

City Readiness System Assessment of Electric Vehicle Adoption in China

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ABSTRACT

The Chinese government initiated the “Ten Cities, Thousand Vehicles” program for electric vehicles from the year of 2009 to 2012. The demonstration results indicate that an integral city readiness system is required in the promotion of electric vehicles, including the government policies, charging infrastructure, after-sales service, business models and consumer awareness. Through the analysis of related literature and summary reports from 25 demonstration cities, a partial least squares (PLS) path model with 5 major factors and 13 observation indicators was developed to assess the city readiness of electric vehicle adoption. The 5 factors consist of government policies and investment, charging infrastructure construction and operation, business models and maintenance service system, consumer awareness education, operation scope and environmental benefits. Based on the PLS results, 25 cities are classified into 6 groups with the clustering analysis model. The assessment results show that Shenzhen, Beijing, Hefei, Shanghai, Hangzhou are the 5 cities which perform better in the city readiness assessment. Purchasing subsidies, quantity of electric vehicles per resident, quantity of cumulative charging times per vehicle, total infrastructure investment per resident, quantity of charging piles per vehicle, quantity of cumulative electricity per vehicle and quantity of operators are the 6 biggest indicators impacting on the level of city readiness system. To promote the electric vehicle commercialization, the key issues of improving the charging network construction, developing reasonable charging and service price and raising consumer awareness need to be solved.

KEYWORDS: Electric vehicle, City Readiness, Partial Least Square Path Modelling, Clustering Model

CITATION: Wang, N. and Liu, Y., "City Readiness System Assessment of Electric Vehicle Adoption in China*," *SAE Int. J. Mater. Manuf.* 8(3):2015, doi:10.4271/2015-01-0469.

1. INTRODUCTION

The “Ten Cities, Thousand Vehicles” demonstration program was jointly launched by the Chinese Ministry of Science and Technology, Ministry of Finance, Development and Reform Commission and Ministry of Industry and Information Technology in January 2009. And in December 2012, the first three-year demonstration operation has been finished. The four ministries firstly selected 13 demonstration cities, and then in 2010 the number of cities expanded to 25. The application mostly focuses on public areas such as buses, taxis, official vehicles and postal vehicles. The four ministries launched private purchase subsidies program in the six cities of Beijing, Shanghai, Hefei, Shenzhen, Hangzhou and Changchun since 2010. The main purpose of the Chinese government to promote this activity is to achieve energy-saving and emission reduction. However, at the end of the demonstration, the vehicle quantity of all demonstration cities reached only 27,400, which is 26% of the whole deployment goals. In September 2013, the four ministries and commissions (MOST, MIIT, NDRC and MOF) introduced the development program of new energy vehicle industry with the production and sales volume up to 5 and 50 million in the year of 2015 and 2020, respectively. To achieve this goal, the four ministries and commissions have selected 88 demonstration cities to launch a new round of demonstration and develop policies to encourage the EV adoption.

The electric vehicles are demonstrated in both the private and public sectors. In the public sector, the electric buses and electric taxis are given priority to operate in many cities of China, such as Shenzhen, Beijing, Shanghai and Hangzhou. In Shenzhen, the bus company purchased the electric buses (without batteries) and rented the batteries from the Putian (a charging infrastructure operator). In Hangzhou, the battery swapping mode was developed for the electric taxis. The State Grid provided battery swapping service for the taxi company. In the private sector, the directional purchase was adopted in Hefei. JAC Motors sold 585 electric vehicles to its employees and the staff of the battery companies and the State Grid.

In the process of EV demonstration, there are still some problems hindering the EV adoption. For example, the charging infrastructure is inadequate and consumers will get into the “range anxiety”. Besides, the policy intervention is not effective and the consumers are reluctant to purchase EVs. In terms of the demonstration at the city level, the 25 cities in the first round perform differently with the aspects of government policies, charging infrastructure, maintenance services and consumer education, etc. Thus it is necessary to assess the city readiness system of the 25 demonstration cities to obtain the city ranks in various aspects and improvements that certain cities need to make. With the help of the assessment, specific policies and strategies can be developed to promote the EV adoption according to

the cities' various conditions. In this way, the 88 cities in the new round of demonstration can effectively promote the development of the electric vehicle industry.

