Customer Perceived TCO and BEV Platform Development Approach

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Abstract: The attention to customer perception factors is helpful for automobile companies to better implement "customer-oriented" product development methodology. In this paper, customer perception factors are introduced into TCO framework, and BEV TCO model based on customer perception is established. Compared with TCO model without comprehensive introduction of customer perception factors, comparison calculation shows that introduction of customer perception factors can help identify real customer needs more effectively and improve the pertinence of product development. Based on MATLAB GUI and '0-1' integer programming method, this paper builds a development tool for BEV platform based on customer perceived TCO, it can realize TCO target setting, analyse TCO optimization alternative schemes and propose decision-making suggestion for achieving TCO target. Using the development tool set up in this paper, TCO optimization is carried out on a vehicle model of BEV platform which is under development and achieved optimization goal, indicating that the development tool is beneficial to guide the development of BEV platform.

Keywords: Customer perception, TCO, BEV platform, Development approach

1 INTRODUCTION

Research on customer perception covers purchasing and using phases of goods. Customer perceptions include cost perception, value perception, quality perception, brand perception, green perception, etc. Current researches mainly use sampling questionnaires and online comment information extraction to obtain data, and use empirical methods to reveal the role of perceived value and perceived risk in purchase decision-making process.

TCO (Total Cost of Ownership) and the practice of cost management based on it are from 1990s. TCO extends cost concept to whole life cycle cost of products: including purchase price, using cost, maintenance cost and waste disposal cost (Ellram, 1993), it has been widely used in various industries and effectively improved companies' operation performance. TCO has been widely used to analyse the competitiveness comparison between NEV (New Energy

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Vehicle) and ICE (Internal Combustion Engine) vehicle, as well as various technical routes within NEV (Godwin etc., 2022, Danielis etc., 2018, Brian etc., 2020, Erik etc., 2022, Thomas etc., 2021). Current researches provide meaningful insights into current situation and development trend of cost competitiveness of NEV, as well as success conditions and necessity of government subsidy policies (Letmathe etc., 2017, Santos etc., 2021). However, in current TCO research framework, the researches mainly focus on procurement costs such as parts & materials cost and energy cost (Pap etc., 2013, Karlin, 2004), the connotation is limited.

The integration of current research on customer perception, TCO and the development of BEV (Battery Electric Vehicle) platform (including chassis and powertrain) needs further development: research on customer perception is generally not related to TCO, current TCO research is mainly based on market tag price and generally deviates from customer perception, and insufficient attention is paid to TCO in BEV platform development process.

In view of above analysis, this paper firstly carries out quantitative method research on customer perception, then establishes BEV TCO model based on customer perception, finally builds a BEV platform development tool based on customer perceived TCO and conducts case verification. The development tool set up in this paper can effectively support automobile companies to better implement "customer-oriented" product development methodology in BEV platform development process.

2 BEV PLATFORM TCO MODEL BASED ON CUSTOMER PERCEPTION

2.1 Customer Perception Data Analysis Method

This paper proposes a quantitative method on market transaction data to identify impact on customer perceived cost of key vehicle features (such as BEV range). Main steps are as following:

Step 1: Assume that needs to identify impact of three key features a~c on TP (Transaction Price of new cars).

Step 2: With attention to above three key features, select n vehicle models: model 1~n.

Step 3: For model 1~n, select vehicle grades (such as high-grade model, low-grade model, etc.) for difference processing: A~W. A~W satisfy that the values of key features k_1~k_n which are not concerned are equal in the pair of vehicle grades for difference processing, so as to ensure that their influences on TP can be eliminated by difference processing.

Step 4: In the difference processing of step 3, if the influence of key features k_1~k_n on TP can't be completely eliminated (due to data defects), compensation will be made by means of value judgment. For example, assuming that key feature k_1 is different in two vehicle grades of model m, this paper compensates with the value of key feature k_1 in "value table" which is often used by automobile companies to eliminate its influence on TP.

Step 5: Carries out difference processing for the grades within same model, only retain the influence on TP of key features concerned, and obtain $\Delta TP'_1$~$\Delta TP'_n$ as shown in Table 1.

