Abridgment

General-Purpose Solution Methodology for the Bus Garage Location Problem

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A methodology is outlined that can (a) optimally locate bus garages, (b) optimally allocate buses to those garages, and (c) provide a mechanism to estimate the costs sensitive to change in locations and allocations. When applied to a large-scale transit system, the methodology can efficiently find an optimal garage system. The model developed is a general-purpose model and requires the user to develop his or her own estimates of the model cost parameters. That is, it provides a tight structure for relating the trade-offs between all costs and garage system attributes related to the problem but the exact cost inputs and system characteristics are dependent on the system analyzed.

The purpose of this paper is to outline a methodology that can be used by transit operators to test the cost implications of various combinations of garage locations and capacities and select the optimum combination from any number of possibilities. Although the topic that this methodology addresses is a common problem faced by expanding transit agencies, little independent research has been devoted to this area. As a result, currently used methods are often less than satisfactory (1). The importance of the use of a standard and accurate technique for this purpose lies in (a) the tremendous cost commitments that operators are required to make over the effective life of the project and (b) the controversy that often surrounds garage location decisions.

GARAGE-RELATED COSTS

Costs related to the components of the garaging system are quite significant. These costs can be divided into three categories: (a) nonproductive transportation costs, (b) garage operating costs, and (c) garage capital costs. Each of these costs is described in the following sections, and examples are given of their magnitudes and of how they vary with garage system parameters.

Nonproductive Transportation Costs

The costs of deadheading buses to and from their work assignments and of providing relief for drivers depend on the locations of garages with respect to the bus routes each garage services and on the characteristics of the highway network surrounding the garage. Nonproductive transportation costs per vehicle have been shown to increase with the increase in the size of garages as more vehicles are drawn from more distant routes (diseconomies of scale) (1). In addition, past studies have shown that these costs can vary significantly as a function of the location of a garage in relation to the transit network and with respect to other garages (2-4). Thus, nonproductive transportation costs are a function of the capacity allocated to the garages and the location of garages in a transit system.

The magnitude of nonproductive transportation costs can be quite consequential. For instance, the transit agency in the St. Louis metropolitan area, the Bi-State Development Agency, projected its 1985 nonproductive transportation costs to average almost $9000/year/bus (2). Since Bi-State operates approximately 1200 vehicles, its 1985 annual nonproductive transportation costs will be approximately $10 million, which demonstrates the significance of these costs. A study of transit operation in the Washington, D.C., metropolitan area estimated that approximately 10 percent of its annual operating costs is consumed by nonproductive transportation (5). Presumably, nonproductive transportation costs account for even greater shares of operating costs in more sparse transit networks than that of Washington, D.C.

Garage Operating Costs

The cost per vehicle of servicing and maintaining buses in a garage has been shown to be sensitive to the number of buses stored in a garage (4,6). When more vehicles are stored in a facility, labor and equipment can be more efficiently used (economies of scale). For example, a study of AC Transit, the East San Francisco Bay Area transit agency, found that its costs for operating a garage dropped from $14 570 to $13 530/bus/year when the size of a garage increased from 150 vehicles to 300 (6). AC Transit currently operates 760 buses and 4 garages; its total cost of operating its garages is approximately $10.5 million/year. Operating costs can be much more for larger operators such as those in the Philadelphia and Chicago areas, which have 10 and 12 garages, respectively (6). The magnitude of the annual costs of garage operation indicates the importance of this cost component.

Garage Construction Costs

Unlike the other costs related to garages, the costs of garage construction and of buying equipment for a garage are fixed capital costs. Once a decision is made to construct a facility, capital costs are sunk into the garage for the life of the structure. Because larger facilities can use storage and repair space more efficiently, the total costs per vehicle decrease as size increases (economies of scale). For example, the AC Transit study estimated that capital cost per bus dropped from $38 570 to $30 460 when garage size was increased from 150 to 300 vehicles (4). Because a typical size garage for 250 vehicles has an initial cost of approximately $10 million, capital costs of garage additions are quite important.

Total Costs

Nonproductive transportation costs, garage operating costs, and garage capital costs are all affected by garage planning decisions. Although they can be estimated separately, their interdependence locks these three cost components together in determining the cost implications of bus garage changes or additions. Because each represents an important cost component by itself, the total cost implications of all three, in aggregate, have even greater importance within the overall perspective of this garage location problem.

Usually, each of these costs is considered separately in garage planning studies. Often, the investigators select a desirable size for a garage addition, thus fixing the allocation of vehicles to the proposed facility, and then later look for an efficient location. By solving the problem in two steps, the investigator has really performed two discrete suboptimizations that, when combined, may not lead to a global optimization. The reason for not considering the total optimizations of all costs simultaneously is that this presents a very complex problem.

The problem of determining optimal locations and sizes for bus garages is one of trading off the garage construction and operating cost savings of large facilities for the nonproductive transportation cost savings of small dispersed garages. Since these costs represent competing and interdependent forces, the minimum cost combination can only be determined when all three are considered simultaneously.

PUBLIC SENSITIVITY TO GARAGE PLANNING DECISIONS

The process of locating and sizing bus garage additions or changes often constitutes one of the more controversial aspects of transit planning. Bus garages often occupy prime industrial sites but, because transit operators are public agencies, the construction of new garages does not enhance the local tax base. Further, the movement of buses into and out of a garage often has a disrupting effect on the traffic flow on adjacent arterials. For these reasons and others, public or local municipalities have often stopped bus garage additions slated to be built in their neighborhoods and communities.

