Methodology for GIS-based Assessment of Rural School Transport Routes in Espírito Santo, Brazil

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ABSTRACT

Given the difficulties and high costs of providing school transportation in rural areas, the UFMG School of Engineering, in partnership with the government of Espirito Santo, have developed a route optimization software. The present article presents a methodology for the assessment of existing routes using ArcGIS software. The municipality of Linhares was chosen as a case study. The results of the GIS-based analysis and the optimization demonstrate that it is possible to significantly reduce the cost, and therefore excessive spending of public funds in rural school transportation.

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

1. INTRODUCTION

The Brazilian countryside is characterized by a very low population density that stretches over great extents of land. Such population spread combined with poor infrastructure mean that students in these regions have to travel long distances to arrive at the nearest school every day. The rural population in Brazil corresponds to 15.64% of the total and has been gradually decreasing both in percentage and in absolute terms since 1970 [1]. As a consequence, there has been a constant trend to reduce the number of rural schools, placing them in more centralized locations. This means, however, that the distances travelled by the students to and from schools has also increased substantially, especially for those living in more remote places. The number of schools in rural areas fell from 92,172 in 2006 [2] to 63,049 in 2016 [3], a drop of 31.6% in only ten years.

According to the Brazilian constitution, it is the State's obligation to provide free basic education and to guarantee the means of transportation for the students [4]. In rural areas, the need for school transport is essential, as the distances are often very long and there are no regular and reliable bus services as in the urban centers. To fulfill its duty the State must either hire private transportation providers or purchase vehicles to be publicly operated. In either case, it must comply with the requirements of the law Nº 8.666/96, which regulates the public bidding process, intended to ensure the best use of public funds [5]. A comprehensive database is an essential tool for the implementation of the optimal solutions. With more data available, it is possible to establish reliable parameters to support the economic feasibility studies for the best option, whether public or private, and analyze the bids made by the bidding companies.

In order to create a tool that provides a solid base for this process, the Federal University of Minas Gerais (UFMG) developed a project in partnership with the Government of the State of Espirito Santo. The aim was to create a database containing georeferenced information on students, schools, routes, stops and vehicles, and subsequently develop a route optimization software. Many governments and organizations have adopted Geographic Information System (GIS) softwares to perform complex problems in a quick and economic way, which greatly improves the efficiency of data analysis [6]. These softwares, however, because of their complexity, require skilled workers to operate them. The smaller municipalities often lack trained personnel for such activities. To avoid this issue, the intention was that the developed software should be easily manipulated by anyone, without the need of extensive previous training. Therefore the interface should be simple and intuitive and the results should be presented in a clear manner. This would thus simplify the access to georeferenced data, enabling even the smaller municipalities to improve their school transport.

This paper focuses on the data acquisition phase, especially in regards to the existing routes. An essential step for a successful optimization is gathering information on the current state of the routes, in order to have a reliable basis for comparison. This data was not readily available, requiring a field research that was carried out in the entire state of Espirito Santo. At the end, a case study is presented for the municipality of Linhares, comparing the results of the optimization to the existing situation.

2. RELATED WORK

GIS (geographic information system) is a "computer-based system that links spatial data (streets, buildings, vegetation, etc.) with tabular data, making it possible to analyze, store, and query the data in map format." [7] This characteristic has made the GIS technology a very useful tool in the transportation sector. It is possible to use it to solve a wide variety of problems, among them school bus routing. "Properly used, GIS can determine the optimum bus route distance, identify student residences, analyze bus stops and their proximity coverage, describe types of land use, and provide road and pedestrian characteristics". [7]

Buliung et al. [8] used ArcGIS to estimate the shortest path from home to school and in the opposite direction. They acquired information on the real routes taken from parents, by asking them to draw them on a map, and were able to compare them to the routes found on ArcGIS using the Network Analyst tool. To generate these routes they "auto-geocoded student home addresses and manually adjusted them to respondent home locations." Then, they proceeded to digitize school locations and respondents' reported to- and from-school routes using orthoimagery. They "manually adjusted school locations to the main door of the school building associated with the school address". They estimated for each of the two routes taken by the students (to- and from-school) a mode-conditioned (walked or driven) shortest path between each child's home and school, using different impedances and data sets for each of the modes.

