Developing an Environment for Cost Calculation of Rural School Transportation

Marcelo Franco PORTO
Aline Anacleto MACHADO
Nilson Tadeu Ramos NUNES
Lucas Vinicius Ribeiro ALVES
Rafael Henrique Carneiro TAVARES,
Patrícia Baracho PORTO

Department of Transport Engineering and Geotechnics, Federal University of Minas Gerais
Belo Horizonte, Minas Gerais, Brazil. marcelo@etg.ufmg.br

ABSTRACT

The Transcolar Rural project comes with the purpose of improving the student transportation system within the countryside. The government of Brazilian state of Espírito Santo, through its secretary of state for education (SEDU), formed a partnership with the Universidade Federal de Minas Gerais (UFMG) to use the Transcolar solution for managing its rural student transportation system. After concluding preliminary studies, data collection, database formatting and feeding, the optimization phase generates new routes with the given data. With the trips defined, the system calculates the cost and creates reports that summarize the entire process. The automatic procedure of cost calculation seeks to complete the developed intelligent transportation system towards its complete independency. The main objective of the whole Transcolar Rural project is to optimize the use of funds, reduce travel distances and standardize vehicles and procedures regarding public student transportation of rural areas.

Keywords: Intelligent Transport Systems, Rural School Transport, Software Engineering, Spatial Information, student database.

1. INTRODUCTION

Education is a right secured by the Federal Constitution [1] and each state is responsible for its provision. Brazil went through an intense urban growth by late 90s, but there are still many families living within the countryside. Around 15% of the Brazilian population lives in rural areas. A social research about illiteracy in 2010 pointed out a 6.8% rate for urban areas. In rural zones, the rate of illiterate people was 21.2% [3].

A study of the national research of households [2] shows that most students living in rural areas have poor learning outcomes and school achievements. Common factors associated with low school rates are difficulties in school transportation, such as long distances from home to school, low availability of transport modes and precarious conditions of country roads. The Brazilian scholar census of 2013 [4] shows fewer schools available in rural areas between 2003 and 2013. It is a government issue to provide school transport to assure access and stay of students in school. Therefore, improvement of rural scholar transport is essential for developing the country and guaranteeing the best use of State funds.

Investments in transportation are constantly increasing to follow the growth of large urban areas. Despite its extensive territory, a great deal of Brazil’s economic activity develops in rather small areas of densely populated urban centers. While such areas are increasingly growing due to economic and political reasons, rural areas are usually destitute in terms of social policies. This scenario contributes to lower quality of life and reduced access to public services such as school transportation [5]. To assure student access to schools and avoid dropouts, there is a clear need for social programs.

Free school transportation plays a significant role on preventing school evasion. Studies led by the National Fund of Education Development (FNDE) shows that over 4.8 million of students within the Brazilian public elementary education system living in rural areas depend on school transport [6]. Over the past years, several programs emerged in order to meet this basic need.

The Transcolar Rural project is a tool designed to contribute to solving the mentioned problems. The Secretary of State for Education of Espírito Santo (SEDU) in partnership with the Universidade Federal de Minas Gerais (UFMG) has proposed the project for statewide execution. The system is free of charge for whoever interested on using it. The only required investment is for development of initial studies, data collection and additional modifications necessary to meet the final users’ specific needs.

In summary, it starts with creating a georeferenced database of students, schools, vehicles, roads, routes and stops. The Geographic Information System (GIS) is a useful tool for large systems and data analysis. The developed system runs continuously within a dedicated server generating outputs shortly after inputting a set of parameters. Data access is through a website on which the user can choose the desired form of visualization: tables with trips and other related information, maps, and report files (PDF and spreadsheets) designed according to its needs.

As the project was designed, there was a lack of tools for solving some of the issues. For instance, when the optimization phase generates the trips, the respective cost of execution is unknown. Additionally, a calculation method was developed from basic guidelines and earlier studies on passenger private transport. The result were spreadsheets containing formulation regarding passenger transportation costs. However, such spreadsheets do not communicate with or store data within the project database.

For this purpose, there was a need of a specific application that would perform the same cost calculations of the spreadsheet.
and store values for each trip in the database. This article bounds the procedure for such automatic process. Programming is based on the previously mentioned spreadsheets. Some of the inputs for cost calculation are the routes generated by the optimization and other necessary parameters.

2. PROJECT HISTORY

The developed tool gathers a group of students with the purpose of transporting to its respective schools. There are organized input parameters so that the optimization method can allocate vehicles and generate trips. The graphic interface of the system consists on a website. Each request refers to optimization of a municipality’s school transportation. For the implementation of the system application, firstly there was an environment configuration and management tools adjustments.

