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Invited paper

Assigning students to schools to minimize both transportation costs and socioeconomic variation between schools

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ABSTRACT

Several studies have found that students' academic achievement is as much determined by the socioeconomic composition of their school as their own socioeconomic status. In this paper we provide a methodology for assigning students to schools so as to balance the socioeconomic compositions of the schools while taking into consideration the total travel distance. Our technique utilizes a biobjective general 0–1 fractional program that is linearized into a mixed 0–1 linear program that can be submitted directly to a standard optimization package. We show how a parametrized model could be utilized to provide a spectrum of different possible assignments so that a decision maker can decide how to balance socioeconomic factors with transportation costs. As a test case for our approach we analyze data from the Greenville County School District in Greenville, South Carolina.

1. Introduction

Does the socioeconomic composition of a student's school matter in their academic success? Several studies have suggested that it does. The Coleman Report [7], which examined 600,000 students in over 4,000 schools, concluded that “the social composition of the student body is more highly related to achievement, independent of the student's own social background, than is any school factor.” Rumberger and Palardy [21] found that students attending the most affluent schools receive the greatest academic benefit, presumably benefiting from such process variables as higher parental involvement, greater teacher expectations, and more advanced (college prep) classes, among others. Mickelson and Bottia [18] found an inverse relationship between a school's socioeconomic makeup, as defined by the percentage of students eligible for free or reduced-price lunch, and outcomes in mathematics, irrespective of their age, race, or family's socioeconomic status. A Brooking's study [20] found that nationwide, the average low-income student attends a school that scores at the 42nd percentile on state exams, while the average middle/high-income student attends a school that scores at the 61st percentile on state exams.

Despite the identification of socioeconomic composition as a correlating factor between education and achievement, most public schools still fill their hallways by the attendance zones defined by the county or state officials. More often than not, these zones are primarily based on distance from the student's home to the particular school. While zoning based on distance typically provides convenience for families and lower transportation costs for the schools, it effectively zones by socioeconomic status since people of similar economic backgrounds form the neighborhoods that are zoned to particular schools.

There have been a number of different approaches taken to assigning students to schools so as to balance socioeconomic composition, including a lottery system, aggressive district efforts to integrate schools, and implementation of new zoning policies. The lottery system and redistricting efforts carry with them potentially high transportation costs as well as political consequences [19]. One of the most effective implementations of zoning policies to achieve socioeconomic integration can be seen in Montgomery County, Maryland. Montgomery County ranks among the wealthiest counties in the nation. Its zoning policy allows the public housing authority to purchase one-third of the zoning homes within each subdivision to operate as federally subsidized public housing. Public housing families are randomly assigned to public housing apartments, which prevents families from self-selecting neighborhoods and elementary schools of their choice.

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In a study of Montgomery County Schools [26], it was found that over a period of five years, children in public housing who attended the school district's most-advantaged schools far outperformed in math and reading those children in public housing who attended the district's least-advantaged elementary schools.

While the outcomes of these studies are encouraging, there are challenges associated with economic integration of schools. Since American housing is relatively segregated by income, assigning students to high schools to create socioeconomic uniformity would require students to travel greater distances. Not only could the associated transportation costs be prohibitive, but the greater travel distances could provide a barrier to active PTA and extracurricular participation. As home prices and tax structures are often tied to school districts, there are political challenges that must be considered as well—parents who pay high property taxes are often very protective of their access to high-performing schools. Thus, school districts must seek to balance the benefits of socioeconomic uniformity with longer busing distances.

In this article, we develop a methodology to assign students to schools that minimizes socioeconomic variation between the schools while also minimizing the total busing distance. Our technique utilizes a biobjective general 0–1 fractional program, which is recast as a linear mixed 0–1 program. The linearized model has the advantage that it can be solved using standard commercial software. As a test case, we apply our technique to a school assignment problem based on data from the Greenville County School District in Greenville, South Carolina.

The remainder of this paper is organized as follows. The next section reviews the literature related to the use of optimization techniques for assigning students to schools. Then we introduce our school assignment model that minimizes both the socioeconomic variation between the schools and the total busing distance. The results of our test case are presented in the fourth section, where we apply our technique to a data set based on the Greenville County School District. The last section provides our concluding remarks.

