Applying a QoS-based Fleet Dimension Method to Reduce Fleet Emissions

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***Abstract*—Car sharing is a successful commercial application based on the collaborative consumption model. In this paper, we apply a recently proposed idea from a car sharing scheme to solve a fleet dimension problem emerging in utilities with large vehicle fleets. Within this framework, EVs are used to replace Internal Combustion Engine Vehicles (ICEVs) to reduce fleet pollutants. A small number of additional ICE vehicles are purchased to service long trips. The number of such vehicles are determined using a queueing model. Our studies show that pollutants can be significantly reduced while still providing a good quality of service (QoS) for staff to access vehicles.**

I. Introduction

EV-based transportation has been shown to be very promising in reducing urban pollutants. In our previous work [1], a vehicle sharing model was applied to address the issue of customer range anxiety for electric vehicles. In this follow-on work, the same idea from the car sharing model is applied to dimension a fleet of vehicles to reduce fleet pollution levels. Our objective here is to both reduce total fleet pollutants and guarantee a good quality of service for fleet users by ensuring flexible vehicle access based on statistical guarantees.

Large fleet owners (municipal authorities, universities, delivery companies) usually own various kinds of ICEVs for multi-functional purposes [2]. For example, in the case of a university, some of the vehicles are only adopted as campus vehicles with intermittent use, and others have longer travel demands based on continuous access. On any given day, these vehicles can be used for different purposes, for instance, security, cleaning, gardening and building maintenance. Some of these vehicles have fixed routines on campus (e.g. cleaning, postal), while other types of vehicles may have unpredicted driving requests (e.g. security vehicles for emergencies). Clearly, given the different demands placed on vehicles, there is a choice in the way we dimension this fleet. Electric vehicles are cleaner, and quieter, but ICEs offer more flexibility in terms of driving range [3]. In other words, EVs cannot be assigned as the only type of vehicles for universities which will occasionally be required to travel long distances.

Our idea is to replace the entire existing vehicle fleet with electric vehicles (with zero tail-pipe emissions) in order to reduce fleet emissions and we shall also purchase a small number of additional ICEs to service longer travel demands. We shall embed this idea in a statistical framework following [1] and use the solution presented there to dimension the number of ICE-based vehicles. Implicit in this assumption is that the use of such vehicles can be planned a number of days in advance, and that all EVs can be fully charged overnight. Specifically, we shall consider the following problem.

Problem: If a user wants access to an ICEV, is it possible for him/her to have access to this vehicle from the fleet in a certain number of days? What is the probability that access will be denied? And, how many vehicles do we need to ensure that this latter probability is lower than some bound?

Based on the solution of the above problem, we then establish by how much pollutants can be reduced when compared with a fleet of only ICEVs.

II. Access Model

In this section, we will introduce the model for the proposed fleet dimension method. Our model follows identically that given in [1] and the solution presented therein is also the solution to the problem presented here. A schematic diagram for the problem we considered is illustrated in Fig.1. For convenience we recall the problem considered in [1].

When an electric vehicle is purchased, the new EV owner also automatically becomes a member of a car sharing scheme, where a shared vehicle may be borrowed from a common pool on a 24hr basis. The shared vehicles are large ICE-based vehicles suitable for long range travel and with large goods transportation capacity.

In our application a large fleet owner wants to buy a number of EVs and ICE's to replace a current fleet of ICE-based vehicles. Since different vehicles may have different driving demands, a probability profile for different driving distances can be described. In particular, we assume that for the fleet a distribution of daily driving distance is available based on historical information. Beyond that, we have N users per day who request these EVs for different travelling purposes. Let M define the minimum number of ICEVs required to service larger distances. We wish to find M so that the probability of not being able to access an ICE when needed, is very small. In other words, the QoS measure is then the probability that each user has to make alternative arrangements (e.g. hire a car outside of the company). For requests that cannot be responded to on any given day, they are automatically postponed to the following day and so on. In order to guarantee the QoS for all the users, *Lemma 1* from [1] is reproduced here: *Define QoS*

