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Vehicle Routing Problem with time and path flexibility an approach with GIS-T

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***Abstract*— Urban traffic planning plays an important role in the planning, construction and management of urban areas. However, due to the boost in commercial relations that has occurred over the years, the demand for deliveries has been increasing in cities, and, in the case of small companies, solutions that optimize routes and transportation costs have made a difference in a market that has shown to be highly competitive. As a result, the need to adopt managerial measures to reduce logistical costs has become one of the key factors for increasing the competitiveness of small companies. In this way, solutions that allow for the adaptation and re-planning of cargo distributions are part of this new routine. For these reasons, this work aimed to present an approach to the practical resolution of the Vehicle Routing Problem in small companies, using Geographic Information System for Transport. Traffic characteristics and parameterizations were raised through on-site visits and the results of the calibration of the traffic flow estimate suggest that the differences between the estimated and actual flows are 16.4%. Thus, this work can be used by researchers, students, entrepreneurs, managers and transport planners to test improvement scenarios and study performance.*

I. INTRODUCTION

Impacts generated by the COVID-19 pandemic in activities converging to the Supply Chain (SC) have acquired visibility in the contemporary scenario in view of the need to mitigate the intercadency of supply and favor the sustainability of the entire garrison system at global levels (Sarkis, 2020). However, due to the current circumstances, themes related to the behavior of the SC in the face of the challenges of the global health crisis, have presented a limited scope in the literature, as well as work aimed at solving problems involving vehicle routing (Hackl & Dubernet, 2019, Tan, Cai, & Zhang, 2020).

In view of the restrictive scenario, positive and / or negative impacts on commercial relations are observed due to the transformations driven by factors related to the economy, politics and infrastructure. In this context, transport logistics affects and is affected as a result of these external interferences. And, with the worsening of the pandemic generated by the Sars-CoV-2 virus, restrictions such as, for example, regarding the circulation of vehicles, exposed the vulnerability regarding the efficiency of supply chains (Chen, Pan, Chen, & Liu, 2020).

Considering this reason, among others, that makes up the current society, which has been gathering in urban centers, Vehicle Routing Problems (VRP) play a decisive role in distribution and transportation logistics and, in view of this, several variants have been widely studied in the literature (Laporte, Gendreau, Potvin, & Semet, 2000, Alonso-Mora, Samaranayake, Wallar, Frazzoli & Rus, 2017, Oyola, Arntzen & Woodruff, 2017, Oyola, Arntzen & Woodruff, 2018, Ferreira, Steiner & Junior, 2020).

Thus, as the main axis of this work, he devoted himself to deterministic problems, in which all parameters (dimensions and variables) are, in some way, connected to the data of the problem and, therefore, known in advance (Houlihan, 1985, Pisinger & Ropke, 2007, Ferreira *et al*., 2020).

However, in the real market everyday it is common for incidences of uncertainty, which, even with a short time to deliberate, decision makers must take into account. In this context, small companies are highly susceptible to the weather in the market, needing solutions that are adaptable to their daily lives. Thus, the motivation of the VRP studied in this work originates from the urban movement of cargo transportation, in which route decisions are complex and, in most cases, determined by delays that can significantly affect routing plans and delivery times (Fisher & Jaikumar, 1981, Davis, 1993, Thomas & Griffin, 1996, Oyola *et al*., 2018).

For Szczepański, Żak, Jacyna-Gołda and Murawski (2017), VRP must be seen as a broad issue involving several aspects, including technical, economic and social issues. In the opinion of these authors, the determination of the goods delivery plan in the urban area should take into account the questions presented, considering that to solve the tasks, the use of appropriate planning methods is required, as well as verification and confirmation of the results obtained.

Corroborating this view, Brotcorne, Perboli, Rosano and Wei (2019) point out that since the 2000s, with the advent of e-commerce and other widespread information technologies, the way of understanding cargo logistics and transportation has changed extremely. According to these authors, with the increase in deliveries for the Business-to-Consumer (B2C) modality in urban areas, associated with the competition fostered by the platforms of e-commerce giants, raised the market's leveling parameters to deal with growing orders for fast deliveries and decreasing costs.

Therefore, this work presents a practical approach to VRP resolution based on the use of a Geographic Information System for Transport (GIS-T), which, being based on the principle of adaptive search, is capable of providing excellent quality solutions for small companies. companies. To test this approach, an application was made to solve a routing problem in a small coffee processing company.

