Holistic analysis of the Vehicle Routing Problem: an approach for GIS-T

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***Abstract*—*Urban cargo transport movements, due to their characteristics and particularities, involve different dimensions and variables. As a result, it demands specific logistics costs, consisting of a relevant portion of the total business costs, being directly linked to the route taken by the vehicle fleet. In that way, it is necessary to define roadmaps for vehicles in order to minimize the total distance traveled, total cost and total elapsed time when supplying clients. With the development of hardware and software in the 90's, complex Vehicles Routing Problems (VRP's) (containing multiple clients and vehicles) started to being solved by iterative mathematical methods. Thus, this article aim to solve the VRP's of a garlic-based products fabricate company using a Geographic Information System for Transportation (GIS-T), performing comparative analysis with the current company operations and presenting alternative scenarios that may provide any cost reduction.*

***Keywords*— Decision making support, Transportation System Planning, Balancing urban freight transport.**

I. INTRODUCTION

The contemporary market has indicated that for the survival of an organization, there is a need for prior planning of strategies to improve the management of its market share.

Reducing costs is a crucial point in a modern market strategy and, as a result, reducing waste, rework and especially logistics costs. This approach is cited by Christopher (2016) and Göpfert et al. (2016), which add the need for the organization to reinvest part of the balance obtained with these strategies, in other activities that may add greater value to the business. For Ivanov et al. (2017), the main bottleneck in logistics costs is transportation-related costs. For these authors, this explains the complexity surrounding transport operations considering different origins and destinations.

Within this context, Novaes (2016) highlights the importance of optimizing distribution routes due to their direct contribution to the increase in transportation costs. According to this author in the United States of America, the transportation matrix is more balanced than in other countries, logistics costs, including transportation, represent 59% of this matrix. In Brazil, besides the unbalance of transport matrix, in which the largest portion (60%) of cargo and goods are transported by road (ARAÚJO et al., 2014). According to Rodrigues et al. (2016), this type of problem should be treated as a Vehicle Routing Problem (VRP) and, from this, the generated alternatives should minimize transportation costs.

Corroborating this view, Wang et al. (2017) highlights that from the coming of modern technologies, it has been possible to provide innovations in VRP resolution. These authors further point out that current VRP models are different from those introduced by Dantzig and Ramser (1959), Clarke and Wright (1964), as they increasingly aim to incorporate real-life complexities such as collection time windows. and delivery, and demand information, which changes dynamically over time.

According to Laporte (1992), VRP's are a class of combinatorial optimization problems that allow optimizing vehicle routes and, in urban cases, their resolution associated with transportation planning provides better mobility. This optimization, according to Ribeiro et al. (2019), is considered significant because it represents a large part of the flow of vehicles for good distribution in cities. Earlier research demonstrating how vehicle routing optimization can lead to significant savings, which can be estimated between 5 and 30% by Hasle and Kloster (2007) or between 5 and 20% advocated by Toth and Vigo (2002), corroborate this view of Laporte (1992) and

Ribeiro et al. (2019). However, route optimization in cities provides specific features that foster the development of new approaches.

Considering the contexts presented here, this paper presents an approach to VRP resolution, which can be parameterized for different situations and cases. Importantly, our goal is not just to provide a solution in light of the literature on the subject. In fact, we seek two additional scopes, namely: providing a broader view of city distribution research and thereby helping researchers better understand the practical motivations involved in vehicle routing and, identify major challenges in urban vehicle routing.

In addition to this introductory part, the work brings in the second section a brief literature review about distribution and transportation channels, emphasizing VRP as a challenge within the logistics area. Following, the third section presents the methodological approach used. Subsequently, the results of the application are presented. And finally, the conclusions and reflections on the main findings.

II. THEORETICAL REFERENCE

Logistics is a key element of competitive advantage, concerned with managing the physical flow of resources, starting at the source of supply and ending at the point of consumption. It can then be defined as a process that integrates, coordinates and controls the movement of resources such as humans, materials or services. Transportation management is an essential part of a logistics system, and the activity is responsible for the flows of raw material and finished product between links in the logistics chain (PRAJOGO et al., 2016).

Transport within a production unit can be seen as the most significant cost element when it comes to logistics costs. Economic variables such as high fuel prices, poor roads, high taxes, tolls, among other aspects, have a direct influence on the composition of logistics costs. Thus, organizations face important challenges related to the planning of logistics activities and the management of the corresponding costs, and at the same time need to offer more quality and speed to the consumer market. Thus, a well-structured logistics aims to minimize the costs of moving products in time (inventory) and space (transportation), and seek to contribute to the company achieve a greater scope of operation in the market and greater recipient or customer satisfaction (DONALD et al., 2014).

Among the essential decisions involving logistics, it is noteworthy that shipment routing, vehicle scheduling and freight consolidation are important variables for decision making, as they impact the total costs of logistics activities. One of the tools to assist managers in this activity is vehicle routing, which consists of defining itineraries to be traveled by vehicles serving a warehouse or distribution center. Within this context, cargo routing is the process of scheduling the distribution of cargo on delivery routes or routes, by cross-checking cargo volume or weight information, vehicle capacities and delivery locations in order to obtain the best result in terms of truck occupancy and delivery deadlines. In this sense, routing can be fixed route, in which the system distributes the loads to be transported by a previously stipulated route and characterized by the Postal Code and dynamic route numbers, where the best delivery route is suggested depending on the analysis of information about cargo to be transported, vehicle capacities, street, road and delivery information (BOTELHO et al., 2017).

Within this context, there is the Vehicle Routing Problem (VRP), which is defined as a problem designed to find optimal delivery or collection routes from one or several depots to a number of locations, whether cities or customers, while satisfying certain restrictions. VRP plays an important role in distribution and transportation logistics. And, a prerequisite for solving this problem is that customers are known in advance. In addition, the travel time between customers and the service times at each also need to be known (LEVIN, 2017).

Formally, the classic vehicle routing problem (VRP) is represented by a directed graph $G=(V,A)$, be for example a graph in which $V=\{1\ldots n\}$ is a set of vertices representing cities with the depot located at vertex 1 A , is the set of arcs. With each bow $(i,j) i \neq j$ is associated with a nonnegative distance matrix $C=\left(c_{ij}\right)$. If $c_{ij}=c_{ji}$ then the symmetric VRP and otherwise the problem is asymmetric. In some specific contexts, c_{ij} can be interpreted as a travel cost or as a travel time. When C is symmetrical, it is often convenient to replace A by a set E of undirected edges. Also, suppose there are m available depot-based vehicles where $m_L < m < m_U$. So, when $m_L = m_U$, m It is said to be fixed. And in the event of $m_L = 1$ e $m_U = n-1$, m It is said to be free. When m not fixed it often makes sense to associate a fixed cost f when using a vehicle.

From the point of view of complexity, according to Soysal et al. (2018), the classic VRP is known as NP-hard (Non-deterministic Polynomial-time hardness) as it

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generalizes the Traveling Salesman Problem (TSP) and the Bin Packing Problem (BPP). A relevant review of variants and mathematical formulations for the classic VRP can be found in Laporte (1992).

III. METHODOLOGICAL APPROACH

As a research unit was approached the optimization of the route used by a manufacturer and distributor of garlic products located in the city of São Mateus (Espírito Santo / Brazil). In this work it was considered exclusively the departure of the company with the cargo to be transported and its return after unloading at its stopping points.

Although the company studied has a large number of stopping points in the state of Espírito Santo and also in other states, the sample of this work consists exclusively of the points located in the city of São Mateus and, which have delivery route and known demands. Thus, considering that the regular service cycle ends within a week, the interval of the collected data will also correspond to this period.

Data collection was started from a documentary consultation about the routes of the studied company, in order to elucidate the routes to be performed and their characteristics (technical and geographical).

From this, the collected data were distributed and related to the variables of the mathematical model of VRP, namely: Number of vehicles belonging to the wholesale company; Battery capacity; Number and geographical location of customers in the north of Espírito Santo state and the warehouse; Total and each customer demand; Window of service time of each customer; Total size of the route traveled; Fuel consumption during the journey; and Other costs directly related to the route traveled.

The results obtained through the VRP solution were triangulated with the current ones employed by the company through a Geographic Information System for Transportation (GIS-T) - TransCAD version 6.0, which allowed for a route feasibility analysis, taking into account consideration the direction and direction of the flows of city traffic.