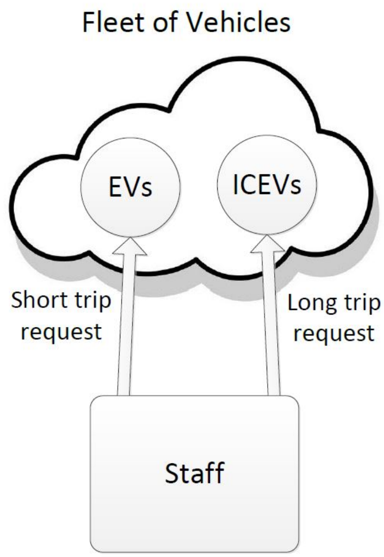

Fig. 1. Schematic diagram for the fleet dimension problem

as:

$$X_l \sim Bin\left(N, p\right) \quad (1)$$

$$P\left(X_l > kM\right) < \varepsilon \quad (2)$$

Lemma 1: Define:

$$\mu = M - Np,\ \sigma^2 = Np\left(1 - p\right),\ \alpha = \frac{\mu}{\sigma^2}$$

Then for all $k \geq 1$

$$P\left(X_l > kM\right) \leq \frac{1}{2} e^{-1(k-1)M\alpha} \left(e^{\frac{\mu\alpha}{2}} - 1\right)^{-1} \quad (3)$$

Where X_l is a binomial random variable and which can be regarded as the outstanding requests at the end of lth day. k is number of days in advance a user is prepared to book an ICE vehicle. p is a fixed probability that determines the likelihood of a vehicle being required for a long distance trip on a given day. Let ε represent the probability that the user cannot get the required ICEV at the end of k days. Therefore, our problem of interest can be solved by using the model introduced in [1]. A detailed case study is given in the following section.

III. Case Study

In this section, we consider the following scenario: a large fleet company owns 200 ICE based vehicles. This company wishes to update all of these vehicles to reduce pollutants. In the meantime, they also wish to know how many extra large sized ICEVs they need to buy for effective fleet management.

Here we adapt a real distribution of the driving distance range for the US postal services [5]. The profile for the distribution is illustrated in the Fig.2. To be consistent with the assumption made in [5], it is considered that any delivery vehicle travelling more than 40miles/day (64.37km) is regarded as making a long journey, thus requiring large size ICEVs. From Fig.2, the probability for each user requesting an ICEV is calculated as 3.28%. We assume that the pollutant index for each long-journey ICEV is taken as $350g/km$ according to [4]. For simplicity of result comparison, it is assumed that the mean value for each driving range is taken for calculation (e.g. the mean value for the [5-9] range is 7 miles/day) and the mean value for the range bigger than 50 is taken as 60 miles/day. Some comparison simulation results are listed in detail in Table I below:

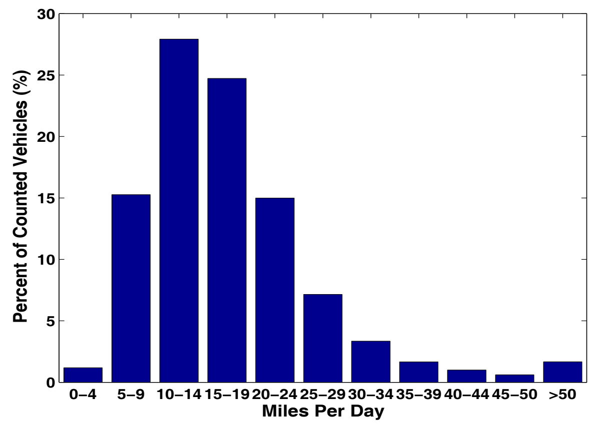

Fig. 2. Real distribution profile of the driving range for the vehicles in the delivery company

TABLE I. Comparison Table for the Simulation Results

Total	k	ε	M	Reduced CO_2 (kg/day) [4]	Percentage CO_2 Reduced (%)
200	1	0.05	12	1594	81.87
200	3	0.05	8	1711	87.91

IV. Conclusion

Our simulation results have shown that significant amount of pollutants have been reduced and good QoS can be provided with only a small proportion of extra ICEVs. A more detailed investigation on real data and parameter sensitivity analysis will be the subject of our future work.

Acknowledgment

This work was supported in part by Science Foundation Ireland grant 11/PI/1177.

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