Jin and Lee [9] analyzed the accessibility improvement for bus users due to a reassignment of bus routes in the city of Chungju in South Korea using GIS software. The "GIS framework was employed for collecting data on demands (total population, senior citizens , and student population), road networks, bus routes, etc." The new routes were compared to the previous settings, examining the "serviceability improvement due to city bus reform without further monetary investments, by analyzing some changes in the number of citizens who can access the service before/after the reform and the time saving effect."

Sanjeevi and Shahabudeen [10] used ArcGIS to plan efficient routes for solid waste transportation in Chennai, India. They cite several cities around the world that have already used GIS tools for the same purpose and that achieved substantial reductions in total distance travelled. Since the cost of transporting solid waste is measure in monetary cost per tonne-km, reductions in the distance translate into financial savings. Using the network analyst tool in ArcGIS they solved the shortest path problem and achieved a decrease of about 10% in the total distance traveled, and around 11.5% in time travelled. The problem of solid waste transportation is very similar to the school bus routing problem from a transportation viewpoint. ArcGIS enables the solution of shortest routes in a considerably simple manner.

Chen et al. [11], citing previous literature on school bus routing (Boyer, R.; Juckett, E. A.; Reeder, W. G.; Wimblish, R. L. and G. W. Gilbert), enumerates a few examples of heuristics used for determining good route plans. These examples are: "Select remote bus stops as route origins and draw bus routes toward the school. Select the shortest route to school if there are alternative routes. If the route origin is remote from the school, plan a "shoestring" route (Juckett). If the route origins are close to the school, plan a "loop" route (Juckett)." These heuristics were taken into consideration while analyzing the pre-existing routes in Espirito Santo.

3. METHODOLOGY

In order to assess the current situation of the rural school transport routes, all existing routes were mapped and exported to a GIS shapefile format using GPS trackers installed inside the vehicles. This process was carried out in the entire State of Espirito Santo, in all 76 municipalities, some of them containing several dozen routes. In addition, the georeferenced location of all students and schools was obtained using data provided by the electric utilities, which already had this information in their databases. By merging these data and plotting them on a map, the routes could then be analyzed for their characteristics. These included: path chosen, distance traveled and fulfillment of other requirements such as maximum walking distance for the students. The results could therefore be compared to the information that the State government possessed, which, among other things, it used to pay the transportation providers. The routes that were analyzed were only the ones that served state-run schools, whether they had only state students or were shared with municipal students. Municipal-only routes were not analyzed, as the State is not responsible for those, and therefore does not possess the data.

All routes went through a double-checking process. First, an external company hired by the state's Secretary of Education analyzed each route, comparing the information filled out by the bus driver in a form, the data obtained by the GPS equipment, and the government's spreadsheets. Each student's name belonging to each route was checked, based on available information and the pick-up order informed by the driver. This allowed for the discovery of students registered in the wrong routes or schools, or who were not georeferenced, as well as the analysis of the path adopted by the driver. If routes presented stretches without students or too many detours from the main road, those were cut from the route, as long as the maximum walking distance of 3 km was not surpassed. Return trips through the same road were also cut, as these nearly doubled the total distance. The result was saved into two shapefiles, "total routes" and "embarked routes". The former was the original file and the latter was comprised only of the distance traveled with students on board. It was this second file's routes that were used for the comparison with the information that the state has in its possession, which was mostly manually filled.

The parameter used by the State to hire the transportation service is total traveled kilometers; therefore the main output of the spreadsheet was the length of each route and the grand total for the municipality. If a route had a measured length smaller than expected, the state was probably paying the driver more than it should. On the other hand, lengths greater than expected could mean that the drivers were being underpaid. Errors of less than 10% were within the tolerated margin, but larger discrepancies called for special attention. Some routes presented very different recorded and measured lengths. In many cases the operation of the routes was offered via public biddings which were won by drivers' cooperatives that operated a large number of routes. Therefore, if they received less for one route but more for another, in the end it was still profitable for them. With the accurate measurements now available and the real lengths of all routes known, there is no more need for a margin of error or financial trade-offs among routes. As a result, it is possible to pay the right sum for each route, which benefits both the drivers and the State, and makes the process more transparent and fair for all parts.

