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Optimization model for school transportation design based on economic and social efficiency

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A B S T R A C T

The purpose of this paper is to design a model enabling recommendation for the new school transport planning proposals to achieve greater operational efficiency. It is a multi-objective optimization problem which includes minimization of the bus costs and total travel time for all students. The model is based on bus route planning according to changes in school starting times, so the buses can make more than one route.

The methodology is based on the School Bus Routing Problem, so that routes from different schools within a given time window are connected, and within the problem constraints so system costs are minimized. The proposed model has been programmed for application in any generic case.

This is a multi-objective problem, for which there are several possible solutions, depending on the weight assigned to each of the variables involved, economic versus social point of view. Therefore, the proposed model will be useful in school transport planning policy, given that it is a support model for making decisions, which seek efficiency in economic and social terms.

The model has been applied in some schools located in an area of Cantabria (Spain), resulting in 71 possible optimal options, which minimize school transport cost between 2.7% and 35.1% regarding current school transport routes, with different school start time and minimum travel time for students.

1. Introduction

School transport in Spain is a Special Regulated Public Transport Service financed by the Spanish regional governments through private sector contracts awarded via public tender each school year and represents a heavy financial burden for the regional government Departments of Education (Ibeas et al., 2006). This is partly because the companies find it difficult to use these vehicles for other purposes throughout the rest of the day, coupled with the existence of historically defined routes which have never been scrutinised for optimisation, not to mention the rigid school timetables.

The main goal of this study is to design an optimisation model enabling route planning proposals to be defined so they maximise efficiency from operational, economic and social standpoints. School opening and closing times will be modified by establishing time windows enabling the buses to cover more than one school route (see Fig. 1).

The aim of the research is to simultaneously optimise the group of school routes and connections between them. School route and connection optimisation is created so the differences among school opening times become dependent on the route planning to combine them and vice versa.

The analysis and research are aimed at finding a balance between profitability and quality of service, making it a multi-objective problem: economic (cost optimisation, regional government) and social objectives (journey time optimisation, users).

The initial hypotheses were: (1) bus capacity would be homogenous; and (2) the bus should arrive at the school 2–10 min before classes start. This would enable the students to arrive punctually but without having to wait too long. The input data required to resolve the model are: (1) location of the stops; (2) number of students per stop; and (3) destination school of each student.

The rest of the paper is organized as follows. Section 2 presents a brief review of existing literature. Section 3 describes the multi-objective optimization model proposed here to maximise school transport efficiency, and presents a brief description of the programme written to plan the bus fleet. Section 4 applies the proposed model in a specific area of Spain and presents the results obtained for this area. Finally, some conclusions have been made in section 5.

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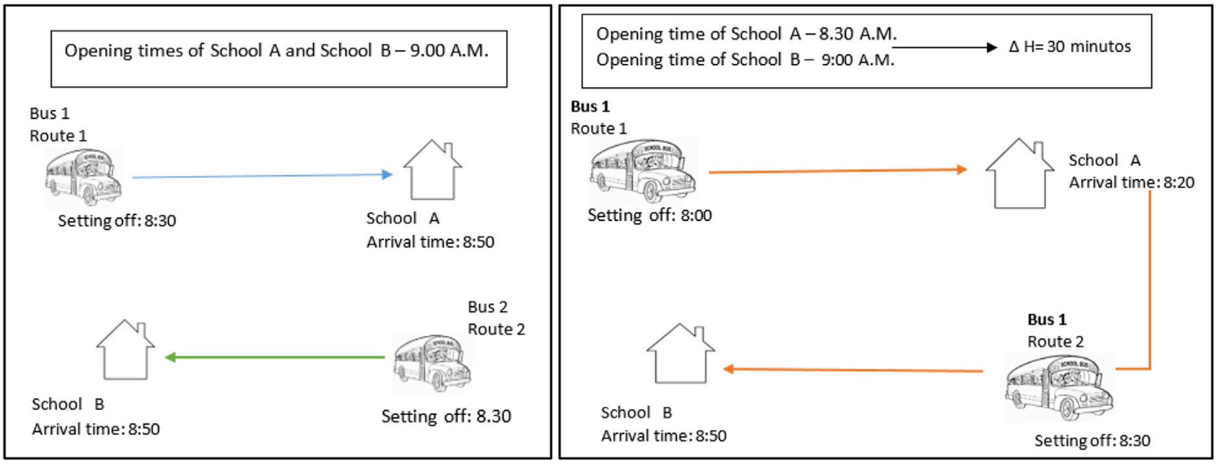

Fig. 1. The main idea (before-after).