Naturally, dealing with controversial and sensitive issues is a difficult task, but in this case, because transit planners have no accurate means of measuring the cost penalty of not optimally locating a garage site, it is impossible to make trade-offs between public concerns and the transit operator's interest. Thus, it becomes extremely difficult for operators to justify locating a garage at any site that might be publicly challenged.

METHODOLOGY

The need for having standard and accurate methodologies available to aid in planning fixed facilities is quite apparent. The methodology outlined in this paper is an attempt to fill that need by developing an optimization model with the objective of minimizing all three costs related to bus garage decisions (nonproductive transportation, garage operating costs, and garage construction costs). The outlined methodology is computationally efficient and permits the modeler to introduce judgmental inputs. Examples of judgmental inputs would include a cost penalty for locating a garage in a politically sensitive community or a maximum or minimum garage size. Although this paper only outlines the methodology, the Urban Mass Transportation Administration (UMTA) study report on which this paper is based demonstrates the model through application to a large-scale metropolitan transit system (7).

The objective of the methodology is to minimize the costs related to garages located and to the allocation of buses to garages located. Since the objective is to minimize costs subject to physical and transit system constraints, the problem is structured as a mathematical program. The costs to be minimized are the sum of nonproductive transportation costs, garage operating costs, and garage construction costs. The constraints are the feasible bus scheduling and garage capacity constraints.

Definition of Cost Inputs

Nonproductive Transportation Costs

Route assignments of buses are known as blocks. Each block begins when a bus leaves the garage and ends when the bus returns. One driver may stay with the bus throughout the block, or a block may have more than one driver if the block is longer in time than one work shift. In the latter case, the initial driver is relieved at some intermediate point in the block. Because each block defines one individual trip, nonproductive transportation costs are examined on a block-by-block level (1,3,8).

If a block is assigned to a particular garage site, the nonproductive transportation cost of the assignment is added to the costs included in that particular garage combination. However, the number of blocks assigned to a garage will probably not equal the number of buses necessary to service the blocks. Therefore, to allocate capacity to garages, blocks must be converted to bus equivalents.

Blocks can be categorized by the period the block spans. There are generally four types of blocks: all-day, midday, morning, and evening. All-day blocks are bus assignments that, at least partly, overlap both the morning and afternoon peaks. Morning and evening blocks are assignments that cover respective peaks. Thus, the number of active buses assigned to a garage site has to be greater than or equal to the sum of the morning blocks plus all-day blocks assigned, and it must be greater than or equal to the sum of the evening blocks plus the number of all-day blocks. Similarly, the number of midday blocks plus the number of all-day blocks assigned to a garage must be less than or equal to the number of active buses assigned to a garage. These types of blocks occur during weekdays, Saturdays, and Sundays, all of which may have different schedules.

Garage Operating Costs

Operating costs are an increasing function of the number of buses assigned to a garage. Available estimated total operating cost functions have a fixed cost for the first increment of capacity assigned to a garage and a portion that linearly increases with the number of buses assigned (4,9). More specifically, for opening a garage of any size there is a fixed operating cost, and from that point on costs increase linearly.

Garage Construction Costs

Construction costs are also an increasing function of the number of buses assigned to a garage. Available estimated total construction cost functions have a fixed cost for the first increment of capacity assigned to a garage and a portion that linearly increases with the number of buses assigned (4,9). More specifically, for opening a garage of any size there is a fixed construction cost, and from that point on costs increase linearly.

Cost Relations

Once the three cost inputs have been defined as variables that change with respect to changes in location and size, the model can be constructed. The model is not shown here because of its length and complexity (7,8). However, the objective of the methodology is to minimize the sum of the three costs subject to scheduling and physical constraints. Therefore, the problem is formatted as a mathematical program.

The mathematical programming model starts with a list of existing and feasible candidate garage sites and the estimates for all three costs for all garages and candidate garages. As output, it produces the optimal number, sizes, and locations of bus garage additions or changes. The model considers garage operating and garage construction costs and the cost of deadheading and driver relief under separate operating schedules for morning, all-day, midday, and evening assignments on weekdays, Saturdays, and Sundays.

Although all the cost inputs to the model are linear, the fixed charges of garage operating and construction costs preclude the problem from being solved as a linear program. The fixed-charge problem is initially formulated as a mixed-integer program. However, because of the difficulty involved in solving a large-scale problem with a general-purpose, mixed-integer program, the problem is solved by a special-purpose, branch-and-bound process. This process uses an efficient sequence of classical transportation problems plus a number of easy-to-use side calculations that rule out a wide variety of potential computations. Consequently, the model can be applied to relatively complex systems and requires a very modest amount of user effort.

CONCLUSIONS

This paper outlines a methodology that will determine the optimal locations and sizes of bus garages. The problem is formatted as a mathematical program and is solved by using a mixed-integer program that uses a special-purpose, branch-and-bound technique. The methodology has been tested on a large-scale transit system (more than 1000 buses) and has been found to work efficiently in terms of computation effort (_7_). Further, the methodology has been shown to be adaptable to the inclusion of a number of judgmental inputs.

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