In a second round of the checking process, the spreadsheets filled out by the hired company were also checked by the Transcolar team at UFMG to ensure that they had analyzed correctly the routes' situation. Using ArcGIS software, we were able to visualize all routes, students and schools on a map, and assess their compliance with the guidelines. The map was loaded with shapefiles of municipal borders, vicinal roads, highways, schools, state students, and embarked routes. The layers "municipal borders", "routes" and "students" were filtered to display the data of one municipality at a time, using the layer "Definition Query" tool in ArcGIS. The students' and routes' layers were then divided into up to four separate layers based on the time of day of the existing routes (morning, afternoon, evening or integral) to facilitate visualization.

Once everything was loaded on the map, the checking process followed some basic steps. First, one of the route layers, i.e. morning routes, was displayed while all others were hidden. By opening the route layer's attributes table, we were able to order the routes by their number, and clicking on a route caused it to be highlighted on the map. The students' layers were then further queried by route number to display only the students that were registered in the route being evaluated. Once the route was highlighted and the students and school(s) it serves were shown on the map, it was possible to make a visual examination of the route to check for possible issues (figure 1).

Figure 1: Route examination in ArcGIS

The main characteristics that were analyzed were: the path chosen, based on the existing road network; the location of the students in relation to the route; and eventual problems such as routes that did not end in a school or that had no registered students. If students were visually too far from the route, their distance could be checked using the Measure tool, which returns the Euclidian distances between two or more points along a path.

This resulted in an extensive and double-checked analysis of each and every rural school transport route in the State of Espírito Santo. It provides a solid study that allows the government to know where the problems are, and supplies clear criteria for the renegotiation of future transportation contracts, thus reducing wasteful spending of public funds. The possibilities for improvement are even more clearly visible when comparing the existing routes with the optimized routes, as will be discussed in the next section.

4. CASE STUDY

The municipality of Linhares is the sixth most populous in the state of Espirito Santo, with over 166 thousand inhabitants in 2016 [12]. It was chosen as an example as it is one of the first to implement the new optimized routes for school transport.

The total daily length of all existing routes in Linhares was recorded as 7013 km in the government's existing spreadsheets. The GPS measurement showed that the real length travelled by all vehicles in a day amounted to 5293 km, about 25% less (figure 2). About 15 percentage points of this difference can be explained by routes where the state provides the students with bus passes to be used in regular bus services, since Linhares is a larger municipality and has a better offer of public transportation. Nevertheless, the school bus routes on the spreadsheet still add up to 5870 km, which is 10% in excess of the real length measured. This difference shows that there was a possibility of excessive spending or misuse of public funds even before the routes were optimized.

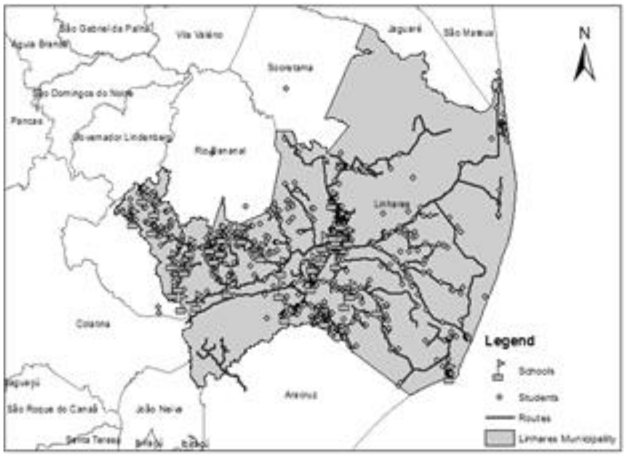

Figure 2: Existing school bus routes in Linhares Municipality

After the two types of optimization performed by Transcolar, the results provided a much enhanced and economical set of routes, for both types. It is important to note that the number of students previously registered for rural transportation was much lower than the number considered for the optimization. Previously, there were 2447 georeferenced students, all of which are state students. 843 of them used bus passes, which brings the total that used school buses to 1604 students. The optimization considered 3938 (3930 for type 2) state students and 2878 (2872) municipal students. Hence, the total number is 6816 students for type 1 optimization and 6802 for type 2, over four times as many. The total daily km travelled, was 18248.08 km for type 1 (figure 3) and 16220 km for type 2 (figure 4). It is difficult to make a direct comparison given the difference in the number of students. However, in proportional terms the optimized network presents a substantial improvement in the ratio km/students, which directly means less spending on transportation per student. Before the optimization, this ratio was 3.66 km/student, whereas for type 1 it is 2.68 km/student and for type 2 it is 2.38 km/student, a decrease of 26.78% and 34.97%, respectively. The results are summarized in table 1.

