Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**
DOI: 10.4322/bjopm.2011.006

# A Free Geographic Information System as a Tool for Multi-Depot Vehicle Routing

**Orivalde Soares da Silva Júnior**
Pontifical University Catholic of Rio de Janeiro (PUC-Rio), Rio de Janeiro, RJ, Brazil

**Luiz Antônio Silveira Lopes**
**Ulf Bergmann**
Military Institute of Engineering (IME), Rio de Janeiro, RJ, Brazil

## Abstract

The classic Vehicle Routing Problem (VRP) has been extensively studied in recent decades due to its practical application as a tool to support logistics and transport. The main focus of most studies in the literature is the development of methods aimed at finding solutions to tenths of improvement for bodies established in the literature. However, the main focus of this work is the practical application of a variant of this problem through integration with a free Geographic Information System (GIS). From a problem identified in a food sector company, we identified the need to extend the VRP to Multi-Depot VRP (MDVRP) and use heuristic techniques to solve large problems of the company. The prototype showed better results than the commercial software out on the market.

***Keywords:*** *Vehicle routing, Multi-depot, Geographic information system, Free software.*

## Introduction

Among the diverse applications integrated into the Logistics sector through Information Technology, one that stands out most is the Geographic Information System (GIS), which provides decision-making support for diverse areas of planning and operation. It is basically a system composed of hardware, software, spatial information and computational procedures that permits and facilitates the analysis, management or representation of a given space and the phenomena in which it occurs.

As known today, the first developed GIS was created in Canada in the 1960s and was referred to as the CGIS (Canada Geographic Information System) (Breternitz, 2001). However, the large explosion in the use and development of GIS came in the mid 1990s, when the new generation of microcomputers with high capacities for processing and storage became low cost and at the same time an increasing amount of spatially identified socio-economic and environmental data (georeferenced) were made available.

With the invention of vehicle navigation systems, more commonly known as GPS, a geographic revolution began in which diverse data banks were created for the representation of highway systems at federal, state and municipal levels. Allied with

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

a GIS, these data allow for a significant increase in the details of a practical vehicle routing application because they permit the incorporation of information such as the direction of the highways, the real distance traveled by vehicles, the exact location of the clients and the graphical visualization of the routes with satellite images.

Therefore, the majority of GISs available on the market are proprietary, i.e., they are developed and commercialized by private companies. Because these are specialized systems, the cost of acquisition is generally quite high. One disadvantage of proprietary GIS is their low flexibility for the inclusion of new tools, as it is generally necessary that the developer use a determined programming language. Their algorithms function only as black boxes, making computational improvements impossible.

One alternative to these problems is the use of free software, as there are no costs of acquisition, the software programs are highly flexible for the development of new tools because they utilize programming languages known around the world, such as Java, and the algorithms can be modified and improved using the original source code. This is considered the best option for academic studies, because it allows the continuity and improvement of the functions that are developed.

The objective of this study was to develop a procedure to solve the Multi-depot Vehicle Routing Problem (MDVRP) and implement it as a plug-in to a free Geographic Information System (GIS).

## Free Geographic Information Systems

There are various software programs that aid in performing GIS tasks. Currently, the most globally utilized software programs in companies, universities and public organizations are patented and commercialized. In this case, the diverse program packages in binary archives, resultant from the compilation of the source code, are commercialized for specific operational systems.

However, there are also interesting free software alternatives for this purpose, developed by several groups around the world. Free software programs are also expressive in their capacity to develop GIS tasks. According to Kinberger and Puncher (2005), the use of free software in the geoprocessing field is gaining more traction in business and public administration because it is often capable of substituting for commercial software.

In this study, free software programs are those whose source codes are freely distributed and normally licensed by the GNU General Public License or by the LGPL (GNU Lesser General Public License). The use of free software offers the advantage of not having to pay for the software. This may be advantageous in certain situations, for example, when a large number of copies must be installed on various workstations. Moreover, free software may offer the advantage of easily obtaining software updates upon the rapid evolution of the hardware. However, with regard to the labor for installation, training and maintenance, it is currently more difficult to find professionals qualified in free software than those qualified in patented software.

In the development of specific software for GIS, whether free or proprietary, two trends can be observed that are also related to the usage license. On the one hand, complete and complex systems are developed that are capable of performing almost

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

all involved functions, offering graphical interfaces that are user-friendly. This is the case for proprietary software. In free software, development occurs differently. The incentive is normally financed by research and development funds from businesses, universities or public organizations around the world. There are also enthusiastic programmers who contribute independently. Development is therefore more spread out, with smaller-scale software normally developed for specific necessities. Câmara and Onsrud (2004) presented a similar conclusion.

These, among other facts and discussions related to the subject, have become relevant for the identification of a set of free software that, working together, is capable of storing georeferenced data and offering tools for the management, consulting, processing and visualization of alphanumeric and geometric information, constituting a GIS. This study seeks to satisfy this task, wherein possible solutions for desktops are analyzed.

Based on the lack of understanding of free software due to either the lack of documentation or the greater associated difficulty, this influences the decision to use this alternative. The software chosen in this study must be as user-friendly and intuitive as possible. This implies that graphic interfaces will be available to perform the greatest number of tasks possible, avoiding the use of command-line terminals. Moreover, the degree of software development and the consistency of the mounted system are also decisive factors in the selection. At the end of the study, a complete GIS should be characterized, constituted exclusively by free software.

### *Softwares*

The process of searching for software may be performed with the aid of a search tool on the internet. Free software development groups normally maintain pages on the internet where it is possible to obtain the source code of the software, pre-compiled packages for specific operational systems, documentation and other resources. There is a large quantity of software that can be found in this way. The work of selecting a particular software application, according to the presented criteria, relies on its installation and the performance of tests with specific data.

Three main groups of software can be established, and when working together they are capable of constituting a complete GIS. These include the specific software for GIS operations, database software and support software.

Primarily, specific software applications for GIS were sought, where these included data reading and writing functions and tools for consultants, visualization and processing. Quantum GIS (version 0.8.0 Preview 1, obtained at http://download.qgis.org), GRASS (version 6.0.1, obtained at http://grass.itc.it/download/index.php) and OpenJUMP (version 1.2.0, obtained at http://sourceforge.net/projects/jump-pilot) were chosen from among several other analyzed software programs.

Quantum GIS is a GIS with a user-friendly graphic interface and characteristics that mainly compete with the commercial ArcView software from the ESRI company. It is capable of loading a large variety of data utilizing support libraries in rectangular and vectorial formats and has a large capacity for editing the visual properties of layers. This allows for the editing of the alphanumeric and geometric information of vectorial layers in archives and direct editing in data banks. It also offers a tool for the development of imprinted maps (layouts).

