A Study on Pupils Transportation

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***Abstract*—The Swiss Municipality of Capriasca was in need of reorganizing the pupils transportation service for the local primary school and to evaluate different strategic changes to the current organization. This paper describes the problem and the requirements of the Municipality together with the tools we developed for the study. The resulting solutions, later adopted by the Municipality, are also described.**

***Index Terms*—computer science applications, tranportation, combinatorial optimization**

I. Introduction

The Municipality of Capriasca is located in the southern part of the Italian-speaking Canton Ticino, Switzerland (see Fig. 1). The municipality covers a relatively large territory of 36.35km^2 mainly in the mountains (see Fig. 2) and is the results of a merger between year 2001 and 2008 of several previously independent municipalities, with approximately 6300 inhabitants in total (year 2011).

One of the services provided by the Municipality is primary education, involving approximately 300 pupils for a total of 15 classes, three for each of the five levels of the local elementary education [1]. A side-service offered to the families is the transportation of pupils from the area where they live to school and back, for a total of four journeys per day, covering morning school start and end at 8:15 and 11:30, respectively, and afternoon start and end at 13:15 and 16:30, respectively [5]. Due to the relatively recent merging process, in 2011 (the time of the study presented in this paper) classrooms were spread among five different school locations (see Fig. 3). The transportation had been previously run by a private company, but due to the increase of the number of inhabitants, and by some changes of Federal regulations, the previous plan was not economically sustainable for the scholastic year 2011-12. The Council decided then to open a call for a new contract, and in parallel launched initiatives to incentivize a sustainable lifestyle, incorporating also public buses into the system and especially the so-called *green zones*, where a walk-to-school systems, called *pedobus* [2], was implemented for pupils leaving close enough to their school. Public bus lines (blue, red, azure, yellow), pedobus green zones (green lines) and actual location of classrooms are depicted in Fig. 3 [3].

In the context depicted above, we were given Origin-Destination (OD) matrices for pupils for the four phases of a school day (transportation is eventually provided also for the lunch break). For example, the morning requests for school start are presented in Table I. For each request i an origin (i), a destination $dest(i)$ and the number of pupils are given. Notice that OD matrices changes for the different day times. The Municipality was interested in estimating:

1. At an operational level, how many private buses would have been necessary to provide the service;
2. At a strategic level, what was the impact on transportation costs if some, or even all the school locations were moved to Tesserete, the central town of the Municipality (see Fig. 3). This last request was motivated by an already forecasted long-term consequence of the merging process mentioned before.

The rest of the paper provides further details of the problem, describes the approach we developed to answer the questions above, and finally presents our findings and discusses them.

II. Solution Approach

The tool we developed is based on mixed integer linear programming (MILP) and incorporates private buses routes to complement public buses and pedobuses in order to serve all pupils with an acceptable quality-level. The engine is described in the rest of this section. Travel times were estimated from Google Maps (www.google.com/maps/), the timetable for public buses was available online (www.ffs.ch), while the Municipality provided the pedobus service timetable.

The approach we developed is based on the following considerations:

1. The geographic configuration of the area is shaped like a star, with the town of Tesserete in the center. For this reason, Tesserete is used as a hub where pupils can change transportation mode or connecting from one bus to another;
2. The time horizon for pupils transportation is very restricted. A hard constraint is imposed such that each transportation cannot take more than 30 minutes. On top of this, minimizing the travel time is important, since it is a direct measure for the quality of service;
3. Pupils cannot change transportation more than one, in order to keep the quality of service at an acceptable level;

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4. Pupils with the same origin and destination will travel together. This is important to avoid complains from the families about discriminations;
5. Given the current transportation requests and their scattered nature around the territory, bus capacity is not a problem, since in no reasonable solution it exceeds that of a typical large bus (55 seats).