II. THEORETICAL REFERENCE

Min, Zhongming, Xiaolan, Jiajie and Xueqiang (2017) address the perspective of integrating Geographic Information Systems (GIS) within logistics as a tool to aid VRP and, it has been disseminated as Geographic Information Systems for Transport (GIS-T) since the 1990s with the works of Miller (1999) that present characteristics such as frameworks for transport modeling, data storage and preparation and graphical visualization through coordinates.

According to Loidl *et al*. (2016) in the scope of GIS-T, with regard to transport modeling, there is similarity in mobility behaviors that depends on the proximity and spatial grouping of the respective agents and their origins and destinations. For Ribeiro, Ribeiro and Aquino (2019), this work is significant because it represents a large part of the flow of vehicles for good distribution in cities, seeking a solution for VRP.

Other works that also stimulate this spatial analysis are those by Toledo, Cats, Burghout, and Koutsopoulos (2010) and Caldas and Sacramento (2016), which describe the traffic flow, according to these authors there are three models to consider, being they are the microscopic that usually accompany the destination of each vehicle individually, the macroscopic that takes into account the behavior of a set of vehicles and the mesoscopic that is a combination of dynamic aspects of the previous models.

Over time, there has been a significant development of historical databases. Recent research (Zhou *et al*., 2020) use tools such as Big Data in conjunction with GIS and show trends that make it possible to manage all variables within a given space, in almost real time. Crawford, Watling and Connors (2017), for example, relate transportation with data from mobile devices, smartphone registrations and Bluetooth data, while Tamblay, Galilea, Iglesias, Raveau and Muñoz (2016) associate with electronic ticket data for transportation public. Chow (2016) and Hu and Jin (2017) present tools such as fixed sensor data, Global Positioning System (GPS) and automatic vehicle identification technology (AVI), loop detectors, automatic traffic counters, Trafficmaster cameras, reconnaissance automatic number plates (ANPR) and also the use of location-based social networks network data.

Therefore, these models presented demonstrate how the combination of VRP and GIS concepts contribute to a broader and more precise work and, through current tools, are more effective for very complex situations, which is the case of the COVID-19 pandemic. However, according to Shaw, Kim and Hua (2020) although the pandemic was global, the responses were local, as decision-making depends on the governmental, socioeconomic and cultural context. According to these authors, this analysis must be associated with the sensitivity of the data in different perspectives, thus allowing to illustrate the behavior of SC for better decision making.

III. METHODOLOGICAL APPROACH

VRP has been widely studied in the literature (Laporte *et al*., 2000, Oyola *et al*., 2017, Oyola *et al*., 2018, Ferreira *et al*., 2020), however, as pointed out by Brotcorne *et al*. (2019) there is a need to present proposals that make VRP resolution feasible in the small business operating environment. For this reason, the methodological approach of this work was elaborated for this purpose and, also, that it is adaptable to different situations and scenarios of the urban daily life.

To this end, based on the premises indicated by Miguel (2007), Lohmann, Lacerda, Camargo and Dresch (2019) and Hina, Szmerekovsky, Lee, Amin and Arooj (2020), a conceptual-theoretical structure based on the planning of operationalization and simulation actions, considering casual relationships between control and performance variables, which were analyzed and tested.

As a research unit, the product distribution schedule of a coffee processing company located in the extreme north of the state of Espírito Santo (Brazil) was used. Thus, in agreement with the company's managers, in order to serve as initial parameters for data collection, quantitative items were listed that would be delivered in a given week, in addition to the full addresses of the respective customers, available fleet and routes used.

Thus, the methodological approach was developed through 4 steps (Fig. 1), based on the principles: characterization, modeling, simulation and analysis of results (Miguel, 2007, Lohmann *et al*., 2019, Hina *et al*., 2020). In addition, a georeferenced map of the region to be served was used. The realization of this map was based on the concomitant use of the search and visualization service for maps and satellite images of the Earth - Google Maps and the Google Earth Pro software - version 7.3.