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

GRASS (Geographic Resources Analysis Support System) is a complete GIS, including more than 350 functions for geospatial analysis, environmental modeling, thematic mapping, data bank interaction, image processing and visualization. It also includes a well-developed graphical interface, but it is not as intuitive as Quantum GIS. GRASS is normally utilized to execute more complex GIS operations. According to Kinberger and Puncher (2005), the possibilities offered by GRASS are difficult to reach with the use of today's proprietary software, where GIS support for rectangular and vectorial data are combined with visualization and image processing techniques.

The project OpenJUMP is a GIS with a user-friendly graphical interface and is also capable of loading a wide variety of data in both rectangular vectorial formats. It was developed entirely in Java and possesses a high modularity, facilitating the development of new plug-ins. Many previously developed plug-ins can also be found that solve problems in the diverse fields of GIS use.

### *Adopted Free GIS*

The number of available free software programs performing GIS tasks is substantial. There are many possible choices, and each has specific advantages. Various degrees of development are also encountered among the software programs. Taking into consideration the established requisites for selecting software to constitute a complete GIS, which include the availability of the source code, the degree of development, the system establishment and the user friendliness, this study chose OpenJUMP.

## The Multi-Depot Vehicle Routing Problem

Despite possessing diverse functionalities for geospatial analysis and processing and a connection with data banks, none of the analyzed GIS programs had support tools for logistical decision-making, for example, determinations of the shortest route and vehicle routing. In this work, the filling of this gap through the integration of the OpenJUMP GIS with the vehicle routing procedure is proposed.

The Vehicle Routing Problem (VRP) has been extensively studied due to its wide applicability in many real-life situations. This problem considers a company with a single depot, an unlimited capacity, a fleet of vehicles with a homogeneous (equal) capacity and a group of clients with information on demand and location. Generally, the total demands of the clients exceed the capacity of one vehicle, so more than one vehicle is used for product distribution from the depot to the clients. Each vehicle is designed for one route, and one client is served by one vehicle in a single route. Each route begins and ends at the depot.

The objective of the VRP is to determine the shortest total distance or time spent to serve all clients. A minimal delivery time results in a higher level of client satisfaction. Additionally, the objective also aims to reduce the necessary number of vehicles. Fewer vehicles imply a reduction of the fleet and consequently the total cost of the operation. Therefore, it can be concluded that the final objective of the VRP is to increase delivery efficiency and reduce company costs (Ho *et al.*, 2007).

Many applications of the VRP have been utilized, but all are based on a single depot. Although this problem is the most attractive among researchers in the field, it is not appropriate for companies with more than one depot. In these cases, it is necessary

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

to solve the Multi-Depot Vehicle Routing Problem (MDVRP). In these problems, the decision-makers must also determine which clients will be served by which depots. For this, it is necessary that the clients be allocated to the depots according to the objective of optimizing the overall cost. The MDVRP has been observed to support the three decision-making processes, as shown in Figure 1.

Therefore, the objective of the MDVRP consists of assigning the clients to the depots and forming sub-problems of VRPs, which are solved individually. To better understand this problem, a practical example with 2 depots and 12 clients is illustrated in Figure 2.

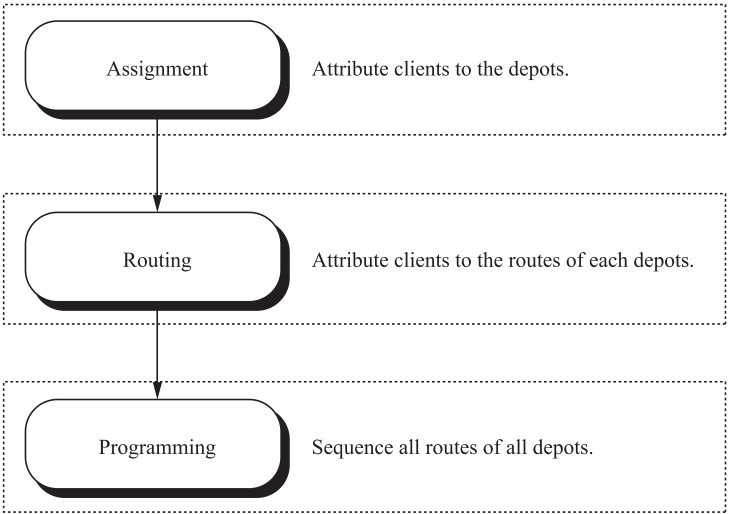



**Figure 1.** Sequence of decision-making in the MDVRP.

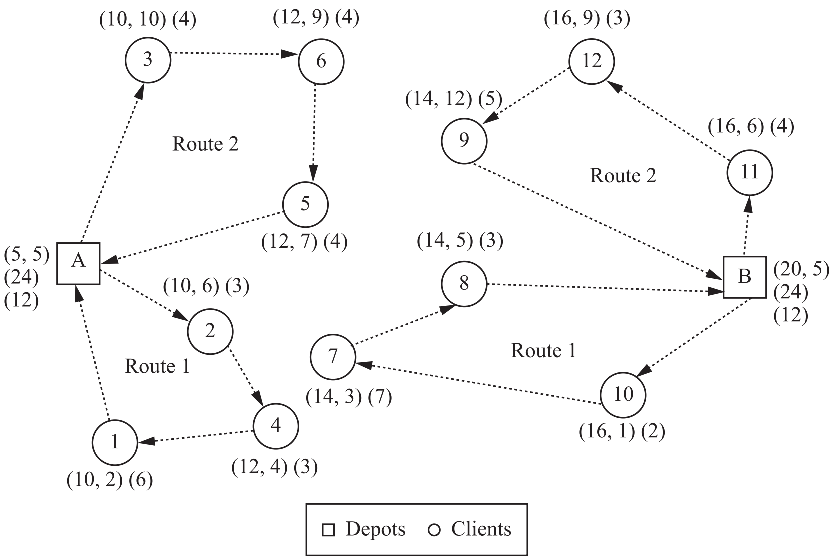



**Figure 2.** Example of a MDVRP.

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

The values in parentheses beside the depots and above or below the clients represent the coordinates. The second values in parentheses above or below the clients indicate the demands of the clients. Each depot has a limited storage capacity and various vehicles with a homogeneous (equal) and limited capacity. In this example, each depot has the capacity for 24 units and each vehicle can transport up to 12 units per route, as is shown in the second values within parentheses beside the depots.