Thus, considering the geographical limitations and technical possibilities, three hypotheses were elaborated to guide the VRP study, based on the costs and the number of vehicles involved in the routing, to be implemented as VRP inputs. Thus, the first hypothesis considered the script currently adopted and which, according to the experience of drivers, is therefore not an optimal solution. In the second hypothesis, with the help of GIS-T where routing techniques were applied, the representation of the road network aimed to reduce the length of the routes. And finally, in the third hypothesis the result obtained with the optimization process should generate a set of routes that reduce the logistics costs related to the VRP of the studied company.

IV. RESULTS

The research unit used is a manufacturer and distributor of garlic products, which are subdivided as follows: fresh garlic in 200g and 300g packagings, minced (or garlic paste) and fried garlic with a monthly output of approximately 24 tonnes - if all product variations are added together. This production is distributed among the company's customers in São Mateus (restaurants and retail chains such as supermarkets, bakeries, butchers and grocery stores).

In the sector responsible for product distribution there are two employees: the driver (responsible for driving the company's truck) and the delivery assistant. It is important to note that by providing the delivery service, there is a fee charged by the company proportional to the quantity (mass) of product requested by the customer - which causes some to dispense with this service.

Thus, the intrinsic characteristics of the truck used in the deliveries were initially raised, namely: Brand: Mercedes Benz; Model: Acello; Year: 2008; Fuel Used: Diesel; Average fuel consumption: 5.5 km / l (kilometers per liter); Payload capacity: 5.5 tons; Tire change period: every 6 months (approximately 50,000 km); Oil change: From 15,000 to 15,000 km and, Box capacity used on delivery: Average 9.5 kg. This information was verified to indicate the possible expenses and the available transport capacity, to assist in the parameterization regarding the VRP model.

Deliveries are made every Wednesday in the afternoon, starting activities from 14h. This delivery time is used due to unavailability by some customers to receive cargo at alternative times (Restaurants: receiving unavailability period - 11h to 13h and Supermarkets: receiving unavailability period - 11h to 14h). On delivery days, the driver and aide with the help of some employees load the truck in the morning with each customer's requests - listed in a spreadsheet with their unit values and totals to be paid.

The company divides its customers into three groups according to the volume and cycles of each order; Group 1 consists of small buyers located in the city of São Mateus (restaurants, snack bars, butchers and industrial kitchens); Group 2 consists of all supermarkets and; Group 3 by supermarkets located in the region of Guriri Island - being an area located about 12 km away from the city center, was not understood in the scope of this work.

To obtain information on delivery routes, data collection was performed with the support of the driver and the assistant on the dates of 27/02/2019 and

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06/03/2019, with the first intended for Group 1 information and the second to Group 2. To quantify the values of each route, the follow-up of deliveries was made with a private car equipped with its odometer and a Global Positioning System (GPS), a time marker and a table containing information on: Order of attendance; Relationships of customers' fantasy names; Time of arrival at each customer's premises; Time of departure from each customer's premises; Quantity of product delivered in kilograms; and Distance from one customer and the next to be served.

Thus, after data collection, it was possible to obtain the following performance measures to be related between the routes used by the company and the results from GIS-T: Customer Travel Time i customer i + 1 (TVCi) - difference between customer arrival time i + 1 and customer departure time i; Total Travel Time (TVT) - The time the delivery truck spends traveling between customers. It is represented by the sum of TVCi's; Customer Service Time i (TSCi) - The time at which company employees perform customer delivery service i. It is calculated by subtracting the departure time from client i by the arrival time at the same client i. It is noteworthy that this time is not only composed of the act of delivery, but also verification of notes, possible receipts and other human factors - which makes it difficult to standardize service times taking into account the same customer; Total Service Time (TST) - Total time employees spend to perform deliveries. It is represented by the sum of the TSCi's; Total Distance Traveled (DTP) - represented by the sum of the distances traveled between customers; Total average speed (VMT) - ratio between DTP and TVT; Total Journey Time (TTP) - Subtraction between the time the truck arrives at the depot after making all deliveries by the time it begins its distribution journey. It can also be obtained by summing between TST and TVT and; Average fuel consumption (CMC) - obtained by dividing DTP by the average distance traveled by 1 liter of fuel per truck (5.5 km / l, according to the company).

It is noteworthy that the quantities of products and the addresses of each customer were obtained through the delivery notes individually. Thus, and after obtaining a georeferenced map (Figure 1) with a database of the city of São Mateus, a composite database was created.

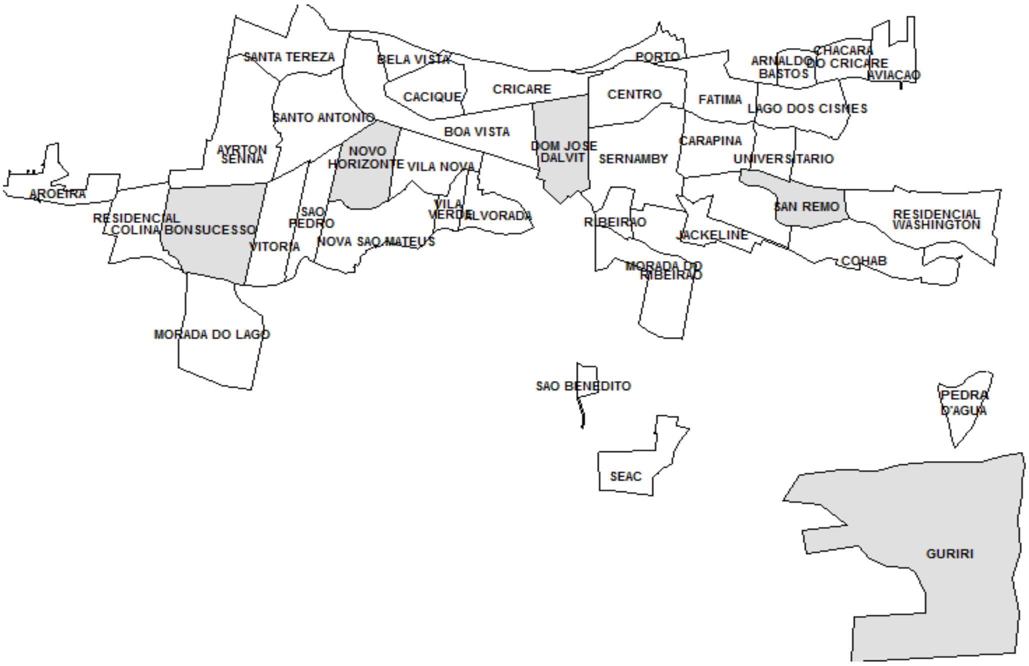

Fig. 1: Municipality of São Mateus

From this, a line layer was created to demarcate the city's streets and avenues (Figures 2 and 3), including intersections, road directions, speeds and street names for proper simulation. Then, the layers of points were elaborated, responsible for indicating the exact location of each client (costumer, in the TransCAD) as well as the location of the deposit. The database includes the following information: open_time; close_time; demand i; Fixed service time; and node_id i (node ID).

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Dataview1 - Customers

ID	Longitude	Latitude	[NÚMERO]	NAME	CAPACITY	OPEN_TIME	CLOSE_TIME	DEMAND	[FIXED SERVICE TIME]	[TIME PER UNIT]	NODE_ID
2	-87405813	30499849	2	RESTAURANTE O GA	--	1400	1700	14	6	0	1712
3	-87404614	30501193	3	RESTAURANTE ROBE	--	1400	1700	14	6	0	1454
4	-87404272	30501511	4	SAB. ROÇA, PALAD	--	1400	1700	51	47	0	1823
5	-87404290	30499213	5	RESTAURANTE AVEN	--	1400	1700	6	7	0	1565
6	-87402145	30500828	6	REST. WANTUIL	--	1400	1700	6	3	0	1481
7	-87401523	30501255	12	AÇOUGUE CARAN	--	1400	1700	10	6	0	1487
8	-87401506	30500914	8	CHURRASQUINO PRE	--	1400	1700	5	3	0	1496
9	-87400649	30501317	9	REST. ARAPONGAS	--	1400	1700	30	4	0	1508
10	-87400001	30501224	10	COZIVIP 1	--	1400	1700	75	7	0	1161
11	-87399829	30501185	11	COZIVIP 2	--	1400	1700	75	2	0	1530
12	-87399334	30499268	12	CEPE/ COZITA DA	--	1400	1700	10	7	0	1083
13	-87405435	30499284	13	PICANHA GRILL	--	1400	1700	14	4	0	831
14	-87407949	30500759	14	REST. BOROTO	--	1400	1700	8	6	0	872

