A routing vehicles model for the delivery of furniture and home appliances of a retail company in southern Brazil

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Abstract

Logistics has been recognized one of the key elements of the competitive strategy of companies including the supply of products and services from a supply point to a demand point. In retail market, companies' net income is usually low and the expenses with distribution are relevant in the composition of logistic costs. In addition, there are challenges in the distribution of products such as high customer churn, requirement of specific delivery times and high product variability. This paper proposes a model of routing that aims to reduce costs of transportation of companies in the distribution of products, having as a base, a network of stores of furniture and home appliances in the south of Santa Catarina state, in southern Brazil. By combining Clarke and Wright heuristic with own developed heuristics, a computational system has been implemented so that routes considering truck driver work days, truck load capacity and time interval for consumer delivery can be found in acceptable computation time. Obtained solutions with the routing tool were nearly 1% above the optimal solutions obtained by enumeration, showing that the model leads to good results, i.e., reducing trucks travel time by low computational effort.

Keywords
Distribution logistics, Search in graphs, Vehicle routing problem with time windows

1. Introduction

Retailing includes the activities of selling products and services for the final consumer. The definition of strategic alternatives and their implementation through operations management are essential to retail organizations success. In Brazil, retailing has been modifying and stablishing itself with increasing companies' efficiency and adaptability to the market's needs. According to Delloite's report "*Os Poderosos do Varejo Global*" (2015) net profit margin of the 250 biggest world retailer was 3.4% in 2013 (DELLOITE, 2015). Furthermore, in respect to the 26th Annual State of Logistics Report (2014), US's total logistics costs in 2013 were US$1.5 trillion, or 8.3% of their GDP. According to this report, 48% of total logistics costs is associated with road transportation whose 30% is local transportation cost, namely transportation within the same city (WILSON, 2015). A reduced net profit margin along with highlight transportation costs make the delivery routing process with portable optimized app to be crucial for companies in which logistics is considered one of the key elements in strong competitive markets. In addition, an increasing bargain of computational capacity has increased firms' number with sophisticated software to support decision in logistics strategy. Therefore, the aim of this paper is to propose a delivery schedule model that consider truck load capacity and time interval for consumer delivery on routing of goods in retail organizations.

2. Routing and programming problems

Routing and programming problems are characterized by searching for effective vehicles management and associated crews (RAFF, 1983). In routing problems, the routes to be covered by the vehicles must be defined considering the demands of deliveries at various points in a transport network. If time intervals for the vehicle passing through each point are considered then we have a programming problem to be solved. For many cases, spatial and temporal decisions interact resulting in the combined problem of routing and programming (RAFF, 1983). A solution of a routing and programming problem consists of a route and a schedule to each vehicle and driver. The track indicates a sequence of points to be visited and the schedule indicates a time interval of each visit (RAFF, 1983).

The root of vehicle routing problem is the CVRP (Capacitated Vehicle Routing Problem) in which customers group must be complying with an equivalent fleet vehicle and with limited capacity (LEVI; CHEN; BRAMEL, 2013). According to the authors, vehicles start in a warehouse and the aim is to find a route that minimizes trucks travelled with requirement capacity restriction.

Problem of single warehouse, multiples vehicles and knot routing is considered a common problem vehicle routing. The model is based on a vehicle departing from a central warehouse, each one with its route that satisfies every node in order to decrease total distance travelled. The request is known at each node, as well as the truck load capacity (RAFF, 1983). This problem is a not oriented graph $G=(V,A)$, where V is a series of vertex and A is a series of edges. Each edge $(u,v) \in A$ owns a non-negative length $l(u,v)$. The total length of a path is given by length's edge sum that composes this path (BAST *et al*., 2016). The vertex v_o is the warehouse where m vehicles of same capacity Q start a track. The other vertices are end users. It has been defined a matrix, a distance or a travel time non-negative $C=(c_{ij})$ in A. Every consumer has a non-negative demand q_i and a non-negative service time s_i (CORDEAU *et al*., 2007). The aim is to set a route group to each vehicle with the lowest total cost and that follow some restrictions as:

- each vehicle must start and end the route at the warehouse;
- each consumer is visited by only one vehicle;
- a total demand for each route must not exceed Q;
- a total time of each route must not exceed a fixed limit D.

