

Comparative Analysis between Routing Methods Systems Applied to the Rural School Transport Problem in Brazil

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ABSTRACT

The Rural School Transport has particularities such as the complexity of the routes, the students' dispersion in the geographic areas, the practical costs and the lack of capable professionals to work with geographical data. For this reason, the solution of the rural school transport routing problem requires an application of specific methodologies.

The School of Engineering at the Federal University of Minas Gerais, Brazil (UFMG) developed a tool entitled TRANSCOLAR to calculate school bus routing. The implanted methodology allows the georeferencing of every existing school, student and route, thereby enabling the optimization of these routes and providing better-qualified transport at a lower cost to the population.

The assumption was that the model should be intuitively handled, so the platform was designed for web-format use, personalized for rural school transport, in which the commands are easily utilized, dismissing a geoprocessing specialist for its application.

In the present article, the proposed model is compared to traditional routing softwares: TransCAD and ArcGIS. The city of Santa Leopoldina/ES, in Brazil was chosen as a case study. The objective of this article is to evaluate the benefits added to the new proposed methodology.

Keywords: GIS, Rural School Transportation, Spatial Analysis and vehicle escolar routing.

1. INTRODUCTION

Rural School Transport is a primary and important service offered by the government to guarantee school access to many students that live in rural areas. Studies conducted by the National Educational Development Fund of the Brazilian Ministry of Education (MEC) in partnership with the University of Brasilia (UnB) – Learning Center of Human Resources in Transport (Ceftru), point out that in Brazil 6.7 million students enrolled in basic education public schools reside in rural areas or study in schools that are in those regions. From this total, more than 4.8 million students depend on public school transport to get to school.

With the objective of reducing the time spent by students in the journey from home to school, the total distance covered by the vehicles and the number of vehicles required, vehicle routing is performed, enhancing the quality of the offered service and reducing the costs expended in its provision.

According to Silva *et al.* (2007) [2], the paths in a rural scenario are significantly longer if compared to an urban configuration. This justifies the proposition of a specific methodology that focuses on defining an optimal route in order to minimize travelling time, optimize vehicle occupation and better meet the existing demands. This results in lowered costs and enhanced quality of the system.

The use of GIS tools has been largely explored in routing problems' solutions, in order to make complex decisions in a quickly and safe way, saving time and money in data analysis [3]. However, the use of GIS tools requires specialized labor and equipment for its operation, which hampers its applicability in Brazilian rural areas, since there is a shortage of skilled labor to deal with this kind of technology.

Considering the needs of a specific methodology to apply in routing for rural areas, the Department of Transportation and Geotechnical Engineering at the School of Engineering at the Federal University of Minas Gerais, with resources from the National Educational Development Fund (FNDE) developed the Transcolar Rural project [4]. Transcolar Rural is a routing system designed from georeferenced data that generates the best route for student transportation considering fixed and operational costs of the service.

As a validation of the designed model, this work proposes a comparative analysis between Transcolar and two other traditionally used software's in routing problems: TransCAD and ArcGIS, in order to evaluate it in terms of its applicability and operational ease.

2. BACKGROUND

Geographic Information Systems (GIS) is a computational database management system to capture and treat space data that is used in Transports Engineering.

Transcad

TransCAD is a GIS software developed to plan, manage operate and analyze transport data [5]. The software disposes of various modules for data manipulation in terms of entrance, storing, analysis and final presentation. TransCAD has a modular and open architecture that can be amplified by

procedures scripted by the user in coding languages. The software has its own programming language, denominated GISDK (Geographic Information System Developer's Kit). GISDK allows the creation of a wide variety of products to make analysis and mapping functions. Approximately 800 language functions can be used to extend TransCAD capacities with the creation of customized interfaces for the user targets [5].

Clarke and Wright heuristic (1964), also known as economies method, is one of the most consecrated heuristics of constructive methods, and also one of the most utilized in TransCAD routing problems solutions. Its objective is to minimize total distance covered by the vehicles and, as consequence, the number of needed vehicles. It permits generating routes that embody diverse types of time restriction and capacity [6].

Prata (2009) utilized the TransCAD software for the routing of rural school transport. However, the author didn't use the Clarke and Wright algorithm. Prata developed an algorithm that was more adequate than Clarke and Wright's for Rural School Transport routing and created an interface in TransCAD to use it to make the route. To analyze her tool's performance, she successfully performed the school transport routing of two towns [7].

