CALCULATING THE OPTIMAL SCHOOL BUS ROUTING AND ITS IMPACT ON SAFETY AND ENVIRONMENT PROTECTION

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Travelling to school, is a complex undertaking and refers to students’ daily trips from their residents to their school units and vice versa. The School Bus Routing Problem, differs from a conventional vehicle routing problem due to the fact that it involves a procedure of reception and delivery of “vulnerable objects” to be transported (students). Regarding the school transportation system of Greek Schools, this is basically executed in complex transport networks, following a series of routes that are formulated using an empirical approach and not a mathematical model. Many school units, design these routes using a manual process, mostly taking into account the parents’ requirements. On the other hand, complexities of school bus routing problems, such as local conditions, operating costs, customer needs etc., make the whole procedure extremely challenging, rendering the adoption of a software solution a rather imperative necessity. At this framework, the current paper presents a seven-step methodology developed for optimizing the school bus routes of a private school in Thessaloniki, Greece. The methodology is based on cluster analysis and genetic algorithms while taking into account the geographical characteristics of the road network as well as the distribution of the student’s travel behavior and requirements. The results derived from the pilot testing, verify initial considerations; a reduce of distance and travel time due to the school bus routing optimization, lessens the possibility for students to be implicated on road accidents and enhances the levels of air quality due to fuel emissions’ reduce.

Keywords: School bus routing, route optimization, school bus, student
INTRODUCTION
Travelling to school, is a complex undertaking and refers to students’ daily trips from their residents to their school units and vice versa. For a society, it is one of the most crucial, costly and responsible provided services, as it substantially ensures the equal children’s access to school. On the other hand, an inefficient provision of it, may cause a lot of problems to the student’s learning process (1). Similarly, for a society it is considered as one of its main functions, aiming to combine quality services with a population’s needs and requirements (2).

For the completion of a school trip, different modes of transport are used such as private vehicles, walking, and cycling. More collectively, the school transportation is provided in several ways. In some cases students make use of the local public transport system while in others, students are served by dedicated and special equipped school buses (3). This kind of provided school transportation services represent high safety records, instating the school buses on the top of the list between other alternative transport modes. Statistics suggest that a child travelling by car is seven times more likely to be involved in a road accident than a child travelling by bus (4). At the same time, the use of school buses appears to be an economic and flexible solution regarding issues related to routing and scheduling.

Regarding the School Bus Routing Problem (SBRP), it is well known that it differs from a conventional vehicle routing problem due to the fact that it involves a procedure of reception and delivery of “vulnerable objects” to be transported (students). More specifically, the SBRP is defined as the problem dealing with the planning of an efficient schedule for school buses’ fleet where each bus picks up students from various bus stops, transfers them to their school unit, and vice versa. A very important aspect of the problem is to determine the exact location in which students are either being picked up or delivered. In particular, it should be well known from the beginning of the problem’s solution, if the bus stops are central points or areas agreed and accurately predefined through a specific methodology, or if they are indicated by students’ parents according to their needs. A prerequisite for the determination of the problem to be solved, is the way that the term "efficient routing" is interpreted in any case. This interpretation will determine the main functions that will be developed in order to solve the problem, the priorities to be followed and finally the impact of the implementation of this procedure.

LITERATURE REVIEW
The SBRP has been studied since 1969, when Newton and Thomas propose for the first time an efficient and automatic two-step procedure for solving the school bus scheduling problem. In their study, bus capacity and riding time are the constraints taken into account (5). In 1970, Bodin and Berman make an effort to minimize both the travel time and travel costs for each student, using an heuristic approach. The maximum travel time a student is allowed to be on the bus as well as the bus capacity are the two main constraints on which their research is based on (6). In 1980, Dulac et al. analyse an operative planning process for the students’ transportation, posing as a constraint the number of stops defining a school route. Heuristic methods are used in order to assign students to bus stops and generate school routes. The minimization of the total distance and the number of routes generated are the main criteria considered in this heuristic (7). Desrosieurs et al. through their research, aim to generate the minimum number of routes by using the students’ maximum travel time within the bus, the walking distance and the bus capacity as the main constraints (8,9).