Fig. 2: Route 1 customer care information (Group 1)

Dataview8 - PONTOS ROTA 2 :1

ID	Longitude	Latitude	NUMBER	NAME	CAPACITY	OPEN_TIME	CLOSE_TIME	DEMAND	[FIXED SERVICE TIME]	[TIME PER UNIT]	NODE_ID
2	-87408949	30499670	2	SUP. VILA NOVA	--	1400	1700	17	6	0	1773
3	-87412067	30500262	3	SUP. SANTO ANTON	--	1400	1700	175	18	0	393
4	-87412767	30500876	4	REDE MULTISHOW	--	1400	1700	23	7	0	348
5	-87404279	30501523	5	SUP. ANCHIETA	--	1400	1700	14	7	0	1824
6	-87404012	30501030	6	SUP. ZAMPIROLLI	--	1400	1700	15	8	0	1457
7	-87404037	30500130	7	SUP. CASAGRANDE	--	1400	1700	207	22	0	980
8	-87401938	30498919	8	SUP. RONDELLI	--	1400	1700	24	7	0	1798
9	-87401289	30501386	9	SUP. CARIOCA	--	1400	1700	11	6	0	1487

Fig. 3: Route 2 customer care information (Group 2)

Thus, after gathering this information (characterization of routes 1 and 2 and, from customers), these were ordered, creating a database for GIS-T operationalization. And following, The diagnosis was performed for the purpose of data collection, in which specific characteristics of the Group 1 clients' care route were observed (Wednesday, February 27, 1919), and the collected data were arranged in a layer (Figure 4), as well as, the route used in urban movements for these deliveries (Figure 5).

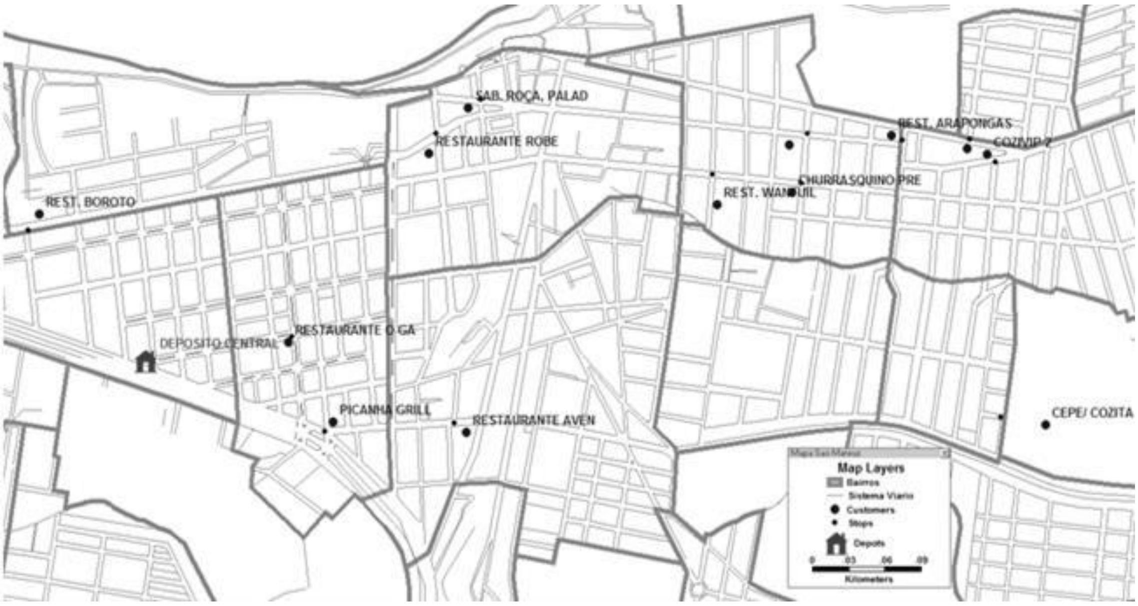

Fig. 4: Layer representing the geographic location of Group 1 customers

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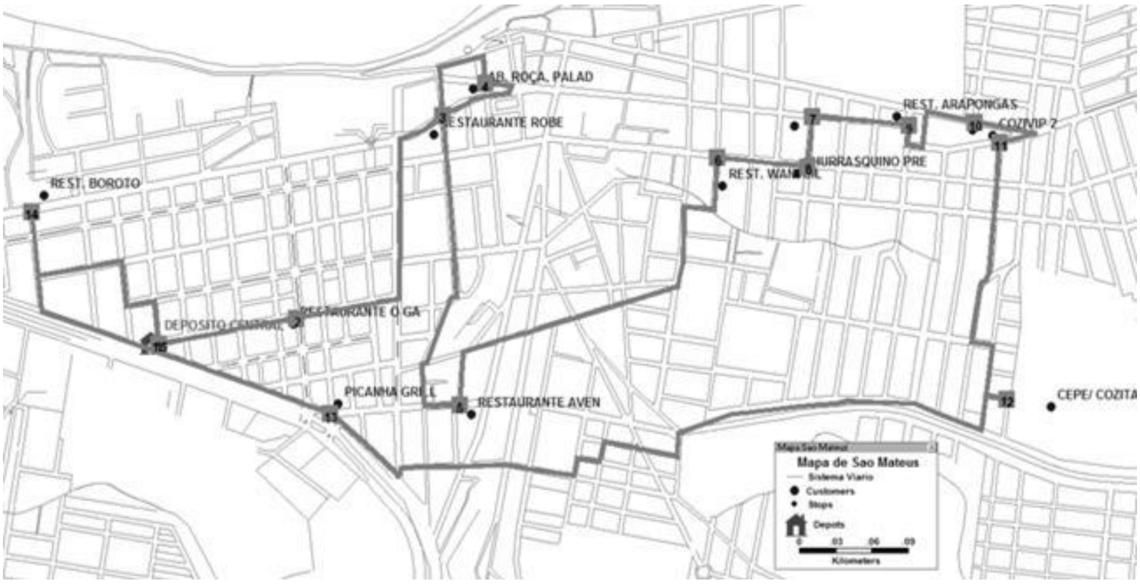

Fig. 5: Current route to service Group 1 customers

Completing the initial information diagnosis, data were collected that characterized the order fulfillment operations of each Group 1 customer by order of fulfillment. Thus, beacon parameters were raised that served as inputs in the resolution of the VRP, through GIS-T (TransCAD), being verified: the arrival and departure times of each delivery; the distances traveled between the stopping points and the quantities of products moved (Table 1).

Tab. 1:Group 1 route data compilation

Order	Client	Arrival Time (hours:minutes)	Departure time (hours:minutes)	Quantity (kg)	Distance (km)
1	DEPÓSITO	-	01:40 pm	-	-
2	Restaurante O Gauchão	01:42 pm	01:48 pm	14	0.4
3	Restaurante Robertinho	01:50 pm	01:56 pm	14	0.6
4	Sabor da Roça*	01:58 pm	-	8	0.4
5	Restaurante Paladar *	-	-	14	-
6	Restaurante Nó na Madeira*	-	-	6	-
7	Restaurante Atobá*	-	-	8	-
8	Lanchonete Arymas*	-	-	10	-
9	Restaurante Fogão a Lenha*	-	02:45 pm	5	-
10	Restaurante Avenida	02:49 pm	02:56 pm	6	1.0
11	Restaurante Wantuil	02:58 pm	03:01 pm	6	0.7
12	Açougue Caran	03:04 pm	03:10 pm	10	0.8

13	Churrasquinho da Pretinha	03:11 pm	03:14 pm	5	0.2
14	Restaurante Arapongas	03:15 pm	03:19 pm	30	0.2
15	Cozivip 1	03:21 pm	03:28 pm	75	0.3
16	Cozivip 2	03:29 pm	03:31 pm	75	0.2
17	Restaurante do CEPE	03:34 pm	03:41 pm	10	0.8
18	Restaurante Picanha Grill	03:47 pm	03:51 pm	14	1.8
19	Restaurante Boroto	03:54 pm	04:00 pm	8	1.0
20	DEPÓSITO	04:03 pm	-	-	0.6

Although the company's initial listing indicated 20 customers to serve, the route used visited 18 customers. This is explained by the fact that some parts of the city have limited parking and time window for loading and unloading. Thus, in Table 1, The customers who are in this condition and who, the service was shared, are identified and highlighted by (*), due to a stoppage. Travel and service times of each customer visited are shown in Table 2.