Arcgis

ArcGIS is a Geographic Information System developed by ESRI. Network Analyst is an extension of ArcGIS that allows the solving of routing problems in a rather simple and straightforward manner [8]. The route solver in ArcGIS NA uses the Dijkstra algorithm to find a route through the set of stops with minimum cost [9]. It breaks the network into nodes and lines, and each line connecting two nodes has an associated cost (length). The shortest path between two nodes is selected after a series of comparative iterations. This process presents acceptable solutions that demand low computational time; however, it does not always yield the best solution. For this reason, ArcGIS NA improves the solution through the Tabu-Search heuristic process.

Sanjeevi and Shahabudeen [10] used the Network Analyst extension In ArcGIS to plan efficient routes for solid waste transportation in Chennai, India. This type of problem works in the same manner as school transport, with pick up points (nodes) and the road network (lines). The aim is to visit each node only once, and to do so traveling the minimum distance. They solved the shortest path problem and were able to improve around 10% the total distance, and around 11.5% the travel time, compared to the previously existing routes.

Transcolar

Transcolar Rural system is a GIS system developed by researchers from the School of Engineering at the Federal University of Minas Gerais. It embraces, from the municipally scope, schools, students and the road network, and determines a group of routes and their respective costs to transport every residing student in the area in order to obtain the smaller possible transportation cost [11].

Quality parameters as the time a student can stay inside the vehicle in a trip, the distance a student can cover on foot to the bus stop, among others, are considered and can be modified by the users to obtain new results. An important factor in the

developed system is that the user does not need to be a GIS specialist. The system has been fitly designed to avoid the need of a qualified professional in every city hall. The system's operation is simple, and the result is fully generated in an automatic and transparent way to the user. The proposed methodology guarantees the consistency of obtained results along with the government's control institutions that also support the initiative.

3. METHODOLOGY

A real routing problem can be defined by three fundamental factors: decisions, objectives and restrictions. The decisions involve the scheduling and visit sequencing of a group of clients that must be reached by a set of vehicles and its respective drivers. The main objectives will be defined according to the problem but consist in providing the client with a high-level service through variables optimization. The routing problem solution must obey the imposed restrictions and the routes must be defined in a way to achieve all the undertaken compromises with the available resources [8].

To Perform rural school transport, many vehicles leave one or various parts of town, pick up the students in their residences or pre-determined bus-stops and lead them to the school or its surroundings. At the end of the school shift, the vehicles pick up the students at school and take them back home. This routine is performed to students in the morning, afternoon, evening and full-time shifts, and the students may be in daycare, kindergarten, pre-school, middle-school, high-school or even adult education and special education.

The proposed Methodology consists in performing the routing process in TransCAD, ArcGIS and Transcolar, the case-study being the town of Santa Leopoldina, ES/Brazil.

Characterization of the study area

Santa Leopoldina (Figure 1) is located in Espírito Santo/Brazil and has 718,097-km² of area [9]. The municipality is located 46 km from the state capital, Vitória, and is surrounded by mountains with relief that reaches more than 900 meters above sea level. In 2016, the estimated population was 12.887 inhabitants and its population density is 17,95 hab/km² [9]. In IBGE's Demographic Census (2010) it was noted that, in 2010, 79% of Santa Leopoldina's population lived in rural areas, which reinforces the need for public policies to improve the quality of life in rural areas.