A few years later, Chapleau et al. introduce a new approach for generating school routes in urban areas. Their main purpose is to minimize the travel costs from one hand and maximize the number of students served by the school buses’ fleet on the other. The constraints included in the process...
are related to the bus capacity, the walking distance from the residence to the bus stop, the number of bus stops and the length route (10). In their research, Bowerman et al. develop a methodology in order to minimize simultaneously the number of routes, the route length, the student walking distance from the residence to the bus stop and the number of students along each route (11). Main constraints are travel time and each route’s length. Trying to minimize the total distance travelled by school buses, Schittekat et al propose a branch-and-cut algorithm posing the bus capacity and the students’ walking distance as main constraints in solving the problem (12). In an effort to optimize the service level of the school bus system, Spada et al. present a new model using heuristic approaches where among others the minimum bus capacity is posed as one of the main constraints (13). Table 1 summarizes literature findings on constraints taken into account when solving a school bus routing problem.

### Table 1 Literature findings on constraints taken into account in the SBRP

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Constraints taken into account in solving the SBRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bus capacity</td>
</tr>
<tr>
<td>Newton &amp; Thomas (1969)</td>
<td>x</td>
</tr>
<tr>
<td>Bodin and Berman (1979)</td>
<td>x</td>
</tr>
<tr>
<td>Dulac et al (1980)</td>
<td></td>
</tr>
<tr>
<td>Desrosieurs et al (1981,1986)</td>
<td>x</td>
</tr>
<tr>
<td>Chapleau et al (1985)</td>
<td>x</td>
</tr>
<tr>
<td>Bowerman et al (1995)</td>
<td></td>
</tr>
<tr>
<td>Spada et al (2005)</td>
<td>x</td>
</tr>
<tr>
<td>Schittekat et al (2006)</td>
<td>x</td>
</tr>
</tbody>
</table>

### METHODOLOGICAL APPROACH

In Greece, the Private Schools’ transportation system follows a series of routes executed in the cities’ complex road networks and formulated using an empirical approach and not a mathematical model. Many school units, design these routes using a manual process, mostly taking into account the parents’ requirements. On the other hand, complexities of school bus routing problems, such as local conditions, operating costs, customer needs etc., make the whole procedure extremely challenging, rendering the adoption of a software solution a rather imperative necessity. The developed methodology, recommends an automated mechanism for solving the SBRP Greek Private Schools daily face.

The current section, presents the “i-student trip” methodology followed for calculating optimal school bus routes, while covering specific criteria. The seven steps methodology is based on cluster analysis and genetic algorithms and has been pilot tested in order to cover the needs of
a private school serving students throughout the metropolitan area of Thessaloniki city. The steps
are described in the “i-student” methodology in the relevant section of this paper.

The genetic algorithm
The genetic algorithm used for optimizing school routes solving a Transport Salesman Problem
(TSP), presents specific characteristics. The algorithm creates a group of initial solutions by
constructing a weighted combination of a set of greedy solutions which prioritizes the connection
of the nearby stops / students, a set of solutions resulting from the application of the heuristic
algorithm Clarke & Wright's Savings (14), as well as a small set of totally random solutions. It
chooses afterwards the better two members of the population (routes), which combines to produce
a new solution (route) with better expected efficiency. While this process is being repeated, the
new, shortest routes, replace the longer ones. Finally, the iterative process continues until the result
meets the user's criteria or the predefined number of the maximum allowed iterations has been
reached.

The above methodology ensures a possible balance between the students. This balance is
defined by the ratio of the time that students travel by bus to their school unit, to the time that
would be needed in case they were driven there using the minimum path. This ratio provides
essentially a performance index (Key Performance Indicator, KPI) showing the increase of the
path length for the students travel by bus. If the index value is close to the unit, no significant
difference on trip time is confirmed thus the algorithm has almost achieved the best solution for
the student. Index values near two, mean that students need almost twice the time, near three the
triple time etc. Index values between 1.3 and 1.6 are considered as satisfactory for the school
transport service.