It can be observed that Depot A is utilizing 24 units to serve its clients via two routes. Each route is associated with a vehicle that is attending to the total demand of 12 units. It can be noted that despite Client 7 being closer to Depot A, he had to be served by Depot B because Depot A did not has the capacity to serve his demand.

Under computational logic, both VRPs and MDVRPs are NP-hard, i.e., as the problems increase in size the computational forces to solve them grows exponentially. This signifies that it is not possible to obtain a solution by means of exact methods, such as linear programming, in an acceptable processing time.

Thus, it is necessary to use intelligent techniques known as heuristic and metaheuristic techniques. Due to the additional complexity that the MDVRP possesses, a reasonable approximation should involve dividing the problem into various routing and programming sub-problems, initially assigning the client to a depot and solving the sub-problems individually (Renaud *et al.*, 1996).

Methods to solve the MDVRP can be classified according to the number of stages necessary to find a solution. Each stage consists of an independent solution in a complex problem. In the first stage, the decision to assign the clients to the depots is solved by the Assignment Problem (AP). In the second stage, the decisions to allocate the clients of the same depot to diverse routes and to sequence them for delivery are solved by the Vehicle Routing Problem (VRP). The first method for solving a MDVRP possesses one stage and consists of solving the AP and VRP simultaneously. The second method has two stages and consists solving the AP and VRP separately, i.e., it initially assign the clients to the depots and then solves the sub-problems one by one with the VRP.

Among the 14 methods are shown in Table 1, two utilize the one-step method and 12 utilize the two-phase method. Among the solutions to the problem utilizing the one-step method, that solving the greatest number of problems was proposed by Laporte *et al.* (1988), who used the branch and bound exact method and reported results for the asymmetric problem with three depots and 80 clients.

Among the solutions in the literature utilizing the two-stage method, that solving the greatest number of problems found was proposed by Chan and Baker (2005), who applied the minimum spanning forest to solve the first phase and the method of savings of Clarke and Wright in the second phase. The authors presented results for the problem with up to 12 depots and 181 clients.

## Proposed Methodology

### *Mathematical Formulation*

The MDVRP is classified as NP-hard, thus limiting the use of exact methods to viably solve the problem. However, even with these limitations, the importance

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

**Table 1.** Methods for solving a MDVRP.

| Author (year) | AP solution method | VRP solution method | Size |
|---|---|---|---|
| Tillman (1969) | Heuristic – parallel | Constructive heuristic – savings *(Clarke and Wright)* | d = # c = # |
| Wren and Holliday (1972) | Heuristic – parallel | Constructive heuristic – Cluster-first – Route-second | d = 2 c = 176 |
| Gillett and Miller (1974) | Heuristic – parallel | Constructive heuristic – Cluster-first – Route-second | d = 2 a 5 c = 249 |
| Golden *et al.* (1977) | Heuristic – sweep | Constructive heuristic – savings *(Clarke and Wright* modified) | d = 4 c = 100 |
| Laporte *et al.* (1984) | Exact method (symmetric problem) branch and bound | | d = 2, c = 50 |
| Laporte *et al.* (1988) | Exact method (asymmetric problem) branch and bound | | d = 3, c = 80 |
| Chao *et al.* (1993) | Heuristic – sweep | Constructive heuristic - savings *(Clarke and Wright* modified) | d = 9 c = 360 |
| Renaud *et al.* (1996) | Heuristic – improved petal | Metaheuristic – tabu search | d = 9, c = 360 |
| Nagy and Salhi (2004) | Heuristic *borderline customers* (Salhi and Sari, 1997) | Constructive heuristic – multiple giant tour (Salhi *et al.*, 1992) | d = 5, c = 50 a 249 |
| Lim and Wang (2005) | Heuristic *borderline customers* (Salhi and Sari, 1997) | Metaheuristic – tabu search | d = # c = 200 |
| Bonasser (2005) | Heuristic – parallel | Hybrid metaheuristic - tabu search and ant colony (AnTS) | d = 7 c = 182 |
| Chan and Baker (2005) | Heuristic – minimum spanning forest | Constructive heuristic – savings *(Clarke and Wright)* | d = 12 c = 181 |
| Crevier *et al.* (2007) | Exact method – branch and bound | Metaheuristic – tabu search | d = 7, c = 288 |
| Ho *et al.* (2007) | Heuristic – parallel | Hybrid metaheuristic – generic algorithm | d = 2, c = 50 a 100 |

of developing a mathematical formulation for these problems is recognized both for evaluating the results from approximation methods in small cases and for obtaining lower quality limits for the optimal value (the value or objective function associated with the optimal solution). Therefore, a mathematical formulation of the MDVRP is proposed in this section, modeling it as integer programming problem with linear and

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

non-linear restrictions. Thus, the following constants and variables are employed in this model:

| | | |
|---|---|---|
| $V = \{1,\ldots,n\}$ | nodes | |
| $A = \{(1,2),(1,3),\ldots,(1,n),(n,1),(n,2),\ldots,(n,n-1)\}$ | all arcs for each pair of nodes | |
| $I = \{1,\ldots,v\}$ | vehicles | |
| $J = \{1,\ldots,d\}$ | depots | |
| $U \subset V$ | sub-sets of the nodes | $\ni 2 \leq \lvert U \rvert \leq \lvert V \rvert - 2$ |

Parameters:

$RL_i$ = maximum route size for vehicle $i$;

$CAP_i$ = maximum capacity of vehicle $i$;

$MAX_j$ = maximum demand that can be met by depot $j$;

$dist_{k,l}$ = distance of the arc $(k,l)$;

$dem_k$ = demand of the client located at node $k$.

Decision variables:

$$x_{ijkl} = \begin{cases} 1 & \text{if vehicle i is attributed to depot j passing through arc (k,l)} \\ 0 & \text{otherwise} \end{cases}$$

$$min \sum_{i\in I} \sum_{j\in J} \sum_{(k,l)\in A} dist_{kl}\, x_{ijkl} \tag{1}$$

$$\sum_{i\in I} \sum_{k:(k,l)\in A} dem_k x_{ijkl} \leq MAX_j \quad \forall_j \in J \tag{2}$$

$$\sum_{j\in J} x_{ij} \leq 1 \quad \forall i \in I \tag{3}$$

$$x_{ijkl} \leq x_{ij} \quad \forall i \in I, j \in J, (k,l) \in A \tag{4}$$

$$\sum_{i\in I} \sum_{j\in J} \sum_{k:(k,l)\in A} x_{ijkl} = 1 \quad \forall l \in V \tag{5}$$

$$\sum_{i\in I} \sum_{j\in J} \sum_{l:(k,l)\in A} x_{ijkl} = 1 \quad \forall k \in V \tag{6}$$

$$\sum_{(k,l)\in A} x_{ijkl} - \sum_{(l,m)\in A} x_{ijlm} = 0 \quad \forall i \in I, j \in J, l \in V \tag{7}$$

$$\sum_{i\in I} \sum_{j\in J} \sum_{\substack{(k,l)\in A: \\ k\in U, l\in V\setminus U}} x_{ijkl} \geq 1 \tag{8}$$

$$\sum_{j\in J} \sum_{(k,l)\in A} dist_{kl} x_{ijkl} \leq RL_i \quad \forall_i \in I \tag{9}$$

