proposed by Johann Gregor Mendel in 1865.
A growing number of studies on Genetic Algorithms, Memetic Algorithms, Parallel Genetic Algorithm, Genetic Algorithm Hybrid, Evolutionary Search Lamarckian, Genetic Programming and Evolutionary Programming took off from the First International Conference on Genetic Algorithms carried through in 1985 (Moscato, 2001).
Genetic Algorithm in Dial-a-ride were also implemented by Rekiek et al. (2006), Cubillos et al. (2009) and Bergvinsdottir (2004), which was based on service performed in Denmark.
The reference point is to generate, from a population of individuals, new elements with superior genetic properties to the ones of their parents.
In optimization, this phenomenon results in the birth of a set of solutions are obtained other than those records according to some established criteria.
However, the quality of the generated solution and the processing time for genetic algorithms are disadvantageous when compared with other heuristics, stimulating new modifications, including the incorporation of new techniques for local search and other tools of the Simulated Annealing, Tabu Search, Scatter Search. (Dalboni, 2003)

Ant Colony

According to Ballou (2006), a new type of routing inspired by the collective behavior of ants named swarm intelligence, which can be observed in self-organizing in the workplace without supervision due to specific interaction between the ants.
Baba et al. (2004) apply this meta-heuristics on real data from a heterogeneous fleet and multiple garages in the city of Sorocaba, 95 km from Sao Paulo.

Parallel Insertion Heuristic

Jaw et al. (1986) considers at the problem of Dial-a-ride innovations such as multiple vehicles. They created the Parallel Heuristic Insertion that consists in inserting the requests in sequence decreasing of a criterion of time involving at least increase in cost.
A process for improving local search was added to the Insertion Heuristic Parallel by Toth and Vigo (1996) into a problem with multiple vehicles and restrictions on time windows. Later, the authors included a method derived from the Tabu Search in order to improve the results gotten for the original version of the improvement process (Toth, Vigo, 1997). Znamensky (2000) applies this algorithm to Dial-a-ride in São Paulo.
Parragh et al. (2010) proposed a method of searching the neighborhood variable, while Calvo and Colorni (2007) created a heuristic based on the use of an auxiliary graph.
Other heuristics insertion were studied by Diana and Dessouky (2004), Luo and Schonfeld (2007).

DIAL-A-RIDE OF SÃO JOSÉ DOS CAMPOS

São José dos Campos is a technological city, especially the aviation industry. It has 615,871 inhabitants (IBGE, 2009) and is located in the state of São Paulo, as the following figure:

Figure 1 – Location of São José dos Campos (Clube Europa, 2007).

The service is offered for free since 1999. In 2008, the service was conducted by three companies, which had thirteen vans.

Figure 2 – Images of the vehicle (Prefeitura Municipal de São José dos Campos, 2008).

The process of scheduling service for Dial-a-ride and development of vehicle routing consists in four phases (Kikuchi, 1987). In the studied Dial-a-ride include:

Reserve: the request for transport is made by telephone from Monday to Wednesday, from 8 AM to 5 PM, to use the service over the weekend and on weekdays from next week. The user or the responsible informs to the attendant the number of register, the destination and the arrival and departure. The number of registration allows the identification of the location of the residence through a database, as well as specific information such as monitoring and type of equipment it uses;

Routing: the routing is done manually with the aid of a map and spreadsheet. The result of routing, which takes about 16 hours/employee, is delivered to utilities with at least one day in advance;

Monitoring the location of the vehicle and adjust the schedule: drivers are warned of changes in the route, and cancellations; Statistical and accounting records.

The annual attendance has increased rapidly in 2000-2001 and 2004-2005 biennia, but in the next two years, a reduction was recorded, affected by the decrease of 20% of the fleet of vans adapted.

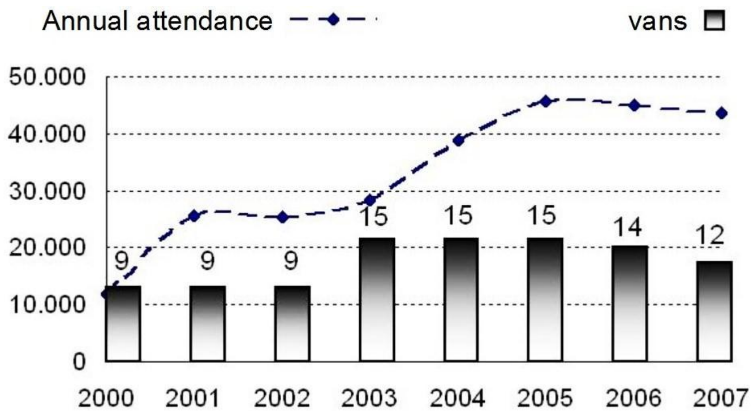

Figure 3 – Total calls per year and vehicle fleet, 2000-2007.