The case study
The case study concerns one of the largest Primary Private School located in the Eastern part of
Thessaloniki city, Greece. Students are served by two morning itineraries, and three evening due
to the different activities and extra classes taking place after the obligatory daily schedule. Students
are spread out in the whole metropolitan area of Thessaloniki, however the methodology
developed in the present research focuses on two sub areas as depicted in Figure 1, one in the
South-East part of the city (Kalamaria) and one in the North-East part (Panorama).
The specific routing problem is particularly demanding, as it has to meet a number of specific requirements listed below:

- Serve the demand of a large area taking into account the fact that the school premises are not center-located but at the eastern end of the city
- Serve a large number of students
- Keep the maximum vehicle capacity strictly at 29 students/bus
- Keep the maximum trip journey strictly at 45 minutes/routes
- Bus stops are predefined by parents
- Comply with "time windows" defined by the bell ring and by the parents regarding the students’ return
- Reduce the total vehicle/km of school bus routes

The road network used, represents the prefecture of Thessaloniki, Greece. As for the local road network, it is defined as a graph $G(V, E)$ where $V$ is a set of nodes and $E$ is a set of edges that provide the actual connectivity between the nodes. The road network is weighted, as every connection between the nodes has been assigned with a mathematical value representing the actual travel time in seconds between those nodes. In addition, due to the traffic restrictions applying on every city road network (i.e. one way links, turn restrictions) it is also considered as an undirected network.

The network consists of 42,003 links and 19,984 nodes. Table 2 depicts the degree of connectivity between the nodes of the road network: 26% of nodes is directly connected with 4 other nodes, while 23% is directly connected with previous and advance neighbors in the graph. Finally another 23% is directly connected with 6 nodes.
TABLE 2 Degree of nodes connectivity

<table>
<thead>
<tr>
<th>Total connections</th>
<th>Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>91</td>
</tr>
<tr>
<td>2</td>
<td>4.748 (23%)</td>
</tr>
<tr>
<td>3</td>
<td>2.164</td>
</tr>
<tr>
<td>4</td>
<td>5.238 (26%)</td>
</tr>
<tr>
<td>5</td>
<td>1.749</td>
</tr>
<tr>
<td>6</td>
<td>4.714 (23%)</td>
</tr>
<tr>
<td>7</td>
<td>338</td>
</tr>
<tr>
<td>8</td>
<td>913</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

Focusing on the South-East part of the city, the demand analysis required the allocation of 198 students in 177 different addresses representing the pickup and delivery points.

The “i-student trip” methodology

Herein, the “i-student trip” seven steps methodology is presented, as applied in the case of the South-East part of the city. For each step described below, a separated process is required.

Step 1: Scenarios development

The scenarios were developed taken into account both the data and the requirements regarding each shift. More specifically, the daily itineraries were divided in two morning shifts (AA and AB starting at 7:00 and 8:00 am respectively) and three afternoon shifts (BA, BB and CC starting at 13:00, 14:00 and 15:00 pm respectively). Figure 2 depicts the distribution of the 198 students in the two morning shifts.

FIGURE 2 Students’ distribution during the morning shifts in the South-East part of the city.
The average trip duration ranged from half to one hour. Given the limitation that it is not efficient to provide each student with a different routing plan regarding each week day, a general weekly routing plan was calculated, satisfying the maximum demand.

Step 2: Geocoding
In this step, all students’ addresses were geocoded. As mapping is one of the main stages of a route planning process, the depiction accuracy in the road network is critical. Therefore, each address needs to be exactly assigned to the correct direction of the road, especially in the case of two-way direction roads. For this procedure the digital road network of the wider area of Thessaloniki was used.

For the verification of each address on the map several autopsies took place. Autopsies, except from the confirmation and correction of the points’ exact location, also recorded significant features of the road network. After the procedure’s completion, the coordinates of each point were accurately determined while the road network characteristics taken into account in route optimization were also updated. Moreover a prohibitive weighting factor was given in road sections considered as unsafe/irregular.

Step 3: Calculation of driving distances between the demand points
The calculation of the driving distances’ matrix between the students’ pickup and delivery points takes into account the time window of each route. This creates a matrix of distance values (minimum for each pair), thus distance matrixes were created for five different scenario (morning /afternoon shifts).

