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Modeling and Analysis of Life Cycle Cost for (LCC) Battery Electric Vehicles (BEVs) and Conventional Combustion Engine Vehicles

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In order to predict, analyze and compare the LCC for battery electric vehicles and conventional combustion engine vehicles, provide support for the decision of design, policy, market strategy of vehicles, as well as the procurement decision as perspective of consumers, this paper creates a LCC model for the vehicles. Both BEVs and conventional combustion engine vehicles are then evaluated with this model for LCC of different phase of vehicles' life cycle.

1. Introduction

Peak oil and climate change are the most critical issues in the world, both of them are complicated because of impacting to energy security. The fossil fuels consumption in the transport and power sectors accounted for about 59% of greenhouse gas emissions in 2004 in America. The use of clean energy will be the motility of industry development. Due to excessive energy consumption and serious environmental pollution, the developmental space of conventional combustion engine vehicles industry is limited. BEVs are the most efficient replacement of conventional combustion engine vehicles due to various reasons from environmental issues to economic aspects (Sheikhi et al., 2013). The importance of environmental impacts of different vehicles was highlighted and effective policy for mitigating the environmental impacts by personal transportation was proposed (Troy, Ola and Anders, 2012). At present, new energy vehicles as an important product development direction of automobile industry are becoming an alternative to conventional combustion engine vehicles while the BEVs are the most popular type in the degree of industrialization. BEVs have been equipped with necessary conditions for market development, such as technical level and the macro policy level. While high cost is the most critical issue to be solved to achieve industry scale development.
Life cycle cost (LCC) can identify the accumulative cost in the product design, production, use, waste disposal and other phases from the economic perspective of decision makers, and try to reduce the total cost. Based on the combination of life cycle assessment and LCC analysis, environmental impact caused by activities of the enterprises can be minimized and cost management can be more effectively.
LCC is accumulated cost of the products from the concept design stage to product disposal stage. BEVs' consumers will take the safety, reliability and maintenance capability into consideration. Furthermore, the LCC of BEVs is becoming more and more important. Therefore, BEVs' manufacturers must design available, reliable, safe and cost competitive products. At present, the LCC of vehicles were studied and achieved remarkable results. However, the vehicles' LCC study in China is still in the primary stage. China has put forward the LCC of the vehicles as important economic indicators for the evaluation of vehicle capability. The literature was carried out study on vehicles' LCC for several fields. The methodology for evaluating LCC of BEVs for their buyers was presented with detail evaluation on major systems such as battery, motor and chassis (Vyas, Cuenca and Gaines, 1998). The model for the vehicle, fuel cells, battery and motor was established, and then computer simulation was developed to overall vehicle design in order to evaluate the LCC of the fuel cell hybrid vehicles with the simulation result (Kwi and Byeong, 2002). A lot of powertrain designs were evaluated with a computer tool named THEPS, and LCC for powertrain in different operational environment was calculated (Jonas, 2007). LCC for different stage of Plug-in Hybrid Vehicles was evaluated and some proposal from policy point of view was provided (Constantine and Kyle, 2008). The economical