MODELING

This modeling is based on the work of Cordeau and Laporte (2003a) and Cunha (2006).

Graph

The Problem of Dial-a-ride, it is considered a graph $G=(N,A)$, where nodes (N) are neighborhoods of the city and the edges (A) are associated with a travel time equivalent to that used in the manual. Thus, the graph is not directed and strongly connected because there is at least one path from each node to other nodes of the graph, and path can be understood as a sequence of arcs, in which the starting node of arc is the end node of the arc precedes that it. (Arenales et al., 2007)

Nodes

The nodes represent points of stops. The travel time of a point i collection (shipping) or delivery (arrival) until a stopping point *j* is independent of the length t_{ij} of the vehicle used. In most cases, a user makes two requests per day: one inbound request, where part of the residence to the destination, and one outbound, on a trip to return home.
Is $P^{collection}=I^{collection}\cup O^{collection}$ the set of points to be visited to collect, and $P^{delivery}=I^{delivery}\cup O^{delivery}$ the set of points that occur deliveries. Thus the set of all points of stops is: $P=P^{collection}\cup P^{delivery}=I^{collection}\cup I^{delivery}\cup O^{collection}\cup O^{delivery}$.
By universal set (U) of points is necessary to consider the Garage: $U=G^{arage}\cup P$.

Inbound Requests

For one day of operation, $\mathrm{I}^{\text{collection}} = 1, 2, ..., \mathrm{n}$ is the set of requests to collect in the residence, inbound, and $I^{delivery} = \{\mathrm{n}+1, \mathrm{n}+2, ..., 2\mathrm{n}\}$ all of the nodes of inbound deliveries are local destinations. For each $j \in I^{delivery}$, we have a downtime between the time required for arrival $d_j^{Inbound}$ and arrival time, believes that a waiting time ($\delta^{delivery\_Inbound}$) determined by the level of service. This manner, the time interval in which the arrival is allowed to lad is $[d_j^{Inbound} - \delta^{delivery\_Inbound}]$. In turn, do the set $I^{collection} = \{1, 2, ..., \mathrm{n}\}$ as the nodes of inbound collections, that is, the residences. For each $j \in I^{collection}$, there is a window of time between the minimum and maximum hours of shipment represented by $c_j^{Inbound}$ and $c_j^{Inbond} + \delta_j^{collection\_Inbound}$, respectively. This interval, represented by $[c_j^{Inbound}, c_j^{Inbond} + \delta_j^{collection\_Inbound}]$, has $c_j^{Inbound}$ the scheduled departure in case that one were carried through travels in the maximum time (w_j) to the destination on time required.

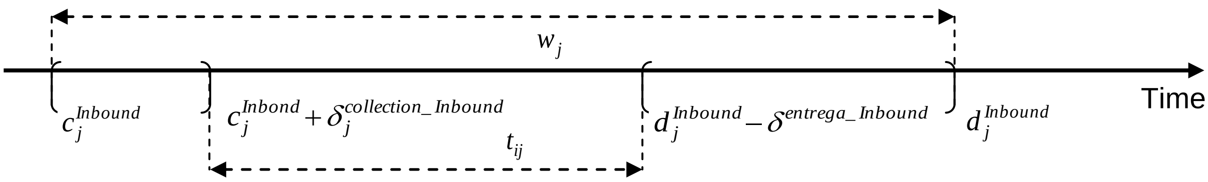

Figure 4 - Time windows in an inbound request.