ESPIRITO SANTO STATE - BRAZIL

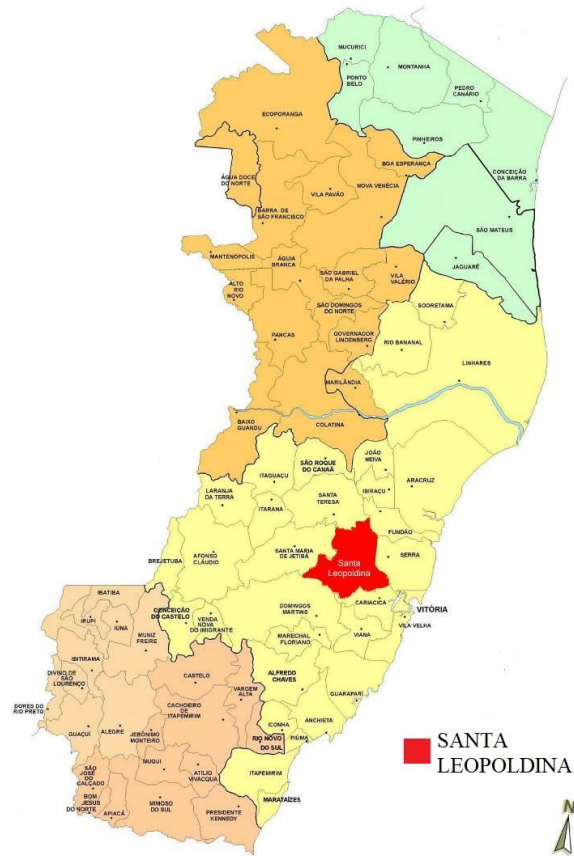


Figure 1: Location of Santa Leopoldina in Espírito Santo State, Brazil

Restrictions Definitions

The restrictions defined by Transcolar Rural will be considered in the model application, which are shown in the Tables 1, 2,3 and 4.

Table 1: Vehicle Information

Vehicle	Capacity	Quantity
Bus	40 students	Unlimited

Table 2: Students Entitled to Rural School Transport

Students	Minimum distance between school and residence
State School	3000 meters
Municipal School	2000 meters

Table 3: Maximum distance covered by foot by the students

Student Type	Maximum Distance
High School	3000 meters
Elementary School	2000 meters
Pre-School	1000 meters
Special School (APAE)	0 meters

Table 4: Other Restrictions

Maximum advance for a student to arrive at school	15 minutes
Maximum distance a student can cover in the vehicle	60 kilometers
Vehicle's maximum speed	40 kilometers/hour
Maximum Distance between the pooled schools	2000 meters
Average time spent by the vehicles at each stop	1 minute
Average time spent by a student to board the bus	15 seconds

Considering the maximum distance allowed for a student to cover inside the vehicle and the maximum speed determined, it is concluded that the maximum time spent by the student inside the vehicle is 1h30.

The designed model will consider all the roads are two-way. The average speed considered for the whole network is 40 km/h. For this reason, while analyzing the defined routes and schedule it's necessary to keep in mind that the trajectories' duration may be longer or shorter, depending on the type of road it covers. Sometimes the path will need to be redefined, if it goes through a road that does not allow vehicle flow in the defined direction.

Despite 1198 students being registered to use the Rural School Transport service in Santa Leopoldina, only 962 could be located. From this total, some will not be inserted in the routing process because the current traced road network does not cover their residences areas. As the model improves, these students should be included in future work.

4. ROUTING PROCESS APPLICATION

Transcad Routing

The results presented in this article include only the routing of the morning shift, going trips, to illustrate the obtained results (Figure2). For the TransCAD model three possible scenarios were executed: First the routing process is applied considering all the registered and located students; then a new scenario is created, ignoring students that live near the schools; lastly, the third scenario considered the existence of bus-stops located between close schools, the stops being located two kilometers away from the schools, at most.

The routing was successfully executed, observing the number of vehicles needed being reduced when compared to the different scenarios designed in the software. The third scenario was the one that showed the least vehicles needed in the school transportation.