Tab. 2: Service and travel times by Group 1 route customers

Order	Client	Travel time(hours:minutes)	Service time(hours:minutes)
1	Restaurante O Gauchão	00:02	00:06
2	Restaurante Robertinho	00:02	00:06
3	Sabor da Roça*	00:02	00:47
4	Restaurante Paladar*	-	-
5	Restaurante Nó na Madeira*	-	-
6	Restaurante Atobá*	-	-
7	Lanchonete Arymas*	-	-
8	Restaurante Fogão a Lenha*	-	-
9	Restaurante Avenida	00:04	00:07
10	Restaurante Wantuil	00:02	00:03
11	Açougue Caran	00:03	00:06
12	Churrasquinho da Pretinha	00:01	00:03
13	Restaurante Arapongas	00:01	00:04
14	Cozivip 1	00:02	00:07

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15	Cozivip 2	00:01	00:02
16	Restaurante do CEPE	00:03	00:07
17	Restaurante Picanha Grill	00:06	00:04
18	Restaurante Boroto	00:03	00:06
19	Restaurante O Gauchão	00:02	00:06

Then, after gathering the collected data, information on performance measures for the Group 1 route was generated, obtaining: Total Travel Time (TVT): 35 minutes; Total Service Time (TST): 1 hour and 48 minutes; Total Distance traveled (DTS): 9 km; Total Average Speed (VMT): 15.43 km / h; Total Travel Time (TTP): 2 hours and 23 minutes and; Average Fuel Consumption (MCC): 1.64 liters of diesel. As a result, when the VRP of this route was operationalized in TransCAD, the route optimization totaled 10.12 km, which differs from the distance obtained with the use of the vehicle odometer at the time of data collection. This gap between values, besides being related to the model of optimization, too, is linked to the fact that the vehicle odometer works with 100-meter multi-distance measurement and is reset after each delivery. Therefore, for the purpose of future comparisons, the data provided by GPS, which were entered in GIS-T will be effectively used in the result analysis.

Analogous to the procedures performed with the Group 1 service route, the Group 2 data collection operations were started. Thus, the clients of this other group were served on the following Wednesday (03/06/2019), and as Figure 6, as well as the routes used by the company (Figure 7).

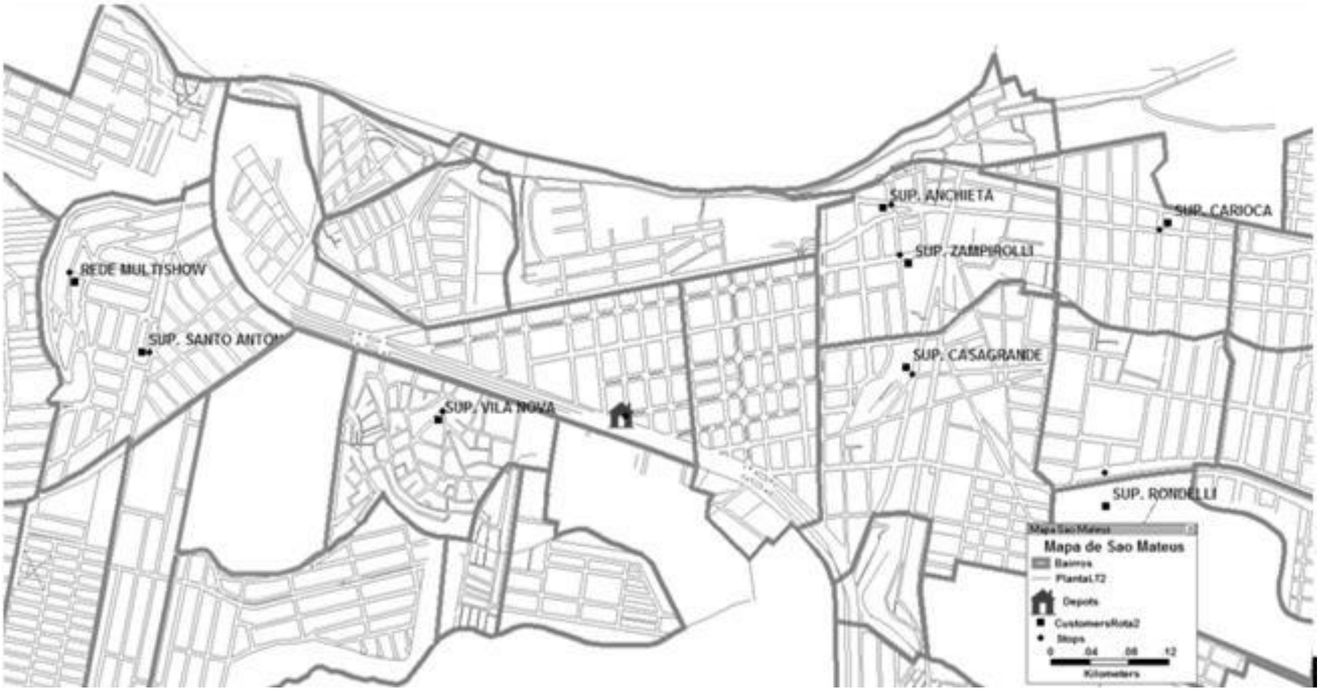

Fig. 6: Layer representing the geographical location of Group 2 customers

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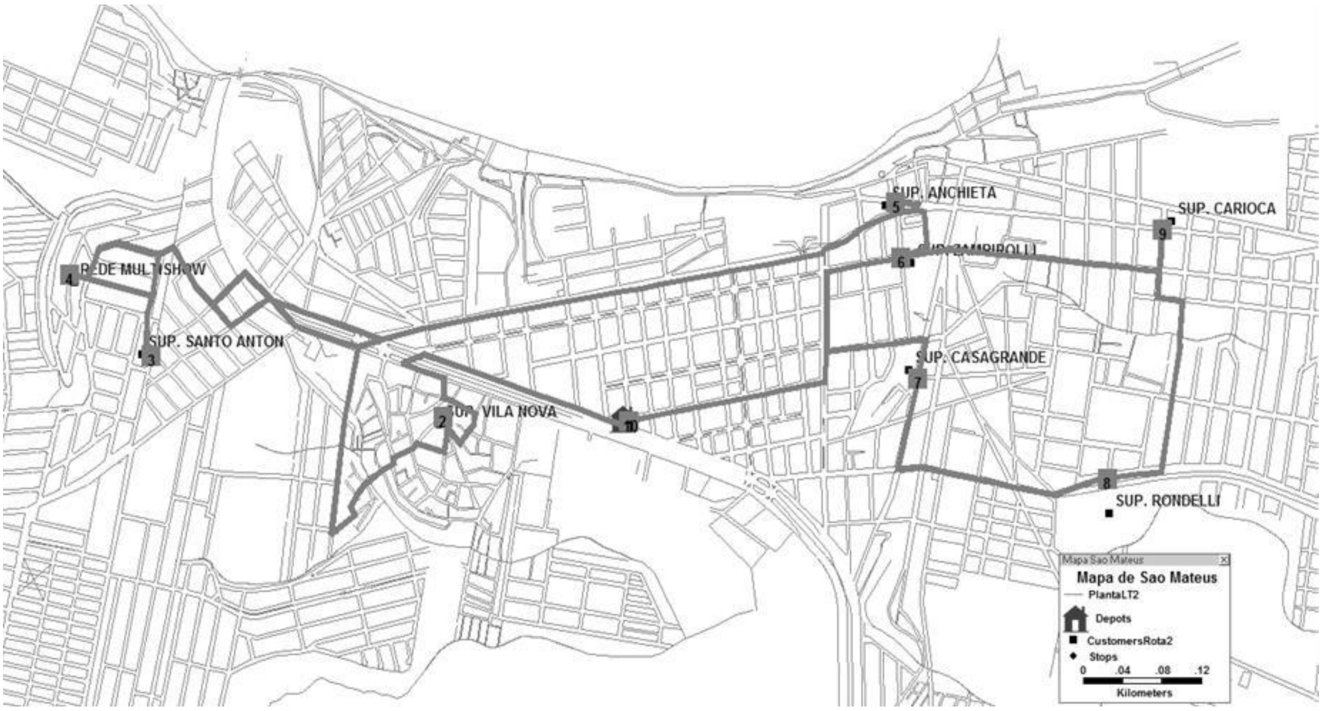

Fig. 7: Current route to service Group 2 customers

After these parameterizations the customers were sorted according to the service, arrival and departure times of each delivery, distances traveled between stopping points and quantities of products moved to Group 2 (Table 6 and 7).