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feasibility of hydrogen as competitive transportation fuel using a LCC methodology was identified. The cost reduction factors in the life cycle were found and effective strategies for hydrogen becoming the competitive transportation fuel were finally devised (Lee et al., 2009). A LCC analysis method was proposed based on product structural tree, and then software was created to analyze and manage the LCC (Tang, 2010). An optimization model with integration of the physical vehicles, battery degradation data, and driving data of America was developed in order to identify optimal vehicle designs (Ching-Shin et al., 2010). The modeling of vehicles' material LCC with extended LCC evaluation from manufacturing stage to use and end of life stage was created. Furthermore, cost sensitivity analysis was carried out (Witik et al., 2011). BEVs would play a key role in decreasing crude oil consumption, easing global warming trend, and reducing dependency on oil importation in the transportation sector (Orkun and Jeremy, 2013). An evaluation model was created for the LCC evaluation. The LCC of an HEV with present value analysis theory (PVAT) was calculated (Lin, 2013). The design of vehicles' systems was optimized via vehicle simulation software ADVISOR. The LCC of different vehicles was evaluated. The significance of the operation conditions, the conflict between efficiency and LCC in vehicles' design was highlighted (João and Carla, 2014). A LCC model for rolling stocks was developed via VBA software to calculate LCC of various rolling stocks in maintenance phase (Fang and Ji, 2015). The incremental exhaust emissions impacts and the use cost of non-plug-in and plug-in light-duty vehicles were evaluated in the life cycle (Saville and MacLean, 2015).
Creation of the model, market diffusion and so on pure theory analysis was carried out to LCC of BEVs. In order to analyze and compare of the LCC between BEVs and conventional combustion engine vehicles, reduce the costs of BEVs, promote the industrialization of new energy vehicles, we create LCC model for BVEs in five phases. The influence of BEVs and conventional combustion engine vehicles to external environmental is taken into account to create the external environmental cost model in the use stage. Empirical analysis is carried out to the LCC of the specific type of the BEVs and conventional combustion engine vehicles. Feasible suggestions are promoted for the scale development of BEVs' industry at last.

2. Modeling for LCC of BEVs

Promoted by Chinese energy conserving and emissions reducing policies, BEVs have gradually become one of the contentions copping with the energy crisis. The BEVs are the vehicles system takes the batteries as energy storage units, such as nickel cadmium batteries, lead-acid batteries, nickel metal hydride batteries and lithium ion battery and electric motor as a drive system. The work breakdown structure of BEVs can be created based on PST (Product Structure Tree). The Product Structure Tree is used to describe the layer structure of product, component and part which can show the functional layer structure and constructional relationship. According to the structure and function of product characteristics, the basic structure of BEVs is mainly composed of four subsystems named car body subsystem, electric power drive sub system, energy system sub system and auxiliary sub system. Each system consists of its modules and parts. Each sub system can be broken down based on the requirements of the LCC evaluation. The car body sub system includes car body structure, frame and buffer. The electric drive sub system includes an electronic power, power converter, electric motor, mechanical drive device and wheels. The energy sub system includes an energy source, energy unit and energy control unit.
The auxiliary sub system includes power steering unit, temperature control unit and auxiliary power supply unit. Modeling of LCC of BEVs can be created from two aspects. The first one is from the manufacturer's perspective. It mainly includes development, design, manufacturing, sales, repair, maintenance and disposal costs of BEVs; the second one is from the external environmental perspective. The impact to the environment is also taken into consideration measured by cost. The disposal cost of BEVs is one part of the costs in LCC. In conventional production mode, disposal costs are borne by the society and the environment which means the society and the environment will bear the environmental damage costs caused by scrap costs and environmental costs. The scrap costs are mainly the costs for waste disposal, recycling after products and their packaging's waste disposal. LCC of BEVs shall include not only the actual loss paid by enterprises, customers and society, shall also include the intangible loss of social resources in each stage. Therefore, this paper divides life cycle of the BEVs into 5 stages named development stage, manufacturing stage, logistics stage, use stage and repair stage based on manufacturer's perspective combining the characteristics of BEVs and the life cycle theory. 5 LCC sub models are created for 5 life cycle stage. This paper does not take the various taxes, traffic punishment, parking, vehicle's decoration and washing costs into account in the because of uncertain expenditure which would be similar between similar vehicles. The scrap costs are also ignored for missing the exact figure which would be a further study field.

2.1 Cost model of development phase

The cost of research and development are important index to reflect the enterprise's technological innovation ability and fundamental guarantee of the enterprise technical innovation. The research and development cost include market research cost, feasibility studies cost, product design cost, product preproduct cost and product test cost. The cost of research and development is $C_{develop}$ as below.

$$C_{develop} = C_{research} + C_{feasib} + C_{design} + C_{prepro} + C_{test} \tag{1}$$

2.2 Cost model of manufacturing phase

Cost of manufacturing phase is composed by material procurement cost and vehicle production cost. Material procurement cost majorly refers to the cost of raw materials. The vehicles' production cost includes the manufacturing cost of the parts and assembly cost. Thus, LCC model of BEVs in manufacturing stage can be expressed below.

$$C_{product} = \sum_{i}^{N_{material}} (P_{material,i} Q_{material,i}) + \sum_{i=1}^{N_{part}} C_{part,i} + \sum_{i}^{N_{assem}} C_{assem,i} \tag{2}$$

$P_{material,\,i}$ means the price for material number i; $Q_{material,\,i}$ means the quantity of material number i.