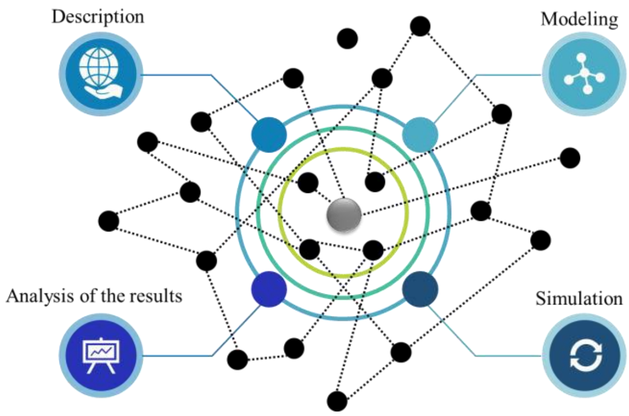

Fig. 1: Synthesis of the methodological approach.

The first stage of the methodological approach carried out the characterization of the VRP considering the local particularities and limitations and, from that, elements were obtained that subsidized for the modeling of scenarios. Afterwards, these scenarios were inserted in a Geographic Information Systems for Transportation (GIS-T), based on a georeferenced map of the region to be served (second stage).

Subsequently, simulations were carried out considering the conditions verified with the company, the service capacity, demand and in loco (third stage). These simulations consisted of using a routing method based on a computational application performed using GIS-T.

Finally, the results obtained were checked for the relevance of service to the company and customers, as well as the adaptability to variations in local conditions (fourth stage). Using GIS-T to analyze routes, in order to minimize the total distance traveled, when comparing routes defined by the empirical method used and the computational solution.

In addition, to help operationalize the proposed methodological approach and, considering that VRP at specific points in the urban environment is an arc routing problem (Laporte *et al*., 2000), this work used a GIS-T for the development of routes (Yona, Birfir, & Kaplan, 2021), using TransCAD (Transportation Planning Software - Version 6) which uses arc routing algorithm to model and optimize routes on roads using minimum path and less time.

IV. RESULTS

The target company of this work has a purity and quality seal from the Brazilian Coffee Industry Association and its main processes are refining, baling and distribution. Currently, it works with 2 types of products, Conilon coffee type 6 and type 7, which are packed in 500-gram packages and subsequently distributed in bales of 10 units.

The distribution of products is carried out in some municipalities in the north of the state of Espírito Santo (Conceição da Barra, Pedro Canário, Pinheiros, Nova Venécia, Jaguaré, Linhares and São Mateus) covering retailers, from small establishments to medium-sized companies, located in urban area, however, in a decentralized way. Due to its geographical location and social and economic importance for the development of the region, the municipality of São Mateus was selected, as it also hosts the company that is the object of the research unit. At the time this work was carried out, it had a structure composed of an office, a refining station and two vans (Volkswagen Kombi) to operationalize the distribution of products.

However, due to the company's marketing and sales strategies, the vans have different functions, one is intended to provide prompt delivery in small establishments, and the other to telemarketing, in order to guarantee weekly deliveries of quantities. requested, with each order adjusted via the company's communications channels. Within this context, the telemarketing delivery system was used as a research unit, due to the fact that it fits as a VRP when it has fixed locations for service, something that does not happen with the distribution through prompt delivery, in that demand is variable, thus making it impossible to develop optimal routes.

The first stage of the methodological approach started considering the particularities of the company, and so the present work sought to elaborate routes that help in solving a problem about vehicle routing and, with this, aimed to optimize the total distance covered and, consequently, the time and the costs associated with transport in the distribution network. Thus, when previously analyzing the locations and possible routes to serve the company's weekly customers, it was possible to notice that the sequence of stops significantly influences the distances and times (Table 1).

Table 1: Compilation of fixed calls to be made.

Customer	Address
Sup Vila Nova	Rua Colômbia, 56, Vila Nova
Sup Santo Antônio	Rodovia BR-101, 2063, km 64, Santo Antônio
Extrabom C	Av. Jones dos Santos Neves, 504, Centro
Extrabom BR	Hwy. BR-101, 2063, km 64, Santo Antônio
Sup Zampirolli	Av. José Tozzi, Centro
Sup Casagrande	Av. Jones dos Santos Neves, 616, Sernamby
Sup Carioca	St. Arlindo Sodré, 260, Ideal
Rondelli	St. Monsenhor Guilherme Schmitz, Sernamby

Legend: Supermarket (Sup). Center (C). Avenue (Av.). Street (St.). Highway (Hwy.).