The trip generation process supplies the students demand with the shortest distance and economic vehicle distribution. Vehicle classification is by capacity: up to eight passengers, up to 15 passengers, up to 23 passengers, and more than 23 passengers. These types are usually microvans (or Kombis), vans, minibuses, and buses, respectively.

The cost program opens a console application, which displays basic information such as processing phase, identification of the set of trips, start time and occasional error warnings. It also generates a log file. The trips output table supplies the input parameters for cost calculation and results are also stored in the same table.

Additionally, the final user requested for an alternative calculation procedure called Resolução. It is a table with fixed values of costs for each vehicle type and distance range. It was used both for the transition phase from the old model to the Transcolar proposal and to compare the optimized results with existing practices.

3. CORRELATED WORK

Silva [7] defines rural school transportation as a free service offered for students living in low-density areas. It is also implied that a great deal of families has low income. Thus, providing free transport is of great financial and social help for the target population.

The study made by Carvalho [8] portrays the conditions of the physical school access of children living in rural areas. It emphasizes that public authorities have not always been able to guarantee safe and adequate transportation for such students. Thus, it jeopardizes their social inclusion process that should be assured by the education system. Among other aspects and conclusions, it highlights that developing the school transportation system is key to at least lessen the difficulties faced by such population.

The paper of Vasconcellos [9] analyzes the situation of school transportation in the state of São Paulo, where a large rural school transport system exists since the 1960s. It mainly takes policy issues as a guide to the provision of rural pupil transport. It also considers the advantages and limitations of different improvement strategies regarding access to schools in rural areas of developing countries. A real example of rural school transportation is provided (city of Taubaté) along with a preliminary framework for the definition of a specific public policy. Even though this study was conducted in 1997 and its data is still relevant, it can be concluded that few changes of this scenario occurred in the latest decades.

Sakellariou et al. [10] investigated qualitative factors that affect a school transportation system’s services executed by school buses. To do so, there was conducted a questionnaire survey to parents of private high school students of the city of Thessaloniki area, Greece. The satisfaction index is estimated using linear regression analysis, determining the factors of influence. The applicability of this study can be extended to the Brazilian case. Highly influence factors include time and distance from the student’s residence to the bus stop, vehicle and road conditions, schedule accuracy, and rerouting information at bus stops in case of emergency incidents.

Porto [11] defined the Transcolar project’s main objective as the analysis of rural school transportation in the State of Minas Gerais. It commenced to serve the National Support School Transport and the Way to School Program. Among other goals related to school transportation, the main objective is optimizing the use of financial resources, improving the methodology use for conducting surveys, and standardizing vehicles.

Carvalho et al. [12] presents an overview of the rural transportation school and underlines the importance of this service free of charge. The paper evaluates the evolution of Brazilian school transportation starting from the Way to School program developed by the Federal Government. It also presents the situation before the program implementation. There was a perceived improvement regarding the quality of vehicles.

The first step of the Transcolar project consisted on geoprocessing information regarding schools, students, and existing routes. To generate new optimized trips, the development team used the principles of Vehicle Routing Problem (VRP), which is a combinatorial optimization and integer-programming problem. VRP methods of optimizations can reduce transportation costs by an average of 5 to 20% [11].

Faraj’s work [13] presents a research that seeks to optimize the daily transportation of students considering the real available vehicle fleet of a municipality. The case study is a selected rural area of Minas Gerais using the real database of Governador Valadares. The aim was to reduce the total distance traveled by a heterogeneous fleet of school buses. The authors used a mixed integer linear programming model and an algorithm based on GRASP (Greedy Randomized Adaptive Search Procedure). The results were suitable and, in some cases, faster than previously used methods. Additionally, the GRASP algorithm can find good quality solutions for all instances.

Teichmann et. al [14] described a collaborative approach to optimizing resource utilization of vehicles by forming dynamic networks in logistics and passenger transport. The approach is a cloud computing solution capable of optimization and cost simulations based on real data. The software can integrate all planning components and algorithms necessary for creating individual timetables.

Neto [5] provides the details, procedures and premises of the final transportation cost. In summary, it is the sum of fixed and
variable costs of each trip. Variable expenses are the sum of expenses with fuel, lubricating oil, tire wear and maintenance. The fixed cost includes drivers’ (and occasionally a supervisor’s) wage, return of capital (ROC), car depreciation, compulsory insurance, IPVA and other taxes based on the vehicle contract type (private, cooperative, bid, among others). If a vehicle makes multiple trips through the day, the method divides the fixed cost among those trips. Normally, the optimization allocates vehicles to work all day to reduce costs and maximize revenues. The following diagram illustrates the calculation process.