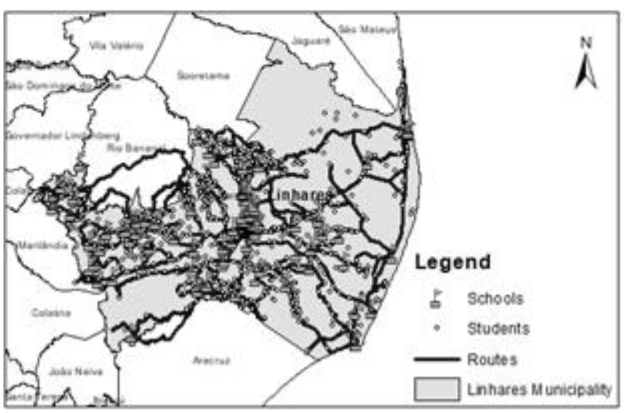

Figure 3: Transcolar type 1 optimization results

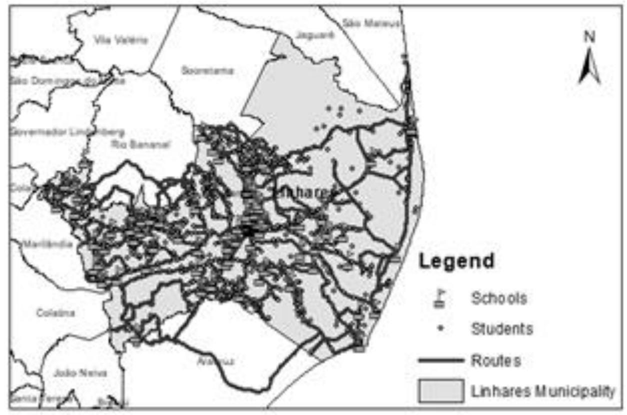

Figure 4: Transcolar type 2 optimization results

5. CONCLUSION

The main focus of this paper is the acquisition and analysis of data on existing school transport routes in the state of Espirito Santo, Brazil. This step was needed to validate the optimization that is being conducted by Transcolar, providing data for the comparison among preexisting and optimized routes. Data was obtained through GPS devices installed in the school buses, which was later double-checked and compared to the existing information. Two types of optimization were then performed by Transcolar.

The results show that there is much room for improvement. The efficiency of the current routes measured by the km/student ratio is low compared to what can be achieved through optimization.

The reduction reached a maximum of almost 35% in km/student. More efficient school bus routes mean better use of public funds, especially in a sector that weighs heavily on the budget of small municipalities. It is also a sensitive sector in respect to its social aspects: while only 14% of the student population is rural, they represent 62.7% of the total number of riders [13]. Thus, optimizing the routes mean reduced excess spending which can in turn lead to improvements in other areas, such as safety and comfort.

Table 1: Summary of routes before and after optimization

	Number of Students	Total Distance	km/student	% change
Existing Routes	1604	5870	3.66	
Existing Routes (post-analysis)	1604	5293	3.30	-9.83
Transcolar Type 1 Optimization	6816	18248.08	2.68	-26.78
Transcolar Type 2 Optimization	6802	16220	2.38	-34.97

The limitations of this study include insufficient data on route length and number of students for some georeferenced routes that were not available. Therefore, a more precise comparison of route efficiency and total distance travelled was not possible. Also, the cost per km of the existing routes was not provided in the spreadsheets, which would have allowed for a monetary comparison with the optimized routes. However, since distance is the main parameter used for the cost analysis, the substantial improvement in efficiency indicates a reduction in the cost per student.

Once the new routes are implemented and running, it will be possible to further analyze the benefits of the optimization.

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