Supply movement operations in the urban environment, according to Rodrigues, Rocha, Alves, Junior and Junior (2016) and Najaf, Thill, Zhang and Fields (2018), can take different forms and, with this, different strategies to be implemented, for example, traditional collections known in the literature as direct collection or collection, and consolidated collection (milk run). In this work, the milk run strategy was selected to be used, as it provided conditions to operate with more than one collection point related to a single vehicle for the modality studied (Ramos, 2015).

At first, to prepare the modeling of the company's current distribution scenario, the fixed services (Table 1) were inserted in a map (Fig. 2) in order to subsidize the survey of parameters and characteristics of the roads (Yona *et al*., 2021).

In addition, considering that customer service is provided by the main routes and vicinal, through a GPS and on-site observations, the following were raised: conditions of the road infrastructure; travel generating hubs; average speed; number of traffic lights and average time per stop.

However, it is worth noting that the survey carried out in loco provided visualization in addition to the geometric and spatial conditions and parameterization of roads, being possible to verify that the total average order in a cycle of the delivery process is 945 kilograms, less than the capacity of the vehicle, approximately 1000 kilograms, something equivalent to 200 bales of coffee. Therefore, this delivery process does not constitute a restriction on the distribution process, being considered in the inputs for the modeling (Fig. 3).

To assist in the modeling of the VRP, a georeferenced map of the urban region of the municipality of São Mateus (Espírito Santo - Brazil) was prepared using Google Maps and the Google Earth Pro software (Fig. 2), in order to support the modeling and scenarios (second stage of the methodological approach).

Fig. 2: Geographic positioning of customers. Adapted from Google Earth.

In this way, the routing matrix was formed from the parameters of the dataview - Customers (Fig. 3). Thus, the distance between each customer was used in the analyzes. Based on this definition, and when using the Facility Location tool from TransCAD, simulations considered the grouping of customers at random, taking into account that all would need to be compared with each other.

Fig. 3: Dataview parameters - Customers.

ID	Longitude	Latitude	NUMBER	[NOME FANTASIA]	[DEMANDA]	OPEN_TIME	CLOSE_TIME	SERVICE_TIME
2	-87408949	30499670	2	SUP. VILA NOVA	60.00	14.00	17.00	6.00
3	-87412067	30500262	3	SUP. SANTO ANTON	110.00	14.00	17.00	18.00
10	-87409784	30500274	10	SUP. EXTRA BOM B	110.00	14.00	17.00	15.00
11	-87403848	30500640	11	SUP. EXTRA BOM C	180.00	14.00	17.00	20.00
6	-87404012	30501030	6	SUP. ZAMPIROLLI	70.00	14.00	17.00	8.00
7	-87404037	30500130	7	SUP. CASAGRANDE	245.00	14.00	17.00	27.00
8	-87401938	30498919	8	SUP. RONDELLI	130.00	14.00	17.00	20.00
9	-87401289	30501386	9	SUP. CARIOCA	40.00	14.00	17.00	6.00

Source: TransCAD.

However, the development of optimal routes for the distribution process (meta-heuristic problem), used the optimization of the distance covered as a resolution of the VRP. It is worth mentioning that due to security conditions, a high rate of robberies and thefts in the region, the circulation of the van was established through the main access roads of the city.

According to Min *et al.* (2017) and Yona *et al.* (2021) to use a GIS-T, it is necessary to know the location of each client on time and, from that, build scenarios that can optimize routes that consider time and distance traveled. Thus, considering the initial data entry preparation (Table 1, Fig. 2 and Fig. 3) and the georeferenced map of the area under study, geographic characterizations (Fig. 4), routes, directions (hand and opposite direction) were verified), speed limits, company warehouse location and delivery points (customers), as well as information on demand and supply time restrictions (Open Time and Close Time).

Achieving an economy in the distribution of products that expands the range of results of the studied company, depends on several dimensions and variables present in the "universe" of urban mobility that, although they are present in the daily business, for several moments, do not present themselves in a deterministically and neither are they interrelated in order to provide consistent analyzes to assist in decision making (Castillo *et al.*, 2018).