Table 1. Customer perception data analysis on key vehicle features.

Model	Grade	TP	Key features					
			a	b	c	k_1	$k_{2\sim n-1}$	k_n
Model 1	A	TP_A	a_{11}	b_{11}	c_{11}	k_{11}	…	k_{1n}
	B	TP_B	a_{12}	b_{12}	c_{12}	k_{11}	…	k_{1n}
	Difference (B-A)	$\Delta TP'_1$	Δa_1	Δb_1	Δc_1	0	0	0
Model 2	C	TP_C	a_{21}	b_{21}	c_{21}	k_{21}	…	k_{2n}
	D	TP_D	a_{22}	b_{22}	c_{22}	k_{21}	…	k_{2n}
	Difference (D-C)	$\Delta TP'_2$	Δa_2	Δb_2	Δc_2	0	0	0
Model ...				…				
Model n	V	TP_v	a_{n1}	b_{n1}	c_{n1}	k_{n1}	…	k_{nn}
	W	TP_w	a_{n2}	b_{n2}	c_{n2}	k_{n1}	…	k_{nn}
	Difference (W-V)	$\Delta TP'_n$	Δa_n	Δb_n	Δc_n	0	0	0

Step 6: For $\Delta TP'_1 \sim \Delta TP'_n$ obtained in step 5, they are processed based on sales ratio and obtains the reasonable difference value of TP perceived by customer, named as $\Delta TP_1 \sim \Delta TP_n$. Take model 1 as example: $\Delta TP_1 = \Delta TP'_1$ x B sales ratio x (A sales ratio + B sales ratio).

Step 7: Proceeds regression analysis about $\Delta TP_1 \sim \Delta TP_n$, identify impact weights of key features a~c on customer perception of TP reasonable difference: β_1, β_2, β_3, and establishes regression model: $\Delta TP=\beta_0+\beta_1\Delta a+\beta_2\Delta b+\beta_3\Delta c$.

2.2 Customer Perceived Cost of BEV Range

Using above data analysis method to proceed market data of 5 BEVs between 1st to 3rd quarter in 2022 (Qin PLUS EV, Geometry A, P5, P7 and AION Y, data from WAYS). The impact of BEV range on ΔTP is taken as customer perceived cost of BEV range. SPSS software is used for regression analysis on "BEV range ~ customer perceived cost", result is as shown in Table 2. In this paper, the average regression coefficient which is 48.5 RMB/km of first 3 quarters in 2022 is taken as customer perceived cost of BEV range, named as R_{ner}.

Table 2. Customer perceived cost regression analysis results of BEV range.

	2022. Q1	2022. Q2	2022. Q3
Dependent variable		ΔTP	
Independent variable		BEV range	
Adjusted R^2	83.8%	71%	76%
Significance of coefficient	1.9%	4.6%	3.4%
Regression coefficient (RMB/km)	51.7	48.9	45.0

2.3 Customer Perceived Discount Rate

In TCO model, almost all factors' contributions link to discount rate except purchase price (including energy cost, insurance fee, maintenance fee, etc.). Automobile companies generally use customer investigation to identify customer perceived cost of ICE vehicles fuel consumption (change in vehicle purchase price accepted by customer for every unit fuel consumption change). In this paper, the discount rate implied by customer perceived cost of fuel consumption of ICE vehicle is taken as customer perceived discount rate in TCO model.

The customer perceived discount rate IC_p is calculated based on following assumptions: driving distance R=30,000 km/year, fuel price P_f=7.5 RMB/L, lifecycle Y=6 years; based on survey by one automobile company, customer perceived cost V_p=300 RMB corresponding to change of fuel consumption Q=0.1 L/100km, the above data should meet following requirement:

$$V_p = \sum_{n=1}^{Y} P_f \times Q \times R \div (1 + IC_p)^{(n-1)} \tag{1}$$

IC_p=300% is calculated which indicates that customers pay great attention to near-term cost.

2.4 Used-Car Value-Preserving Rate

According to China Automobile Dealers Association and Jingzhengu company, 3-year value-preservation rates of China local brand vehicles are between 53.7% and 67.7%. This paper speculates that used-car value-preservation rate decays exponentially:

$$P_s = TP \times e^{-AY} \tag{2}$$

Where: P_S is selling price of used-cars, TP is transaction price of new cars, A is decay rate of selling price of used-cars over time, and Y is lifecycle (assumes 6 years).