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

$$\sum_{j \in J} \sum_{k:(k,l) \in A} dem_k x_{ijkl} \leq CAP_i \quad \forall i \in I \tag{10}$$

The objective function (1) represents the total distance to be minimized. Restriction (2) imposes that the depot capacity must not be exceeded; restriction (3) implies that each client may be served by a single vehicle; restriction (4) states that an encountered vehicle must be used; restrictions (5) and (6) impose, respectively, that only one vehicle arrives and leaves from a client; restriction (7) imposes that the vehicle arriving at a client should be the same vehicle that leaves the client; restriction (8) imposes the sub-route limit; restriction (9) implies the route size limit; and finally, restriction (10) imposes the capacity limit of the vehicles.

***Adapted Heuristic Methods***

The proposed procedure for solving the MDVRP is based on the two-stage method. Although this method does not provide an optimal solution when not considering the two stages simultaneously, it was selected because of its large-scale problem-solving capacity with reduced computational time.

The parallel assignment algorithm (Giosa *et al.*, 2002) was selected for the ascription of the clients to the depots in the first stage. This algorithm was selected due to its good computational performance and simplicity of implementation.

The parallel assignment derives its name because the priorities for each client are calculated considering all depots at the same time. This heuristic compares the cost of assign a client to the closest depot with the cost of assign the same client to a different depot. This heuristic has the following operation:

1) Each client belongs to only one of the following groups:

a) *A* if a client was assigned to a depot;

b) *NA* if the client was not yet assigned to a depot.

2) Each depot belongs to only one of the following groups:

a) *DS* if the demand of the depot was satisfied;

b) *DNS* if the demand of the depot was not yet satisfied.

3) An assignment of a client to a depot is possible if:

a) the depot belongs to the *DNS* group;

b) the client belongs to the *NA* group.

4) The urgency $u$ of each client is then calculated using the following expression:

$$u_c = \sum_{c \in D} (dist(c,D) - (dist*(c,D^*))$$

5) An ordered client list is created in descending order by the value of urgency $u$, and the client with the greatest urgency is assigned to the closest depot contained in the *DNS* group.

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

6) The heuristic is finished when all clients are served.

For the second stage, a constructive heuristic of savings by Clarke and Wright (1964) was selected for the routing and programming of the vehicles from each group of clients assigned to their depot. This heuristic was chosen because it provides good results in a reduced computational time. According to Ballou (1993), the utilization of this algorithm may result in solutions approaching 2% deviation from the optimal solution. This method can also be considered the most flexible among those available, permitting the incorporation of diverse restrictions that adapt to the characteristics of a business.

The Clarke and Wright (1964) heuristic is based on the notion of savings, which can be defined as the cost of the combination, or union, of two existing sub-routes. Initially, each client is served by one vehicle, establishing routes between the depot and each client.

The variable $c_{ij}$ is the cost of the trip from client *i* to client *j* and can be given in the distance traveled or the time of displacement. Two routes connecting clients *i* and *j* may be combined as long as *i* and *j* are on the first or last positions of their respective routes and if the total demand of the combined routes does not surpass the capacity of the vehicle and/or the total traveling time. In each iteration, all route combinations are analyzed using the formula $S_{ij} = c_{io} + c_{0j} - c_{ij}$, where *0* represents the depot. The two routes that yield the greatest savings are united. The Clarke and Wright algorithm is detailed as follows:

1) Calculate the $S_{ij}$ gains for all *ij* pairs (*ij*, *i0*, *j0*);

2) Order the *ij* pairs in decreasing order of the $S_{ij}$ gain;

3) Begin with the *ij* pair with the greatest $S_{ij}$ gain and proceed in the sequence obtained in 2;

4) For a pair of nodes *ij* corresponding to the *k*-th element of sequence 2, verify whether *i* and *j* are or are not included in an existing route:

4.1) If *i* and *j* are not included in any existing routes, create a new route with the nodes *i* and *j*;

4.2) If exactly one of the points *i* or *j* already belongs to a pre-established route, verify whether this point is the first or last of the route (adjacent to the node *0*, depot); if this occurs, add the *ij* arc to this route; if not, continue to the next step, skipping the *ij* pair;

4.3) If both nodes already belong to two pre-established routes (different routes), verify whether both are extremes in their respective routes (adjacent to the node *0*); if this is the case, consolidate the two routes into one; if not, continue to the next step, skipping the *ij* pair;

4.4) If both nodes *i* and *j* belong to a single route, skip to the next step.

5) Continue the process until all clients on the gains list have been considered. If there is a point not included on any route, individual routes must be formed, connecting the depot to each point and returning to the base.

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

***Proposed Methodology***

The methodology divides the elaboration of the problem into five basic steps, logically interconnected with the activities and data necessary for the execution of each. These steps correspond to the first level of information. Each of these steps is detailed using a second level of application, as shown in Chart 1.

The first step is to obtain data on the highways, depots, clients and vehicles. These data can be determined based on the creation or importation of layers in the GIS. The highway layer is represented by lines, and the client and depot layers are represented by points. Information on the vehicles including the load capacity, average velocity, average cost per kilometer traveled, average unloading time and maximum working time are imported based on the manual inputs.

The second step includes the generation of a distance matrix. For this, the traveled Euclidian distance corrected by an adjustment coefficient for highways or the real distance obtained by a shortest path on the road network could be used. Based on the locations of the depots and clients, a minimal distance matrix can be created for each origin and destination using the shortest path algorithm of Dijkstra (1959).

The third step considers the assignment of clients to depots. It is first verified whether the capacities of the depots are sufficient to meet the demands of the clients. If they are not sufficient, it is necessary to alter the capacity of a depot or remove a certain client in order for the capacity to be greater than or equal to the demand. Soon thereafter, the clients are assigned to the depots using the parallel assignment algorithm.