Novaes (2016) suggests the Clarke/Wright heuristic for solving the single warehouse, multiple vehicle and node routing problem. This heuristic is widely used in isolated problems and in routing software because it incorporates different requirements. According to Ballou (1999 *apud* NOVAES, 2016), the results from this heuristic show 2% average deviation in relation to optimal solution. The number of vehicles required to satisfy the request is reduced with this heuristic (NOVAES, 2016). Four steps characterize Clarke/Wright's heuristic:

Step 1. Firstly, each customer must be attended by only one vehicle, which must depart from warehouse, travel up to customer and then return to warehouse;

Step 2. Next, instead of using two vehicles to serve customers i and j, it should use only one vehicle. Thus, it is going to obtain a profit s_{ij} alike to the distance between warehouse and customer i plus the distance between warehouse and customer j minus distance between clients i and j. Earnings must be sorted from highest to lowest.

Step 3. It has been chosen the pair with the highest gain and put it on the same route;

Step 4. Following to the second gain, it is verified whether one of final's stop pair is at one of final route and if the other final stop has been not allocated yet, besides to satisfy the working day restriction's driver and truck load capacity. If this obligation is satisfied, the end is putting in the final point route. If both point are not inside the route, it should start a new route. This step must be repeated until all pairs are checked.

A relevant extension of CVRP is a routing problem with time windows (VRPTW). The problem's definition includes, in addition to the previously described model, a time interval $[b_i, e_i]$ for each client c_i. This interval indicates a time duration within the consumer should be served (GAMBARDELLA; TAILLARD; AGAZZI, 1999). Thus, the requirements that the delivery start time must be greater than or equal to b_i and the departure of client must be less than or equal to e_i is added to the routing problem. If the truck arrived at a final point before b_i, it should wait to start delivery (GAMBARDELLA; TAILLARD; AGAZZI, 1999). By adding start and end restriction there is a solution equal or worse than a solution for the same customers without a time window (RAFF, 1983). According El-Sherbeny (2010) there are algorithms that promise the best VRPTW solution, likewise as Fisher *et al*. (1997), Kohl and Madsen (1997), and also heuristics which do not promise the best solution as proposed by Baker and Schaffer (1989) as well as Solomon (1987).

3. Methodological procedures

This study considered data from a retailer company of furniture and home appliances in the state of Santa Catarina, Brazil. The proposed routing vehicles model for delivery comprises five steps:

Step 1. Map's definition: select a suitable map, which allows multiple inquiry travelled time for a given number of addresses.
Step 2. Implementation of the shortest path algorithm to find the shortest route between delivery point and distribution center considering the chosen map from step 1.
Step 3. Implementation of the routing algorithm to define delivery routes according available vehicles, their time restrictions, load capacity, and attending time window of consumers.
Step 4. Getting the graphic interface for the logistics manager to create a software interface where a worker is going to introduce the delivery report, register vehicles and set up routes.
Step 5. Implementation of an interface for the driver that shows a report with routes that have been created for drivers use as well as all delivery information and other important data.

4. Models Application

The routing model was applied in a retailer company of delivery furniture and home appliances with an annual turnover of $25 million and engaging almost 300 employees. There are nineteen branches offices plus a central warehouse located in the two most southern states of Brazil.
The first step in the methodology to determine the vehicle routing model is the map, because distances or travel times from each final stop and between final stop must be known. The amount of customers is high and changeable. Consequently, the vehicles routing needs to be performed daily. Therefore, searching must be fast and allow a large volume of requests.
OpenStreetMap is a project whose aim is to create a free and editable map, collaboratively, inspired on website such as Wikipedia. It has registered publishers who map new streets by inserting them on the map periodically. Moreover, the map is available on internet for download in a file format that can be edited in Notepad and other free applications. Among the advantages are frequent update, free of charge and possibility of offline editing.
The execution of algorithm's search of the smallest path begin as soon as finished the first step of the model construction methodology. As mentioned, the *OpenStreetMap* is a free map available on internet, because of this, there are other free applications for this platform that are able to make much queries. The *OSRM Project* is one of those applications that are able to get information, either by external server or by C ++ programming. It has been chosen programming in order to ensure independence from mediators.
The project has already got many finished libraries to get distances, travel time and other information that map provides. One of them is the Travel Time Matrix library. It is possible to get a table with many origins and destinations by using few programming lines. In order to know the lowest course between two points, it has been adopted the algorithm proposed by Dijkstra with achieving the method of Contraction Hierarchies. Then, a good answer is found quickly.
The third methodology step is to implemente the routing algorithm. Routing code programme was made by C ++ language to be get together with travel time table algorithm.
Firstly, Clarke & Wright heuristic was programmed following the steps as shown in item 2 of this paper. Two requirements must be satisfied every inclusion destiny t and route r to solve the problem. The variables it means:

r – *indicates the r-th route created by the router, with* $1 \leq r \leq NC$ *where NC is the number of clients with pending deliveries*
t – *indicates the t-th customer (target) of group of clients with pending deliveries, with* $t=1,..,NC$
d – *indicates the d-th driver of company's driver group, with* $d=1,..,NM$*, where NM is the number of drivers*
v – *index indicates the v-th vehicle of company's truck group, with* $v=1,..,NV$*, where NV is number of trucks*
$JT_{t,u}$ – *travel time from t-th to u-th client, with* $t,u = 1, .., NC$*, where NC is the number of clients and* $t \neq u$
JTS_t – *travel time from the Distribution Center to t-th customer, with* $t = 1, ..., NC$
Ta_t – *customer service time of the t-th client, with* $t = 1, .., NC$ *and* $Ta_t > 0$
w_d – *available time of the d-th driver to perform routes on a day, with* $d = 1, ..., NM$
NR_r – *number of clients on the r-th route, with* $1 \leq r \leq NC$*, where NC is the number of customers with pending deliveries*

Since the sum of all travel and attendance times, i.e., total time of a route, cannot not exceed the daily available time of a driver, we then have:

$$JTS_1 + Ta_1 + \sum_{u=1}^{NR_r - 1} (JT_{u,u+1} + Ta_{u+1}) + JTS_{NR_r} \leq w_d \tag{1}$$

The second restriction is about vehicle capacity because the sum of the cubage demanded by the customers cannot exceed truck capacity, as shown in equation (2):

$$\sum_{u=1}^{NC} cb_u \leq c_v \tag{2}$$

Where:

cb_t – *cubage applied by t-th client, with t = 1, .., NC.*
c_v – *truck load capacity v -th, with v = 1,.., NV, where NV is total trucks number.*

After programming basic algorithm, two heuristics were developed to make a solution according to the company's reality. The first developed heuristics aimed to work with different vehicles and presenting a solution that prioritizes na driver occupation (seeking a longer route time). It comprises eight steps:

Step 1. create vector VetC and insert every NV truck load capacities c_v*;*
Step 2. sort VetC vector in decreasing order;
Step 3. choose the largest c_v *element of vector VetC;*
Step 4. set the route with the load restriction for the largest truck;
Step 5. at the end of the route, find the truck with the lowest capacity and that meets the load of created route;
Step 6. choose this truck for the created route;
Step 7. remove that truck from the load capacity vector;
Step 8. If there are clients with no route and available truck, reschedule the vector in decreasing order, choose the truck with the highest load capacity for the next route and proceed to step 4. Otherwise, the heuristic was finished.

The heuristic for different vehicles ensures that routes are going to be assigned with the largest available truck considering the restriction of a daily shift is the first requirement that must be attended. In addition, when the route is finished, the most suitable truck is selected.
The second heuristic created to adapt the basic solution of Clarl/Wright aimed to insert the requirement of time window for the customer, because is a common practice in retailers that clients usually set an time interval to receive his order.
By introducing time window, the restrictions for the problem change. Thus, each destination placed in *p-th* position, with $1 \leq p \leq NR_r$, of the *r-th* route, must attend, besides the equations (1) and (2) described above, the equations (3) and (4). Therefore, the variables it means:

Ti_t – *lower time limit for delivery, established by the t-th customer.*
Tf_t – *upper limit for delivery, established by the t-th customer.*

Therefore, the sum of the travel times and customer service upstream of the customer who is going to be inserted on the route must be greater than the lower time limit for delivery, as shown in equation (3). The customer service time that will be inserted on route added to the result of equation (3) must be less than the upper time limit for delivery, as shown in equation (4):

$$JTS_1 + Ta_1 + \sum_{u=1}^{p-1} (JT_{u,u+1} + Ta_{u+1}) - Ta_p \leq Ti_p \tag{3}$$

$$JTS_1 + Ta_1 + \sum_{u=1}^{p-1} (JT_{u,u+1} + Ta_{u+1}) \leq Tf_p \tag{4}$$

The proposed heuristic that consider time window restriction comprises five steps. It begins after the gains arrangement of Clarke/Wright heuristic:

Step 1. Sort the destination in the two groups defined below:
A - comprises the destinations that have some restriction of maximum time for delivery and have given priority. For example, a delivery should be done until midday;
B - involve all destinations;
Step 2. Define a matrix and a gain vector for the destination that belong to set A. Go through every gains of the normal gains matrix and, if the gain refers to a pair of destinations that belong to set A, copy the value of the gain to matrix and to the gain vector of the set A. For another gains, replace the original value by negative infinity;
Step 3. Sort the gain vector of set A, from highest to lowest;
Step 4. Select the pair with the highest gain and verify if it meet the following equations requirement (1), (2), (3) and (4). If restrictions are satisfied, the two destinations on the route are added. Otherwise, the restrictions are set to only one destination. If it is satisfied, the destination is added on the route. Otherwise, jump to the next vector.
Step 5. If there are still destinations in group A that were not allocated on any route and trucks are available, follow to destination of group A with the Clarke/Wright heuristic. Otherwise, follow the Clarke/Wright heuristics for destinations of group B.

A test bed with three experiments were performed to measure performance of the proposed heuristic. The first one aimed to compare the best found solution with all possible solutions for the same problem. The number of all possible solutions for a route with *n* addresses is given by *n!*. Thus, by high *n* values it is impossible - in a plausible time - to create and evaluate all possible solutions in order to find the optimal solution. For the purposes of this study a relatively small number of addresses were therefore selected. The number of destinations chosen was 8, which generates *8! = 40,320* possible solutions.
The Distribution Center is placed at the address "*10 Rui Barbosa Street, Turvo, SC, Brazil"*. The best found solution by the proposed router is shown in Table 1 while the route and its detail can be visualized in the graphic representation of Figure 1.

Table 1. Addresses' sequence route

Sequence	Addresses
0	Rui Barbosa Street, Turvo, SC, Brazil
5	Imigrantes Poloneses Avenue, Criciúma, SC, Brazil
3	Gilio Búrigo Avenue, Criciúma, SC, Brazil
6	Jorge Elias Lucca Avenue, Criciúma, SC, Brazil
4	Humberto de Campos Avenue, Criciúma, SC, Brazil
8	Centenário Avenue, Criciúma, SC, Brazil
2	Getúlio Vargas Avenue, Criciúma, SC, Brazil
7	Luiz Lazzarin Avenue, Criciúma, SC, Brazil
1	Catarinense Avenue, Criciúma, SC, Brazil
9	Rua Rui Barbosa Avenue, Turvo, SC, Brazil

Table 2 shows a comparative between optimal, average, worst and best found solutions.

Table 2. Different solutions comparison

	Routing time (min)	Regarding to optimal solution	
		Range (min)	Range (%)
Optimal solution	142.37	0.00	0.0%
Average of other possible solutions	176.23	33.86	23.8%
Worst possible solution	195.97	53.60	37.6%
Best found solution	144.07	1.70	1.2%