2. Literature review

Modeling school assignments to provide racial balance [1,6,11,13,25,27] and low cost transportation [3,14,15,23,28] has a long history in the OR/MS literature. For a good review of the early studies see Church [5]. Malezowski and Jackson [16] provide a general framework for modeling and solving problems of efficient allocation of educational resources. They note that there are really two conflicting criteria at play when modeling these problems: resource efficiency and equity. Resource efficiency usually has involved efficient use of facilities, teachers, buses, etc. For example, objective functions and constraints have been imposed to ensure minimization of the maximum busing distance or total travel distance, to enforce school capacities, or to achieve certain student/teacher ratios. Equity has usually involved achieving equal opportunities for all students, and constraints are used to ensured a racial balance amongst schools or a balanced expenditure per student. Often though, these criteria are in conflict. Schoepfle and Church [25] exhibit an inverse relationship between the total weighted travel (busing) distance and the maximum allowable percent deviation from the community racial balance amongst optimal school assignments. Further, Malezowski and Jackson [16] point out that school administrations stress decisions based on operational efficiency while the public tends to concern itself with equity. Given the competing criteria of balancing socioeconomic factors and transportation costs, researchers have modeled this problem as a multi-criteria decision problem. Solution approaches have generally fallen into either the use of parametric programming or goal programming methods [16].

Traditionally, those studies using parametric programming have taken one of two approaches. Some researchers optimize a single-criteria objective function while constraining other criteria to fall within some specified acceptable range [5,6,8,9,11,12,15,17,24,25,27,28]. Other researchers assign a weight for each criterion function and convert the problem to a single objective function consisting of a combination of weighted objective functions [16]. The parametric programming approach is attractive because it gives the modeler the ability to vary parameters to provide a range of options to the decision maker.

Other authors have employed goal programming [2,13,23,29], which allows the decision maker to specify preferences with respect to solution evaluation criteria, such as travel distance and socioeconomic balance in our case, through establishing an aspiration level for each criteria. The program seeks solutions that are within acceptable ranges around these aspiration levels. The downside of this approach is that it requires criteria preferences to be stated a priori, but methods like the Analytical Hierarchy Process (AHP) [22] can be used to help with this as was demonstrated in Ref. [2].

Our approach to making school assignments utilizes a biobjective model, where the first objective is to minimize the total busing distance and the second objective is to minimize the socioeconomic variation between the schools. Specifically with regards to the second objective, we minimize the sum of the absolute deviations of the average median household income of the students assigned to each school from that of the entire school system. Thus, our model attempts to assign students to schools so that the average median household income is the same for all schools. To the best of our knowledge, this approach has not appeared in the literature before, possibly because of the challenges of formulating and solving a nonlinear model of this form. However, after we apply a novel linearization technique, our model can be submitted directly to a standard optimization package.

3. School assignment model

As is typical in school assignment models, rather than assign individual students to schools we make assignments based on larger subdivisions. We have chosen to use *block groups* as defined by the United States Census Bureau (other possible options include neighborhoods, tracts, etc.). Block groups are statistical divisions of census tracts, typically containing between 600 and 3,000 people, and usually cover a contiguous area. There is an extensive amount of public data on block groups that is collected at least every ten years, including socioeconomic data such as average household income, median household income, and median home value. To balance the socioeconomic backgrounds of the schools we chose to utilize the median household income (MHHI) for two reasons: the median is more resistant to outliers than the average and the median income provides a more accurate reflection of a household's wealth (home value is not necessarily as accurate because home values can fluctuate dramatically based on the real estate market).

The parameters of our model, which are defined in terms of the index sets $BG =$ the set of block groups in the school district and $S =$ the set of possible high schools, are as follows:

$n_i =$ the number of students in block group $i \in BG$;
$c_j =$ the student capacity of high school $j \in S$;
$h_i =$ the MHHI in block group i;
$d_{ij} =$ the distance from the center of block group i to high school j; and
$p = \frac{\sum_{i \in BG} n_i h_i}{\sum_{i \in BG} n_i} =$ average MHHI of the entire school system.