**Chart 1.** Steps of the methodology.

| | Level 1 | Level 2 |
|---|---|---|
| Step 1 | Data input | 1- Creation or importation of the road network<br>2- Client records<br>3- Depot records<br>4- Vehicle information records |
| Step 2 | Creation of the distance matrices | 1- Reading of the road network<br>2- Creation of a graph with the road network<br>3- Creation of the distance matrices using the Dijkstra shortest path algorithm |
| Step 3 | Assign of the clients to the depots | 1- Verification of the capacities of the depots and demands of the clients<br>2- Assign of the clients to the depots using the assignment algorithm with parallel urgencies |
| Step 4 | Routing and programming | 1- Routing and programming of the vehicles from each depot using the Clarke and Wright algorithm<br>2- Application of post-optimization using the 2-opt algorithm |
| Step 5 | Production of reports | 1- Generation of the graphical routes in GIS<br>2- Generation of the itineraries for each vehicle |

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

The fourth step relates to the routing and programming of the vehicles. For each sub-problem generated by the assignment algorithm, the routing and programming of the vehicles is done for each depot using the Clarke and Wright algorithm. Next, in the post-optimization phase, the iterative 2-opt optimization algorithm is applied (Croes, 1958).

The fifth step includes the production of reports. A new layer is generated for graphical visualization in the GIS for all routes. For each route, information on the itinerary of the vehicle, total distance traveled, total time, total route cost and total demand met by the vehicle is included.

### *Developed Prototype*

To solve the studied problem, a computational tool was developed based on the proposed methodology, and the Java programming language was used within the object orientation paradigm. This tool was designed as a plug-in of the free OpenJUMP GIS. The system was modeled based on the UML diagrams for the case of use, activities and classes. The system was also internationalized and translated into the languages of English, Spanish, French, Italian and Japanese, in addition to the original language of Portuguese, with the objective of amplifying its dispersion in the free software community.

## Case Study

The present case study was performed with a well-known Italian food company, Parmalat. This study contemplated the company units in the Brazilian subsidiary.

When purchasing new plants, the Parmalat had an increase in production capacity, but according to internal reports, there was increased demand in proportion to the new capacity installed. One of the hypothetical hindering the increase in sales, generating difference between demand and supply is the constraint on the existing distribution in the current model, the main customer for the large retailers. The large retailers consume, according to an interview held at Parmalat, 70% of the production plant.

The positive is the reduction in logistics costs due to the low capillary delivery held by its own fleet of trucks through closed (each vehicle carries all your cargo to a single destination). But the problem is the large degree of dependence generated by this model.

To minimize excess capacity generated by the purchase of new plants, Parmalat has analyzed the modification of your model from diversification of its parent company sales of simulating customers of all sizes. This may give greater capillarity in the scope of Parmalat’s care, increasing the current production above demand and minimizing the degree of dependence to major retailers. The increased coverage will aim to increase the number of milk suppliers in various basins in Brazil, minimizing the risk and dependency caused by the excessive concentration of suppliers and large customers.

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

In order that future changes in the array of sales, Parmalat has to worry about the logistics, looking for tools that provide decision support to the vehicle routing and meet their physical and operational characteristics, such as:

- Multiple depots: It possesses 13 factories, 12 distribution centers and one cross-dock (distribution center without storage), totaling 26 depots according to the denomination utilized in this study;
- A homogeneous fleet with a capacity restriction: The company's fleet is constituted of large-scale vehicles (semi-trucks with a capacity of 26 thousand kilograms each);
- A large quantity of clients: Four hundred clients are served.

The area of study was the Brazilian territory. The geographic road network was obtained together with the Military Institute of Engineering and was in its final phase of updates, with some roadways still to be added. It constitutes federal, state and municipal highways totaling 6,756 road stretches.

The client and depot bases were imported using the GIS. Information contained in the client base included a description, the address and the demand. The deposit base contained a description, the address and the capacity. From the addresses, each client was georeferenced to his real location. Thus, each client was represented by a point. To obtain the routes for each vehicle, the user must click on the *Search Routes* button (Figure 3).

Upon finishing this execution, the total cost of the encountered solution is shown, i.e., the sum of the costs of all routes encountered (Figure 4).

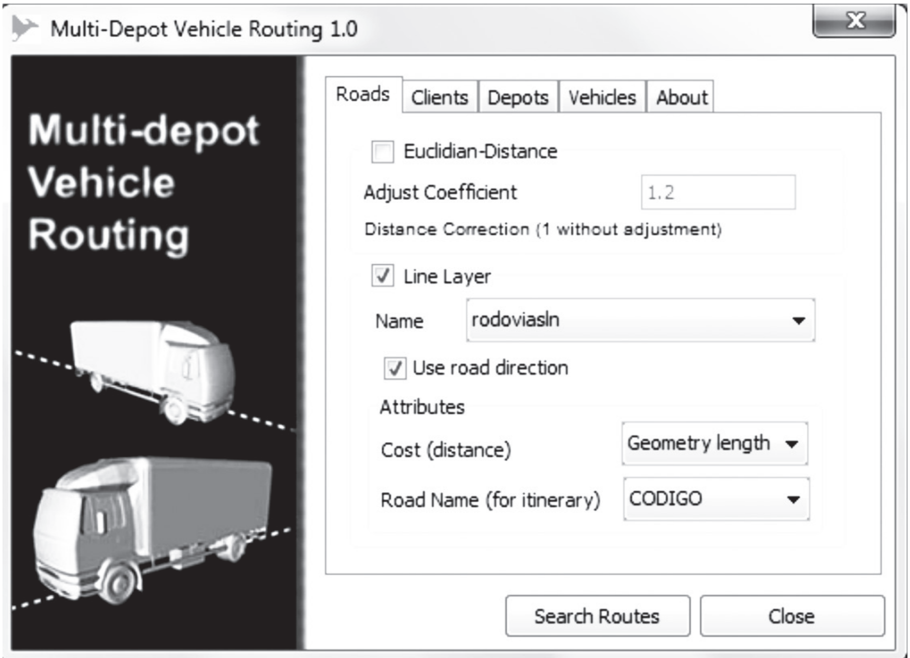
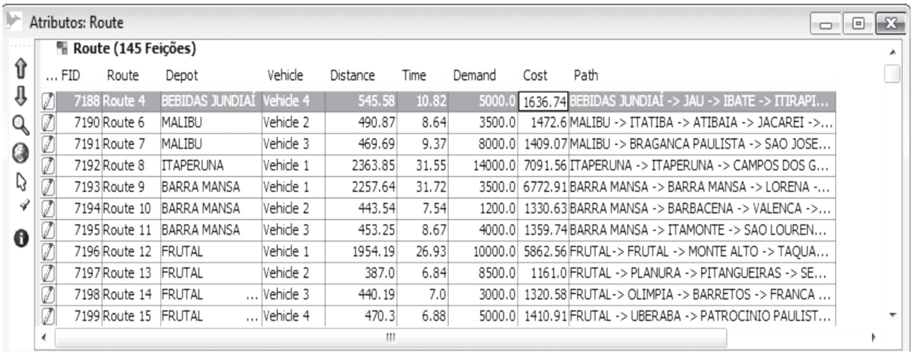