Outbound requests

Similarly, it proceeds with the requests. $O^{collection} = \{1, 2, ..., \mathrm{m}\}$ is the set of points of outbound collections. For each $j \in O^{collection}$, there is a request to scheduled departure $c_j^{Outbound}$ and a maximum waiting time for the collect, called $\delta^{collection\_Outbound}$. This manner, the amplitude of the downtime for shipment is associated with $[c_j^{Outbound}, c_j^{Outbound} + \delta^{collection\_Outbound}]$. Consider $O^{delivery} = \{\mathrm{m}+1, \mathrm{m}+2, ..., 2\mathrm{m}\}$, as the set of points of return. In that case, are the residences. For each $j \in O^{delivery}$, an interval for delivery $[d_j^{Outbound}, d_j^{Outbound} + \delta_j^{delivery\_Outbound}]$ exists which $d_j^{Outbound}$ corresponds to the minimum time and $\delta_j^{delivery\_Outbound}$ an offset associated with the time required and the maximum travel (w_j).

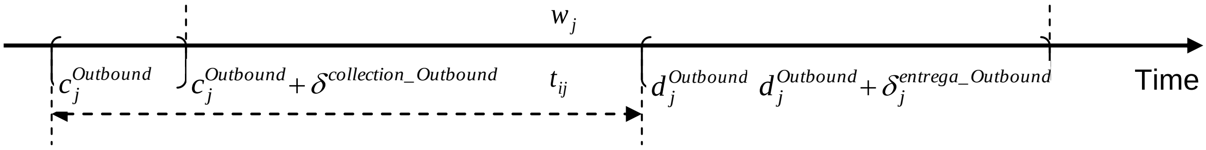

Figure 5 - Time windows in a request outbound.

Occupation of the vehicle

A set of categories is adopted that influence in the calculation of occupation of the vehicle. For every point $j \in N$, it will need a number of places for passengers by category q_j^a to modify the occupation of the vehicle. This demand (q_j^a) represents the amount of category passengers $a \in A$, assuming integer values in two ways:

$$\begin{cases} q_i^a > 0 & \text{, if } j \in P^{collection}; \\ q_j^a < 0 & \text{, if } j \in P^{delivery}. \end{cases}$$

The fleet corresponds to a set $V = \{1, 2, \ldots, V\}$ of available vehicles with capacity (C^{va}) to carry a number of passengers in the category $a \in A$. $G = \{1, 2, ..., G\}$ is the set of garages $U = P \cup G$ so that the whole universe of all points of stops.

Variables

Determine whether a vehicle v will travel or do not see the path of i to j:

$$x_{ij}^v = \begin{cases} 1, \text{ if the vehicle } v \text{ visits } j \in U \text{ from } i \in U; \\ 0, \text{ otherwise.} \end{cases}$$

Total passengers (Q_j^{av}) of the category $a \in A$

Start time service (T_j) at point N.

Objective Function

The goal of Dial-a-ride is to provide a quality comparable to a taxi, at a reduced cost (Jaw, 1984). To Bergvinsdottir (2004), this is to minimize the total cost of transport and simultaneously maximize the level of service, described by the principle that no passengers are carried from the collection place to the destination directly, but other users should be collected or delivered to the route to minimize the cost of transport. According Aldaihani and Dessouky (2002), the objective function of the main works on the problem of Dial-a-ride center on reducing the total distance traveled to be substituting the reduction of disadvantages by restrictions.
In this work, the objective function focuses on minimizing the time used by the fleet.

$$\text{Minimize} \sum_{v \in V} \sum_{i \in P} \sum_{j \in P} t_{ij} . x_{ij}^v$$

Although the mathematical model does not address the inconvenience of the service, Znamensky (2000) detaches that publications consider that came from developed countries, while in Brazil, public resources for Dial-a-ride are scarce. This manner, it is optimization of the usage time of the fleet, it is associated with maximizing the number of people served as operational objective.

Restrictions

The solution takes binary values: $x_{ij}^{v} \in \{0,1\}$, $v \in V$, $i \in S$, $j \in S$

Every point of collect is visited only once: $\sum_{v \in V} \sum_{j \in P} x_{ij}^{v} = 1$, $i \in P$

Every point of delivery is visited only once: $\sum_{v \in V} \sum_{i \in P} x_{ij}^{v} = 1$, $i \neq j$

For the same vehicle, the amount of travel to the point k, which can be 0 or 1, coincides with the total number of trips that leaves from this point:

$$\sum_{i \in P} x_{ik}^{v} = \sum_{j \in P} x_{kj}^{v} \text{ , } v \in V \text{ , } k \in P$$

Every vehicle must start from the garage the one that belongs: $\sum_{j \in P} x_{gj}^{v} = 1$, $v \in V$, $g \in G$