Apparently, the current route used by the company was well balanced in terms of ease of use and delivery options. However, for calibration and validation of the modeling, 1-hour assignments were used as they provide important information for adjusting network and / or land use errors. This premise was adopted according to Chow (2016), Szczepański *et al.* (2017) and Brotcorne *et al.* (2019), considering that any signage (vertical and/ or horizontal), bulkhead or "centroid connector" that does not have a direct function to regulate traffic can be important for traffic analysis or incorrect use of the soil. Another point to be highlighted is that this premise helped in the counting reconciliation process, thus, the matrix estimation procedure was replicated until a set of acceptable attributions was obtained.

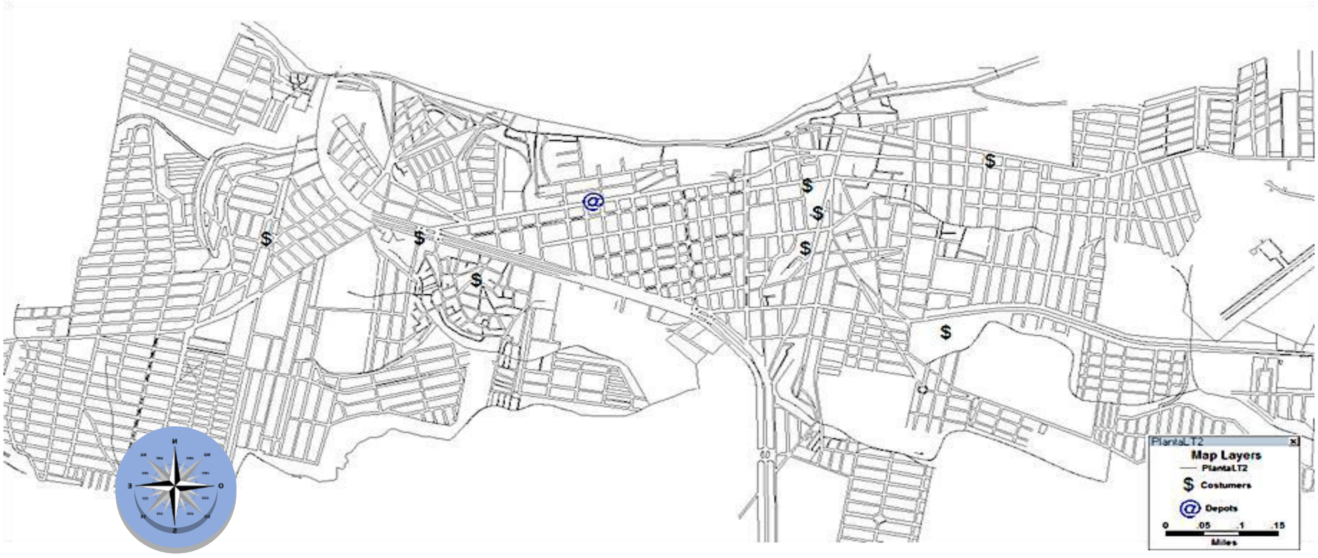

Fig. 4: Location of the company and customers for use in TransCAD.

Source: TransCAD.

Then, the TransCAD routing routine was used to solve the VRP, creating optimized routes for the vehicles of the company's fleet. Thus, for the operationalization of this routine, time windows were considered to meet the demand, that is, to operate loading and unloading of goods on Mondays to Fridays from 8:00 pm to 8:00 am; on Saturdays from 2pm and on Sundays and holidays throughout the day (São Mateus, 2017), and from employees. In addition, travel time restrictions, collective headway (time interval between departure and arrival by bus) and time for loading and unloading operations for employees and goods were also considered.

From this context, the characterizations of the base scenario presented so far, sought to reproduce the current pattern of distribution of goods used by the small coffee processing company. On the other hand, according to Zhou *et al*. (2020), to help obtain the optimal route, 3 scenarios were generated in order to identify the one that provides satisfactory results and optimize the route in terms of distance traveled. Thus, the first scenario considered the mandatory return of vehicles to the company's deposit in the event of the possibility of discontinuing the service of 2 or more customers, maintaining the same parameters established in the base scenario; in the second scenario, the use of multiple bases was introduced, that is, data from alternative routes in case of physical obstructions, to operate the van, without returning the vehicle to the base. All parameters of the base scenario being maintained and, finally, the third scenario also uses multiple bases, however, with the determination to return the vehicle to the base in case of discontinuity of operation for some reason, also considering the parameters of the base scenario.