Figure 1: Diagram of calculation procedure proposed by Neto

The geographic information system (GIS) used on the database is a valuable tool in transportation. It allows approximating a simulation to its reality. Alterkawi [15] illustrates the application of GIS in transportation planning in general with a case study in Riyadh city, the capital of Saudi Arabia. It illustrates the usage of GIS on project identification on the network and link tables for travel demand planning. Moreover, the process seeks to anticipate future areas of congestion and investigate shortest path and travel time allocation of major activity centers.

Nayati [16] developed a method on how to transport students as safe and economical as possible by using GIS. It improves the existing fleet management system and decreases maintenance costs. It also relies on the premise that increasing fuel prices raises operating costs faster than passenger revenues.

Applying current methodologies of urban collective transportation for rural school transport is very common. It can provide, to a certain extent, approximate values without the need of a specific study. As a result, to approximate the estimates to perceived real values, specific studies are necessary. There are many peculiarities of rural school transport, mainly related to consumption of fuel, lubricants and tires. Because it is a rural area, vicinal roads compose a great deal of routes. Normally, methods use fixed coefficients for each type of vehicle. Thus, it is best to adapt such coefficients in a function regarding the road characteristics (horizontal and vertical geometry and type of pavement) [5].

In the cost perspective, GIS allows the analysis of physical features of the routes. Examples are pavement type and condition, slope and recently created roads. Hence, modern approaches seek to develop methodologies and algorithms applied to this system.

4. METHODOLOGY

At first, there was conducted an extended research regarding rural school transport, transportation planning systems, process automation and software engineering. The work of Neto [5] resulted in a spreadsheet that calculates the cost of trips with a set of parameters and given entries. However, this cost calculation procedure is not efficient in terms of time and resources since it is manual.

Developers could not find a tool that would take data from the database, insert into the spreadsheet and output the calculate values. Therefore, there was a need for an application that would make this procedure automatic. The programming language used for developing the cost application was C# within the Visual Studio Professional 2015 software. Guidelines for implementation of calculation routines are from preexistent formulas of a spreadsheet presented by Neto [5].

The first step was defining the needed information and making it available for each trip. New tables were created to support the application and so that every information is within the database. The C# application access the project’s database using the Npgsql tool, connecting to the database software pgAdmin III.

5. DEVELOPMENT

The program has two main parts: the executable Console Application called “AppCalculaCustos” and the class library “CalculaCustos”. This division is for better organization and
understanding of the computing procedure. The classes within the library “CalculaCustos” are the body of the cost program. The executable program must reference this class and invoke its methods in the correct order when executing.

The database must have a table with all types of vehicles arranged by type and model year. The table provides information such as vehicle’s value, residual and depreciation index, number of tires, fuel consumption and type, lubricant consumption per km, tire wear, and maintenance factor. The more complete and accurate the information, the more realistic the resulting output.

Every 5 minutes, the program scans if there are new trips to calculate costs. If positive, the first procedure of the application is to load all the registered vehicles in the database organized by type and year of production. The vehicles are objects within the code, and its properties are the collected parameters. The user can modify the vehicles’ table information at any time, observing that one vehicle type with its respective year of production appears only once so the methods work properly.

The second step is to load all trips generated by the optimization procedure. A trip is also an object with the following parameters: license plate, vehicle type and properties, capacity, total distance traveled, number of drivers and supervisors in the vehicle, accessibility for wheelchair, shift (morning, afternoon, night, integral), direction (outward or return trip) and amount of state and municipal students. Another property of the trip is the corresponding property of the trip is the corresponding trip and amount of state and municipal students. (morning, afternoon, night, integral)

The application stores every used parameter for cost calculation of every trip on a table. This works as an execution history if necessary to verify the parameters used in the execution, since the entry tables can (and must) be updated. Other parameters are: IPVA, price of tires by vehicle type, drivers’ and supervisors’ wage, compulsory insurance, syndical tax to natural or legal person, number of school days in the year, extra for dirt road (an increase between 0 and 1 on the final cost), and standard school days per month (currently 20 days). The IPVA is a Brazilian tax charged for every motor vehicle, calculated as a percentage of the vehicle value.

The final calculated costs are total cost per km, total monthly cost, fixed monthly cost, variable cost per km, monthly cost per student, state and municipal monthly cost, state and municipal annual cost, total daily cost and total annual cost. Each cost fills the corresponding column for each trip within the database.

The base calculated value is the cost per km. From this, the application calculates several other costs to meet any need. For the case study, many final users are involved and each one has its own needs and specifics.