Every vehicle must return to your garage: $\sum_{j \in P} x_{jg}^{v} = 1$, $v \in V$, $g \in G$

The same vehicle that collects a passenger, delivery him at the requested place:

$$\sum_{j \in P} x_{ij}^{v} = \sum_{j \in P} x_{j,n+i}^{v} \text{ , } v \in V \text{ , } i \in P^{collection} \text{ , } (n+i) \in P^{delivery}$$

The occupation of the vehicle in a category in a node corresponds to the total of this group of passengers in the immediately previous stop, plus the loading or unloading of that category at that location:

$$x_{ij}^{v} = 1 \Rightarrow Q_{j}^{va} = Q_{i}^{va} + q_{j}^{a} \text{ , } v \in V \text{ , } i \in U \text{ , } j \in U \text{ , } i \neq j \text{ , } a \in A$$

There is no loading or unloading of passengers in the garage: $q_{i}^{a} = 0$, $a \in A$, $i \in G$

In all stopping point, it has loading or unloading: $\sum_{a \in A} q_{i}^{a} \neq 0$, $i \in P$

The capacity of the vehicle will not be exceeded: $0 \leq Q_{i}^{va} \leq C^{va}$, $v \in V$, $i \in P$, $a \in A$

The hours of operation must be in the time window, whose values are determined considering the nature of the trip, time of direct trip and maximum interval of permanence in the vehicle: $a_i \leq T_i \leq b_i$, $i \in P$

The load must precede the unload: $T_i + s_i + t_{i,n+i} \leq T_{n+i}$, $i \in P$, s_i is service time

Coherence time: $x_{ij}^{v} = 1 \Rightarrow T_i + s_i + t_{ij} \leq T_j$, $v \in V$, $i \in P$, $j \in P$, $i \neq j$

SIMULATION

This method is based on the work of Madsen et al. (1995) and Znamensky (2000).

Criteria for insertion

The sort order of insertion was amended by Madsen et al. (1995) to consider the difficulty of inserting a request with the use of non-negative parameters $c1_{window}$, $c2_{window}$, $\max_{window}$, $c1_{travel}$, $c2_{travel}$, $\max_{travel}$ and c_w, and according to three characteristics of the requests that affect the difficulty of insertion, where *k* is a request:

Time Window:

$$D^k_{window} = \begin{cases} c1_{window} + \dfrac{c2_{window}}{\delta t_{window}} & \text{case } \delta t_{window} > 0 \\ \max_{window} & \text{case } \delta t_{window} = 0 \end{cases}$$

Maximum time of trip: δt_{travel} is the difference between the maximum duration of trip and the lesser possible time of trip, which would correspond to the directly displacement to the destination.

$$D^k_{travel} = \begin{cases} c1_{travel} + \dfrac{c2_{travel}}{\delta t_{travel}} & \text{case } \delta t_{travel} > 0 \\ \max_{travel} & \text{case } \delta t_{travel} = 0 \end{cases}$$

Category: vehicles have suitable seats to the categories of passengers in different amounts. Then the characteristics of the User may impede the insertion of a request. c_{nc}, c_{cd}, c_{cf} and c_a are the constants corresponding to the number of seats for people who not use wheelchairs, users with folding wheelchair, not foldable wheelchair and seats for companions. d_{nc}, d_{cd}, d_{cf} and d_a are adopted as the needs of proper seats.

$$D^k_{category} = \sum c_i . d_i$$

Associated to a *k* a request difficulty of inserting the sum of the partial problems of the above equations:

$$D^k = D^k_{window} + D^k_{travel} + D^k_{category}$$

As Znamensky (2000), the parameters $c1_{window}$and $c1_{travel}$ are equal to zero, while, $c2_{window}$, $\max_{travel}$, $c2_{travel}$ and $\max_{category}$ are equal to 1. c_w is 0 or 1.

The combination of passengers considers the 133 possibilities of occupation of the vehicle in function of the dependence on a wheelchair (fixed or non-folding), folding wheelchair, without a wheelchair or companion.