Based on the scenarios presented above, a comparative analysis between them was carried out through TransCAD. The first scenario in which the return of the van is necessary, 5.43 km traveled in 4.12 hours, when confronted with the base scenario, in which this obligation does not exist, it was observed that there is an increase in the total distances and times of trip compared to the base scenario (3.20 km traveled in 3.18 hours - measurements obtained in monitoring delivery when the data collection stage was performed). These differences can be attributed to the distance traveled being greater and, therefore, the return to the deposit.

When evaluating the reason for the increase in the total travel time in the first scenario, higher than the second scenario (6.27 km covered in 3.35 hours), it was observed that this occurs, among other possible causes, due to the increase in time and travel distance of the van for mandatory return to the deposit. Confronting the second scenario, which uses multiple bases in the preparation of the routing (without returning the van to the warehouse), and the base scenario, which uses a single base, it is noted that there is an increase in the distance traveled and travel times for the second scenario in relation to the base scenario. The explanation for this increase may be related to the poor conditions of the circulation routes used (Bartholomeu & Caixeta Filho, 2008, Moreira, Freitas Júnior, & Toloi, 2018, Brotcorne *et al*., 2019), as well as, in the high number of vehicles in a precarious situation used on these roads.

After this verification, a comparison was made between the second scenario and the third scenario (2.75 km covered in 2.33 hours), in which the difference between both is the mandatory return of the vehicle to the base in case of discontinuity of operation. for some reason (third scenario), for this reason, there was a proportional increase in distances and travel times.

Regarding the service time, considering the stop time and bus stops nearby, there was no difference between the scenarios tested. This fact can be attributed to the rigor of inspection and, also, to the observation and attendance of fixed times for each bus stop (about 1.5 minutes on average) and, for each boarding or disembarkation (9 seconds on average).

Thus, considering the comparative analyzes and the result of the optimal route that minimizes the total distance to be traveled among the scenarios (Fig. 5), the results indicate that the best alternative for the company's goods transportation is the third scenario, that is, the one that adopts multiple bases without return of the van. The optimal route consists of leaving the vehicle from the warehouse to make the distribution according to the route and numbering that can be seen in Figure 4, in which: (1) Santo Antônio Supermarket, (2) Extrabom BR, (3) Vila Nova, (4) Rondelli, (5) Carioca, (6) Zampirolli, (7) Extrabom Centro and (8) Casagrande. At the end of the journey, the delivery vehicle returns to the warehouse.

