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School location and capacity modification considering the existence of externalities in students school choice ☆

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ABSTRACT

Geographic and socioeconomic characteristics of rural zones in Chile have made schools located in these areas present inefficiencies such long travel times and multi-degree courses[1] that affect the academic performance of their students. In this paper, a model of location and modification of school capacity is presented as an alternative to reduce these inequalities. In Chile a student school choice is a process that depends not only on the time and income constraints but also on the decisions made by other students (segregation). This behavior is modeled using a microeconomic approach; thereby a constrained multinomial logit discrete choice model is derived. By incorporating the student's school choice in an optimization model, it becomes nonlinear. A Tabu Search metaheuristic is proposed, which unlike other implementations requires solving a fixed point system of equations to evaluate each solution. A computing experience for instances of 10 and 45 zones is developed; in the first the quality of the solution is evaluated compared to the optimum obtained by enumeration and in the second different scenarios are analyzed.

1. Introduction

Geographic and socioeconomic characteristics in rural zones in Chile and many Latin American countries have made that rural education present inefficiency. The schools located in these zones have a very low teacher-student ratio and many of their courses are multi-degree. According with SIGER (2009) Report, in Chile in 2007, 59.26% of rural establishments had less than 4 teachers and 69% of the courses were multigrade.

Another important aspect is that students are affected by long travel times to attend their schools. In SIGER (2009) it is shown that about 36% of the high school students (segundo medio) using public transportation indicated that they travel more than 60 min. With respect to the students' socioeconomic status (SES), more than a half belong to the poorest group, so that the financial resources they have for education are quite low. The above inefficiencies definitely affect school performance. 12% of rural schools have a poor performance on math state tests.

Furthermore, since 1981 the Chilean educational system is open for private providers to enter the market of education. This allowed that all families can freely choose the school where their children will attend, only restricted by the time and income they have. This deepened inefficiencies of rural education. Cordova (2006) indicates that between 1992 and 2006 enrollment in rural zones fell by 16%, which shows that many students are willing to sacrifice themselves doing long travels and attending urban schools in search of a better education.

An alternative to reduce the rural education inequalities could be the location and modification of schools. A new configuration that improves the school's structural variables that affect the students' performance could lead to a higher quality education.

Thus, this paper proposes a location and modification school capacity model. In Chile as well as in other countries, a student school choice is a process that depends not only on the time and income constraints but also on the decisions made by other students (segregation). This behavior is modeled using a microeconomic approach; thereby a constrained multinomial logit discrete choice model is derived. By incorporating the student's school choice in an optimization model, it becomes nonlinear. A Tabu Search metaheuristic is proposed, which unlike other implementations requires solving a fixed point system of equations to evaluate each solution.

The other part of this paper is organized as follows: In Section 2 a literature review of schools location works is presented and it is established the context in which this research is conducted. In Section 3 the behavior of students and the optimization model is

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[1] Courses in which in one classroom attends students of two or more grades.

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described. Section 4 is devoted to the heuristic of solution. In Section 5 computational and evidence is reported, applied to a test zone. Finally, Section 6 describes the conclusions and final remarks.

2. Literary review

The models used in the location of schools have been developed in parallel with those that locate other facilities such as hospitals, households, firms, etc. Two contexts in which these models have been developed are: mathematical programming or optimization and the urban economy.

Optimization models seek the most efficient location with respect to a profit measure as distance, time, cost, etc. subject to different constraints such as security, resources availability, and time. The location of schools in this context was studied initially as a problem of students' allocation and known in the literature as *the school (re)districting problem*. The two features that distinguish the problem are that students in a geographic zone must be allocated to a school according to some criterion, for example distance, and that this allocation should not exceed the available capacity. In this sense, in the work of Caro, Shirabe, Weintraub, and Guignard (2004), the properties of a good allocation are established, they formulate an MIP with the aim of reducing the distance traveled by students and they make an application using a GIS, it is proved that imposing maximum impedance to travel generates more compact allocations.

Later, models of location and allocation were developed. While locating schools, students are allocated to them, with the aim of optimizing the distance. Early works only considered the opening and closing of schools. Tewary and Jena (1987) use a maximum coverage model to locate a fixed number of schools and maximize the population covered within a maximum travel distance. These models do not explicitly consider the capacity and only locate schools of the same size. Pizzolato and Silva (1997) use a p-median model to make a population clustering, each cluster is analyzed by comparing the educational supply and demand, so that, the opening or closing of schools in areas of shortage or oversupply is considered.