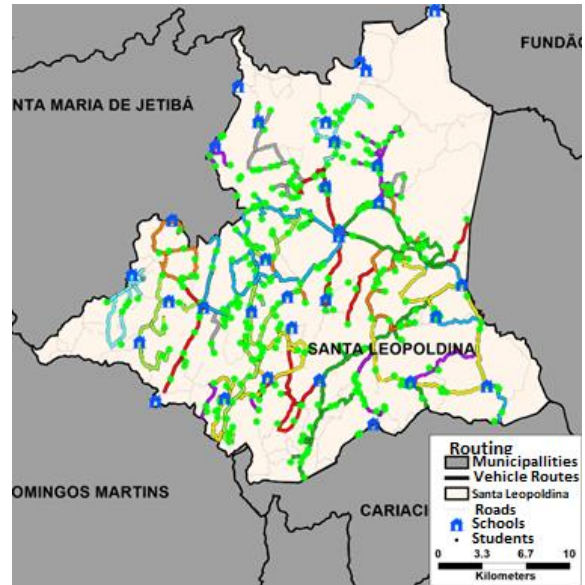


Figure 2: Third Scenario using TransCAD: Morning Shift – Going Trip

The main difficulty in finding a good solution to the routing problem using the TransCAD software is the algorithm it uses to find the solution: the Clarke and Wright method (1964). This algorithm considers that the vehicles depart from a deposit, cover all the collection points and go back to the same deposit. In the school transport offered by most of the municipalities the vehicles may leave not only from the schools, but other garages (the driver's place, city hall garage, or transport company deposit), for which locations are unavailable. The vehicles pick up the students at their residences or nearby bus stops and take them to school. The algorithm provides good solutions if the vehicles only transport students from the same school, since the schools can be considered as the previously mentioned deposits. However, it depends on a wider data treatment to calculate the route in a way that the same bus can transport students from different schools, optimizing vehicle occupation.

The creation of a TransCAD interface through the compilation of a macro in GISDK language to automatize the needed procedures to apply the methodology is recommended. It is also possible to use the GISDK language and other available functions in TransCAD to create an interface that uses a more adequate algorithm to Rural School Transport than Clarke and Wright's.

ArcGIS Routing

The best route can be determined in ArcMap using the Network Analyst extension. A Network Dataset must be created by selecting the feature classes that will participate in the optimization. Following this step, the output will be a network dataset that can be used to find the best routes. Once the network dataset is created, we use the network analyst toolbar, where we can select from the drop-down menu the type of analysis we wish to make.

The next step is to select the layers that will be used as stops, which in this case are the students' and the schools' layers. It is important to query the layers to display only the students and the schools that are of interest for the analysis. The school's

location must be locked as first or last stop, since it is always either at the start or at the end of the routes. Once this is done, we only must click on the “solve route” button on the network analyst toolbar and it will find the best route that covers all stops.

This procedure was adopted for the students in the morning shift for the School (EEEFM) Alice Holzmeister. Two scenarios were adopted and the results of the second scenario are presented on Figure 3. While very efficient and time saving, the results that the ArcGIS yield are not always the best solution. It is possible to find better solutions using different algorithms, and in some cases even making manual changes in the route, such as moving the initial stop. However, as Karadimas *et al.* [8] have noted, the Network Analyst solution still presents a substantial improvement over the empirical model, and very similar to the results yielded by the ACS algorithm, taking much less computing time.

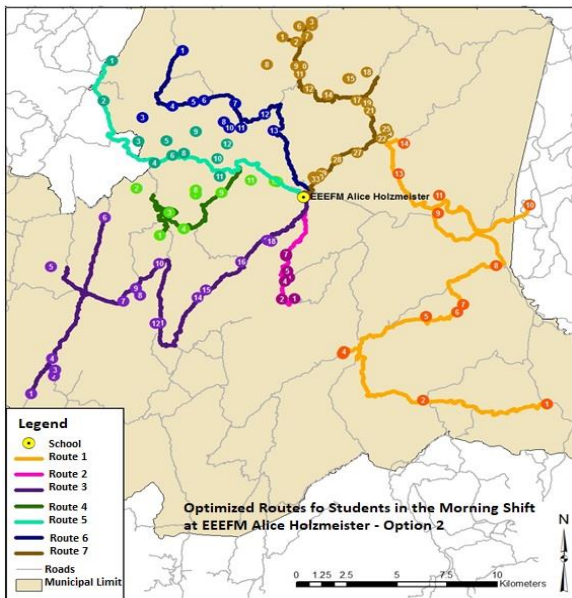


Figure 3: Second Scenario using ArcGIS: Morning Shift – Going Trip

Transcolar Routing

The TRANSCOLAR routing process is performed through the website <http://transcolar.eng.ufmg.br/>, in which every registered municipally has a login and password. The entire routing process is designed specifically to provide the rural school transport, in which the data are inserted in a simple, intuitive way, dismissing the need of a geoprocessing specialist to operate it. Furthermore, the online model does not demand the acquisition of advanced software or state-of-the-art equipment. It is a free, accessible and user-friendly platform.

In the “Optimization and Traveling Cost” tab, the user defines parameters such as maximum distance covered by a student by foot to arrive at the bus stop, if the routing will include municipal, state, or both types of students, and the maximum distance traveled by a student inside of the vehicle. If the parameters are established, new route scenarios were generated.

Figure 4 presents the routing result obtained for the morning shift, going trip.