Table 1: Group 2 route data compilation

Order	Client	Arrival Time (hours:minutes)	Departure time (hours:minutes)	Quantity (kg)	Distance (km)
1	DEPÓSITO	-	03:06 pm	-	-
2	SUP. VILA NOVA	03:11 pm	03:17 pm	17	1.3
3	SUP. STO ANTÔNIO	03:27 pm	03:45 pm	175	4
4	REDE MULTISHOW	03:52 pm	03:59 pm	23	1.2
5	SUP. ANCHIETA	04:07 pm	04:14 pm	14	3.8
6	SUP. ZAMPIROLLI	04:17 pm	04:25 pm	15	0.7
7	SUP. CASAGRANDE	04:28 pm	04:50 pm	207	0.5
8	SUP. RONDELLI	04:54 pm	05:01 pm	24	1,2
9	SUP. CARIOCA	05:05 pm	05:11 pm	11	2
10	DEPÓSITO	05:18 pm	-	-	2.3

Table 2: Service and travel times by Group 2 route customers

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Order	Client	Travel time (hours:minutes)	Service time (hours:minutes)
2	SUP. VILA NOVA	00:05	00:06
3	SUP. STO ANTÔNIO	00:10	00:18
4	REDE MULTISHOW	00:07	00:07
5	SUP. ANCHIETA	00:08	00:07
6	SUP. ZAMPIROLLI	00:03	00:08
7	SUP. CASAGRANDE	00:03	00:22
8	SUP. RONDELLI	00:04	00:07
9	SUP. CARIOCA	00:04	00:06
10	DEPÓSITO	00:07	-

Similar to previous procedures, after data collection, it was possible to obtain the following performance measures to be related between the routes used by the company and the results from GIS-T: Total Travel Time: 51 minutes; Total Service Time: 1 hour and 21 minutes; Total Distance traveled: 17 km; Total Travel Time: 2 hours and 12 minutes and; Average Fuel Consumption: 3.09 liters of diesel.

Thus, after compiling all the information, GIS-T, when solving the VRP for the Group 2 route, obtained a total distance traveled of 13.22 km, which differs from the total recorded by the odometer which is 17 km.

After obtaining the parameters of both groups, the generation of routes was performed based on the resolution to VRP by GIS-T. However, in order for the VRP to be solved by TransCAD, in addition to information from the customer database, warehouse and road system, it was also necessary to elucidate other elements that helped in the optimization of routes, such as: minimum paths between all network node pairs (client and depot).

TransCAD uses the layer that represents the road system to obtain the distances, however, this layer has associated with it a layer of points, called intersections (GUERREIRO et al., 2018). And so, according to these authors, at each intersection between two segments (street or avenues), a new point in the intersection layer is generated with a unique ID (ID).

From this, it was initially necessary to create a relationship between the intersection, customer and warehouse layers, obtained by the NODE_ID field present in the georeferenced database of these last two layers. This field is assigned the ID code of the intersection layer s closest to the customer or warehouse being analyzed. A distance matrix is generated by TransCAD, which refers to the relationship between customers and the warehouse for Group 1 (Figure 8).

Matrix4 - VRP Time Matrix File (Time)

	831	857	872	1083	1161	1454	1481	1487	1496	1508	1530	1565	1712	1823
831	0.00	0.41	1.14	2.09	2.86	1.70	1.65	2.16	1.90	2.52	2.64	0.35	0.50	1.84
857	1.41	0.00	0.82	3.50	4.28	1.63	3.07	3.58	3.31	3.93	4.05	1.77	0.76	2.00
872	2.07	1.10	0.00	4.16	4.23	1.15	3.02	3.48	3.27	3.89	4.01	2.42	1.48	1.51
1083	2.39	2.81	3.54	0.00	1.90	3.00	2.07	2.08	1.82	2.09	1.53	2.37	2.90	2.99
1161	2.94	3.35	3.23	1.90	0.00	2.36	1.22	0.97	0.97	0.44	0.55	2.70	3.07	2.34
1454	1.79	1.71	1.49	3.42	3.08	0.00	1.87	2.33	2.12	2.74	2.86	1.68	1.34	0.36
1481	1.72	2.13	2.01	2.07	1.21	1.14	0.00	0.51	0.25	0.87	0.99	1.49	1.85	1.12
1487	2.23	2.64	2.52	2.08	0.99	1.65	0.51	0.00	0.26	0.53	1.00	2.00	2.36	1.63
1496	1.97	2.38	2.26	1.82	0.96	1.39	0.25	0.26	0.00	0.62	0.74	1.73	2.10	1.37
1508	2.50	2.91	2.79	1.83	0.65	1.92	0.78	0.53	0.53	0.00	0.61	2.26	2.63	1.90
1530	2.71	3.12	3.00	1.53	0.55	2.13	0.99	1.00	0.74	0.78	0.00	2.47	2.84	2.11
1565	0.63	1.05	1.77	1.74	2.51	1.51	1.30	1.81	1.55	2.17	2.29	0.00	1.14	1.49
1712	0.66	0.76	1.50	2.74	3.52	1.25	2.31	2.82	2.55	3.17	3.29	1.01	0.00	1.61
1823	2.22	2.15	1.93	3.80	2.95	0.65	1.74	2.20	1.98	2.60	2.73	2.11	1.77	0.00

Fig. 8: Minimum path matrix between customers and warehouse

By obtaining the minimum path matrix and the previously obtained data, a simulation was performed and an optimized route was obtained from these parameters (Figure 9). Sequentially, the arrival and departure times, distances traveled, each customer's demand, total time and total distance traveled on the generated route, and order of service (Figures 10 and 11).

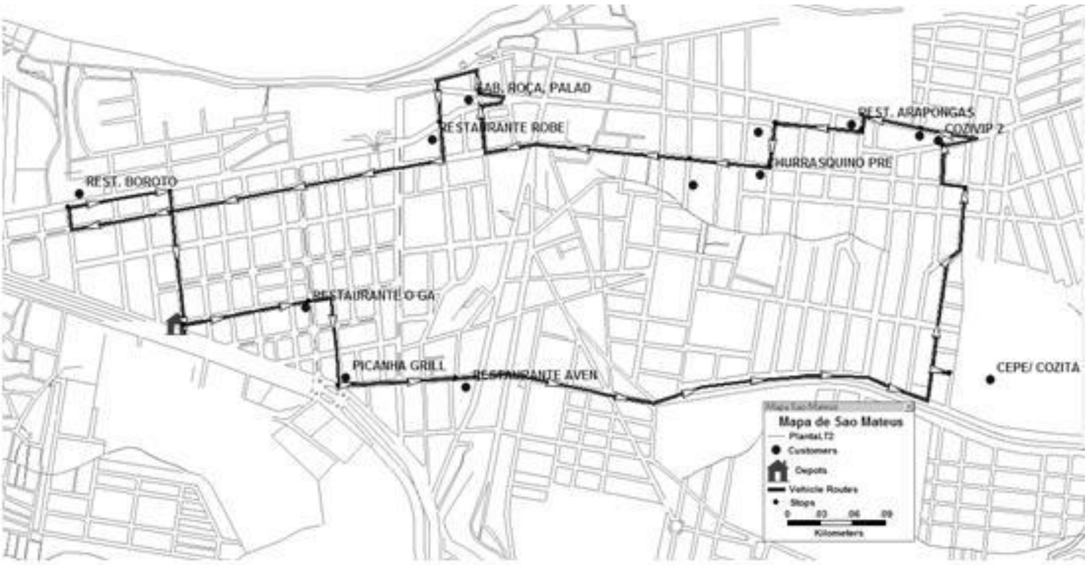

Fig. 9: Graphical representation of the optimized route from VRP to Group 1 customers

Dataview4 - Stops

ID	Route_ID	Milepost	STOP_ID	Route	[Veh. Type]	Stop	Name	Node	Sequence	[Open Time]
1	1	0.000000	1	1	1	1	DEPOSITO CENTRAL	857	0	1400
2	1	0.115141	2	1	1	2	RESTAURANTE O GA	1712	1	1400
3	1	0.214520	3	1	1	13	PICANHA GRILL	831	2	1400
4	1	0.321150	4	1	1	5	RESTAURANTE AVEN	1565	3	1400
5	1	0.803243	5	1	1	12	CEPE/ COZITA DA	1083	4	1400
6	1	1.046268	6	1	1	11	COZIVIP 2	1530	5	1400
7	1	1.129126	7	1	1	10	COZIVIP 1	1161	6	1400
8	1	1.196043	8	1	1	9	REST. ARAPONGAS	1508	7	1400
9	1	1.276354	9	1	1	7	AÇOUGUE CARAN	1487	8	1400
10	1	1.316329	10	1	1	8	CHURRASQUINO PRE	1496	9	1400
11	1	1.390715	11	1	1	6	REST. WANTUIL	1481	10	1400
12	1	1.666686	12	1	1	4	SAB. ROÇA, PALAD	1823	11	1400
13	1	1.764568	13	1	1	3	RESTAURANTE ROBE	1454	12	1400
14	1	2.163206	14	1	1	14	REST. BOROTO	872	13	1400
15	1	2.377135	15	1	1	1	DEPOSITO CENTRAL	857	14	1400