The works described previously do not consider the capacity explicitly and therefore they only locate schools of a same size. For that reason, Teixeira and Antunes (2008) use a p-median model with capacities, so that the allocation is performed to the nearest school with available capacity. In those works, the authors present a discrete hierarchical location model for the public facilities planning (schools). The main features of the model are: accessibility maximizing, several levels of demand and facilities, and capacity constraints. However, the authors assume that the system has the capacity to meet the demand. Pizzolato, Broseghini, and Nogueira (2001) also use a p-median model with insert capacities in a GIS to re-locate schools of different sizes in zones with shortages and oversupply of these ones, however, the authors assume that the system has the capacity to meet the demand.

The works described above do not take into account that it is financially appropriate to amend the current schools than opening new ones. Thus, Cohen, Martinez, Donoso, and Aguirre (2003) and SIGER (2009) develop models that locate new schools and modify the existing ones. The latter uses an MIP within a GIS for determining which schools should be opened, closed or modified. The model allocates students to the nearest school with available capacity to minimize transportation cost, operation and investment costs.

Antunes and Peeters (2000, 2001) describe a dynamic optimization model to formulate planning proposals for the school networks development based on an extension of the capacitated p-median model. The model allows the facility closure or downsizing, as well as the facility opening and its size expansion. The costs of the facilities are divided into a fixed component and two variable components, which depend, respectively, on the capacity and attendance. In Antunes, Berman, Bigotte, and Krass (2009) a model that seeks to maximize the total accessibility of the population to all different kinds of facilities is presented, considering that the location decisions influence the spatial distribution of the population growth.

Delmelle, Thill, Peeters, and Thomas (2014) develop a multi-period capacitated p-median model for the facility location planning that minimizes transportation costs, whereas the functional and operational costs of the education system are subject to a budget constraint. Furthermore, the allocations which are considered impractical because of the distance are penalized with a parameter associated with travel time.

The works described above assume that the students attend the nearest school. However, today's competitive markets allow a student to choose freely the service provider. Thus, a line of research that incorporates user behavior through discrete choice models in location models emerged.

The application of this methodology in other industries for example the location of airline hubs proposed by Eiselt and Marianov (2009), where the user's choice is defined by a gravitational function that considers travel time and fares; the problem is solved using a heuristic concentration method.

Marianov, Ríos, and Icaza (2008) propose a model for locating facilities, so that the market capture is maximized under the assumption that customers choose the facility where they want to be assisted according to the travel time and the waiting time, such choice is represented by a multinomial logit model. The authors demonstrate that under certain conditions there is an equilibrium demand and the problem is solved through a metaheuristic.

Colomé and Serra (2001) define several ways to incorporate the user's behavior in the context of location models and coverage. Such paper analyzes the optimal location from a competitive viewpoint including consumer's behavior aspects such as distance and transportation costs. To solve their formulations metaheuristics based on GRASP and tabu search are used.

With respect to the schools location, Gac, Martinez, and Weintraub (2009) develop a linear optimization model in which the students' preferences are introduced through a utility function whose variables are the characteristics of each school, travel and school costs. The bidders' utility is defined as the difference between revenue minus operating costs. The model seeks to maximize the profit of the bidders and applicants in the education system. However, the solution found does not involve a balance in prices, so this could get away from optimality.

A recent work is Hasse and Müller (2013), a model of location planning of the school network is proposed, seeking to maximize the expected utility of all students taking into account capacity constraints and a given budget. The utility value of each student is derived from a random utility model thus obtaining an endogenous demand. However the existences of externalities are not considered neither the impact of endogenous constraints in the students' utility.

Another context in which location models are developed is the urban economy. These models mainly seek to balance in the location of facilities (supply) and customer allocation (demand), the type of solutions generated are of a macro level and are mainly used for urban planning. School location methodologies were also developed in this context. Martínez, Tamblay, and Weintraub (2011) develop two models, one of equilibrium and another of optimization. The first one considers that households are agents who choose to attend school in accordance with each school characteristics, distance and price, and supply acts as an agent that maximizes its profit. The behavior of all the agents is modeled by logit constrained models. The second model seeks an optimal