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Reducing transit fleet emissions through vehicle retrofits, replacements, and usage changes over multiple time periods

Timon H. Stasko, H. Oliver Gao *

School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853, USA

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ABSTRACT

Bus transit is often promoted as a green form of transportation, but surprisingly little research has been done on how to run transit systems in a green manner. Both vehicle task assignment and purchase models are generally constructed to minimize financial costs. Integrating vehicle task assignment with purchase decisions is made challenging by the different time scales involved. An integer programming approach is used to combine vehicle purchase, retrofit and aggregated task assignment decisions. The formulation is designed to operate in sequence with traditional vehicle task assignment models, to add emissions and long term financial cost elements to the objective, while maintaining computational tractability and feasible input data requirements. In a case study, a transit agency saves money in the long term by using stimulus money to buy CNG infrastructure instead of purchasing only new buses. Carbon prices up to \$400/(ton CO_2 equivalent) do not change vehicle purchase decisions, but higher carbon prices can cause more diesel hybrid purchases, at a high marginal cost. Although the motivation and numerical case study are from the US transit industry, the model is formulated to be widely applicable to green fleet management in multiple contexts.

1. Introduction

Bus transit is often promoted as a green form of transportation, but surprisingly little research has been done on how to run transit systems in a green manner. Research on transit vehicle assignment (the process of assigning vehicles to routes) focuses on minimizing capital and/or operating costs, or factors related to cost, such as the number of vehicles required. Even without including related problems such as driver scheduling, vehicle assignment problems can be very large and difficult to solve (Kliewer et al., 2006; Banihashemi and Haghani, 2000; Haghani et al., 2003). Li and Head (2009) stands out from other vehicle assignment research by including emissions constraints and penalties in its formulations. Unlike typical transit vehicle assignment models, they explicitly model vehicle purchases, limited by a capital budget.

Transit vehicle assignment models, including that of Li and Head (2009), are generally constructed to optimize the vehicle movements needed to cover all routes on a timetable, which is usually one day long. In transit, the timetables tend to repeat regularly (perhaps with variants depending on day of the week). It is a common practice to rework transit vehicle assignments several times per year, as adjustments to routes are introduced (Banihashemi and Haghani, 2000). Li and Head (2009) do not forecast how operational costs will change due to future route adjustments, or other factors such as shifting fuel prices. The impacts of current vehicle purchase and usage decisions on future capital expenditures are not considered. The fine grained nature of the time–space network, which is essential to short term vehicle assignment

* Corresponding author. Tel.: +1 607 254 8334; fax: +1 607 255 9004.
E-mail addresses: ths9@cornell.edu (T.H. Stasko), hg55@cornell.edu (H. Oliver Gao).

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decisions, makes longer term planning difficult. As a result, vehicle purchase decisions are made with a very short planning horizon compared to the life of the vehicle. Simms et al. (1984) presented a long term model for planning the timing of bus purchases, as well as the degree to which buses are used in a given period. This model does not distinguish between different bus technologies, or between different duty cycles, and it does not include emissions objectives or constraints.

This paper proposes an integer programming method of making vehicle purchase decisions over a long time horizon, while simultaneously making vehicle task assignments at an aggregated level. The integer program minimizes operational costs, plus penalties for emissions, given capital budget constraints. Retrofits are incorporated as an alternate method of reducing emissions. Retrofits may only be compatible with some vehicles, and they may only be compatible with some tasks (depending on the exhaust temperatures generated). Gao and Stasko (2009) presented a model for developing retrofit and replacement strategies, but it only considered retrofits and replacements made at one point in time, and did not include the connected problem of vehicle task assignment.

Section 2 presents the integer programming methodology, while Section 3 describes a case study for a transit operator, and Section 4 outlines conclusions and potential extensions.

2. Model formulation

2.1. Expanding on traditional vehicle scheduling

Although the motivation and case study are from the transit industry, the model is formulated to be widely applicable to multiple types of fleets. The goal is to be able to model vehicle purchase, retrofit, and aggregated task assignment decisions over multiple periods, while considering both financial costs and emissions.

Perhaps the most straightforward way to lengthen the planning horizon of a traditional vehicle assignment model would be to include multiple connected networks. Each network could represent a typical day in a longer (perhaps quarterly) period. There are multiple reasons why such an approach would likely prove unreasonable, the most obvious being computational tractability. Solving a single time–space network problem for a decent sized transit system is already challenging, and multiple connected networks could easily be far worse. There is also a question of data availability. Exact timetables for the next few months are generally available, but it is extremely rare to know exactly how routes will change in the next decade.

The lack of detailed information about the future prompts consideration of a more aggregated approach. Budget constrained transit agencies might assign vehicles to routes to minimize the number of vehicles and drivers required, as well as operational expenses, before even considering emissions. The model presented in this paper assumes that such an assignment has already been made using traditional connection-based or time–space network approaches. The result is a set of assignment runs dictating what routes the bus assigned to that run will drive throughout the day. Each run requires one bus, and no bus may complete multiple runs. The next question is: how much flexibility remains in terms of which bus conducts which run, and how much is already dictated by the completed assignment?

It is conceivable that the vehicle assignment produced retains a fair amount of flexibility. The bus assignment may require that a single 40 ft. bus be used for a set of routes, but not necessarily which of such buses is used. There could be "swaps" of buses which are practically identical from an operational cost perspective, but quite different from an emissions perspective.

The degree of flexibility can be expanded if the costs associated with running a particular vehicle on a particular run (e.g. fuel and maintenance) are incorporated into the second stage optimization. Assignment swaps may increase operational costs, but only if other factors, such as emissions reductions, are worth the increase. Because the runs are kept intact, the general structure of the initial vehicle assignment will remain.

This sequential approach amounts to a decomposition, and there is the possibility that a truly optimal solution would involve changing which routes are included in which runs, based on emissions objectives. The fact that the details of future routes are unknown limits the likelihood that such a situation will seriously harm the quality of the solution produced. While it is difficult to predict the details of future routes, it may be much easier to predict the kind of daily runs which will exist (e.g. total mileage, the percentage of time spent on highways). For further simplification, assignment runs can be grouped, based on characteristics which impact costs and emissions, such as length and duty cycle, but this level of aggregation is optional. Groups can be of size 1.

The complete model formulation follows in Sections 2.2–2.7.

2.2. Sets

T	set of time periods
$R[t]$	set of assignment run groups for period t (including nonuse)
I	set of vehicle types in initial fleet
N	set of new vehicle types for possible purchase
J	set of retrofit options (including unretrofitted)
A	set of pollutants tracked