For the calculation of the driving distances matrix, a Dijkstra algorithm implementation (15) taking into account the road network characteristics (speed restrictions, road segments’ directions, turn restrictions) was applied. Furthermore, the travel times between the students’ pickup and delivery points were calculated based on macroscopic traffic assignment, conducted in the greater Thessaloniki road network (16). Travel times were required for estimating the total trip duration, thus to ensure that the specific requirement regarding the maximum allowed total trip duration was satisfied.

Step 4: Creation of stop clusters
Using the K-means algorithm, clusters of stops with the minimum between them distance were created. The above algorithmic procedure created four demand clusters, each one corresponding to a bus route. The order of the students’ pickup/delivery in each cluster is the main result of the algorithmic procedure and was developed within the next step. The clustering process “directs” the routing results as it suggests solutions which accordingly to cost and time criteria may not be the optimal ones. However, in the current case study the clustering process covered additionally a school’s requirement, for a unique bus crossing from the local road network at any given cluster. Figure 3 depicts the clusters created for the first morning shift.
FIGURE 3 Clusters of students’ pickup/delivery points in the South-East part of the city during the first morning shift.

Step 5: Route development based on genetic algorithm
The routing process follows specific phases until the optimal ones are obtained, namely those which fully meet the above requirements.

Routing Phase 1: for each cluster created in the previous step, the student having the greatest distance from the school unit, is specified. The distance is not related to the Euclidean distance, but the actual length the school bus travels in the road network in order to reach the pickup point in relation to the time restrictions.

Routing Phase 2: Following the same procedure the next pickup point is calculated and the route continues to that student. The process is repeated until it meets all the requirements regarding the trip’s total duration as well as the capacity. In each repetition, both audits take place before the calculation of the pickup point.

Routing Phase 3: The route is completed when all cluster students are picked up, or when the route exceeds the time limits set by the school management

Routing Phase 4: Following, a genetic TSP algorithm is applied upon the generated route (partial solution)

Routing Phase 5: The clusters to be further optimized are identified by comparing the efficiency of each partial solution with the efficiency of the un-clustered solution. Slight modifications to the clusters are performed if required, and the process is repeated until the efficiency of every solution is beyond an acceptable threshold. If the scenario does not cover all students’ transit, it is examined whether they can be served by another route nearby. If this isn’t feasible the process returns in the first step and creates new clusters increased by one student.

Figure 4, depicts the ratio of the time students travel by bus to the time needed in case they were driven using the minimum path for cluster A shown in red color in Figure 3. Following, a comparison between the existing and the proposed route is conducted in order to assess the
efficiency of the algorithmic process. The ratio is acceptable, as it is being kept below the acceptable threshold (1.3-1.6) for the students’ majority, while it is also reduced compared to the initial executed route.

![Key Performance Indicator per bus stop (Cluster A)](image)

**FIGURE 4 Key performance indicator per bus stop.**

Step 6: Creation of route schedules per vehicle. After the routes’ completion the sequence of stops was automatically created, depicting the optimal school bus route per scenario. Figure 5, depicts the pseudo-code developed for the completion of steps 5 and 6.
FIGURE 5 Pseudocode developed for the completion of steps 5 and 6
Step 7: Routes visualization
The whole procedure was finally visualized, in a digital background of Google maps V3. Figure 6 depicts the visualization of an optimized school route in the examined area. Information regarding the student ID, the trip’s duration and the total trip distance are also included. The user can get information regarding the number of students at each stop and their pickup/delivery time by clicking on a stop.

FIGURE 6 Routes visualization.

IMPACT ASSESSMENT

Impacts on CO2 and NOx emissions in the South-East area of Thessaloniki
The school bus routing optimization is a viable alternative that has a positive impact on both the environment and the students’ health and safety. Fuel economy is a hot-button topic in today’s world. In theory, school buses reduce air pollution. As estimated in the U.S., 480,000 school buses can replace 17.3 million cars (17). However, inefficient school bus route management still results in more energy usage and more pollution than is necessary. Reducing the total km traveled, leads to a reduction of CO2 as well as NOx emissions. CO2 is one of the main emissions come out of vehicles (US Department of Transportation 2008) while NOx is a primary pollutant mainly emitted by vehicle exhaust in the vicinity of arterial roads (18).