We decided to work with a set covering-like model (see, for example [7]) where each column represents a route of a bus (private or public) or a pedobus route. Such a choice was motivated by the observation that pedobus and public buses routes are given, while feasible private buses routes are limited in number due to the very tight time constraints, combined with the overall limited number of roads available in such a mountain region.

The first step was therefore to generate, by inspection, all possible reasonable private bus routes. Routes typically serve more than one school, exploiting the fact that school locations are close to each other, and a few minutes time flexibility is tolerated for pupils. In total approximately 250 (depending on the time of the day) were identified, covering public buses, pedobus and possible private buses, with the latter repeated several times with slightly shifted starting times.

Formally, the problem we modeled can be described as follows. A set K of transportation routes is given, with the routes by private bus identified as $K_P \subseteq K$. For each stop (villages/quarters) i touched by route $k \in K$, the arrival time is indicated as T_i^k. A set of requests R, representing group transportation requests as in Table I, is also given. For each request $i \in R$, the origin and destination locations are indicated with (i) and $dest(i)$ respectively. Tesserete is referred to as hub in the formulation, and connection times between 2 and 10 minutes are allowed in there. A constraint on the maximum number of private buses to hire, regulated based on parameter $NrPrivBusses$, is imposed. The aim was to use this parameter to propose alternative solutions using a different number of private buses (eventually larger or smaller). The target of the optimization is to provide a fair service to all the families, so the worst-case travel time was identified as a good objective function. The following binary variables are used in the model:

$$z_k = \begin{cases} 1 \; if \; route \; k \in K \; is \; selected \\ 0 \; otherwise \end{cases}$$

$$x_{i+}^k = \begin{cases} 1 \; if \; request \; i \; is \; picked \; up \; by \; route \; k \in K: orig(i) \in k \\ 0 \; otherwise \end{cases}$$

$$x_{i-}^k = \begin{cases} 1 \; if \; request \; i \; is \; picked \; up \; by \; route \; k \in K: dest(i) \in k \\ 0 \; otherwise \end{cases}$$

A further free variable is also present:

$$\delta = maximum \; time \; service \; over \; all \; requests$$

TABLE I. REQUESTS FOR THE MORNING SCHOOL START.

Request	Origin - orig(i)	Destination - dest(i)	Nr pupils
0	Lugaggia/Sureggio	Tesserete	18
1	Lugaggia/Sureggio	Cagiallo	8
2	Lugaggia/Sureggio	Sala	5
3	Lugaggia/Sureggio	Vaglio	6
4	Lugaggia/Sureggio	Roveredo	6
5	Lelgio, Odogno, Bettagno, Garamè, Pezzolo, Gola di Lago	Tesserete	27
6	Lelgio, Odogno, Bettagno, Garamè, Pezzolo, Gola di Lago	Sala	14
7	Lelgio, Odogno, Bettagno, Garamè, Pezzolo, Gola di Lago	Vaglio	9
8	Lelgio, Odogno, Bettagno, Garamè, Pezzolo, Gola di Lago	Cagiallo	1
9	Bigorio	Sala	7
10	Bigorio	Vaglio	8
11	Vaglio	Sala	20
12	Vaglio	Tesserete	2
13	Vaglio	Vaglio	9
14	Sala	Vaglio	8
15	Sala	Sala	13
16	Campestro	Tesserete	7

Request	Origin - orig(i)	Destination - dest(i)	Nr pupils
17	Campestro	Bidogno	2
18	Campestro	Roveredo	1
19	Campestro	Cagiallo	3
20	Almatro	Tesserete	1
21	Almatro	Cagiallo	3
22	Almatro	Bidogno	4
23	Cagiallo/San Matteo	Tesserete	4
24	Cagiallo/San Matteo	Roveredo	6
25	Cagiallo/San Matteo	Bidogno	3
26	Cagiallo/San Matteo	Cagiallo	9
27	Oggio	Cagiallo	1
28	Oggio	Bidogno	2
29	Lopagno	Roveredo	2
30	Lopagno	Cagiallo	6
31	Lopagno	Bidogno	3
32	Roveredo/Treggia	Bidogno	1
33	Roveredo/Treggia	Cagiallo	1
34	Roveredo/Treggia	Roveredo	4
35	Bidogno/Corticiasca /Carusio/Somazzo	Roveredo	6
36	Bidogno/Corticiasca /Carusio/Somazzo	Cagiallo	8
37	Bidogno/Corticiasca /Carusio/Somazzo	Bidogno	4
38	Tesserete	Tesserete	45

