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Preserving an aging transit fleet: An optimal resource allocation perspective based on service life and constrained budget

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ABSTRACT

Local, county and state level transit agencies with large fleets of buses and limited budgets seek a robust fund allocation mechanism to maintain service standards. However, equitable and optimal fund allocation for purchasing, operating and maintaining a transit fleet is a complex process. In this study, we develop an optimization model for allocation of funds among different fleet improvement programs within budget constraints over the planning period. This is achieved by minimizing the net present cost (NPC) of the investment within the constraint of a minimum level of fleet quality expressed as a surrogate of the remaining life of the fleet. Integer programming is used to solve the formulated optimization problem using branch and bound algorithm. The model formulation and application are demonstrated with a real world case study of transit agencies. It is observed that minimizing NPC provides a realistic way to allocate resources between different program options among different transit agencies while maintaining a desired quality level. The proposed model is generalized and can be used as a resource allocation tool for transit fleet management by any transit agency.

1. Introduction

Transit agencies with limited resources depend on federal support for up to 80 percent of the capital cost of buses in the United States (FTA, 1992). The remaining share is provided by state and local governments. These funds are to be judiciously used to meet the dual purpose of replacing and/or rehabilitating aging vehicles. Hence, most transit agencies (local, county and/or state level) need a robust fund allocation mechanism to operate and maintain the aging fleet within budget constraints. Ideally, a bus that completes its service life needs to be replaced. Many states in the US do not have the matching funds needed to procure new buses for their constituent agencies; hence they use different rebuilding alternatives. The rebuild option, however, is not a permanent solution, as it only postpones the replacement of a bus. Therefore, the decision regarding replacement and rehabilitation of a fleet becomes a critical aspect of transit fleet management. While replacing the aging fleet is the most desirable option from a quality point of view, budgetary constraints require transit agencies to use a combination of new and old buses to provide services for their customers. Thus the challenge before the agency lies in finding an optimum combination of new and old buses by partially replacing and partially preserving the existing fleet.

A number of studies conducted between 1980 and 2000 explored the economics of purchasing new buses versus rebuilding of existing buses. These studies found that up to certain limits, it is cost-effective to rebuild an existing bus, thereby extending its effective life by a few years at a fraction of its replacement cost. The topic of optimally allocating resources

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Nomenclature

b_m	budget available for mth planning year
c_k^m	cost of implementation of the improvement program k on mth year
$f_{i,j}^m$	number of buses for an agency i with remaining life of j years on mth planning year
l_k	additional year added to the life of the bus due to improvement program $l_k \in \{2,3,4,7\}$
r_{ij}^m	number of existing buses with remaining life of j years for an agency i on mth planning year
x_{ij}^m	number of buses which received remaining life of i years for an agency i on mth planning year due to the improvement program
y_{ik}^m	number of buses chosen for the improvement program k adopted for an agency i on mth planning year
$\delta_{i,(\alpha,\beta)}^m$	number of buses already improved by α, β years due to rehabilitation in the mth planning year for agency i, ($\alpha,\beta \in \{2,3\}$)
$\delta_{i,(\gamma)}^m$	number of buses already improved by γ years due to remanufacture in the mth planning year for agency i, ($\gamma \in \{4\}$)
$\varnothing$	the interest rate used for NPV
A	total number of agencies
B	total budget available for the project for all planning years
i	1,2,...,A, the subscript for a transit agency
j	1,2,...,Y, the subscript for remaining life
k	1,2,...,P, the subscript used for improvement program
m	1,2,...,N, the subscript used planning year
N	number of years in the planning period
P	number of improvement programs
REHAB1	the first improvement program-rehabilitation of bus yielding α(=2) additional years
REHAB2	the second improvement program-rehabilitation of bus yielding β(=3) additional years
REMANF	the third improvement program-rehabilitation of bus yielding γ(=4)additional years
REPL	the last improvement program-replacement of bus yielding seven additional years
TSWARL	total system weighted average remaining life, $TSWARL = \sum_m TWARL$
TWARL	total weighted average remaining life = $TWARL = \sum_i WARL_i$
$WARL_i$	weighted average remaining life for agency i = $WARL_i = \frac{\sum_j f_{ij}^m r_{ij}^m}{\sum_j f_{ij}^m}$
Y	minimum service life of buses
Z_x	the objective function as minimization of NPV for the resource allocation in the planning period

between new buses and rebuild options was initiated at Wayne State University in 2000 as a part of two studies sponsored by the Michigan Department of Transportation (Khasnabis and Naseer, 2001) and the U.S. Department of Transportation (Khasnabis et al., 2003). The latter study resulted in the development of a two-stage linear programming model to allocate resources among different improvement programs (Khasnabis et al., 2004). A number of studies conducted between 2007 and 2010 attempted to improve upon the original model by suggesting both structural and methodological changes (Mishra et al., 2010; Mathew et al., 2010). These studies attempted to maximize the quality of the bus fleet by optimizing different surrogates of Remaining Life (RL).[1]

The research presented in this paper represents further modifications to these models by minimizing the investment cost, as opposed to maximizing RL (or a surrogate thereof). Initial attempts to formulate this problem resulted in maximizing the Total Weighted Remaining Life (TWARL) defined as:

$$TWARL = \sum_i \frac{\sum_j f_{ij}^m r_{ij}^m}{\sum_j f_{ij}^m} \tag{1}$$

where f_{ij}^m is the number of buses for an agency i with remaining life of j years on mth planning year; r_{ij}^m is the remaining life of j years for an agency i on mth planning year for a corresponding bus; i is the agency, j is the remaining life, and m is the planning year in consideration. Mathew et al. (2010) reformulated the model by maximizing total system weighted average remaining life (TSWARL) defined as the sum of TWARL over the planning period in consideration, i.e. $\sum_m TWARL$, where

$$TSWARL = \sum_m \sum_i \frac{\sum_j f_{ij}^m r_{ij}^m}{\sum_j f_{ij}^m} \tag{2}$$

Both TWRL and TSWARL can be looked upon as surrogates of the quality of the fleet. Research presented in this paper is based upon an alternative approach of cost minimization, and essentially builds upon the work reported by Mathew et al. (2010).

[1] RL can be defined as the difference between the minimum normal service life (MNSL) and the age of the bus. The MNSL of a medium-sized bus, the subject matter of this study is taken as seven years per guidelines of the U.S. Department of Transportation.