2. State-of-the-art

Many papers are available describing research aimed at optimising school transport. Different viewpoints have been expressed in literature. Newton and Thomas (1974) presented a model to minimize both the total time required to complete all the routes (including time lapse) and the number of routes required to serve all the stops associated with the school. Spada et al. (2005) proposed a modelling approach focused on optimizing the bus service level and aims to minimize the children's time losses on the bus and at school before class starts. Another viewpoint is to minimize the economic cost, as in Thangiah et al. (2008) who presented heuristics to solve school routing problems that could lead to cost savings for governments. In Schittekat et al. (2013) the objective function is to minimize the total distance travelled by all buses, and by doing so, they had to determine (1) the stops to be covered; (2) which stop each student should use; and (3) the routes covering the selected stops.

Traditional VRP (Vehicle Routing Problem) seeks to generate efficient routes for a fleet of vehicles in order to deliver or collect products from depots for a set of customers (Laporte, 1992). Later, several extensions to the initial problem involving different constraints were developed. VRPTW (Vehicle Routing Problem Time Window) has vehicles with limited capacity and specific delivery time windows (Jean-Francois Cordeau et al., 2000) or SBRP (School Bus Routing Problem). SBRP seeks to plan an efficient schedule for a fleet of school buses where students are transported to and from school while satisfying various constraints (Park and Kim, 2010). According to Desrosiers et al. (1986), SBRP can be solved by five steps: data preparation, bus stop selection, bus route generation, school bell time adjustment, and route scheduling.

The school bus routing formulations focus on formulating extra constraints and/or objectives to take different factors into account: time window, bus stop selection, assigning students to buses, determining bus routes …. Desrosiers et al. (1986) added a maximum time constraint on each student's journey and/or time window, for their arrival at school. Fügenschuh (2009) considered the problem of programming the school bus by enabling the school opening times to be adapted to student transfer during the journey based on VRPTW, yet considered the routes to be basic input data. Ibeas et al. (2009) proposed the possibility of changing school entry and exit times, whereby the routes of each school in this case were input data, enabling a single bus serve multiple schools. On the other hand, Kim et al. (2012) propose a school bus scheduling problem where a bus can serve multiple trips for multiple schools but the school time window is fixed. Furthermore, Li and Fu (2002) presented an approach with multiple objectives where the number of buses, bus journey time and students' journey times were minimised. Bögl et al. (2015) take into account the possibility that pupils may change buses and analyse the impact of transfers on the service level in terms of user ride time and number of transfers.

As described below, this study differs in several ways from those mentioned above and others (Kontoravdis and Bard, 1995; Ho and Haugland, 2004; Park et al., 2012). In this study, the routing problem was solved at the same time as the vehicle planning problem to minimise journey times for the students and the number of buses being used within different time windows. This will enable future decision makers to give weight to these two economic and social criteria.

3. Methodology

The multi-objective optimisation model is a support tool for future decision makers. We will not be presenting a single solution, but rather various solutions to create a group of solutions which balance the economic and social factors. The objective function of the model is shown in expression 1 which will be decisive in planning school transport. The objective function is one of multi-objective optimization where 2 objectives are simultaneously minimized, i.e. operational costs and average time of routes (these variables will be explained later).

$$Min\ (\ operating\ costs;\ average\ travel\ time\ for\ routes) \tag{1}$$

The schematic shown in Fig. 2 was used in the development of the optimisation model and carried out in the following iterative manner:

- First phase, the routing problem per school is solved. Variables are the number of routes serving each school and maximum journey time allowed for them.
- Second phase, an optimisation model is used to solve the route combination problem; various routes are created for the same bus within the necessary time window, thereby providing multiple alternatives for the planning problem.
- Third phase, a pre-analysis is performed on all the alternatives obtained to find out which could minimise the objective function, and are, therefore, solutions to the model.

3.1. Routing problems per school

The routing problem per school was solved using SBRP (Bektaş and Elmastaş, 2007) (Sanhueza et al., 2012). The SBRP problem can be understood as the intersection of two well-known optimisation problems. The first, the problem of m travelling agents (m-TSP) (Salhi and Sari, 1997) is a generalisation of the TSP (Travelling Salesman Problem),