**Figure 3.** Visual display of the developed prototype.

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**



Atributos: Route

Route (145 Feições)

| FID | Route | Depot | Vehicle | Distance | Time | Demand | Cost | Path |
|---|---|---|---|---|---|---|---|---|
| 7188 | Route 4 | BEBIDAS JUNDIAÍ | Vehicle 4 | 545.58 | 10.82 | 5000.0 | 1636.74 | BEBIDAS JUNDIAÍ -> JAU -> IBATE -> ITIRAPI... |
| 7190 | Route 6 | MALIBU | Vehicle 2 | 490.87 | 8.64 | 3500.0 | 1472.6 | MALIBU -> ITATIBA -> ATIBAIA -> JACAREI ->... |
| 7191 | Route 7 | MALIBU | Vehicle 3 | 469.69 | 9.37 | 8000.0 | 1409.07 | MALIBU -> BRAGANCA PAULISTA -> SAO JOSE... |
| 7192 | Route 8 | ITAPERUNA | Vehicle 1 | 2363.85 | 31.55 | 14000.0 | 7091.56 | ITAPERUNA -> ITAPERUNA -> CAMPOS DOS G... |
| 7193 | Route 9 | BARRA MANSA | Vehicle 1 | 2257.64 | 31.72 | 3500.0 | 6772.91 | BARRA MANSA -> BARRA MANSA -> LORENA -... |
| 7194 | Route 10 | BARRA MANSA | Vehicle 2 | 443.54 | 7.54 | 1200.0 | 1330.63 | BARRA MANSA -> BARBACENA -> VALENCA ->... |
| 7195 | Route 11 | BARRA MANSA | Vehicle 3 | 453.25 | 8.67 | 4000.0 | 1359.74 | BARRA MANSA -> ITAMONTE -> SAO LOUREN... |
| 7196 | Route 12 | FRUTAL | Vehicle 1 | 1954.19 | 26.93 | 10000.0 | 5862.56 | FRUTAL-> FRUTAL -> MONTE ALTO -> TAQUA... |
| 7197 | Route 13 | FRUTAL | Vehicle 2 | 387.0 | 6.84 | 8500.0 | 1161.0 | FRUTAL -> PLANURA -> PITANGUEIRAS -> SE... |
| 7198 | Route 14 | FRUTAL ... | Vehicle 3 | 440.19 | 7.0 | 3000.0 | 1320.58 | FRUTAL-> OLIMPIA -> BARRETOS -> FRANCA ... |
| 7199 | Route 15 | FRUTAL ... | Vehicle 4 | 470.3 | 6.88 | 5000.0 | 1410.91 | FRUTAL -> UBERABA -> PATROCINIO PAULIST... |

**Figure 4.** Attributes of the route layer.

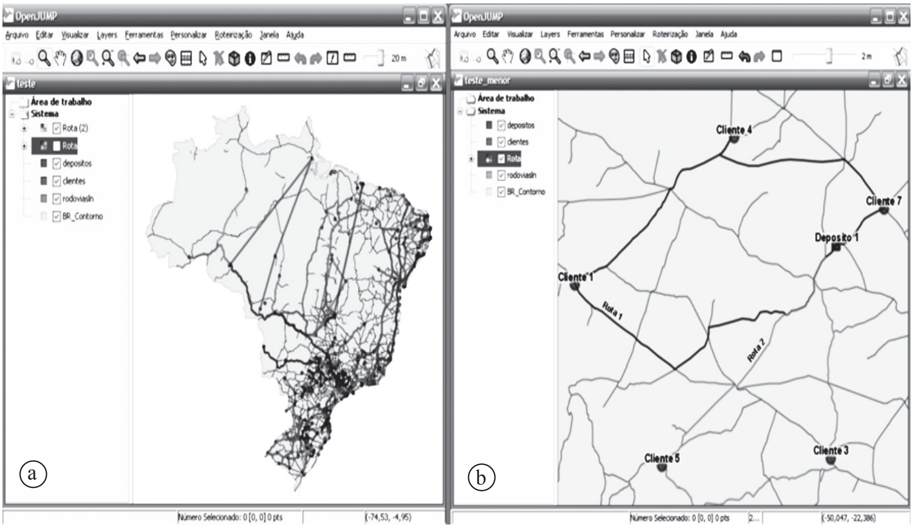



**Figure 5.** The routes obtained for all depots (a), and two routes from one depot in detail (b).

To facilitate the visualization of the individual routes, these were created graphically in OpenJUMP with different colors, as shown in Figure 5. It can be observed in Figure 5 (a) that not all routes utilize the road network. This is because the utilized road network is not connected, i.e., there are some road stretches that are not interconnected to the others, making it impossible to obtain a route from any origin to any destination. For these cases, the prototype automatically assumes the use of a Euclidian adjusted distance.

With the objective of validating the results obtained with the aid of the developed prototype, the same procedure was performed while TransCAD and the same information provided by the company were utilized. Table 2 presents the total values obtained by the two systems. It can be observed that the solution obtained by the developed prototype presents a savings of approximately 5% in the total distance and consequently in the total solution in comparison with that obtained by TransCAD.

