ARTICLE IN PRESS

Transportation Research Part D xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Mixed bus fleet management strategy for minimizing overall and emissions external costs

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ARTICLE INFO

Article history:
Received 30 November 2015
Revised 19 September 2016
Accepted 4 October 2016
Available online xxxx

Keywords:
Mixed bus fleet management
Electric bus
Emissions reduction
Vehicle replacement
Vehicle routing
Bus service coordination

ABSTRACT

Diesel buses add substantially to air pollution. To mitigate this problem, more and more clean-energy buses are introduced. Among them, electric bus has been recognized as the cleanest with lower emissions. But the deployment of electric bus is limited by its short travel distance and long charging time. In this paper, based on the approach of remaining life additional benefit-cost (RLABC), we propose an approach called new life additional benefit-cost (NLABC) to solve the mixed bus fleet management (MBFM) problem. An integer program is developed based on the NLABC analysis for maximizing the total net benefit of early replacement, where both the optimal fleet size and composition under budget constraints can be determined. Arguably, the routing problem is a major issue to be tackled due to the range limitations and operating costs of electric buses in the MBFM problem. Hence, we include the routing problem associated with bus services coordination among multiple routes in this formulation. Two routing methods are proposed to solve the recharging problem to study the tradeoff between accuracy and efficiency. Four types of buses, including electric bus, compressed natural gas bus, hybrid-diesel bus, and diesel bus, are considered, while accounting for their different operating costs, external costs of emissions, and purchase costs. To illustrate the approach, we apply the formulation to some transit lines in Hong Kong. The results show that vehicle routing with bus service coordination and mixed fleet optimization are important considerations for managing the bus fleet; both of which can produce considerable benefits.

1. Introduction

Public transit is often considered a green transportation mode. However, heavy-duty diesel vehicles, a common form of urban transit, are a major contributor to vehicular emissions, accountable for over 45% of nitrogen oxides emissions and 75% of particulate matters (Elkins et al., 2003). To reduce air pollution from diesel buses, buses using alternative energy sources have been introduced, such as Electric bus (Elec), compressed natural gas bus (CNG), and hybrid-diesel bus (Hybrid). How to efficiently manage the bus fleet under budget constraint by gradually replacing the old buses with newer and cleaner ones thus becomes important.

Many studies have been conducted on vehicle fleet management. A review of the literature can be found in Li et al. (2015), such as 'repair limit', the parallel machine replacement problem (PMRP), and so on. Among studies on clean-energy bus man-

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http://dx.doi.org/10.1016/j.trd.2016.10.001
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agement, only few have considered emissions in their cost-benefit analyses. Li and Head (2009) formulated a bus-scheduling problem to minimize the operating costs and excess vehicle emissions. Stasko and Gao (2010) developed an integer program to minimize the combined costs of operations and emissions by considering three different types of buses, i.e. conventional diesel, diesel hybrid and CNG. They indicated that both vehicle task assignment and purchase models are important for managing the bus fleet with multiple power sources. However, earlier studies generally have not considered electric buses. Li (2013) developed a vehicle scheduling model for electric, CNG, diesel, and hybrid buses separately while considering the maximum route distance. Lajunen (2014) presented a cost-benefit analysis of hybrid and electric buses for city operations, and pointed out that their cost-efficiency depended substantially on their capital costs and costs of energy storage systems. Furthermore, operation schedule and route planning were identified as critical factors. Li et al. (2015) proposed an approach called remaining life additional benefit-cost (RLABC) analysis to maximize the total net benefit of optimizing the current diesel bus fleet. They considered the purchase, resale, retrofit and operation costs, emission factors, as well as the budget constraints. But none of these studies have considered managing the bus fleet with multiple power sources.

This paper extends the RLABC approach to formulate the MBFM problem by maximizing the total net benefits resulting from early-retiring, purchasing, and routing the bus fleet within the lifespan of the new replacement buses, referred to as new life additional benefit-cost (NLABC) in this study. We then determine the optimal fleet size, composition, and routing simultaneously. Four types of buses are considered: Electric bus (Elec), compressed natural gas bus (CNG), hybrid-diesel bus (Hybrid), and diesel bus (Diesel), including their various costs, i.e. operations, emissions, resale and purchase. Incorporating bus vehicle routing in the formulation is essential, mostly due to the need of including the range limitations of electric buses. In this paper, we include vehicle routing also to study bus services coordination among multiple routes. To incorporate the recharging issue of electric buses, we propose a multi-period routing approach, as will be explained later, at the cost of increasing the computational complexity. We then develop a two-step solution procedure to improve the computational efficiency of the resultant integer linear program. To illustrate the model, we apply it to a set of transit lines in Hong Kong. The outline of this paper is as follows: Section 2 presents the methodology; Section 3 implements the methodology to a set of Hong Kong bus lines; and Section 4 provides some concluding remarks.

2. Model formulation

2.1. New life additional benefit-cost (NLABC) analysis

2.1.1. Description of NLABC analysis

Following the approach of remaining life additional benefit-cost (RLABC) (Li et al., 2015), we develop the approach referred to here as the new life additional benefit-cost (NLABC) analysis. RLABC calculates the additional benefit-cost for the remaining life of a current bus, whereas NLABC considers the whole lifespan of a new replacement bus, as shown in Fig. 1. Early replacement of a current bus by a new bus can only be justified if its additional benefit is larger than its additional cost; otherwise default replacement at the end of the current bus's nominal lifespan will maintain. When we consider the problem of mixed bus fleet replacement, new buses with higher purchase prices, such as electric buses, will be disadvantaged if we only consider the remaining lifespan of the current bus, as capturing the savings only in the remaining life of the current bus may underestimate the total benefits of the new replacement bus which will extend beyond the life of the current bus. Thus, the whole lifespan of the new replacement bus should be considered instead of its first few years associated with the remaining life of the current bus. Note that RLABC is a special case of NLABC if only a single bus type is considered in the bus fleet.

Similar to RLABC, the additional benefit of NLABC is defined as the savings in external costs associated with emissions reduction in the lifespan of a new replacement bus. Likewise, the additional cost is composed of (1) the extra operation costs of different types of buses in the lifespan of the new replacement bus; (2) the loss from disposing part of the residual value of a bus to be early retired; (3) the price difference between purchasing a new replacement bus in lieu of the default replacement bus earlier than scheduled. Besides, since the routing problem is a major issue in the MBFM problem as contended earlier, we integrate the routing problem in the formulation, allowing buses to travel on multiple routes, instead of using buses' average travel distances as in RLABC.

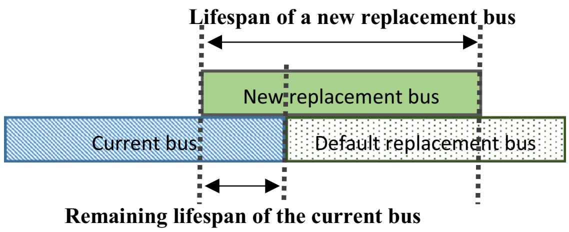

Fig. 1. Relationship between bus lifespans.