Based on data gathered from the existing school bus routes (situation “Before”) and data derived from the pilot implementation of the “i-student trip” methodology (situation “After”), an estimation of the CO2 and NOx emissions reduction followed the final routing calculation.

The road traffic emission modeling was performed with the software COPERT IV (19). The COPERT CO2 emission factor for coach buses < 18 ton (Technological Category HD EURO V – 2008 Standards) and for an average speed of around 35 km / h, is 906.40 gr/Km/vehicle. Respectively, the NOx emission factor is 6,854 gr/Km/vehicle. The main results are depicted in Table 3.
### TABLE 3 Annual CO₂ and NOx emissions in the “Before/After” situation

<table>
<thead>
<tr>
<th>First morning shift (South-East part of the city)</th>
<th>Situation “Before”</th>
<th>Situation “After”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily distance (km)</td>
<td>93,30</td>
<td>77,40</td>
</tr>
<tr>
<td>Annual distance (190 days/school year) (km)</td>
<td>17,727</td>
<td>14,706</td>
</tr>
<tr>
<td>Annual CO₂ (ton)</td>
<td>16,06</td>
<td>13,33</td>
</tr>
<tr>
<td>Annual NOx (ton)</td>
<td>0,12</td>
<td>0,10</td>
</tr>
</tbody>
</table>

Given the results, the methodology implementation led to a reduction of the distance travelled in a rate of approximately 17%. This rate can be considered as a quite remarkable one, taken into account that this concerns only the morning shift of the South-East part of the city. Moreover, in the “After” situation the CO₂ and NOx emissions are reduced by 2.7 and 0.02 tons respectively throughout the school year duration.

### Impacts on students’ health and safety

The improvement of a school bus route optimization, strengthens students’ health and safety. A travelled distance reduction leads to a minimization of the diesel exhaust emitted by a bus fleet. Thus, the students’ exposure to a carcinogen environment that contributes to acute and chronic health concerns, is decreased.

On the other hand, the reduction of the time a student spends on the bus during a daily school trip, reduces the possibility of being implicated in an accident. Although, the school bus transportation is considered as one of the safest modes of travel since it only accounts for 2% of the total number of motor vehicle fatalities of school-aged children, there is still room for further improvement (20).

Figure 7 shows a comparison of the distance travelled and the travel time between the “Before” and “After” situation for a common subset of stops belonging in cluster A. For the majority of stops both the distance travelled and the travel time are reduced in the “After” situation.

**FIGURE 7** Comparison of distance travelled and travel time in “Before” and “After” situation

The comparison among the new school bus services and the existing ones (Figure 8), revealed an improvement of travel time for the 60% of students. Moreover, for the 27% of students
the travel time reduction reached percentages varying from 25% to 75%. In the case of distance this was improved for the 70% of students

According to the new school bus routing, the total time needed for the trip’s completion seemed to be reduced by approximately seven minutes, while the total distance traveled by 2 km.

**CONCLUSIONS**

The school bus routes optimization requires a series of complex procedures due to several restrictions, which in many cases are placed by either the school management or the parents’ needs and requirements. The road network morphology, can also play a key role in the whole scheduling process. These restrictions sometimes, lead to the exclusion of routes which mathematically calculated appear to be the optimal ones. Therefore, the definition of a criterion as optimal is not always acceptable. Parameters such as time or cost savings may be considered as basic parameters of such a problem but are not always the most weighted ones.

The proposed methodology may be the basis for solving the school bus routing problem in other school units, by reforming the corresponding criteria in order to address the objectives and priorities set by each school unit separately.

The present paper, demonstrates a significant reduce on both the travel time and the distance covered by the new school bus routes derived from the “i-student trip” methodology implementation. This leads to a significant reduce on CO₂ and NOx emissions. The present research focuses in a small sub area of the city, obtaining satisfactorily results. Therefore, the extension of the methodology is proposed throughout the affected area. What seems to be more interesting though, is the methodology’s extension, in order to cover the demand and requirements of more than one school units, where combinatorial optimization of fleet and route will be calculated, and a maximization of environmental and safety impact will be achieved.
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