Time travel

The geographical model adopts a model similar to that practiced in the empirical routing, when the path between two locations is estimated Temporal Unit (1 UT = 5 cm). $T = (t_{ij})$ is a matrix of time (M) travel in multiples of five, where $t_{ij} \in T$ represents the time required for a trip in the district i (i is the position of the line) for the district j (j is the column position). The main diagonal of the matrix is null because the offsets in the districts is not considered. This is also reflective matrix ($M = M^t \Leftrightarrow t_{ij} = t_{ji}$), because the travel time of a district i to j corresponds to the time from j to i. In practice, when demand supplants supply, the entire fleet is available used. Therefore, the procedure is, in each interation, insert a request in accordance with the descending order of the function of difficulty in all vehicles. The request is inserted in the vehicle with smallest increment of time since that it exceeds restrictions of occupation of vehicles for each category.
The origin of the vehicles does the distribution of the fleet of vans adapted to the garages of the operating companies. To each day of operation a vehicle has left of the garage carries through the appropriate route and returns the same garage.

Sample

The sample used for analysis of the program are the requests made for one day of operation of the transport service to People with Disabilities in July 2008 when it had 260 requests (inbound and outbound). Such applications are centered in 77 of the 397 districts of São José dos Campos.
The inbound requests, leaving the residence, had been used to describe the spatial distribution of requests. The map below, each circle has a size associated with a number of requests. The demand for residential, represented by gray circles of white center, concentrated in the South, which has a higher population density. The striped circles represent the demands of destination and predominate in the central region, which has the majority of physiotherapy clinics and hospitals.

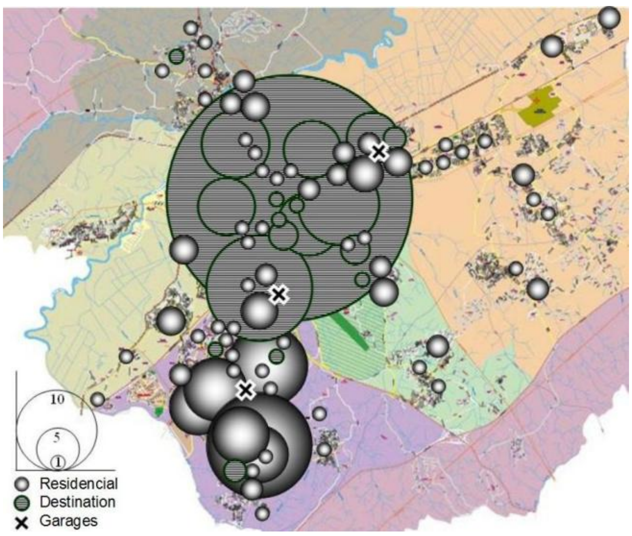

Figure 6 - Geographic distribution of requests per district.

Results

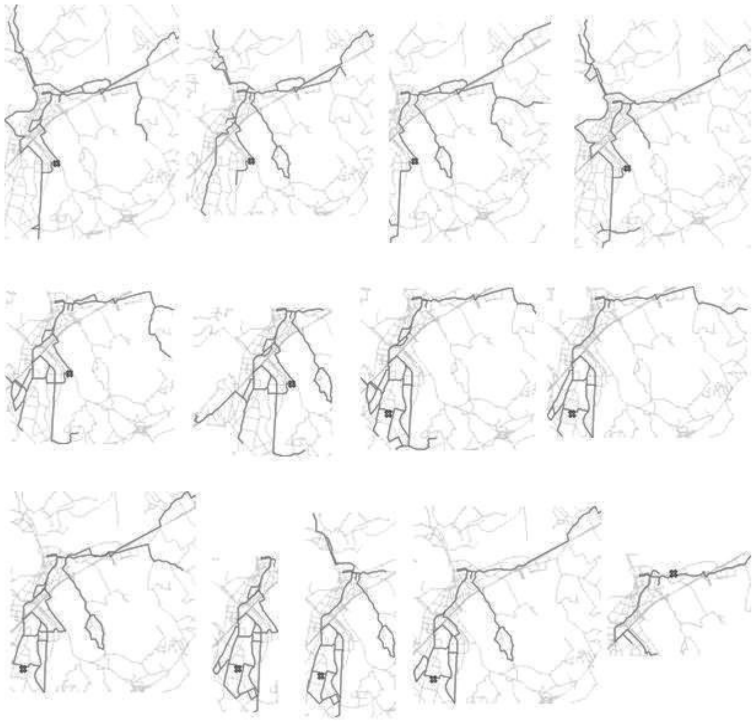

Figure 7 – Representation of the 13 geographical routes.