Fig. 10: Ordered sequencing from VRP resolution

ResRota1 - Bloco de notas

Arquivo Editar Formatar Exibir Ajuda

```
                          Itinerary Report

Route #  : 1                  Tot Time: 1:59         Capacity  : 5500.0
Veh. Type: 1                  Tot Dist: 7.9          Depart Load: 318.0

No.   Name                       Arrival-Depart       Dist    Delivery
---------------------------------------------------------------------
      DEPOSITO CENTRAL                    2:00pm
   1 RESTAURANTE O GA             2:01pm- 2:07pm      0.33     14.0
   2 PICANHA GRILL                2:07pm- 2:11pm      0,3      14.0
   3 RESTAURANTE AVEN             2:12pm- 2:19pm      0,3       6.0
   4 CEPE/ COZITA DA              2:21pm- 2:28pm      1.3      10.0
   5 COZIVIP 2                    2:29pm- 2:31pm      0.7      75.0
   6 COZIVIP 1                    2:32pm- 2:39pm      0.0      75.0
   7 REST. ARAPONGAS              2:39pm- 2:43pm      0.0      30.0
   8 AÇOUGUE CARAN                2:44pm- 2:50pm      0.0      10.0
   9 CHURRASQUINO PRE             2:50pm- 2:53pm      0.0       5.0
  10 REST. WANTUIL                2:53pm- 2:56pm      0.0       6.0
  11 SAB. ROÇA, PALAD             2:57pm- 3:44pm      0.7      51.0
  12 RESTAURANTE ROBE             3:45pm- 3:51pm      0.3      14.0
  13 REST. BOROTO                 3:52pm- 3:58pm      1.3       8.0
 END DEPOSITO CENTRAL             3:59pm              0.7
                                                   -----------------
Total                                                7.9    318.0
```

Fig. 11: GIS-T operationalization scheduling for Group 1 customers

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Following, besides the information obtained in the generated route report, it was possible to obtain performance meters which are: Total Travel Time (TVT): 11 minutes; Total Service Time (TST): 1 hour and 48 minutes; Total Average Speed (VMT): 43.09 km / h and; Average Fuel Consumption (MCC): 1.44 liters of diesel.

Thus, from this, the data regarding the travel times between customers were entered in the layer of the "SM Road System" layer, as well as the speeds with which the truck travels through each road of São Mateus (Figure 12), which take into account the maximum speed allowed on each lane, as well as factors such as traffic and truck weight. Thus, it was possible for GIS-T to analyze the VRP and even point arrival times at each point (customers and warehouse).

Dataview1 - Sistema Viario Sao M

ID	Length	Dir	Nome	Speed	[Time (min)]
521	0.01	0		30	0.06
1487	0.02	1	R JOAO EVANGELISTA MONTEIRO LOBATO	60	0.06
1138	0.02	-1	AV JOSE TOZZI	60	0.06
425	0.01	0		30	0.06
1134	0.02	-1	AV JOSE TOZZI	60	0.06
1811	0.01	0		30	0.06
221	0.01	0		30	0.06
1128	0.02	1	AV JOAO XXIII	60	0.06
472	0.01	0		30	0.05
1338	0.02	0	AV JOSE TOZZI	60	0.05
1270	0.02	-1	AV JOSE TOZZI	60	0.05
1832	0.01	0		30	0.05
1328	0.02	0	AV JOSE TOZZI	60	0.05
1023	0.01	0		30	0.05

Fig. 12: Parameterization of the Road System layer in the roads under study.

Similar to the procedures for obtaining Group 1 routing, the analyzes performed to obtain the Group 2 route continued using the same assumptions. Following these assumptions, the Group 2 customer movement and attendance route was generated (Figures 13, 14 and 15).

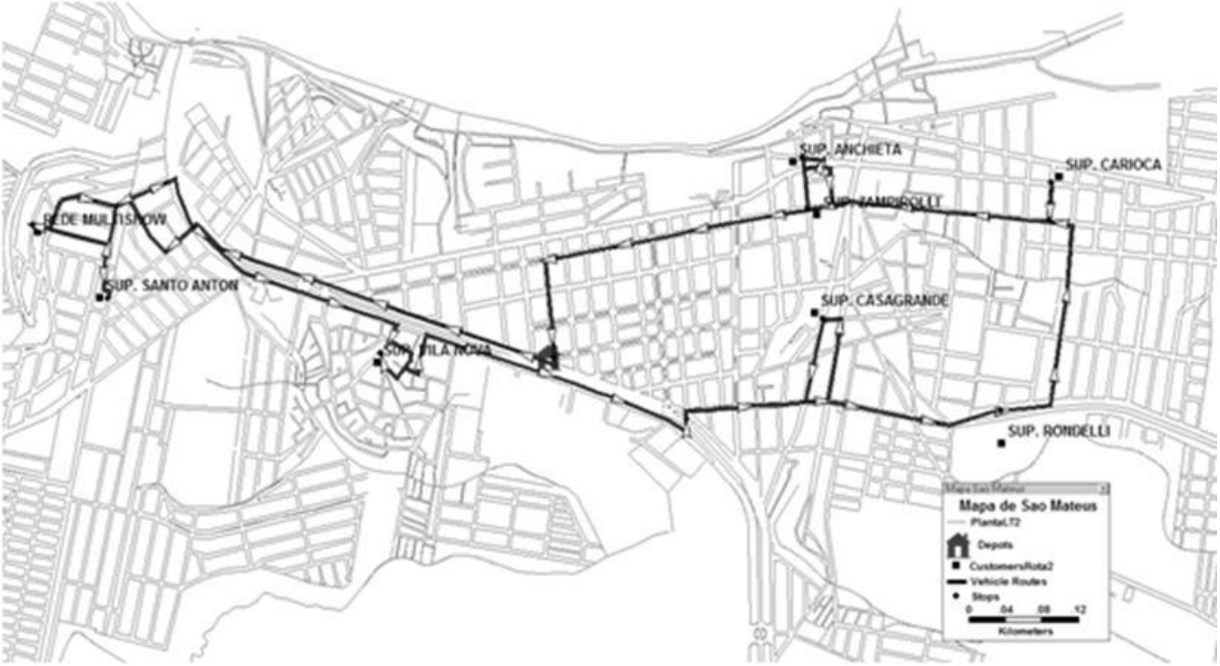

Fig. 13: Route generated to move and serve Group 2 customers

Dataview4 - Stops

ID	Route_ID	Milepost	STOP_ID	Route	[Veh. Type]	Stop	Name	Node	Sequence	[Open Time]
1	1	0.000000	1	1	1	1	DEPOSITO CENTRAL	857	0	1400
2	1	0.650076	2	1	1	3	SUP. SANTO ANTON	393	1	1400
3	1	0.793942	3	1	1	4	REDE MULTISHOW	1663	2	1400
4	1	1.384142	4	1	1	2	SUP. VILA NOVA	1773	3	1400
5	1	2.065919	5	1	1	7	SUP. CASAGRANDE	980	4	1400
6	1	2.369740	6	1	1	8	SUP. RONDELLI	1052	5	1400
7	1	2.676370	7	1	1	9	SUP. CARIOCA	1487	6	1400
8	1	2.977479	8	1	1	6	SUP. ZAMPIROLLI	1457	7	1400
9	1	3.066702	9	1	1	5	SUP. ANCHIETA	1823	8	1400
10	1	3.558987	10	1	1	1	DEPOSITO CENTRAL	857	9	1400

Fig. 14: Orderly sequencing from VRP resolution (Group 2 clients)

