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Optimal resource allocation among transit agencies for fleet management

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ABSTRACT

Most transit agencies require government support for the replacement of their aging fleet. A procedure for equitable resource allocation among competing transit agencies for the purpose of transit fleet management is presented in this study. The proposed procedure is a 3-dimensional model that includes the choice of a fleet improvement program, agencies that may receive them, and the timing of investments. Earlier efforts to solve this problem involved the application of 1- or 2-dimensional models for each year of the planning period. These may have resulted in suboptimal solution as the models are blind to the impact of the fleet management program of the subsequent years. Therefore, a new model to address a long-term planning horizon is proposed. The model is formulated as a non-linear optimization problem of maximizing the total weighted average remaining life of the fleet subjected to improvement program and budgetary constraints. Two variants of the problem, one with an annual budget constraint and the other with a single budget constraint for the entire planning period, are formulated. Two independent approaches, namely, branch and bound algorithm and genetic algorithm are used to obtain the solution. An example problem is solved and results are discussed in details. Finally, the model is applied to a large scale real-world problem and a detailed analysis of the results is presented.

1. Introduction

Transit planners are faced with the task of allocating funds for fleet maintenance and procurement for various transit agencies in the region. An important issue in transit fleet management is the decision regarding the replacement and rehabilitation of a fleet. Procurement of new vehicles to retire old vehicles is a capital-intensive process. Transit agencies with limited resources depend on governmental support for fleet management purposes. Historically, up to 80% of the capital cost of procuring transit buses in the United States has been borne by the federal government, with the remainder shared by the state and local governments (FTA, 1992). These funds are to be used to meet the dual purpose of replacing aged vehicles with new ones and re-building the older fleet.

The problem addressed in this paper is typical to most state Departments of Transportation (DOT) in the US that support the fleet management of transit agencies in the state. The federal support to the fleet management program is typically routed through the state. A bus that completes its service life should ideally be replaced. States that do not have enough funds to procure new buses for their constituent agencies, have several re-building alternatives available to them. It is to be noted that the rebuild option is not a permanent solution; it only postpones the replacement of a bus. Although many rebuild options exist, the two generic categories are bus rehabilitation and bus remanufacturing (Khasnabis and Naseer, 2000).

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Bus rebuild programs usually have some policy constraints associated with them, such as limiting the rehabilitation of a bus to no more than two times, limiting the remanufacturing to one time and so forth. Based upon an analysis of repair and maintenance data of transit fleet in the state of Michigan, US, it was found that up to certain limits, it is cost-effective to rebuild an existing bus (Khasnabis and Naseer, 2000). With a fraction of the procurement cost for a new bus, it may be possible to extend the life of an existing bus by a few more years. This strategy will require the state DOT to allocate funds partially for the purchase of new buses and partially for the re-building of existing buses. In short, the rebuild program will help the state DOT in meeting federal standards, and maintaining the fleet strength with limited budget.

Several issues need to be addressed on such re-building programs for a state DOT. The first issue is to decide whether or not a bus that has satisfied its service requirements should be replaced or re-built. The re-building itself can have multiple schemes that may vary in cost and benefit. The second issue is to allocate resources to the constituent agencies in an equitable manner. Finally, the allocation of funds over several years must also be properly programmed. Normally, funds are allocated on an annual basis according to an approved budget. However, the decision made in a given year will have an impact on the health of the fleet in the subsequent years. Therefore, a decision that considers the future impact of bus replacement actions is preferred. The authors contend that, this is an asset management problem that should be properly interfaced with the state's long term strategic plans. A procedure is not currently available that addresses all these three dimensions, i.e. choice of rebuild/replace option, proportion of funds for each agency and proportion of funds over a planning period. This paper is aimed at the development of a model for state DOT's for optimal resource allocations for transit fleet management.

2. Review

A review of literature in the area of transit asset management is attempted here. Although this term can be very broad in its scope, here we focus on the strategic resource allocation for fleet replacement and re-building programs. Examples of resource allocation problems characterized by a fixed budget and competing requirements are widely reported in literature spanning diverse areas such as operations research, manufacturing, finance, transport infrastructure projects (Ross, 2000; Sheu, 2006; Melachrinoudis and Kozanidis, 2002; Ahmed, 1983). Transit planning is also rich in resources allocation and asset management problems: resource allocation to various agencies (Forkenbrock and Dueker, 1979; Forkenbrock, 1981), determination of location, size and number of transit centers (Uyeno and Willoughby, 1995), allocating fleets in transportation networks (Diana et al., 2006), and the dilemma of purchasing new buses or retiring old buses (Simms et al., 1984; Khasnabis et al., 2002). Fleet management solutions for transit operators can be broadly classified into two groups. The first is fleet maintenance from the perspective of the operator who is concerned with the day to day maintenance for an efficient fleet operation (Etschmaier and Anagnostopoulos, 1984; Etschmaier, 1985; Pake et al., 1985, 1986; Dutta and Maze, 1989; Maze and Cook, 1987). The second is a closely related problem, addressing the needs of a state transit planner in the replacement and/or re-building of buses (Balzer et al., 1980; Rueda and Miller, 1983; Davenport et al., 2005). Each of these problems is characterized by a very specific formulation, stated objectives and constraints, as opposed to a standard formulation and solution methodology. These problems demonstrate the benefit derived from a proper mathematical modeling approach. They usually involve either the maximization or minimization of an objective function comprising a set of decision variables, subjected to various constraints expressed in the form of equations or inequalities.

Depending on the nature of the problem, these methods can be formulated as linear programming or non-linear programming, integer, mixed integer and dynamic programming models. (Ahmed, 1983; Ariaratnam and MacLeod, 2002; Srour et al., 2006; Uyeno and Willoughby, 1995; Melachrinoudis and Kozanidis, 2002; Kozanidis and Melachrinoudis, 2004). Traditionally, such allocation problems are solved by various forms of gradient search methods (Deb, 2001). These methods assume the search space to be uniform and unimodal, to ensure a unique solution. However, seldom would one encounter such convex problems in real world. There are several ways to address such non-convex problems; notable among them are genetic algorithm (GA), a general purpose robust solution algorithm (Mathew and Mohan, 2003; Karlaftis et al., 2007; Deb, 2001), and branch and bound algorithm (BBA) to deal with integer variables and constraints (PSP, 2007; Haggag, 1981; Pillai et al., 1998; Horn, 2004). In this paper, a comprehensive mathematical programming model for fund allocation for transit fleet management is formulated. We propose two solution methodologies: genetic algorithm (GA) and branch and bound algorithm (BBA). We then present the results of an example problem followed by a full scale case study. First, the background of the problem is highlighted.

3. Background

The resource allocation problem addressed in this paper is motivated by the structure of the US federal support to transit agencies. Current federal policies are designed to ensure that buses purchased with federal funds are properly maintained and remain in productive operation for a minimum normal service life, (MNSL). Buses that have achieved their MNSL are qualified to receive federal funds for replacement. The federal funding is complimented in many cases by state DOT's through matching funds to local transit agencies for replacing transit buses. When the state DOT's do not have enough funds to provide necessary matching support to procure new buses for their constituent agencies, they may allocate capital funds partly for the purchase of new buses, and partly for the re-building of existing buses. This strategy may help the DOT in meeting the requirements of all the agencies, as set forth in the MNSL criteria.