The resulting mixed integer linear programming formulation (it contains some abuse of notation) is presented in (1)-(8),

The objective function (1) minimizes the maximum travel time among all requests. Constraints (2) are used to store in δ the maximum difference between arrival and starting time of all requests; constraints (3) and (4) imposes that requests can only use active buses; constraints (5) and (6) state that each request has to be served by some transportation (the starting and ending can coincide when only one transportation mode is used). Inequalities (7) impose constraints on transportation changes in the hub Tesserete. Constraint (8) finally imposes a limit on the number of private buses implemented in the solution.

The resulting model can be solved in a few seconds by common solvers, due to the intrinsic small size of the instances treated. For more general models and approaches for school transportation we refer the interested reader to [6].

$$\min \delta \quad (1)$$

$$s.t. \quad \delta \geq \sum\nolimits_{k \in K: dest(i) \in k} \left(T_{dest(i)}^{k} x_{i-}^{k}\right) - \sum\nolimits_{k \in K: orig(i) \in k} \left(T_{orig(i)}^{k} x_{i+}^{k}\right) \quad \forall i \in R \quad (2)$$

$$x_{i+}^{k} \leq z_k \quad \forall i \in R, \forall k \in K: orig(i) \in k \quad (3)$$

$$x_{i-}^{k} \leq z_k \quad \forall i \in R, \forall k \in K: dest(i) \in k \quad (4)$$

$$\sum\nolimits_{k \in K: orig(i) \in k} x_{i+}^{k} = 1 \quad \forall i \in R \quad (5)$$

$$\sum\nolimits_{k \in K: dest(i) \in k} x_{i-}^{k} = 1 \quad \forall i \in R \quad (6)$$

$$x_{i-}^{k} + x_{i+}^{h} \leq 1 \quad \forall i \in R, \forall k, h \in K: orig(i) \in k, dest(i) \in h, k \neq h, T_{hub}^{k} - T_{hub}^{h} \notin [2;8] \quad (7)$$

$$\sum\nolimits_{k \in K_p} z_k \leq NrPrivBusses \quad (8)$$

Figure 1. The Municipality of Capriasca within Central Europe.

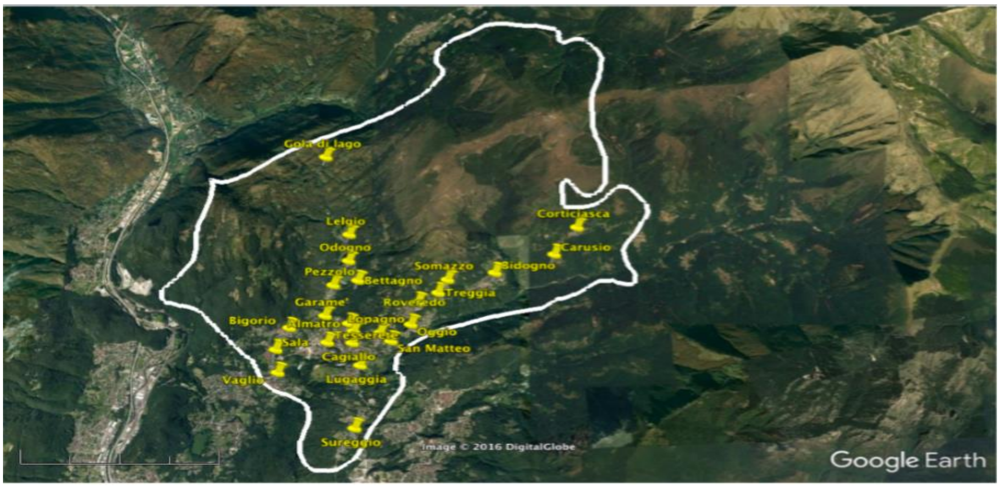

Figure 2. Schematic road network of the villages and quarters covered in the study.