Research into the assessment of EV adoption is mostly limited to one city or municipality. Beiwei Li and Chunli Yang [1] develop the evaluation system to assess the feasibility of EV projects with the indicators of human resources, technical strength, geographical location, macro environment and the economic effectiveness. The assessment results are obtained with the Delphi method and analytic hierarchy process (AHP). Xiaofeng Wang [2] develops a comprehensive evaluation system with indicators of technology, economy and social benefits. The research methods are AHP and fuzzy comprehensive evaluation. Yuning Wang and Fanbiao Bao [3] propose a multi-risk evaluation system in the aspects of technology risk, market risk, management risk and policy risk based on the risk management analysis. The hierarchical processing method is used to obtain the pros and cons of different operation programs. There has been very little research into the readiness assessment of EV adoption at the city level. Jie Zheng et al. [4] make a questionnaire survey of 13 demonstration cities in China to obtain the information of the objective planning, subsidies, operational scale and effects, cooperation with other cities. Based on the survey and analysis, recommendations have been made for the demonstration of electric vehicle. Wiederer et al. [5] assess the operation effectiveness of charging infrastructure of the cities in the international urban coalition by analyzing the obstacles, measures and policies of the infrastructure operation in these cities. The problem of the above research is that the assessment method is rather subjective. An objective evaluation of the city readiness for EV adoption will not be obtained in the existing research.

The multi-indicator evaluation methods are adopted in the city readiness assessment of EV adoption, which include the principal component analysis (PCA), fuzzy evaluation method and analytic hierarchy process (AHP), etc. The general problem of these methods is that the correlation between indicator variables is not considered. When there are serious problems of multicollinearity within the indicator variables, the effects of certain variables in the evaluation system will be exaggerated [6]. In order to solve this problem, we employ the PLS path model to establish a comprehensive evaluation system, which can solve the problem of multicollinearity within the indicators. Besides, this model can make it easy to study the relationship between each latent variable and the manifest variables. A comprehensive index that integrates all the latent variables can be obtained [7, 8, 9].

This paper proposes structure of the city readiness system, the assessment method and assessment results and provides a theoretical basis and practical guidance for the comprehensive evaluation of urban electric vehicle demonstration. [Section 2](#) presents the assessment indicator system of city readiness; [Section 3](#) describes the PLS path model and the assessment results; [Section 4](#) describes the clustering analysis and promotion strategies for different level cities. Finally, in [Section 5](#) we present a viable proposal for the construction and improvement of the supporting environment for EV adoption.

2. ASSESSMENT INDICATOR SYSTEM

In order to promote the development of electric vehicles, it is required for the demonstration cities to be ready in every ways. Based on the analysis of the development process of EV adoption, the city readiness system consists of the “hard” environmental system, “soft” environmental system and the government intervention (G). The “hard” environmental system includes the charging infrastructure readiness (I) and maintenance service readiness (S). The “soft” environmental system includes the business model readiness (B) and the consumer education readiness (C). Thus, the city readiness system is established, which can be shown in [Figure 1](#).

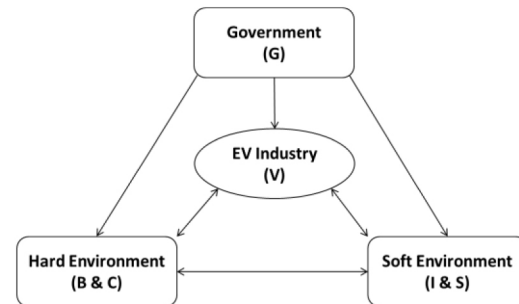


Figure 1. City readiness system of EV adoption

As the driving force of the EV industry development, the government plays a leading role not only in the electric vehicle R&D, but also in the construction of environment for EV adoption. The government needs to coordinate the interests of related stakeholders and develop policies of purchase subsidies, infrastructure subsidies and non-monetary incentives, etc. Research has proved that the government intervention will help to increase the EV adoption. In order to quantify the readiness of government intervention, we employ indicators related to money, such as the investment capital, infrastructure subsidies and purchase subsidies [10-11].

In the readiness of the “hard” environmental system, the charging infrastructure readiness is an important prerequisite and foundation for the large-scale EV adoption. A complete charging infrastructure network should be established to meet the demands of EV users [12-13]. The measuring indicators of the charging infrastructure readiness consist of the quantity and layout planning of charging stations (piles), related standards and specifications, investment, scope of services and infrastructure availability [14]. In addition, the maintenance service readiness is also an integral part of the “hard” environmental system. Efficient and cost-effective maintenance service readiness can ensure the EV usage effectiveness and make up for the technology disadvantages. The measuring indicators of maintenance service readiness include the quantity and layout planning of maintenance service infrastructure, standards and specifications, data monitoring and operational safety guarantee.

In the readiness of the “soft” environmental system, developing innovative business models is the key to promote EV adoption. An effective business model can turn the technical advantages of electric vehicles into consumers' benefits. There are many stakeholders involved in the electric vehicle industry, such as OEMs, auto parts manufacturing enterprises, infrastructure operators, power grid

companies and consumers. The purpose of developing an effective business model in EV industry is to build a suitable environment for these stakeholders to cooperate with each other [15, 16, 17]. The measuring indicators of the business model can include the business model types, the relations among stakeholders, the quantity of operators and the operation effects. The consumer education is also an important part of soft environmental system readiness. Increasing consumers' acceptance of electric vehicles will promote the large-scale EV commercialization. The measuring indicators consist of improving the environment of EV purchase and usage, building the public service platform, carrying out educational campaigns and improving the safeguard mechanism of consumers' rights and interests.