It would be interesting to compare the solution obtained in this case study with a solution that was used by the company to identify the time reduction, fleet and

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

**Table 2.** Comparison of the routes obtained by the developed prototype and TransCAD.

| Depot | Developed prototype | | | | TransCAD | | | |
|---|---|---|---|---|---|---|---|---|
| | Vehicles (units) | Distance (km) | Time (hours) | Cost (R$) | Vehicles (units) | Distance (km) | Time (hours) | Cost (R$) |
| Bebidas Jundiaí | 6 | 4,819.94 | 69.25 | 14,459.84 | 6 | 5,012.74 | 71.66 | 15,038.21 |
| Biscoitos Jundiaí | 2 | 3,005.87 | 45.07 | 9,017.62 | 2 | 3,186.22 | 47.32 | 9,558.67 |
| Malibu | 3 | 4,114.80 | 57.43 | 12,344.41 | 3 | 4,361.69 | 60.52 | 13,085.06 |
| Itaperuna | 4 | 13,968.91 | 179.11 | 41,906.74 | 4 | 14,527.67 | 186.09 | 43,583.00 |
| Barra Mansa | 8 | 7,480.15 | 102.01 | 22,440.43 | 8 | 7,629.75 | 103.88 | 22,889.26 |
| Frutal | 7 | 9,392.33 | 127.90 | 28,177.00 | 7 | 10,331.56 | 139.64 | 30,994.69 |
| Sonata | 3 | 3,481.66 | 49.52 | 10,444.98 | 3 | 3,725.38 | 52.57 | 11,176.13 |
| Carazinho | 13 | 14,302.98 | 206.30 | 42,908.94 | 13 | 14,732.07 | 211.66 | 44,196.21 |
| Santa Helena | 8 | 18,315.07 | 241.94 | 54,945.21 | 8 | 18,681.37 | 246.52 | 56,044.11 |
| Ouro Preto | 7 | 38,036.03 | 498.94 | 114,108.07 | 7 | 39,937.83 | 522.71 | 119,813.49 |
| Garanhuns | 11 | 8,153.83 | 115.41 | 24,461.48 | 11 | 8,724.60 | 122.54 | 26,173.79 |
| Feira de Santana | 2 | 4,355.14 | 55.94 | 13,065.40 | 2 | 4,790.65 | 61.38 | 14,371.96 |
| Centro de Distribuição Jundiaí | 2 | 2,084.05 | 27.55 | 6,252.13 | 2 | 2,146.57 | 28.33 | 6,439.71 |
| Centro de Distrib. Duque de Caxias | 2 | 2,515.30 | 33.44 | 7,545.89 | 2 | 2,741.68 | 36.27 | 8,225.03 |
| Centro de Distribuição Rio Bonito | 2 | 4,336.46 | 62.20 | 13,009.37 | 2 | 4,466.55 | 63.83 | 13,399.66 |
| Cross Docking Brasília | 2 | 6,915.89 | 93.45 | 20,747.67 | 2 | 7,607.48 | 102.09 | 22,822.44 |
| Centro de Distribuição Simões Filho | 3 | 4,478.79 | 60.98 | 13,436.37 | 3 | 4,747.52 | 64.34 | 14,242.55 |
| Centro de Distribuição Viana | 3 | 7,655.76 | 100.70 | 22,967.28 | 3 | 7,808.88 | 102.61 | 23,426.63 |
| Centro de Distribuição Contagem | 3 | 5,292.93 | 74.16 | 15,878.78 | 3 | 5,716.36 | 79.45 | 17,149.09 |
| Centro de Distribuição São José | 3 | 4,024.59 | 61.80 | 12,073.77 | 3 | 4,306.31 | 65.32 | 12,918.93 |
| Centro de Distribuição Pinhais | 2 | 4,357.00 | 63.46 | 13,071.01 | 2 | 4,574.85 | 66.18 | 13,724.55 |
| Centro de Distribuição Londrina | 2 | 6,118.15 | 87.48 | 18,354.44 | 2 | 6,485.24 | 92.07 | 19,455.72 |
| Centro de Distribuição Porto Alegre | 3 | 3,366.26 | 45.58 | 10,098.75 | 3 | 3,500.91 | 47.26 | 10,502.73 |
| **TOTAL** | **101** | **180,571.89** | **2,459.62** | **541,715.58** | **101** | **189,743.88** | **2,574.27** | **569,231.64** |

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

costs obtained from the use of the prototype. But as the company is still analyzing the modification of your model from diversifying its array of sale and routing solutions do not exist, this has become invalid comparison.

## Conclusions

In this study, a procedure for multi-depot vehicle routing utilizing an information technology (GIS) in a physical distribution system was developed. It was elaborated to consider the load and volume restrictions of vehicles and depots, the working limits, the unloading times at the clients as well as the restrictions of the road network and was obtained with the utilization of GIS.

In light of this, a study of the principle existing methods of the MDVRP was necessary. Due to existing operational complexity of solving large-scale problems with various depots, a two-phase method with heuristic algorithms was utilized. In the first phase, assign with a parallel urgencies algorithm was utilized, and the second step involved the Clarke and Wright savings method with a 2-opt post-optimization step. These proved to be quite simple and easy to develop.

To evaluate a practical application, a prototype was developed that integrated the OpenJUMP GIS with a routing procedure, which was designed as a plug-in. Consequently, the principle benefit when using OpenJUMP is the absence of installation licensing and use fees, as it is an open-source system.

The performance of a case study allowed for the application of the proposed procedure and the validation of the developed software prototype. It permitted rapid problem-solving and provided a series of benefits such as a reduction of the distance traveled, a lower fuel consumption, a smaller number of over-time hours and a reduction of the product delivery time. The developed prototype was validated by comparing the results with those from a commercial software program, showing that the prototype provided good results.

The procedure, as well as the prototype can be improved to allow for other operational constraints, eg, time windows, simultaneous pickups and deliveries. It could also be enhanced to treat different types of vehicles, as in the case of refrigerated vehicles, vehicles carrying hazardous materials, etc. This would allow a wider application of the procedure.

The case study requires an analysis designed to assess the degree of reduction of transport costs. This would be of great importance to prove the efficiency of the procedure. After changing the distribution model the company will make a valid comparison between the solution obtained from the use of the prototype with the solution used by the company without the aid of software.

## References

Ballou, R.H. (1993) Logística empresarial: transporte, administração de materiais e distribuição física. São Paulo: Atlas. (in Portuguese)

Bonasser, U.O. (2005) Meta-heurísticas híbridas para solução do problema de roteirização de veículos com múltiplos depósitos e frota heterogênea fixa: aplicação na força aérea brasileira. Tese. Programa de Pós-Graduação em Engenharia de Transportes, Escola Politécnica, Universidade de São Paulo, São Paulo, Brasil. (in Portuguese)

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

Breternitz, V.J. (2001) Sistemas de informações geográficas: uma visão para administradores e profissionais de tecnologia da informação. Jundiaí: Análise, Vol. 4, p. 41-55. (in Portuguese)

Câmara, G. and Onsrud, H. (2004) Open source GIS software: myths and realities, in: Esanu, J.M. and Uhlir, P.F. (Eds.), Open Access and the Public Domain in Digital Data and Information for Science: Proceedings of an International Symposium. Washington: The National Academies Press.