Used-car value-preservation rates (6-year period) of China local brand vehicles are calculated, which is expressed as r in this paper, as shown in Table 3.

Table 3. Used-car value-preservation rate (6-year period).

Brand	SWMW	Trumpchi	Lynk&Co	Changan	NIO	Haval	MG	Roewe
r	45.83%	38.19%	35.88%	35.28%	34.57%	34.57%	33.52%	31.70%
Brand	BYD	Venucia	Geely	Baojun	WEY	Chery	Hong Qi	
r	31.58%	31.02%	30.91%	30.14%	30.03%	29.05%	28.84%	

2.5 Other TCO Parameters

TCO parameters used in this paper such as VAT (Value-Added Tax), purchase tax rate and insurance free are as shown in Table 4.

Table 4. Other TCO parameters.

	2023	2024	2025	2026	2027~
VAT: T_a	13%	13%	13%	13%	13%
Purchase tax: T_g	0	5%	5%	5%	7.5%
Insurance free: I (RMB)	1st year: (TP x 2.35%+1,795). Compulsory liability insurance discount: if first 3 years without accident, successively as 90%, 80%, 70%. Commercial insurance discount: if first 3 years without accident, successively as 75%, 70%, 60%.				

Plate fee (RMB): P_l	500	500	500	500	500
Vehicle tax (RMB): T_v	0	0	0	0	0
State subsidy (RMB): S_c	0	0	0	0	0
Local subsidy (RMB): S_l	0	0	0	0	0
Annual maintenance fee (RMB): F_m	500	500	500	500	500
Annual parking fee (RMB): F_p	5,000	5,000	5,000	5,000	5,000
Annual cleaning fee (RMB): F_c			Sedan: 720, SUV: 1,080		

2.6 BEV TCO Model Based on Customer Perception and Comparative Calculation

In this paper, the BEV TCO model based on customer perception is established and represented by TCO_A, shown as follows:

$$TCO_A = [TP \times (1 + 1 \div (1 + T_a) \times T_g) + P_l - S_c - S_l] - R_{ner} - V_{ed} + \sum_{n=1}^{Y} (R \times E \times P_e + I + T_v + F_m + F_p + F_c) \div (1 + IC_p)^{n-1} - TP \times r \div (1 + IC_p)^{Y-1} \quad (3)$$

Where: in addition to the parameters defined above, V_{ed} is adjustment value of vehicle equipment; R is annual driving distance (assumes 30,000km/year); E is energy efficiency (kWh/km); P_e is electricity price (assumes 1 RMB/kWh).

The BEV TCO model that without comprehensive introduction of customer perception factors is represented by TCO_B, shown as follows:

$$TCO_B = [TP \times (1 + 1 \div (1 + T_a) \times T_g) + P_l - S_c - S_l] + \sum_{n=1}^{Y} (R \times E \times P_e + I + T_v + F_m + F_p + F_c) \div (1 + IC)^{n-1} - TP \times r \div (1 + IC)^{Y-1} \quad (4)$$

Where: IC is discount rate without taking into account customer perception (assumes 10%).

Differences between TCO_A and TCO_B are: adjustment value of vehicle equipment, customer perceived cost of BEV range and customer perceived discount rate are imported into TCO_A. In this paper, two models' TCO are calculated and compared based on TCO_A and TCO_B. Our vehicle model (hereafter as our model) is a BEV under development, the competing model is SL03 (Changan brand vehicle). TCO parameters except those mentioned above are shown in Table 5.

Table 5. Some TCO parameters of our model and SL03.

Model	TP (RMB)	BEV range (km)	Energy efficiency (kWh/km)	Used-car value-preservation rate (6-year period)	Vehicle equipment value adjustment (RMB)
Our model	190,000	510	0.124	31%	0 (base)
SL03	189,900	515	0.123	35.3%	+1,000

The launch time of out model is 2 years later than the time when SL03's TP is 189,900 RMB, it is necessary to consider downward trend of SL03's TP before the launch of our model (based on experience, assumes 2%/year and 4% for two years). The comparative calculation of TCO_A and TCO_B between two models is shown in Table 6.