After 1h and 58min processing in a conventional computer, we obtained the insertion of 56% of the requests, respecting the conditions modeled. In practice, some insertions, can be performed with a delay more especially in times of peaks. The routes generated were represented on the map of the city road system from the Geographic Information System Spring 5.0 (Camara et al., 1996).

CONCLUSIONS

It was programmed to modeling and Parallel Insertion Heuristic for a real Dial-a-ride in a medium-sized city. Also a review of the literature by the group of algorithms used was made. The time devoted to manual routing could be reduced, because the program took two hours to determine the routes for one day of operation. The result generated by Parallel Insertion Heuristics could be supplemented with the manual routing, helping to reduce the routing time, which is 16 man-hours.
The subject Dial-a-ride is a fertile field for study since there are few national publications or papers on this subject. The case study presented allows to be continued, enriching it with analysis or simply supplementing it. Based on the presented heuristic can be developed one project in appropriate programming language and algorithms winning performance and efficiency, leaving the solution into a spreadsheet providing a more technical and professional program. It is possible also to carry through an analysis of the influence and

configuration of the fleet and the window of time in the quality of service Dial-a-ride and thus propose a design of the fleet.

REFERENCES

Aldaihani, M. and M. M. Dessouky (2003). Hybrid scheduling methods for paratransit operations. Computers and Industrial Engineering, 45, p. 75-96.

Arenales, M., V. Armentano, R. Morabito and H. Yanasse (2007). Pesquisa operacional para cursos de engenharia. Campus, Rio de Janeiro.

Attanasio, A., J.-F. Cordeau, G. Ghiani and G. Laporte (2003). Parallel Tabu Search Heuristics for the Dynamic Multi-Vehicle Dial-a-Ride Problem. Parallel Computing, 30, 377-387.

Baba, C. M., F. H. M. Corrêa, S. A. C. Souza, T. M. Wahba and A. C. Medina (2004). Otimizacao da colonia de formigas aplicada ao problema da programacao e roteirizacao de veiculos para o transporte de pessoas portadoras de deficiência. In: XXIV Encontro Nacional de Engenharia de Producao, pp. 2966-2973, Florianopolis.

Ballou, R. H. (2006). Gerenciamento da cadeia de suprimentos: Logistica empresarial. Bookman, Porto Alegre.

Baugh, J., G. K. R. Kakivaya and J. R. Stone (1998). Intractability of the dial-a-ride problem and a multiobjective solution using simulated annealing. Engineering Optimization, 30, 91-123.

Beaudry, A., G. Laporte, T. Melo and S. Nickel (2006). Dynamic transportation of patients in hospitals. Berichte des Fraunhofer Institut für Techno und Wirtschaftsmathematik, 104, 45 p.

Bergvinsdottir, K. B. (2004). The genetic algorithm for solving the Dial-a-Ride Problem. 2004. Technical University of Denmark, Lyngby.

Bodin, L., B. Golden, A. Assad and M. Ball (1983). Routing and Scheduling of Vehicle and Crews: The State of the Art. Journal of Computer and Operational Research, 10, 63-111.

Calvo, R. W. and A. Colorni (2007). An effective and fast heuristic for the dial-a- ride problem. 4OR. A Quarterly Journal of Operations Research, 5, 61–73.

Camara, G., R. C. M. Souza, U. M. Freitas and J. Garrido (1996). SPRING: Integrating remote sensing and GIS by object-oriented data modelling. Computers & Graphics, 20. 395-403.

Chan, S.-Y. E. (2004). Metaheuristics for solving the Dial-a-Ride Problem. North Carolina State University, Raleigh.

Clube Europa (2007). City of Sao Jose dos Campos. Available at http://www.clubeuropa.com.br/virtualeduca/eng/publish/pag_ico/0.3.gif

Cordeau, J.-F. and G. Laporte (2003a). The Dial-a-Ride Problem (DARP): Variants, modeling issues and algorithms. A Quarterly Journal of Operations Research, 1, 1614-2411.

Cordeau, J.-F. and G. Laporte (2003b). A tabu search heuristic for the static Multi-vehicle dial-a-ride problem. Transportation Research B, 37, 579-594.

Colorni, A., and G. Righini (2001). Modeling and optimizing dynamic dial-a-ride problems. International Transactions in Operational Research, 8, 155-166.