Chan, Y. and Baker, S.F. (2005) The Multiple Depot, Multiple Traveling Salesmen Facility-Location Problem: Vehicle Range, Service Frequency, and Heuristic Implementations. Mathematical and Computer Modeling, Vol. 41, No. 8-9, pp. 1035-1053. http://dx.doi.org/10.1016/j.mcm.2003.08.011

Chao, I.M.; Golden, B.L. and Wasil, E. (1993) A new heuristic for the multi-depot vehicle routing problem that improves upon best-known solutions. American Journal of Mathematical and Management Mgmt Sciences, Vol. 13, No. 3-4, pp. 371-406.

Clarke, G. and Wright, J.W. (1964) Scheduling of Vehicles from a Central Depot to a Number of Delivery Points. Operations Research, Vol. 12, No. 4, pp. 568-581. http://dx.doi.org/10.1287/opre.12.4.568

Crevier, B.; Cordeau, J.F. and Laporte, G. (2007) The Multi-Depot Vehicle Routing Problem with Inter-Depot Routes. European Journal of Operational Research, Vol. 176, No. 2, pp. 756-773. http://dx.doi.org/10.1016/j.ejor.2005.08.015

Croes, G.A. (1958) A method for solving traveling salesman problems. Operations Research, Vol. 6, No. 6, pp. 791-812. http://dx.doi.org/10.1287/opre.6.6.791

Dijkstra, E.W. (1959) A Note on Two Problems in Connection with Graphs. Numerische Math, Vol.1, No. 269-270, pp. 269-271. http://dx.doi.org/10.1007/BF01386390

Gillett, B.E. and Miller, L.E. (1974) A heuristic algorithm for the vehicle-dispatch problem. Operations Research, Vol. 22, No. 2, pp. 340-349. http://dx.doi.org/10.1287/opre.22.2.340

Giosa, D.; Tansini, L. and Viera, O. (2002) New assignment algorithms for the multi-depot vehicle routing problem. Journal of the Operations Research Society, Vol. 53, pp. 997-984. http://dx.doi.org/10.1057/palgrave.jors.2601426

Golden, B.L.; Magnanti, T.L. and Nguyen, H.Q. (1977) Implementing vehicle routing algorithms. Networks, Vol. 7, pp. 113-148. http://dx.doi.org/10.1002/net.3230070203

Ho, W.; Ho, G.T.S.; Ji, P. and Lau, H.C.W. (2007) A Hybrid Genetic Algorithm for the Multi-depot Vehicle Routing Problem. Engineering App. of Artificial Intelligence, Vol. 21, No. 4, pp. 548-557. http://dx.doi.org/10.1016/j.engappai.2007.06.001

Kinberger, M. and Pucher. A. (2005) Open Source GIS als Alternative im Desktop-Bereich - Evaluation freier Software im Bereich Geoinformation. In: CORP 2005, Wien, Österreich.

Laporte, G.; Norbert, Y. and Arpin, D. (1984) Optimal solutions to capacitated multidepot vehicle routing problems. Congressus Numerantiwn, Vol. 44, pp. 283-292.

Laporte, G.; Norbert, Y. and Taillefer, S. (1988) Solving a family of multi-depot vehicle routing and location-routing problems. Transp. Science, Vol. 22, No. 3, pp. 161-172. http://dx.doi.org/10.1287/trsc.22.3.161

Lim, A. and Wang, F. (2005) Multi-Depot Vehicle Routing Problem: A One-Stage Approach. IEEE Transactions on Automation Science and Engineering, Vol. 2, No. 4, pp. 397-402. http://dx.doi.org/10.1109/TASE.2005.853472

Brazilian Journal of Operations & Production Management
**Volume 8, Number 1, 2011, pp. 103-120**

Nagy, G. and Salhi, S. (2004) Heuristic algorithms for single and multiple depot vehicle routing problems with pickups and deliveries. European Journal Operations Research, Vol. 162, No. 1, p. 126-141. http://dx.doi.org/10.1016/j.ejor.2002.11.003

Renaud, J.; Laporte, G. and Borctor, F.F. (1996) A Tabu Search Heuristic for the Multi-depot Vehicle Routing Problem. Computer Operations Research, Vol. 23, No. 3, pp.229-235. http://dx.doi.org/10.1016/0305-0548(95)O0026-P

Salhi, S.; Sari, M.; Saidi, D. and Touati, N. (1992) Adaptation of some vehicle fleet mix heuristics. Omega, Vol. 20, No. 5-6, pp. 653-660. http://dx.doi.org/10.1016/0305-0483(92)90009-V

Salhi, S. and Sari, M. (1997) Models for the multi-depot vehicle fleet mix problem. European Journal of Operational Research, Vol.1 03, pp. 95-112. http://dx.doi.org/10.1016/S0377-2217(96)00253-6

Tillman, F.A. (1969) The multiple terminal delivery proble with probabilistic demands. Transportation Science, Vol. 3, No. 3, pp. 192-204. http://dx.doi.org/10.1287/trsc.3.3.192

Wren, A. and Holliday, A. (1972) Computer scheduling of vehicles from one or more depots to a number of delivery points. Operations Research, Vol. 23, No. 3, pp. 333-344. http://dx.doi.org/10.1057/jors.1972.53

## Biography

M.Sc. Orivalde Soares da Silva Júnior is a Doctor Student of Logistics and Transports at the Department of Industrial Engineering - Pontifical University Catholic of Rio de Janeiro in Brazil. He holds a Bachelor’s degree in Computer Science from Engineering School of Piracicaba and a Master’s degree in Transportation Engineering from Military Institute of Engineering, in Brazil. His research interests lie in the application of meta-heuristics and decision-making tools to logistics management.

Contact: orivalde@yahoo.com.br

Dr. Luiz Antônio Silveira Lopes is a Lecturer in Department of Civil Engineering – Military Institute of Engineering in Brazil. He holds a Bachelor’s degree in Civil Engineering and a Master’s degree in Transportation Engineering from Military Institute of Engineering, in Brazil, and Doctor’s degree in Transportation Engineering from Federal University of Rio de Janeiro, in Brazil. His research interests lie in the application of logistics, optimization, rail operation and GIS.

Contact: laslopes@ime.eb.br

Dr. Ulf Bergmann was a Lecturer in Department of Computer Engineering at the Department of Computer Engineering – Military Institute of Engineering in Brazil. He holds a Bachelor’s degree and a Master’s degree in Computer Engineering from Military Institute of Engineering and Doctor’s degree in Informatics from Pontifical University Catholic of Rio de Janeiro in Brazil. His research interests lie in the software engineering, GIS, command and control systems and surveillance for public safety.

Contact: ulf@ime.eb.br

## Article Info:

Received: October, 2010

Accepted: July, 2011