III. Experiments and Results

A. Bus Fleet Dimensioning and Routing

The first request was to dimension the fleet of private buses necessary to integrate the public buses available, in order to operate the transportation of pupils, keeping an accepting level of quality of service. Four different instances were therefore faced, covering school in/out both in the morning and in the afternoon. The routing/matching model described in the previous section was run and in a few seconds was able to provide feasible transportation/matching plans.

The solutions found were using three private buses, but inspecting the tours we realized that there were margins of improvements since public transportation was not fully exploited due to a misalignment of their timetable with respect to that of the school. For this reason, and given that changing the timetable of public buses was not possible, we suggested the Municipality to anticipate of 10 minutes the morning classes, and to postpone of 15 minutes the afternoon classes. Under such conditions we were able to reduce the number of required private buses from three to two for all the transportation phases of the day. An example of journeys for the two private buses in the afternoon school end is provided in Fig. 4. Notice that families were in favor of the changes in the school timetable since it was providing a longer lunch break for the children (previously too tight for those living in peripheral areas).

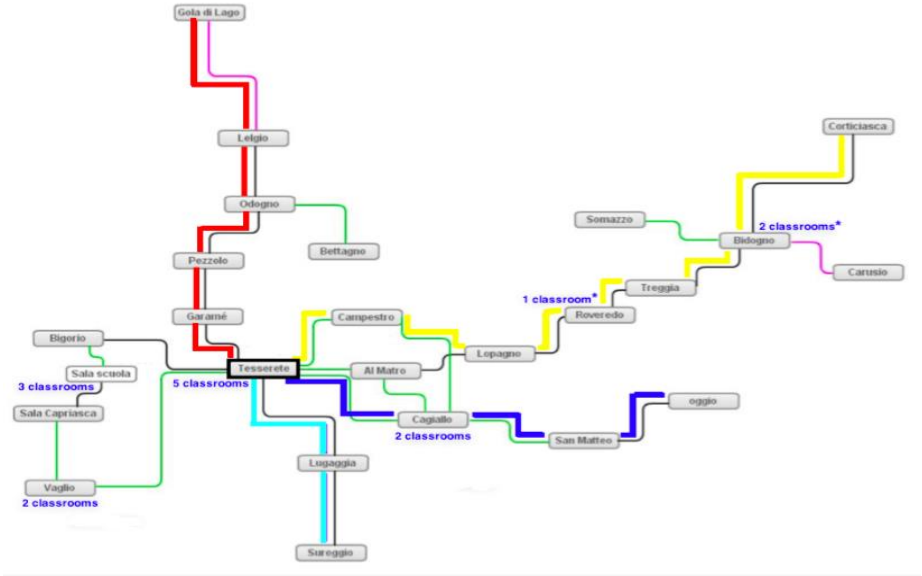

Figure 3. Schematic road network of the villages and quarters covered in the study.

