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Scale Development Simulation for Electric Vehicles

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Abstract

Scale development of electric vehicles (EVs) is the basis for planning the charging infrastructures in the smart grid. For the area with no direct EV historical data, a system dynamics (SD) method is implemented to simulate and forecast the scale of EVs, according to main factors that impact EV scale development greatly. The proposed SD model can integrate various factors and quantify their relationship by comprehensive reasoning. Causal loop diagrams are designed to describe the relationship between factors and variables, and their quantifications are formulated by different business models or formulations. Then the scale development of EVs could be simulated with the given growth pattern data of other factors. The SD methodology is verified and demonstrated by test cases, and sensitivity analysis is also implemented.

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Keywords: electric vehicle , scale development , system dynamics , simulation ;Introduction

1. Introduction

Accurate forecasting the scale of the development and evolution of electric vehicles (EVs) is a sophisticated task, which is a long-term dynamic process and it is determined by many different factors, such as technology, economy, policy, regional development level in [1-3], etc. Regarding the scale forecasting of vehicles, there were several methods proposed. For example, in [4], the well-studied Bass model was proposed considering market potential, coefficient of innovation and imitation, but unable to effectively integrate the other factors, besides the relationship between stages, the population and vehicles cannot be effectively reflected from the microcosmic way. A Gompertz model was proposed in [5], and the exponential smoothing method was integrated and used to forecast the per capita income and population, and urbanization rate index was also introduced to predict the development trend of vehicle penetration in the specific area. As the EVs develops at the early stage, there lacks of data for the relevant research

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and model validation, a consumer purchasing behavior survey was conducted in [6], and the consumers preferences on price, performance, reliability, safety and convenience were extracted from the survey data using analytic hierarchy process.

Different from the conventional market forecasting, the EV is a new automotive technology introduced in the last years and few sales data is available for the validation of any EV market model. So, it is difficult to forecast the evolution of EVs by the classical tools of market forecasting. Besides, the interactive relationship between different factors needs to be considered during dynamic forecasting. To better describe the interrelated complicated relationship between different factors, the system dynamics (SD) approach is introduced. The main procedures using SD are depicted in Fig. 1.

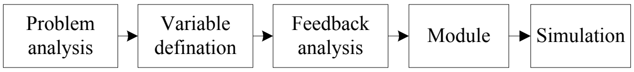

Fig.1. Main flow chart for SD simulation

The rest of the paper is organized as follows: Section 2 gives a description on SD modeling applied to the scale development of EVs. Test cases are presented in Section 3, and conclusions are given in Section 4.

2. SD modeling

Factors influencing EV purchasing are countless in the real world, therefore, majority of them among the whole decision space should be identified in the first place. According to the general classification (e.g. performance, price, policies, psychology, others), this paper first selects several factors [9, 10] which may impact the evolution of EV, and then evaluates the importance of each factor items, in which experts from different professional fields. Specifically, the main factor items which have great impacts on the scale evolution of EVs are selected as follows: GDP, population, vehicle scale, subsidy, fuel price, purchase price difference between conventional vehicle (CV) and EV, vehicle lifetime, charging time, etc.

After the important factors are selected, the relationships between the factors are also needed to be quantified and formulized. For some obvious logic mathematical relationships, e.g. the quantity of population is mainly determined by the initial quantity and its growth rate, they can be formulized directly. While for some relationships with psychological characteristics, such as the willingness to buy EV, it is difficult to be expressed by already known equations, thus the survey-based method [10] can be adopted to obtain the quantitative relationship. The impacts of different factor items (i.e., range, charge time, price difference, purchase price, fuel price) on the customers' choosing ratio can be quantified according to sorting statistics. Survey can be used to provide the system analysis of the EV scale development, and clarify its principal contradiction, the main variables, and formulate the mathematic relationship between the factors with the data obtained from the survey.

According to the factors selected, the SD causality relationship diagram for scale development simulation of EVs can be constructed and the stock-flow diagram for the scale development of EVs can be built and made up of three modules, as presented in Fig. 2. Formulations on each module are briefly drawn as follows.

2.1 Vehicle development module (Fig. 2. (a))

On the one hand, the vehicle development is determined by the vehicle demand increase and vehicle replacement, which can be represented by the interaction between the vehicle scale and its increment or scrap. On the other hand, the vehicle scale is constituted by different types of the vehicles, including EVs and CVs, competing with each other for market share. And the market demand from each type of vehicles determines the maximum size of the overall market. The business model of this module is shown by the mathematical formulas (1) - (4).

$$EV_{\mathrm{parc}}(t) = \sum_{t=0}^{T} (B_{\mathrm{EV}}(t) - D_{\mathrm{EV}}(t)) \quad + EV_{\mathrm{parc}}(t_0) \tag{1}$$