Table 6. Comparison of TCO_A and TCO_B.

Model	TCO_A (RMB)	TCO_B (RMB)	$TCO_A - TCO_B$
Our model	219,442	217,760	1,682
SL03	210,116	204,573	5,543
TCO competitiveness: (our model−SL03)	9,326	13,187	-3,861

The comparative calculation shows that TCO_A is different from TCO_B for both our model and competing model due to introduction of equipment adjustment value, customer perceived cost of BEV range and customer perceived discount rate. The TCO gap between our model and competing model is 13,187 RMB in TCO_B and 9,326 RMB in TCO_A. Compared with competing model, the TCO disadvantage of our model is significantly lower in TCO_A, it can avoid excessive costs when optimizing our model's TCO based on TCO_A. After introducing customer perception factors into TCO model, it is beneficial to identify the real needs of customers more effectively and improve the pertinence of product development of automobile companies.

3 BEV PLATFORM DEVELOPMENT TOOL BASED ON CUSTOMER PERCEIVED TCO

MATLAB GUI is used to establish BEV platform development tool by adopting the BEV TCO model (TCO_A) based on customer perception. The development tool includes: TCO target setting module, to achieve the TCO target setting of our model; TCO optimization module, with the constraints of new investment, TP limit, etc., and using the '0-1' integer programming method, makes decision analysis on TCO optimization alternative schemes in BEV platform development process. The program flow chart is shown in Figure 1.

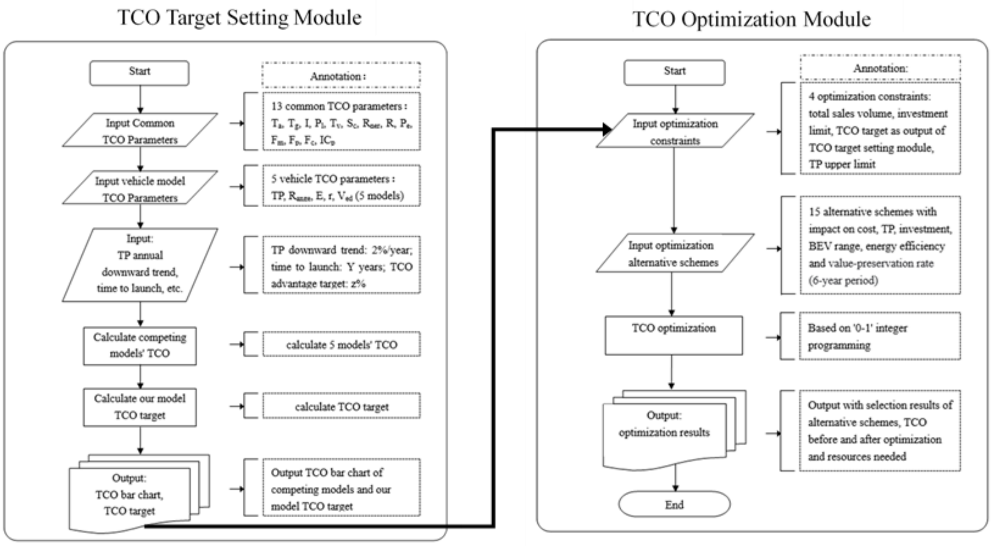

Figure 1. Program follow chart.

3.1 TCO Optimization Algorithm

Based on the '0-1' integer programming method, planning objective is defined to select TCO optimization alternative schemes (15 schemes in this paper in total) with minimum additional cost and investment, and to optimize our model's TCO to target value or better; '0-1' type variables are set as the decision recommendation of "not select" or "select" for each TCO optimization alternative schemes. Function is as follows:

$$\text{Min(z)}=\sum_{i=1}^{15}(\text{Cost\_impact}_i \times x_i \times \text{Platform\_volume} + x_i \times \text{Inv\_impact}_i)$$

$$s.t.\begin{cases}\sum_{i=1}^{15}\text{TCO\_impact}_i \times x_i \leq (\text{TCO\_target-TCO\_initial}) \\ \sum_{i=1}^{15}\text{TP\_impact}_i \times x_i \leq (\text{TP\_limit-TCO\_initial}) \\ \sum_{i=1}^{15}\text{Inv\_impact}_i \times x_i \leq \text{Inv\_limit} \\ x_i=0 \text{ or } 1,\ i=1, 2, \dots 15\end{cases} \tag{5}$$