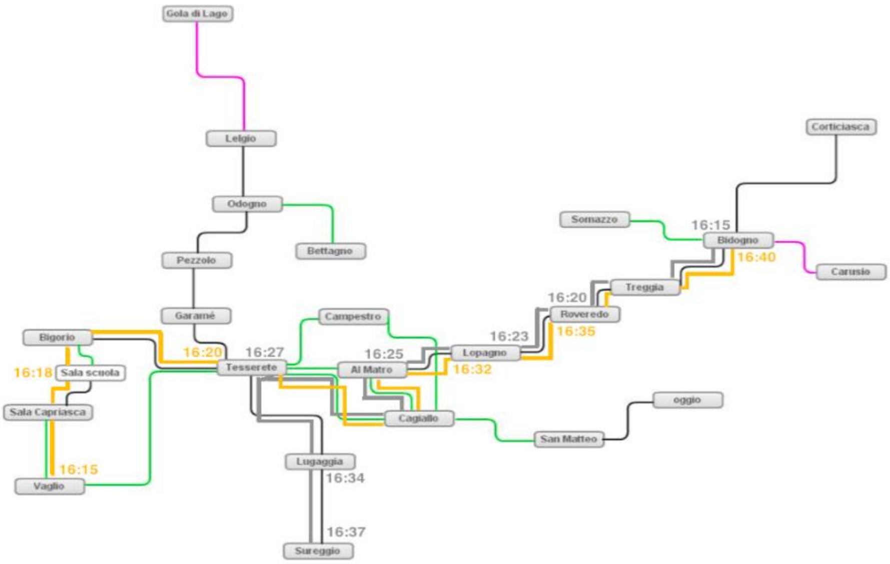

Figure 4. Routes and timetable of two private buses (gray and orange) for the afternoon school end transportation. Notice the synchronization in Tesserete planned at 16:27.

The Municipality adopted the suggestion, and the school timetable was modified for the coming scholastic year. The external economical proposals for the private buses service were evaluated keeping in mind that it was theoretically possible to guarantee the service with two buses only. In fact, the company selected for the service was operating using two vehicles, as forecasted.

B. Future Scenario: Relocating Classrooms

We were also asked to conduct a more strategic study, aiming at evaluating scenarios where classrooms from peripheral towns were moved to the central town Tesserete. The interest of the Municipality for such a study relied on the fact that there was already a plan to group classrooms together in a medium/long term, and the aim was to understand if such an action would have had a negative impact on transportation costs (number of private buses to hire) and quality of service for the families.

The first scenario we evaluated had the two classrooms from Bidogno and the one from Roveredo (marked with an asterisks in Fig. 3) moved to Tesserete. The solution obtained by running the MILP solver described before under these settings shown that the number of private buses required was still limited to two and there was no substantial degradation in the quality of service offered to the families.

The second scenario had all the fifteen classrooms grouped together in Tesserete, with all the peripheral school locations closed down. Also in this case the optimization led to a solution with only two private buses, and no change in the quality of service.

The conclusion that grouping together most or all the pupils in a same location did not imply the use of more private buses, was expected. Intuitively, some pupils might have to travel longer, but a clear star-like flow in and out Tesserete emerges. Therefore, bus routes are much more linear and it is easier to complement public buses. On top of this, a substantial number of pupils that had to move by bus from the center of the Municipality to peripheral school locations, would now be able to reach school by using the pedobus service.

A more in-depth analysis of the results of the study (in Italian) can be found in [4].

IV. Conclusions

Motivated by the need of the Municipaly of Capriasca, Switzerland, we developed a MILP-based tool to optimize the transportation of pupils. The new system had to be integrated with existing public transportation, and with walking paths for students living close to their school. The same tool was also used for a strategic study to forecast the impact of moving classrooms to different locations on the efficiency of the transportation system.

The tools provided the Municipality with the required information. In particular:

1. It was possible to dimension the private buses fleet required to run the transportation service in the four slots of a normal school day. This information was used for the evaluation of the economic proposal of bus companies. The winning company implemented the service with two buses, as we predicted;
2. At a communication level, the document [4] was useful to reassure the families that although changes were in need with respect to the previous (simpler from their perspective) system, the quality of service would have not degraded;
3. In a long term, moving classrooms into different location was not affecting the quality of service for families.

It is finally worth to mention that today in 2017, the transportation system is still running, and the scenario where all the classrooms are in the same central building has been meanwhile implemented. The operational transportation we had forecasted proved feasible, and the service is still well accepted by the community.

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