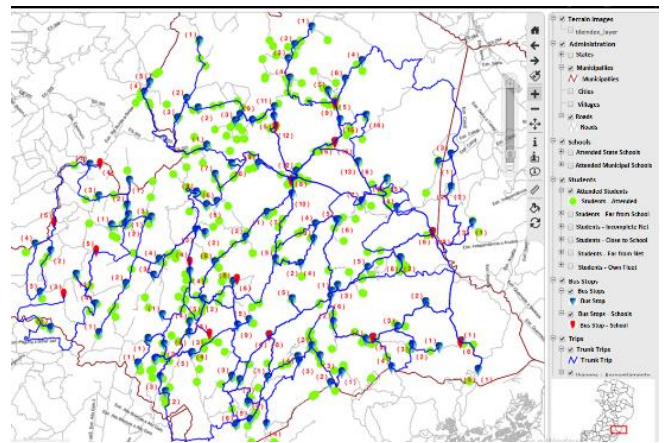


Figure 4: Transcolar - Morning Shift – Going Trip

The proposed model successfully executed the routing and had a simpler performance than the traditionally used models for this kind of problem.

Transcolar has already been applied to the whole state of Espírito Santo, and between all the registered municipalities showed a reduction in the total of vehicles used in the rural student transport. The proposed model has also shown a reduction in the annual cost of the transported students in 2017, for every analyzed municipality of the State (Figure 5).

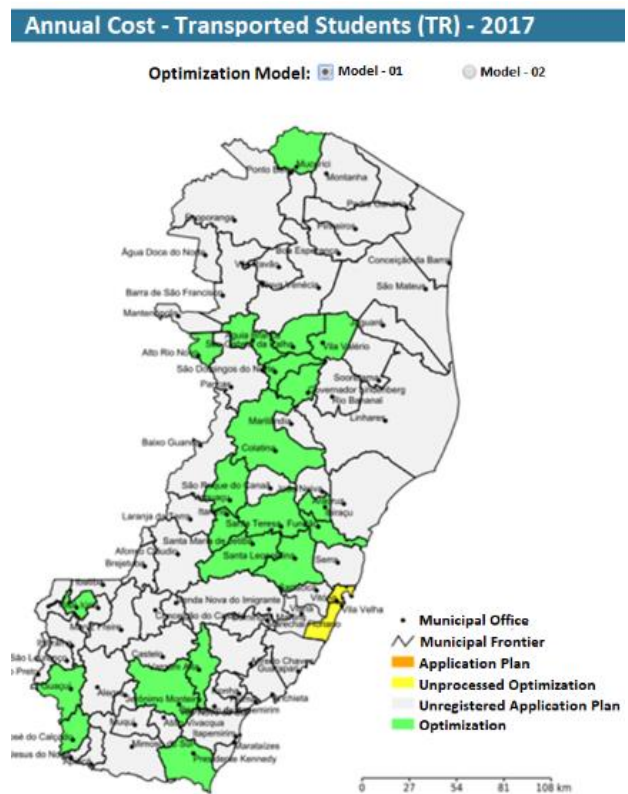


Figure 5: Annual Cost of Transported Students in Espírito Santo, Brazil

5. CONCLUSIONS

Rural school transport is a public service that represents a great challenge for municipalities in the interior of Brazil, since this is a service that requires trained professionals to develop logistics that generate lower operating costs and greater efficiency in the system to meet rural population in the best possible way.

These were the motivations of the School of Engineering at UFMG for the development of the Transcolar: a simple and personalized tool for the rural environment that contributes to the resolution of rural school bus routes.

The platform was designed for web-format use, personalized for rural school transport, in which the commands are easily utilized, dismissing a geoprocessing specialist for its application.

In this article, the Transcolar was compared to two traditional routing methodologies: TransCAD and ArcGIS. The software's were performed in the school's route of the municipality of Santa Leopoldina in Espírito Santo State, Brazil. It is worth noting that this is a mostly rural municipality, which reinforces the need of the optimization of the the rural school transport system in the city.

Comparing the three methods, TRANSCOLAR has advantages for its using easiness, being a free to use platform held in the web, which makes huge-capacity hardware unnecessary for data processing.

TRANSCOLAR is already being implemented in the whole state of Espírito Santo. Every evaluated municipally has shown reduction in the quantity of vehicles needed and, therefore, in the annual cost of the transported students.

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