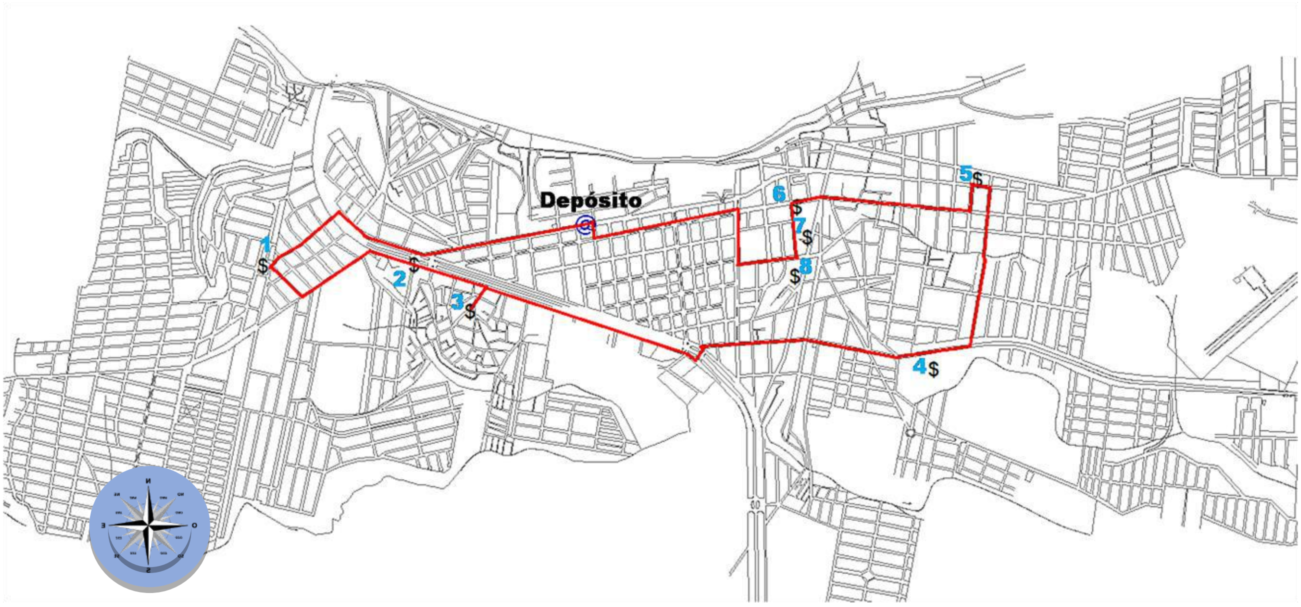

Fig. 5: Map of the optimal route of the distribution operation.

Source: TransCAD.

It is important to highlight that the adoption of a single base for the distribution operation is the only viable alternative and this is confirmed by the shorter distances and shorter travel times used in these operations. Thus, according to the result presented by TransCAD, the solution for the VRP has an optimum distance of 1.71 miles or 2.75 km, compared to the value of the route previously carried out, which has a distance of 3.20 km, resulting in savings of 16.4%. In this way, the variable cost of transportation per kilometer of the company in the distribution by telemarketing will also benefit from this savings. In this way, the variable cost of transportation per kilometer of the company in the distribution by telemarketing will also benefit from this savings. This fact was also confirmed by Luo *et al*. (2017) in their work by highlighting that the approach to a new vehicle routing problem involves simultaneously windows of time, split delivery, related costs, among other dimensions and variables specific to each case. In the opinion of these authors, the cost of travel per unit of distance is a linear function of the vehicle's weight and the customer's demand that can be met by one or more vehicles, solving the VRP effectively.

This economy and the possibility of enhancing gains also include the use of a GIS-T being the least need for manpower to prepare routes manually, in addition to allowing the reduction of working hours in terms of training personnel for this purpose. As well as expanding horizons regarding the planning of distribution logistics. And, from that, it becomes possible to provide improvements in the company's operational efficiency, as well as in the sector's supply chain.

V. FINAL CONSIDERATIONS

This work presented a methodological approach that can contribute to the planning and operation of deliveries in new daily situations of small companies, as well as, in terms of implementation and improvement for local development and other surrounding municipalities. In order to adapt to the new and constant market changes, small companies will need to have solutions that allow them to be competitive and that these solutions work efficiently in at least a year and a half.

In this way, it reached the main objective of presenting an approach for use in the practical resolution of small business VRP, employing a GIS-T in the elaboration of routes. The presented solution allows an adaptation to different scenarios and conditions, in addition to specific parameterizations that become necessary. For example, the company that served as a research unit did not have a computational solution for the elaboration of routes, and the distribution activities took place in an exclusively empirical way.

Therefore, with the presentation and initial implementation of the proposed approach, it was possible to improve efficiency in terms of deliveries and other activities related to product distribution. Today, all routes are previously analyzed, planned and defined, with this, managers now have a resource that allowed them to be financially sustainable, that is, the constant optimization of costs.

However, during the simulations it was noted that the arc routing was not ideal for the locations served. Also, it was not for locations where customers do not have physical service conditions within the dimensioned schedules, that is, they do not have a fit to the needs of adequacy, diversified or alternative schedules - such as time windows, for cost optimization.

The results obtained thus contribute proactively to the planning of distribution and deliveries in an urban environment. The responses with the use of GIS-T compared to that presented by the company, reinforce and highlight the importance of using computational tools to optimize distribution services and delivery routes.

The use of GIS technology has been moderately explored, with regard to small enterprises and in terms of urban transport planning in Brazil, although several actions involving georeferenced maps, information technology and heuristics for VRP resolution are also used in commercial activities frequently. Thus, this work presented some of the difficulties faced by small companies and, certain benefits resulting from the daily use of GIS-T.

Finally, the aim is not to exhaust the topic, but to exalt the use of computational resources that assist in the elaboration of solutions for VRP in the daily life of small companies. Likewise, it was intended to demonstrate to public managers that it is plausible to adopt current concepts of transport planning at different levels of use of the urban environment. Considering trends and variations in market behavior, globalization of commercial relations, among other dimensions and variables that directly and indirectly involve VRP.

It is suggested that the next researches may consider and analyze the existing multivariate relationships between the component elements of this work and, multicriteria analysis to assist in the selection of alternatives.

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