ResRota2 - Bloco de notas

Arquivo Editar Formatar Exibir Ajuda

```
                          Itinerary Report

Route #  : 1              Tot Time: 1:36          Capacity  : 5500.0
Veh. Type: 1              Tot Dist: 11.9           Depart Load: 486.0

No.   Name                          Arrival-Depart      Dist    Delivery
-----------------------------------------------------------------------
      DEPOSITO CENTRAL                       2:00pm

    1 SUP. SANTO ANTON              2:03pm- 2:21pm      2.0     175.0

    2 REDE MULTISHOW                2:22pm- 2:29pm      0.3      23.0

    3 SUP. VILA NOVA                2:31pm- 2:37pm      1.6     17.0

    4 SUP. CASAGRANDE               2:40pm- 3:02pm      2.0     207.0

    5 SUP. RONDELLI                 3:03pm- 3:10pm      1.0     24.0

    6 SUP. CARIOCA                  3:11pm- 3:17pm      1.0      11.0

    7 SUP. ZAMPIROLLI               3:19pm- 3:27pm      1.0      15.0

    8 SUP. ANCHIETA                 3:27pm- 3:34pm      0.0      14.0

 END  DEPOSITO CENTRAL              3:36pm              1.3
                                                      -----------------
Total                                                   11.9     486.0
```

Fig. 15: Programming of GIS-T-generated operation for Group 2 customers

Similarly obtaining results from Group 1, in the case of Group 2 clients, it was also possible to observe performance indicators, as follows: Total Travel Time (TVT): 15 minutes; Total Average Speed (VMT): 47.6 km / h and; Average Fuel Consumption (MCC): 2.16 liters of diesel.

By triangulating the data obtained through GIS-T (TransCAD) and the data obtained by the company's current routes, it was possible to verify that the methodology used in this work was efficient in reducing the distances to be traveled.

The final results suggest that there was a 22.7% reduction in the total route 1 route, something that Therefore, it also reduces costs related to variables such as fuel, total travel time and total travel time, and other vehicle-related costs such as maintenance. Regarding Route 2, although performance optimization did not reach the same level, fuel consumption was reduced by 10%, total travel time minimized by 27% and total travel time decreased by 70% (Table 8).

Table 8: GIS-T Results Analysis Compilation

Performance Measure	Route 1 Company	Route 1 TransCAD	Route 2 Company	Route 2 TransCAD
Total travel time (min)	35	11	51	15
Total average speed (km / h)	17.25	43.09	15.55	47.6
Total travel time (min)	143	119	132	96

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Performance Measure	Route 1 Company	Route 1 TransCAD	Route 2 Company	Route 2 TransCAD
Total distance traveled (km)	10.22	7.9	13.22	11.9
Average fuel consumption (liters)	1.9	1.44	2.4	2.16

Based on this information (Table 8), it can be seen that the route changes suggested by TransCAD from a georeferenced map and properly characterized, it has been able to generate an optimized route, which serves all customers, including minimizing transport costs and distance traveled.

To this end, scenarios were created that met the needs and prerogatives of the customers to be met. Thus, these customers were separated into two groups, in order to contemplate deliveries on different days. Although the company has a truck to handle delivery movements, its capacity can be considered relatively high from the point of view of meeting total order demand. For this reason, in this paper it was considered plausible to verify if the purchase of smaller vehicles can minimize transportation costs for the organization.

Thus, based on these assumptions, the VRP was analyzed using GIS-T, using two scenarios, one using the company's current vehicle (truck) and the other using two pickup trucks.

Scenario one considered a single route, which after specifying the geographical location of the two customer groups on a previously established route, was analyzed using TransCAD (Figure 16). Subsequently, delivery routes were defined and, by entering this data, it was possible to visualize in GIS-T the times and costs that involve the simulated route of scenario 1.

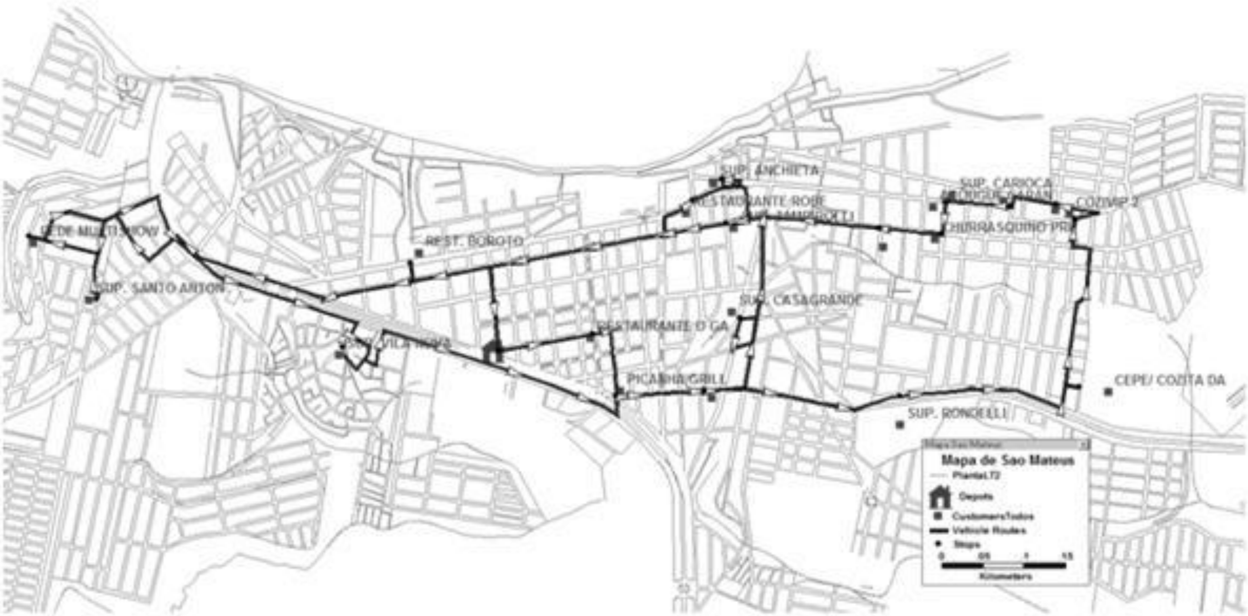

Fig. 16: Route Layer for scenario 1 obtained by GIS-T

Thus, the simulations performed for scenario 1, indicated a total travel time is 25 minutes; total service time of 3h06; average total speed of 38.88 km / h; and average fuel consumption of 2.9 liters of diesel. Numbers that, according to Min (1989) are considered excessive when using a truck on a route that involves urban movements. For Mahmoudi and Zhou (2016) deliveries involving medium and high unit volumes, deliveries by pickup trucks should be operationalized. These authors highlight not only better mobility issues with respect to traditional trucks, but also time and cost savings associated with their use.

Continuing with the analyzes, a new single-route simulation, scenario 2, was designed using two pickup trucks and a unique group of customers. This choice was due to the indication by Mahmoudi and Zhou (2016) to optimize cargo movement in urban areas. This indication was adopted, although the payload capacity of each pickup truck is 8 times lower than the company's truck capacity, however, having a better effectiveness pointed out by these

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authors. Due to the total demand to be moved, it was decided to use at least two pickup trucks to perform a single route (Figure 17).