Coslovich, L., R. Pesenti and W. Ukovich (2006). A two-phase insertion technique of unexpected customers for a dynamic dial-a-ride problem. European Journal of Operational Research, 175, 1605-1615.

Cubillos, C., E. Urra and N. Rodriguez (2009). Application of Genetic Algorithms for the DARPTW Problem. International Journal of Computers Communications & Control, 4, 127-136.

Cunha, C. B. (2006). Contribuicao a modelagem de problemas em logistica e transportes. Universidade de Sao Paulo, Sao Paulo.

Dalboni, F. L. (2003). Algoritmos evolutivos eficientes para problema de roteamento de veiculo. Universidade Federal Fluminense, Niteroi.

Diana, M., and Dessouky, M. M. (2004). A new regret insertion heuristic for solving large-scale dial-a-ride problems with time windows. Transportation Research Part B, 38, 539–557.

Desrosiers, J., Y. Dumas and F. Soumis (1986). A dynamic programming solution of the large scale single-vehicle dial-a-ride problem with time windows. American Journal of Mathematical and Management Sciences, 6, 301-325.

Dessouky, M. M., F. Ordoñez and L. Quadrifoglio (2005). Productivity and Cost-effectiveness of Demand Responsive Transit Systems, California Partners for Advanced Transit and Highways, Berkeley.

European Conference of Ministers of Transport (1991). Transport for people with mobility handicaps policy and achievements in Europe. Paris.

European Conference of Ministers of Transport (2006). Improving Transport Accessibility for All: Guide to Good Practice. Paris.

Everling, M. T., S. F. Bastianello and L. M. S. Medeiros (1997). Recomendacoes ergonomicas para desenho de veiculo destinado ao transporte de pacientes aos hospitais de Santa Maria, Rio Grande do Sul. In: XVII Encontro Nacional de Engenharia de Producao, Gramado.

Haidemann, H. P. (2007). O problema dial-a-ride estatico: Estudo de caso para o transporte escolar. Universidade Federal do Parana, Curitiba.

Highway Capacity Manual (1965). Transportation Research Board, Washington.

Horiwitz, E. and S. Sahni (1978). Fundamentals of computer algorithms. McGraw-Hill, Rockville.

Hutchinson, B. C. (1974). Principles of urban transport systems planning. McGraw-Hill, Nova York.

Instituto Brasileiro de Pesquisa e Estatistica – IBGE (2009). Available at http://www.ibge.gov.br/cidadesat/topwindow.htm?1.

Ioachim, I., J. Desrosiers, Y. Dumas, M. Solomon and D. Villeneuve (1995). A request clustering algorithm for door-to-door handicapped transportation. Transportation Science, 29, 63–78.

Jaw, J.-J. (1984). Solving large-scale dial-a-ride vehicle routing and scheduling problems. Massachusetts Institute of Technology, Cambridge.

Jaw, J., A. R. Odoni, H. N. Psaraftis and N. H. M. Wilson (1986). A heuristic algorithm for the multi-vehicle advance request dial-a-ride problem with time windows. Transportation Research B, 20, 243-257.

Kanafani, A. (1983). Transportation demand analysis. McGraw-Hill, Nova York.

Karabuk, S. (2009). A nested decomposition approach for solving the paratransit vehicle scheduling problem. Transportation Research Part B-Methodological, 43, 448-465.

Kikuchi, S. (1987). Vehicle Routing and Scheduling Development for Transportation of Elderly and Handicapped Persons. Transportation Quaterly, 41, 207-227.

Luo, Y. and P. Schonfeld (2007). A rejected-reinsertion heuristic for the static Dial-A-Ride Problem. Transportation Research Part B-Methodological, 41, 736-755.

Madsen, O. B. G., H. F. Ravn and J. M. Rygaard (1995). A heuristic algorithm for a dial-a-ride problem with time windows, multiple capacities, and multiple objectives. Annals of Operations Research, 60, 193-208.

Mauri, G. R. (2006). Uma nova abordagem para o problema de roteirizacao e programacao de veiculos. Instituto Nacional de Pesquisas Espaciais, Sao Jose dos Campos.

Melachrinoudis, E., A. B. Ilhan and H. Min (2007). A dial-a-ride problem for client transportation in a health-care organization. Computers & Operations Research, 34, 742-759.

