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Recursive expected conditional value at risk in the fleet renewal problem with alternative fuel vehicles

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ABSTRACT

We study the fleet portfolio management problem faced by a firm deciding which alternative fuel vehicles (AFVs) to choose for its fleet to minimise the weighted average of cost and risk, in a stochastic multi-period setting. We consider different types of technology and vehicles with heterogeneous capabilities. We propose a new time consistent recursive risk measure, the Recursive Expected Conditional Value at Risk (RECVaR), which we prove to be coherent. We then solve the problem for a large UK based company, reporting how the optimal policies are affected by risk aversion and by the clustering for each type of vehicle.

1. Introduction

The transportation sector is responsible for a large proportion of CO_2 emissions worldwide (Schiffer, 2008) due to its dependence on fossil fuels. For this reason, it is facing a big challenge regarding the adoption of alternative fuel vehicles (AFVs). As a result, car-makers are under pressure to develop fuel-efficient vehicles such as hybrid vehicles (HVs) and electric vehicles (EVs) as an alternative solution to reduce fossil fuel consumption and greenhouse gas emission levels. This is the main motivation for this work: to analyse the viability of the introduction of alternative technologies in a large fleet of vehicles used in service provision.

In the operations research literature, the problem of renewing an existing fleet is commonly referred to as the fleet renewal or replacement problem (Patricksson et al., 2015). A fleet vehicle replacement optimisation framework requires three types of inputs: economic factors, vehicular characteristics, and initial fleet configuration (Feng and Figliozzi, 2013). Economic factors include the planning time horizon, the annual demand for vehicles, the annual mileage driven, and the energy price forecast. Vehicular factors include the vehicle type, the age, capital costs, fuel consumption, and annual utilisation (miles travelled). The initial fleet configuration includes the number of vehicles per type, and their ages. Once all of the inputs are specified, the model can provide an optimal solution, together with cost breakdown and usage statistics.

In the traditional fleet replacement models, the main concern for a fleet manager is to focus on the minimisation of expected cost over a planning horizon. However, there are uncertainties in fuel and carbon emission prices, environmental regulations, and the technology's life cycle, all of which impact leasing and ownership costs. Therefore, it is essential to view the fleet replacement problem from an uncertainty perspective using risk management methodologies.

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A novel contribution of this article is to provide an optimisation framework to fully take into account risk management in fleet replacement. We view risk as a manifestation of uncontrollability rather than merely a downside possibility, as defined by Arrow (1970).

This article is the result of a study of the problem faced by a large company in the UK that is aiming to reduce CO_2 emissions by optimally choosing which vehicles to include in their fleet. To this effect we have developed a new risk measure for the dynamic stochastic problem, the Recursive Expected Conditional Value at Risk (RECVaR), and analyse how the optimal policies are affected by risk aversion and by clustering the different types of vehicles.

This article extends the work by Ansaripoor et al. (2014) which considered: (a) a two stage model; (b) one vehicle analysed individually; and (c) only one decision is made at time zero. In this article: (a) we present a multi-stage model; (b) we have a large number of different types of vehicles at each node of a decision tree; (c) at each node the firm needs to decide how many vehicles to lease of each type; and (d) the demand for the different types of services (in terms of mileage and technical requirements) is stochastic. Finally, this paper also provides a methodological contribution by introducing a new time consistent version of CVaR, the RECVaR. We have found that RECVaR takes into account the risks that exist in the middle stages of the scenario tree and is a major contribution to the use of risk analysis in dynamic multi-stage problems.

This paper proceeds as follows. In Section 2 we introduce the case study. In Section 3 we review the existing literature. In Section 4 we present a multi-stage stochastic programming model for minimising the weighted average of the expected cost and risk, considering the existing constraints and uncertainties in the market. In Section 5 we derive the analytical results for the RECVaR. In Section 6 we present the computational results and, finally, we present the main conclusions in Section 7.

2. A case of the fleet renewal problem with AVFs

This article is motivated by the problem faced by a large firm in UK that aims to reduce the carbon footprint of its vehicle fleet. The firm leases a large fleet of vehicles used by its engineers. Generally an engineer is assigned a vehicle for the whole lifetime of the lease. Vehicles are assigned depending on the engineer's specialisation.

Currently the fleet has only diesel vehicles with different capacities (small, light, medium size vehicles). The size of the vehicle is an important characteristic because, depending on their specialisation, the engineers have to carry different materials and, thus, have to drive a vehicle with sufficient capacity. For instance, power engineers need light vans with enough carrying capacity. We consider small vans as weighing 300 kg and that light vans weigh 500 kg and have a greater carrying capacity. Medium vans can be used on any type of function, but there are only a few because they are far more expensive to lease and maintain.

In this case study, we consider another four additional possible technologies: petrol, hybrid-petrol, hybrid-diesel, and EVs. Each vehicle type can be leased with different capacities, as they are used for different job types.

An important issue, when developing a model which aims to solve a real-world problem, is to determine whether it is an accurate representation of the studied system, i.e., if it is valid (Landry et al., 1983; Law and Kelton, 1991; Landry and Oral, 1993). The term "accurate representation" is used to mean the extent to which the model fits the real system either in terms of structure and mechanism or in terms of output, depending on the context of the problem. In order to have a representation of the real-world as accurate as possible we have used: (1) data from the fleet analysed, including mileage and consumption per vehicle; (2) data on the leasing costs for different types (capacities) of vehicles; (3) forecasts for the fuel prices for the planning horizon considered, based on real data; and (4) a model for CO_2 prices estimated from real data. Moreover, validity is also tested by comparing the optimal decisions with the current fleet used by the company, as reported in Section 6.3.

3. Review of the fleet replacement problem and time consistency of dynamic risk measures

Decision support systems for fleet operations, capacity decisions, routing problems, and humanitarian operations are well developed in the logistics literature (e.g., Couillard, 1993; Lau et al., 2003; Ghiani et al., 2004; Ruiz et al., 2004; Figliozzi, 2009, 2010, 2011). As the literature on replacement strategies in fleet operations is closely related to our work, we focus our review on this topic. Specifically, our concern is related to parallel replacement models, which are for replacement plans of vehicles that are economically interdependent. In addition, we introduce two important risk measures and then we consider the time consistency issue in a dynamic setting, which is essential for the fleet renewal model presented in the article.

3.1. Parallel replacement models

These models can generally be categorised in two main groups based on different fleet (asset) characteristics: homogenous and heterogeneous. In the homogeneous replacement model, a group of similar vehicles, in terms of type and age that form a cluster (each cluster or group cannot be decomposed into smaller clusters) has to be replaced at the same time. In the heterogeneous model, multiple heterogeneous assets, such as fleets with different vehicle types, have to be optimised simultaneously. For instance, vehicles of the same type and age may be replaced in different periods (years) because of the restricted budget for the procurement of new vehicles. The heterogeneous model is closer to the real world commercial fleet replacement problem. This model is solved by integer programming and, generally, the input variables are assumed to be