2.3 Cost model of sales stage

The costs of vehicles sales are composed of transaction cost and logistics cost. The transaction cost is the profit sharing between vehicles' manufacturers and dealers. Take conventional combustion engine vehicle MAGOTAN from VALKSWAGEN as an example, the dealers can take 7.5% of retail price for MAGOTAN as the commission; the average sales support takes 1.5% of retail price. The transaction cost takes 9% of retail price in total. Logistics cost means the currency consumption of labor in the enterprise logistics and distribution activities. It is the summation of the expenditure for the logistics activities including storage, sorting, distribution, delivery. Logistics cost is an important part of sales costs. Generally speaking, the price difference between the price of the vehicle reached the dealer and the factory price is the logistics cost. The logistics costs are impacted by many external factors which will be different much for different vehicles' manufactures and dealers. The logistics costs mainly include order processing cost, vehicles custodial cost, transportation cost, distribution management cost, vehicle damage cost, expenses of reverse logistics vehicles, insurance, as well as punishment fee during delivery vehicles, etc.

$$C_{sale} = \sum_{i}^{N_{buy}} C_{transa,i} + \sum_{i=1}^{N_{\log is}} C_{\log is,i} \tag{3}$$

2.4 Cost model of use stage

Exhaust emission including sulfur and carbon containing pollutants of conventional combustion engine vehicles causes pollution to environment. It leads to external environmental degradation. The main responsibility of pollution to external environment in vehicles use stage belongs to consumers while the main body is the society currently. The environmental cost caused by exhaust emission of vehicles should be borne by consumers in particular by imposing environmental tax to the consumers. Because it is very difficult to impose environmental taxes to the consumers, the environment tax in the world is imposed to the vehicles' manufactures in manufacturing stage in practice currently. Although China does not start to impose environmental taxes, it is an inevitable trend as the requirements of the oil shortage and environmental protection. Therefore, this paper creates the environmental cost model based on the environmental tax practice in Danish. R is the tax rate of environment; L is the amount of oil consumption.

$$\mathrm{C}_e = \mathrm{r} \times \mathrm{L} \tag{4}$$

2.5 Cost model of maintenance stage

The cost model of maintenance stage includes the materials cost of spare parts and the labor cost for maintenance of parts.

The cost of maintenance the part i of a vehicle for t months can be expressed in $C_i(t)$. Then $C_i(t)$ can be expressed by the predicted maintenance times $M_i(t)$ for part i in a time span t and the expenditure of each maintenance. The maintenance cost model can be expressed below.

$$C_i(t) = M_i(t) \times S_i \tag{5}$$

Where S_i is the average cost of maintenance of parts i.

2.6 Model for LCC of BEVs

The LCC of the BEVs is the summation of the LCC of development stage, manufacturing stage, logistics stage, use stage and repair stage as illustrated in above sections.

3. Cycle Cost Empirical Analysis for BEVs

Processing of data depends on the LCC model. The data obtained from the investigation and statistics maybe not accurate enough. At the same time, some data may be at a large span of time, so the effect of time and inflation shall be taken into account. Therefore, these data can not be directly used for the LCC model of electric vehicles. The data obtained shall be handled with a unified calculation standard according to different assumptive conditions and economic status

In order to make the economic index of the two types of vehicles comparable, the vehicles with good sales and similar performance currently can be selected. This paper compares B grade BEVs with replaceable batteries of a company and B grade Passat of Volkswagen with conventional combustion engine. The performance index of both type of vehicles are showed in table 1.