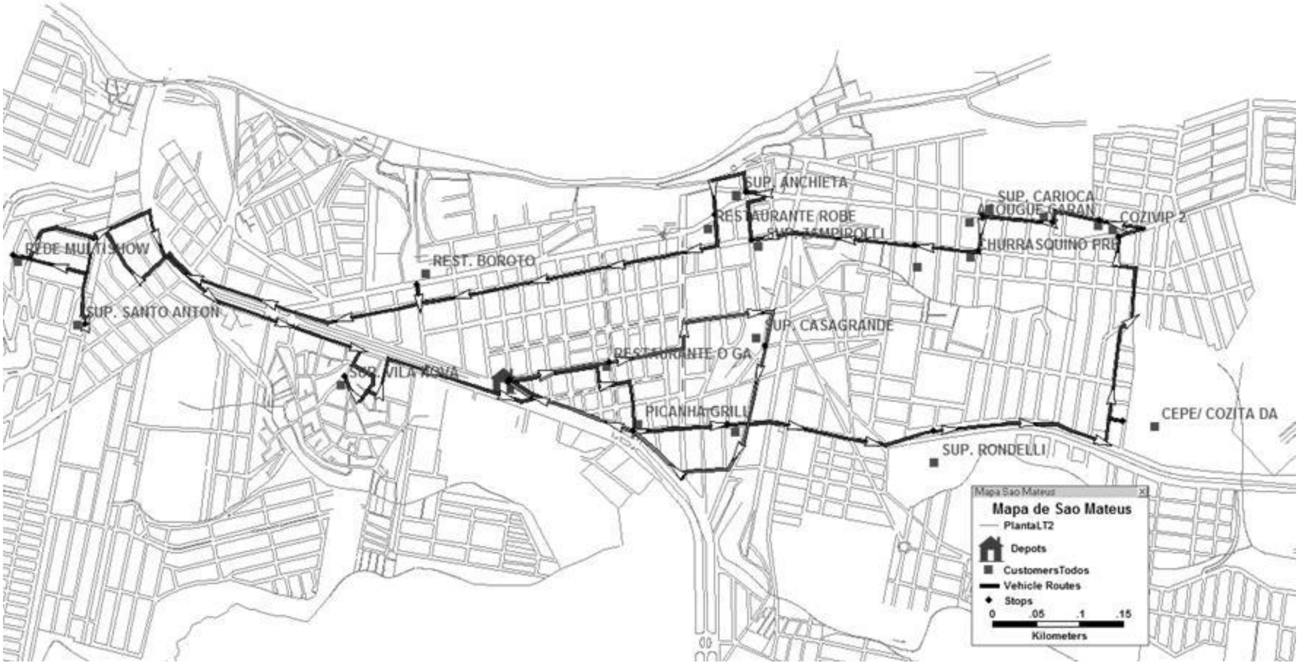

Fig. 17: Route Layer for scenario 2 obtained by GIS-T

Thus, after simulating scenario 2 and verifying the fulfillment of delivery orders, the following results were obtained: Total travel time: vehicle 1 - 21 minutes and vehicle 2: 4 minutes; Total service time: vehicle 1: 2h34 and vehicle 2: 32 minutes and; Total average velocity: vehicle 1: 35.4 km / h and vehicle 2: 39 km / h (Table 9).

Table 9: Arrangement of the various performances between the generated scenarios (current route and optimized route)

Performance Measure	Routes Company	Routes TransCAD	Scenario 1* Route (Diesel)	Scenario2 Routes (Alcohol)*	Scenario 2Routes (Gasoline)*
DTP (km)	23.34	19.8	16.2	15	15
CMC (liters)	4.24	3.6	2.95	1.45	1.02
Cost (USD)	2.37	2.01	1.65	0.92	0.74

** Average fuel prices: Diesel (0.92 USD); Alcohol (0.95 USD) and Gasoline (1.12 USD).*

Thus, when comparing the results of the VRP simulations of scenarios 1 and 2, it was identified that the variables are not directly influenced by the speed defined in the stretches along the route, in this case, the distances traveled and the average fuel expenditure. It is even possible to identify that the route defined by the company is the most financially expensive for the organization (Table 9), indicating, therefore, a need to review the operational and handling procedures related to deliveries. In addition, it is possible to verify that both scenarios are viable and that scenario 1 reduces costs by 30.6% and scenario 2 by approximately 68.6% if fueled by gasoline and 61.3% if fueled by ethanol.

VII. CONCLUSION

Optimizing costs and operations is critical when a company seeks market leadership. Actions such as vehicle routing can reduce transportation-related costs, the largest share of logistics costs. In this work it was possible to verify the reduction of fuel costs by optimizing the routes - reducing the length of the routes and therefore minimizing oil changes, hours worked, maintenance, vehicle change, etc., resulting in optimization of routes to the organization.

Using TransCAD for VRP resolution enabled a reduction of 22.7% and 10% in reducing the length of routes for clients 1 and 2. Scenario simulation was also efficient, allowing to explore better solutions within the possible realities to be faced. for the company. However, some limitations should be taken into account in data analysis, such as the speed on city roads that varies according to traffic and the condition of routes and traffic lights.

The significance, implication and practical contributions of this work can be attributed to the proposed approach, which allows an application to various types of problems with different structures and vehicles. Second, this approach enriches the VRP literature in specific contexts. And, lastly, this work incites research directions regarding the development of approaches and optimization methods to deal with generalized submodels.

As a suggestion for future work, we recommend updating the georeferenced database with more detailed information regarding the average velocity in its various occurrences, as well as the inclusion of times in the semaphorized intersections.

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REFERENCES

[1] Christopher, M. (2016). Logistics & supply chain management. Pearson UK.

[2] Göpfert, I., Stephan, M., Wellbrock, W. and Ackermann, M. (2016). The strategic relevance of logistics: new perspectives. International *Journal of Logistics Systems and Management*, *25*(1), 108-128.

[3] Ivanov, D., Dolgui, A., Sokolov, B. and Ivanova, M. (2017). Literature review on disruption recovery in the supply chain. International *Journal of Production Research*, *55*(20), 6158-6174.

[4] Novaes, A. G. (2016). *Logística e gerenciamento da cadeia de distribuição*. Elsevier Brasil.

[5] Araújo, M. D. P. S., Bandeira, R. A. D. M. and Campos, V. B. G. (2014). Custos e fretes praticados no transporte rodoviário de cargas: uma análise comparativa entre autônomos e empresas. *Journal of Transport Literature*, *8*(4), 187-226.

[6] Rodrigues, E. F., Rocha, A., Alves, M., Junior, I. S. and Junior, L. T. K. (2016). Comparação de custo de transporte de entrega utilizando sistema Milk Run versus entregas ponto a ponto em uma empresa de termoplásticos. *Revista GEINTEC-Gestão, Inovação e Tecnologias*, *6*(4), 3461-3471.

[7] Wang, X., Poikonen, S. and Golden, B. (2017). The vehicle routing problem with drones: several worst-case results. *Optimization Letters*, *11*(4), 679-697.

[8] Dantzig, G. B. and Ramser, J. H. (1959). The Truck Dispatching Problem. *Management Science*, *6*(1), 80-91.

[9] Clarke, G. and Wright, J. W. (1964). Scheduling of vehicles from a central depot to a number of delivery points. *Operations Research*, *12*(4), 568-582.

[10] Hasle, G and Kloster, O. (2007). Geometric modelling, numerical simulation, and optimization. In: Operations Research Computer Science Interfaces. *Springer*, 397–436.

[11] Toth, P. and Vigo, D. (2002). *The vehicle routing problem*. Society for Industrial and Applied Mathematics.

[12] Laporte, G. (1992). The vehicle routing problem: An overview of exact and approximate algorithms. *European journal of operational research*, *59*(3), 345-358.

[13] Ribeiro, J. F. F., Ribeiro, L. C. and Aquino Siquitelli, C. V. (2019). Logística para o recolhimento de frutas: um estudo de caso. *Revista Latino-Americana de Inovação e Engenharia de Produção*, *7*(11), 150-161.

[14] Levin, M. W. (2017). Congestion-aware system optimal route choice for shared autonomous vehicles. *Transportation Research Part C: Emerging Technologies*, *82*, 229-247.

[15] Prajogo, D., Oke, A. and Olhager, J. (2016). Supply chain processes: Linking supply logistics integration, supply performance, lean processes and competitive performance. *International Journal of Operations & Production Management*, *36*(2), 220-238.

[16] Botelho, H.L., Pereira, A.J. and Silva, C.A.M. (2017). Uma Análise Da Roteirização De Veículos Em Uma Empresa Da Cadeia Produtiva Do Aço.*Anais*... I Encontro Internacional de Gestão, Desenvolvimento e Inovação (EIGEDIN), v. 1, n. 1, 1-21, 2017.

[17] Donald J., Bowersox, David J., Closs, M. and Bixby (2014). Gestão Logística da Cadeia de Suprimentos, 101-102.

[18] Soysal, M., Çimen, M. and Demir, E. (2018). On the mathematical modeling of green one-to-one pickup and delivery problem with road segmentation. *Journal of cleaner production*, *174*, 1664-1678.

[19] Guerreiro, T. D. C. M., Kirner Providelo, J., Pitombo, C. S., Antonio Rodrigues Ramos, R. and Rodrigues da Silva, A. N. (2018). Data-mining, GIS and multicriteria analysis in a comprehensive method for bicycle network planning and design. *International journal of sustainable transportation*, *12*(3), 179-191.

[20] Min, H. (1989). The multiple vehicle routing problem with simultaneous delivery and pick-up points. *Transportation Research Part A: General*, *23*(5), 377-386.

[21] Mahmoudi, M. and Zhou, X. (2016). Finding optimal solutions for vehicle routing problem with pickup and delivery services with time windows: A dynamic programming approach based on state–space–time network representations. *Transportation Research Part B: Methodological*, *89*, 19-42.