Where: Min(Z) is the objective function; Cost_impact_i is cost impact of the i-th TCO optimization alternative scheme; x_i is whether the i-th TCO optimization alternative scheme is selected; Platform_volume is the total sales volume of BEV platform; Inv_impact_i is investment impact of the i-th TCO optimization alternative scheme; TCO_target is TCO optimization target value; TCO_initial is TCO before optimization; TP_limit is upper limit of TP after TCO optimization; TP_initial is TP before optimization; Inv_limit is additional investment limit when TCO optimization performed.

3.2 Example of TCO Optimization

The above tool is used to optimize one BEV model's TCO of a BEV platform which is under development. TCO parameters of relevant vehicle models are shown in Table 7 (TP of competing model is the data as of Sept., 2022), equipment value adjustment V_{ed} is calculated based on "value table" of one automobile company. TP downward trend is 2%/ year, and launch time of our product is in Sept., 2024 (Xpeng brand used-car value-preservation rate is not available, takes NIO brand data).

Table 7. TCO parameters of our model and competing models.

Model	TP (RMB)	BEV range (km)	Energy efficiency (kWh/km)	Used-car value-preservation rate (r, 6-year period)	Vehicle equipment value adjustment (V_{ed}, RMB)
Our model	190,000	510	0.124	31.0%	0 (base)
SL03	189,900	515	0.123	35.3%	+1,000
Aion S plus	189,639	602	0.131	38.2%	-21,700

Qin Plus EV	175,222	600	0.129	31.6%	-17,500
Geometry A	175,285	600	0.130	30.9%	-21,100
G3i	184,400	520	0.138	34.6%	-19,400

TCO optimization constraints: The total sales volume of BEV platform is 1 million units; additional investment limit in TCO optimization is 15 million RMB; upper limit of TP after TCO optimization is 200,000 RMB; our model's TCO advantage target is 1% better than average TCO of five competing models. TCO optimization alternative schemes are shown in Table 8.

Table 8. TCO optimization alternative schemes.

No.	Cost impact (RMB)	TP impact (RMB)	Investment impact (10k RMB)	BEV range impact (km)	Energy efficiency impact (kWh/km)	r impact (6-year period)	V_{ed} impact (RMB)
1	-2,976	-3,571	-	-30	0	0	0
2	4,960	5,952	-	50	0	0	0
3	9,920	11,904	-	100	0	0	0
4	-150	-180	-50	-41	0.01	0	0
5	-40	-48	-50	-21	0.005	0	0
6	50	60	100	12	-0.003	0	0
7	80	96	120	21	-0.005	0	0
8	-500	-600	500	-	0	-0.01	0
9	1,000	1,200	2,000	-	0	0.02	0
10	2,000	2,400	4,000	-	0	0.03	0
11	-100	-200	100	-	0	0	-200
12	100	500	10	-	0	0	200
13	120	510	50	-	0	0	240
14	50	200	10	-	0	0	100
15	160	1,000	20	-	0	0	320

The interface of the development tool is shown in Figure 2. The average TCO of competing models is 217,254.6 RMB, TCO of our model is 219,442 RMB before optimization which is 1% inferior to competing models. TCO of our model is 214,656 RMB after optimization which is with advantage of 1.20% over competing models. The optimization decision suggestion is: select the TCO optimization alternative schemes 1, 6, 7, 8 and 11; resources needed for TCO optimization is cost of -3,446 RMB/vehicle and additional investment of 8.2 million RMB. Through this optimization, TCO and manufacturing cost are improved at the same time, both customers and automobile companies gain benefits.