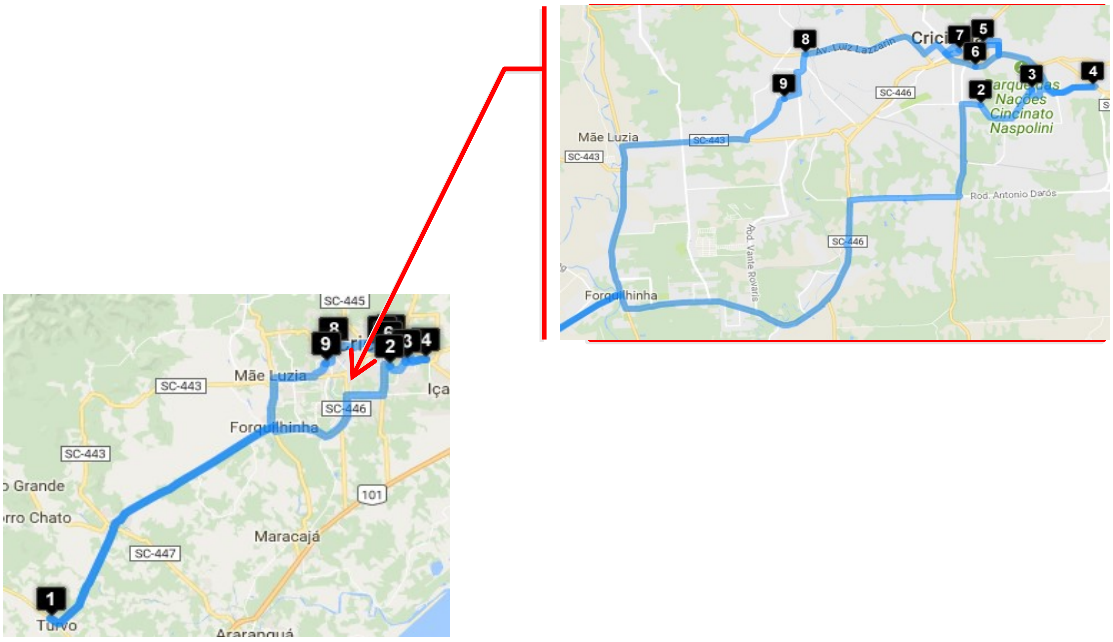

Figure 1. Map showing the best found route and its details

The best found solution is only 1.2% above the optimal solution obtained by enumeration so that can be seen that Clarke/Wright heuristic combined with the proposed heuristic leads to good results.
A second analysis has been done to compare the device route solution without considering priority destinations, with solutions involving this type of destiny. Priority destinities are customers who - through some company sales policy - have priority to receive their commodities when compared to others, such as a loyal customer who needs a product delivered the next day. The addresses applied were the same as those of previous analysis, and solutions were checked ranging between no priority and every priority. Figure 2 shows the range in total route time as a function of the number of priority destinations.

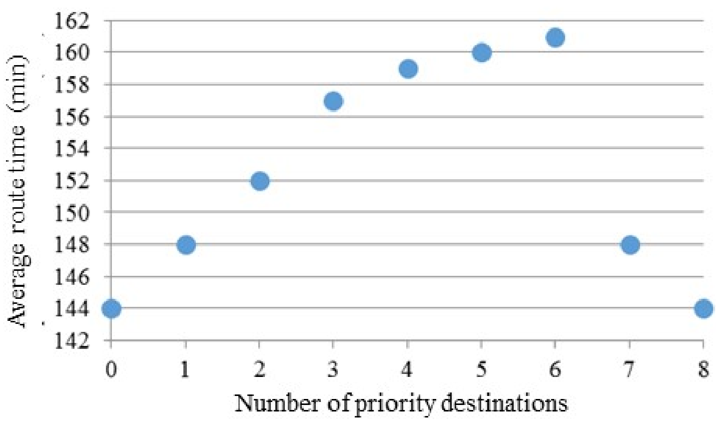

Figure 2. Average route time with priority destinations

The average route's time is the average of all possible combination for each amount of priorities. Although inserting priority destinations in the routing tool tends to impair solution's quality, this practice is quite common among

operational policies. The policy tends to increase sales because it meets customer's needs for products delivered as soon as possible. The developed tool allows to evaluate the *trade-off* between increasing revenues and decreasing transport costs. As the priorities increases, the solution is worse, until there are *n-1* priority destinations. The gradual degeneracy of a solution occurs because the routing device joins the priority destinations in a single block, making it difficult to fit other destinations on the route. The amount of priority destinations is higher when commemorative dates are coming, and the increase in the average duration of the routes may result in an increase in the number of required vehicles for deliveries.
The third experiment aimed to check for correct geocoded addresses percentage. Correct geocoded addresses is important because a high rate of errors in identification of latitude and longitude causes risk on providing incorrect routes and requiring additional effort of the router when using the device routing. The geocoding was performed with queries to the *Bing Maps* database, with help of a program developed in Visual Basic for Applications (VBA), from a list of streets in Criciúma (SC) considering 135 addresses. The determined geocoder accuracy was estimated in 95.6% as detailed shown in Table 3. The location errors root were incorrect address typing (three times) and not registered addresses at the base (three times).

Table 3. Geocoding Analysis

Total Addresses	135
Non localized addresses	3
% Non-localized addresses	2,22%
Addresses with error	3
% Localized location with error	2,22%
% Localized location successful	95,6%

5. Conclusions

The vehicle routing for delivery products to customers is a logistics decision with capability to reduce costs and increase service level. In retailers, the distribution process has specific characteristics that make it difficult to define the best route, such as the daily change of clientele served, the need to fulfill deadlines and delivery times restrictions imposed by consumers. So, in this way, the work contributes with a vehicle routing model for delivery of furniture and home appliances from a retail company, as a base on the implementation of a search algorithm for the smallest path in graphs, a routing algorithm and an interface for the router uses in the company's distribution logistics and drivers.
Results show solutions close to optimality for a volume of deliveries consistent with what is observed daily in the company, and can serve as guidance for the development of commercial application that could answer companies, with trade similar profile.
Additional analyzes such as the preferred customers addition to the model show that companies should limit the number of these customers on the same route in order to get economically acceptable solutions, because a large number of preferential customers tends to get rigid routes concerning to the sequence of clients to be visited and, therefore, solutions with longer travel times.

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