Moscato, P. (2001) Problemas de otimizacao NP, aproximabilidade e computacao evolutiva. Universidade Estadual de Campinas, Campinas.

Naddef, D. and G. Rinaldi (2002). Branch-and-cut Algorithms for the Capacitated VRP. In: The Vehicle Routing Problem (P. Toth and D.Vigo, ed.), pp. 53-84. Society for Industrial and Applied Mathematics, Philadelphia.

Pagano, A. M. and C. E. Mcknight (1983). Quality of service in special service paratransit: The users' perspective. Transportation Research Record, 934, 14-23.

Paquette, J., J.-F. Cordeau and G. Laporte (2009). Quality of service in dial-a-ride operations. Computers & Industrial Engineering, 56, 1721-1734.

Parragh, S. N., K. F. Doerner, X. Gandibleux and R. F. Hartl (2010). Variable neighborhood search for the dial-a-ride problem. Computers & Operations Research, 37, 1129-1138.

Pfliegl, E. (2007). Mixed Integer Programming: Techniques for the Dial-a-Ride Problem. Universität Wien, Viena.

Psaraftis, H. N. (1983). An exact algorithm for the single vehicle many-to-many dial-a-ride problem with time windows. Transportation Science, 17, 351-357.

Quadrifoglio, L., M. M. Dessouky and F. Ordoñez (2008). A simulation study of demand responsive transit system design. Transportation Research Part A-Policy and Practice, 42, 718-737.

Rekiek, B., A. Delchambre and H. A. Saleh (2006). Handicapped person transportation: An application of the grouping genetic algorithm. Engineering Applications of Artificial Intelligence, 19, 511–520.

Rickert, T., C. J. Venter and D. A. C. Maunder (2004). Accessible transport trends in Latin America. In: 10th International conference on mobility and transport for elderly and disabled people, Transport Research Laboratory, Hamamatsu.

Ropke, S. J.-F. Cordeau and G. Laporte (2007). Models and branch-and-cut algorithms for pickup and delivery problems. Networks, 42, 258 - 272 .

Prefeitura Municipal de Sao Jose dos Campos (2008). Secretaria de Transportes. Agendamento de van.

Savelsbergh, M. W. P. and M. Sol (1995). The General Pickup and Delivery Problem. Transportation Science, 29, 17-29.

Suticliffe, C. and J. Board (1990) Optimal Solution of a Vehicle-routeing Problem: Transporting Mentally Handicapped Adults to an Adult Training Centre. Journal of the Operational Research Society, 41, 61-67.

Toth, P. and D. Vigo (1996). Fast local search algorithms for the handicapped persons transportation problem. In: Meta-heuristics: Theory and applications (I. H. Osman and J. P. Kelly, ed.), pp. 677- 690. Kluwer, Boston.

Toth, P. and D. Vigo (1997). Heuristic algorithms for the handicapped persons transportation problem. Transportation Science, 37, 60-71.

Toth, P. and D. Vigo (2002). An Overview of Vehicle Routing Problems. In: The Vehicle Routing Problem (P. Toth and D.Vigo, ed.), pp. 1-26. Society for Industrial and Applied Mathematics, Philadelphia.

Transit Cooperative Research Program (2003). Transit Capacity and Quality of Service: Manual. Report 100, Washington.

Vuchic, V. R. (1981). Urban Public Transportation: Systems and Technology. Prentice-Hill, New Jersey.

Wilson, N. H. M., J. M. Sussman, H. K. Wang and B. T. Higonnet (1971). Scheduling Algorithms for dial-a-ride systems. Massachusetts Institute of Technology, Cambridge.

Wilson, N. H., R. W. Weissberg and J. Hauser (1976). Advanced Dial-a-Ride Algorithms Research Project. Massachusetts Institute of Technology, Cambridge.

Wong, K. I., and Bell, M. G. H. (2006). Solution of the dial-a-ride problem with multi-dimensional capacity constraints. International Transactions in Operational Research, 13, 195–208.

Xiang, Z.H., C. Chu and H. Chen (2008). The study of a dynamic dial-a-ride problem under time-dependent and stochastic environments. European Journal of Operational Research, 175, 534-551.

Znamensky, A. (2000). Um modelo para a roteirizacao e programacao do transporte de deficientes. Universidade de Sao Paulo, Sao Paulo.