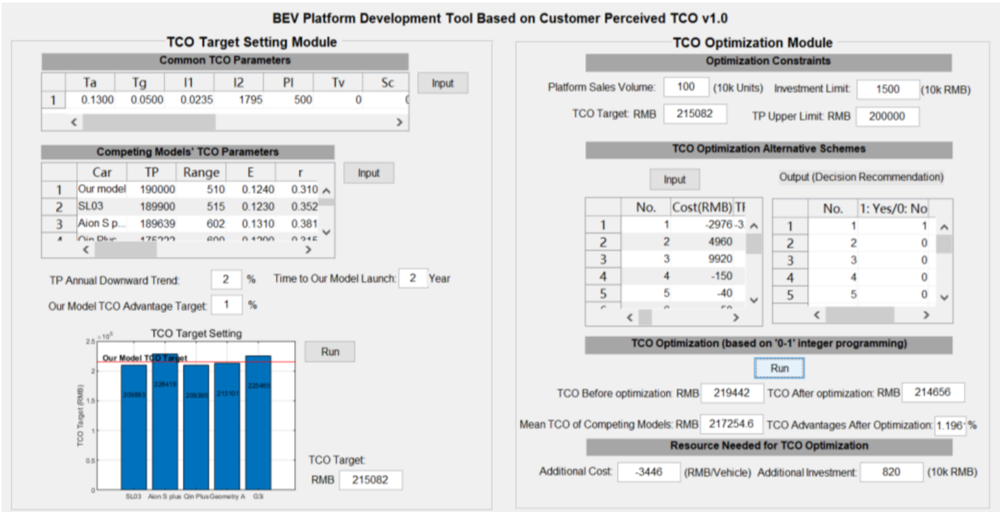

Figure 2. Development tool interface.

4 CONCLUSIONS

Due to the limitation of objective factors, the research work of this paper still has room for further improvement:

Due to the limitation of current market data, only limited difference data of key features of vehicle models are obtained. With the development of the automobile market and the accumulation of abundant data, it is helpful to mine other influencing factors (such as suspension structure type, power performance, etc.) and the corresponding influencing weights of the BEV TCO that have not been effectively identified.

The method proposed in this paper analyses the competitiveness from a specific perspective (TCO) rather than the overall situation of market competition. To a certain extent, it has the significance of guiding the development of BEV platform, but the influence of other factors such as brand and styling design on customers' purchase decision can't be ignored.

REFERENCES

[1] Brian Cox, Christian Bauer, et al. (2020). Life Cycle Environmental and Cost Comparison of Current and Future Passenger Cars Under Different Energy Scenarios. Applied Energy, 269, 115021.

[2] Danielis R., Giansoldati M., Rotaris L. A. (2018). Probabilistic Total Cost of Ownership Model to Evaluate the Current and Future Prospects of Electric Cars Uptake in Italy. Energy Policy, 119, 268-281.

[3] Ellram L. (1993). Total Cost of Ownership: Elements and Implementation. J. Supply Chain Management, 29(3), 2-11.

[4] Erik Figenbaum. (2022). Retrospective Total Cost of Ownership Analysis of Battery Electric Vehicles in Norway. Transportation Research Part D, 105: 103246.

[5] Godwin K. Ayetor, Richard Opoku, Charles K. K. Sekyere, Anthony Agyei-Agyeman, Godwin R. Deyegbe. (2022). The Cost of a Transition to Electric Vehicles in Africa: A Case Study of Ghana. Case Studies on Transport Policy, 10, 388-395.
[6] Karlin J. N. (2004). Defining the Lean Logistics Learning Enterprise: Examples from Toyota's North American Supply Chain. University of Michigan.
[7] Letmathe P, Suares M. A. (2017). Consumer-Oriented Total Cost of Ownership Model for Different Vehicle Types in Germany. Transportation Research Part D Transport & Environment, 57, 314-335.
[8] Pap S, Morar L. (2013). Procurement Approaches in Different Supply Chains. Applied Mechanics and Materials, 436, 551-556.
[9] Santos G, Rembalski S. (2021). Do Electric Vehicles Need Subsidies in the UK?. Energy Policy, 149, 111890.
[10] Thomas Grube, Stefan Kraus, et al. (2021). Passenger Car Cost Development Through 2050. Transportation Research Part D, 101, 103110.