Table 1: Performance index of BEVs and combustion engine vehicle

Car type / **parameter**	**BEVs**	**Passat**
Maximum speed (km/h)	140	200
Rated power of motor (kw)/ capacity of motor (L)	90	1.8
Mileage for one electric charge/ oil charge	300	550
Life cycle (year)	10	10

The annual cost of two types of vehicles is calculated and compared illustrated in table 2.

Table 2: Comparison table of the LCC between BEVs and conventional combustion engine vehicles

Cost	B level BEVs of some company	Passat B level car of VALKSWAGEN company
R&D cost	29 hundred million RMB/506.2 thousand vehicles=5729 RMB/ vehicle	53 hundred million RMB /40.5 thousand vehicles =13086 RMB/ vehicle
Manufacturing cost	Take a vehicle with price 309.8 thousand RMB as an example: 215.4 thousand RMB manufacturing cost including 100 thousand RMB for battery cost and 115.4 thousand RMB for material cost per vehicle	Take a vehicle with price 221.8 thousand RMB as an example: 122 thousand RMB manufacturing cost
Sales cost (9%)	27 thousand RMB per vehicle	19.8 thousand RMB per vehicle
Environmental cost in the use stage	0	10RMB/one hundred kilometer (not considered temporarily)
Repair cost	7500RMB/ year per car	9100 RMB/ year per car
LCC	255.629 thousand RMB	163.986 thousand RMB
LCC after deducting subsidy	141.629 thousand RMB	163.986 thousand RMB

Compared with conventional combustion engine vehicles in structure aspect, the BEVs are equipped with batteries and motors with their control components, but without the engines. The BEVs selected in this paper is equipped with lithium iron phosphate batteries with capability of 200 Ah of a single battery unit. The total capacity is 57kwh, 75 – 160 kw. As per the cost of battery with one kwh is 2000 RMB, the cost of batteries during mass production of the batteries is about 100 thousand RMB. The cost of other materials is estimate to be 115.4 thousand RMB. So the manufacturing cost of the vehicle is 215.4 thousand RMB. The actual manufacturing cost of the vehicle is about 101.4 thousand RMB after minus the national subsidies and local subsidies.

The conventional combustion engine vehicles shall be maintained, such as replacing the engine oil, cleaning the oil path and maintenance of power system and mechanical system. The cost for maintenance of conventional combustion engine vehicles is about 0.04 RMB per kilometer, while the cost for the maintenance of electric motor, electric control system and mechanical system for BEVs is about 0.015 RMB per kilometer.

According to table 2, the LCC of BEVs is higher than that of conventional combustion engine vehicles. However, the LCC of BEVs is greatly decreased, even less than that of conventional combustion engine vehicles after the national subsidies and local subsidies.

4. Conclusions

BEVs have been featured with necessary conditions for market development, such as technical level and the macro policy level. While high cost is the most critical issue to be solved to achieve industry scale development. The LCC of BEVs during manufacturing is higher than that of conventional combustion engine vehicles. The main reason is the high cost of batteries. Therefore, the maturity of power batteries' technology of BEVs is an important factor which will impact much on the LCC of BEVs.

According to the economics theory, economical scale is an important factor to decrease the cost of products and services. With the popularity of BEVs, the mass production effect will appear. The decreased cost of fixed cost of the unit product of BEVs is higher than that of the increased cost of the unit product. Therefore, the average cost can be decreased. Material procurement cost of BEVs can also be decreased with mass production. Finally, manufacturing cost of the BEVs will be reduced as the mass production and the development of new technology.

As the decrease of fuel and the shortage of resources, the government will increase energy tax to consumers; at the same time, the environmental tax will be increased to the vehicles' manufactures in order to enforce environmental protection, while the vehicles' manufactures will transfer the cost to the final consumers which will increase the LCC of conventional combustion engine vehicles.
The model is constructed from the vehicle manufacturer's point of view, considering the vehicles' research and development, production, sales, repair and other aspects of the cost. Green LCC is introduced to help consumers improve environmental protection awareness in daily life. Based on accurate calculation, the enterprises' strategic can be developed from the perspective of consumers which can overcome the short-term but instant benefit action.

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