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A portfolio approach for optimal fleet replacement toward sustainable urban freight transportation

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ABSTRACT

Recently, the use of more sustainable forms of transportation such as electric vehicles (EVs) for delivering goods and parcels to customers in urban areas has received more attention from urban planners and private stakeholders. To provide some insights toward the use of EVs, this work develops an optimization framework using portfolio theory, which takes into account the cost and the risks associated with some input parameter uncertainties, for determining an optimal combination of EVs with internal combustion engine vehicles (ICEVs) in urban freight transportation (UFT) over some planning time period. This model can assist an urban freight operator to choose the best investment strategy for introducing new vehicles into its fleet while gaining economic benefits and having positive impacts on the urban environment. When taking into account the risks that are involved, the numerical results show that EVs have the potential to compete with ICEVs in UFT.

1. Introduction

Nowadays, due to population growth and the high level of urbanization, demand for goods and services in urban areas is increasing. As a result, urban planners are facing challenges that need to be addressed by a tradeoff between policy, logistics and technology solutions so as to provide more sustainable urban freight movements. In research literature, various studies have suggested different solutions for dealing with GHG, noise emission and congestion arising from the freight movements inside urban populated areas (Barter et al., 2012; Tipagornwong and Figliozzi, 2014; Dablanc, 2007; OECD, 2003; Pelletier et al., 2016; Russo and Comi, 2012).

EVs, as a sustainable form of transport, could have a high potential to address the environmental, social, and economic impacts on urban areas. Their low emissions and operating costs make them a viable option for integration into the UFT sector. However, their relatively high purchase cost makes them less attractive from the perspective of private stakeholders in the sector. With regard to the purchase price of EVs, battery cost constitutes a large portion of it. However, with technological advancement, the cost of battery has been decreasing over recent years. In a recent study, Nykvist and Nilsson (2015) have shown that the industry-wide cost of batteries has come down from over $1000 per kW h in 2007 to $410 per kW h in 2014, and they have projected a cost of $230 per kW h for 2017–2018. Thus, the decrease in EV battery prices will bring the purchase price of EVs down. On the other hand, ICEVs have a lower purchase cost. Fuel costs though, which constitutes their largest cost component during their lifetime, is a highly uncertain parameter in the long run. The price of oil has been

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increasing over recent years and it has been fluctuating wildly, which affects the fuel cost of ICEVs. Therefore, any vehicle replacement decision based on the present costs of vehicles alone and ignoring the involved uncertainties could lead to a higher cost in the long run.

In this paper, it is assumed that an UFT operator is interested in choosing the best strategy for introducing new vehicles with different characteristics such as different purchasing cost, and operation and maintenance cost, into its fleet over some planning time horizon while taking into account the cost associated with some uncertain input parameters. The best strategy from the standpoint of the operator is one that minimizes its cost over the planning time horizon. There is a gap in the literature on providing the concerned decision-makers in UFT sector with an all-in-one and easy-to-use optimization framework, which assists them in taking environmentally, economically, and socially sustainable decisions for their vehicle replacement. To fill this gap, paper will develop a new optimization framework for deriving an optimal combination of EVs with ICEVs in UFT using portfolio theory. An objective function, which is a combination of total cost and the variance associated to some of the uncertain parameters of the total cost such as the purchase cost of EVs and the price fluctuation of fossil fuels, subject to some constraints is minimized. It will be shown that, when taking the uncertainties into account, the EVs are competitive versus their conventional counterpart ICEVs. The developed model is geographically independent and it could be applied to any case study for which the required data are available. This model can also be used by public administrators to evaluate the level of tax incentives for accelerating the use of EVs in UFT sector.

The rest of the paper is organized as follows; Section 2 provides the literature review and Section 3 describes the model. The optimization framework will be introduced in Section 4. The data sources and assumption are presented in Section 5, and Section 6 is devoted to the results and discussions. The paper will be concluded in Section 7 with some conclusions and some future lines of research.

2. Literature review

Recently, Wygonika et al., while reviewing the literature on smart growth and goods movement, analyzed the relationship between smart growth and goods movements. One of the principles of smart growth is related to social sustainability (Wygonik et al., 2014; Environmental Protection Agency, 2010). Shifting toward more sustainable modes of transport in urban freight can enhance the quality of life within urban areas. The integration of EVs, as an environmentally, socially, and (potentially) economic sustainable option, in urban goods movement has been the subject of various research studies in UFT literature.

Nuzzolo and Comi (2014) analyzed the effectiveness of the measures set by Rome's administrators on the types of freight vehicles in the inner area of the city between 1999 and 2008. Under the enforced measures, they have shown that the share of more environmental friendly vehicles in the freight fleet has increased over the time period.

Davis and Figliozzi (2013) have presented a model that incorporates routing constraints, speed profiles, energy consumption, and vehicle ownership cost to determine the most important factors affecting the competitiveness of electric commercial vehicles. The model they developed has been applied to three types of commercial vehicles (one diesel and two electric ones) to compare their cost effectiveness. It has been shown that the main factors that can make EVs a viable alternative are maximum distance traveled (close to 161 km per day which is the maximum range of EVs), low speed or congestion, frequent stops, EV engine energy efficiency, reduction of EV initial purchase price, and long planning horizon (over ten years).

Feng and Figliozzi (2013) in a recent study, which is an extended version of their previous work (Feng and Figliozzi, 2012), developed a fleet replacement optimization framework for analyzing the competitiveness of EVs vs. ICEVs in the US market. Various scenarios have been examined for two types of commercial vehicles (Isuzu N-Series and Navistar E-star) and it has been shown that EVs are competitive in scenarios with high utilization level (16,000 miles or more per year). With a low level utilization of 12,000 miles per year, a price reduction of 9–27% can greatly increase the competitiveness of EVs. This work takes an elasticity analysis approach to consider the effects of uncertain parameters on total cost.

Lee et al. (2013) have made a comparison between electric and diesel urban delivery trucks in terms of life-cycle energy consumption, greenhouse gas emissions (GHG), and total cost of ownership (TCO). The authors have shown that, for driving cycles with frequent stops and low average speed, electric trucks have advantages over diesel trucks (42–61% less GHGs; 32–54% less energy consumption; and 22% less TCO). It has been shown that, in drive cycles with less frequent stops and high average speed, the TCO of electric trucks is 1% higher than diesels trucks, and they emit 19–43% less GHGs and consume 5–34% less energy than diesel trucks.

The research work by Van Duin et al. (2013) determines the best combination of different types of vehicles for transporting a known demand of cargo, located at a central depot, to a specific number of customers. The EVs have low autonomy capacity precisely due to the battery limited capacity. The authors have added a new constraint to the previously developed optimization framework in order to clarify this restriction. The model has been applied to a case study in Amsterdam. The study results show a 19% reduction in terms of vehicle kilometers and 90% reduction of CO_2 emission.

Figliozzi et al. (2012) used a mixed-integer linear programming vehicle replacement model to evaluate environmental and policy issues such as taxes on GHG and tax incentives for purchasing EVs. The model has been applied to case studies in the US. The paper's conclusions are as follows: the high price of gas/diesel, or its excessive use, offsets the initial purchase of EVs; a cap-and-trade emissions price of $18.70/ton does not have any significant effect on fleet management decisions; but tax incentives will help increase the use of EVs.