The main algorithm of the software is revealed in the following box. The term “Req” is used for the requisition of the program. Further technical description of the program is not provided due to its complexity and length. The basic guidance of calculation is given on the framework presented in Figure 1. Since the used language (C#) is object oriented, terms such as “municipio”, “vehicle”, and some parameters are internally treated as objects.

```csharp
namespace AppCalculaCustosES {
    class Program {
        public static void Main() {
            StartParameterTables();
            // Start of program
            while (true) {
                try {
                    pendingReq = Method that searches for pending requisitions and returns a list object with selected information;
                    if (pendingReq.Count != 0) // If pendingReq list is not empty
                        // Definition of standard vehicle and state tributes
                        Dictionary standardVehicles; // Object
                        // Stores the information in the object standardVehicles
                        Load_Vehicles(standardVehicles);
                        foreach (var req in pendingReq) {
                            // Store calculation status within the requisition: calculating StoreReqStatus(req);
                            Load StateCalculationParameters();
                            Load ResolutionCalculationParameters();
                            if (StateCalculationParameters.Erro) // exit program;
                                municipio = Load MunicipalCalculationParameters();
                            if (municipio.Erro) // exit program;
                                // Sums the total distance of one vehicle vehicleDistance = LoadTrips
                                (req, municipio, standardVehicles);
                            // If no errors occur, the program stores the calculated values
                            if (!municipio.Erro) {
                                // Spreadsheet cost
                                List<string[]> custosCalculados = CostCalculation(
                                    "planilha", req, municipio, vehicleDistance);
                                // Resolution cost
                                List<string[]> custosCalculadosRes = CostCalculation(
                                    "resolução", req, municipio, vehicleDistance);
                                // Store calculation status within the requisition
                                if (municipio.Erro == false)
                                    StoreReqStatus("success", req); // Status: success else if (municipio.Erro == true)
                                    StoreReqStatus("error", req); // Status: error
                                // End of process
                                System.Threading.Thread.Sleep(5 minutes);
                            } // End of if (pendingReq.Count != 0)
                        } // If there are no pending requisitions
                        System.Threading.Thread.Sleep(5 minutes);
                    } // End of try
                    catch (Exception) { // Connection failure
                        System.Threading.Thread.Sleep(10 minutes);
                    } // End of catch
                } // End of While
            } // End of Main method
        } // End of class Program
    } // End of namespace AppCalculaCustosES
}
```
Bidders carry out a great deal of trips, and the government must pay for this service. The value paid to each driver or company is the multiplication of the cost per km by the total distance of the trips. Some counties may make daily, weekly or monthly payments. The government executes only a small deal of trips because outsourcing the service is much cheaper than owning the vehicles.

The government administration must have the cost divided between State and county portions to properly allocate funds. The value is the total monthly or annual cost multiplied by the number of students of each type divided by the total number of students. The student type refers to the education system, provided by either the state or the county.

6. CONCLUSIONS

After extensive testing and adaptations, the program successfully calculated transportation costs for all trips. This study’s main objective was to make the cost calculation an automatic procedure. Figure 3 shows the example of a detailed trip report for the town of Linhares (ES), which also presents the actual map of the trip. The red rectangle highlights the cost calculated for the trip. For this example, a route with approximately 45 kilometers executed by a minibus has a monthly cost of R$1983.12. The route transports 21 students of the morning classes.

Figure 3: Trip report for the town of Linhares (ES).

Figure 4 shows a map that compares the best results of the optimization with the current spending on school transport for each town or city. The areas on which the optimization was not performed are the cities of Vila Velha and Vitória, the capital of the Espírito Santo state; both are considered urban centers in the context of analysis.

Therefore, this map endorses the success of the Transcolar system in create transport solutions cheaper than those currently applied. The comparison of the current system of rural school transport in Espírito Santo with the routes created by the program, all counties with available data to compare showed a significant cost reduction.

As the project is not yet concluded, minor adjustments may occur. However, it is already safe to assume that the implemented system has the power to save a significant amount of resources available to education.

7. ACKNOWLEDGEMENTS

This work was cooperatively supported and financed by the Espírito Santo’s State Secretary of Education, FNDE – Fundo Nacional de Desenvolvimento da Educação, Minas Gerais State Research Support Foundation (FAPEMIG), the Brazilian National Council for Scientific and Technological Development (CNPq); Coordination for the Improvement of Higher Education Personnel (CAPES).
8. REFERENCES


[12] W. L. Carvalho, Evolução do transporte escolar rural brasileiro no modo rodoviário, Ouro Preto, Brazil: XXIX Congresso Nacional de Pesquisa em Transportes da ANPET, 2015