Based on the literature review and expert interview, the city readiness system for EV adoption can be summarized by five major factors, which are "Government policies and investment", "Charging infrastructure construction and operation", "Business models and maintenance service system", "Consumer awareness education" and "Operation scope and environmental benefits". According to the principles of comprehensiveness and feasibility, an assessment indicator system with 5 major factors (latent variables) and 16 observation indicators (manifest variables) is developed based on the above contents. The latent variables and manifest variables are shown in Table 1.

In order to obtain the data of these 16 manifest variables, we collected the summary reports of the 25 demonstration cities by the end of 2012 from the government departments. The summary reports include the government policies, infrastructure readiness, business models, operation effects and consumer education, etc. Based on the summary report contents, the data has been collected for the 16 manifest variables.

3. ASSESSMENT OF CITY READINESS SYSTEM

3.1. Construction of PLS Path Model

The PLS path model consists of two parts, which are the measurement model and the structural model. The measurement model describes the relationships between latent variables and manifest variables, while the structural model describes the relationships among the latent variables. According to the complex data analysis method proposed by Grunot [18], the evaluation model of the city readiness system is established as shown in Figure 2, which is a special PLS path model. The measurement model in the left side of Figure 2 is the manifest variable set that representing the 5 latent variables. The manifest variables in the same set are affected by the corresponding latent variable. The structural model in the right side of Figure 2 is a variable set consisting of all the manifest variables. The corresponding latent variable (β_6) is expressed as the city readiness of EV adoption. The structural model provides not only a new way to solve the comprehensive assessment problems whose indicators are related to each other, but also a scientific method to determine the weights of each indicator [19].

Table 1. Assessment indicator system of city readiness for EV adoption

Latent variables	Manifest variables	Unit
Government policies and investment (β_1)	Central government investment (X_{11})	Million yuan
	Local government investment (X_{12})	Million yuan
	Charging infrastructure subsidies percentage (X_{13})	%
	Purchasing subsidies (X_{14})	10,000 yuan per vehicle
Charging infrastructure construction and operation (β_2)	Quantity of charging piles per vehicle (X_{21})	1
	Total infrastructure investment per resident (X_{22})	10,000 yuan
	Quantity of cumulative electricity per vehicle (X_{23})	kWh
	Quantity of cumulative charging times per vehicle (X_{24})	10,000 times
Business models and maintenance service system (β_3)	Quantity of monitoring centers (X_{31})	1
	Quantity of operators (X_{32})	1
	Operation mileage per vehicle (X_{33})	1,000 kilometers
	Quantity of service guarantee measures (X_{33})	1
Consumer awareness education (β_4)	Quantity of consumer publicity activities (X_{41})	1
	Quantity of policies for consumers (X_{42})	1
Operation scope and environmental benefits (β_5)	Quantity of fuel savings per vehicle (X_{51})	ton
	Quantity of CO ₂ emission reductions (X_{52})	10,000 ton
	quantity of electric vehicles per resident (X_{53})	1

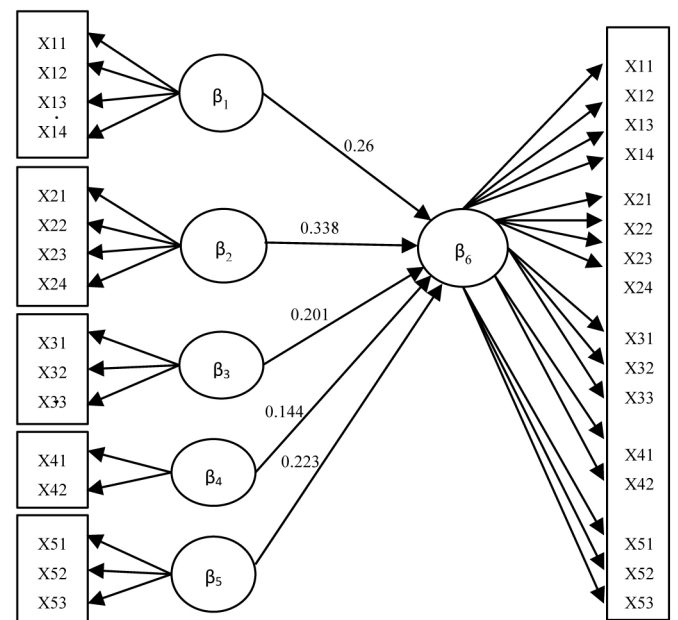


Figure 2. PLS path model of city readiness

3.2. Estimation and Test of PLS Path Model

According to the data requirements of the PLS path model, the principle component analysis for the five set of variables is needed for the one-dimension test (using SPSS). As is shown in Table 2, the first principle component eigenvalues of the five variable sets are all