# FRAMEWORK OF A DECISION SUPPORT SYSTEM FOR ELECTRIC VEHICLE INVESTMENT PROJECT ASSESSMENT

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***ABSTRACT:*** *Air pollution, climate change, and rising fuel expenses are all factors that promote the usage of electric vehicle (EV). Since the investment on an EV project is rather complicated, a well-structured evaluation method for EV investment decision is proposed. This work constructs a framework of a decision support system which includes fleet investment decision model and cost-benefit analysis model within a multi-criteria decision analysis module. Using this decision support system, a decision-maker could adopt simulation to do the scenario analysis to justify economic feasibility, include the criteria of non-economic aspects into account and may obtain the optimal investment scale of the project. A real case regarding a fleet of EV for renting service had been selected to examine the appropriateness of the proposed system and models. The analysis shows that the EV investment would increase its profitability by 51.73% compared to original setup, through the re-arrangement of the fleet by the system. The proposed system is illustrated its usefulness for the practitioners.*

**Keywords:** Electric vehicle, cost-benefit analysis, multi-criteria decision analysis, decision support system

## 1. INTRODUCTION

Increasing concern about high gas price, energy shortage, air pollution, and greenhouse gas (GHG) emission have all led government and industry to seek alternatives other than conventional vehicles (CV) [1]. Since electric vehicles (EV) could reduce energy consumption and greenhouse gas (GHG) emission effectively, promoting EV is becoming a global trend nowadays. While many successful cases have been reported, but the decision to invest on EVs is still quite slow in most of the cases.

Investment decision on a EV project is complicated because it involving with a number of quantitative and qualitative criteria, and extra expenses on battery and charging infrastructure [2]. Lack of effective tools to assess an EV investment project is one of the reasons why EV's market penetration is still limited currently. Various cost structures make the investment model of EV completely different than that of CV. Consequently, investors on EV projects need to be more cautious about decision making. A decision support system, which is capable to take the nature and characteristics of EV into account, is therefore necessary. The primary purpose of this work is to propose a framework of a decision support system, based on multi-criteria decision process and several related mathematical models, and use a real life case to illustrate its usefulness.

Noel and McCormack [3] evaluated the costs and benefits associated with the use of electric vehicles and determined the cost effectiveness by using a vehicle-to-grid-capable electric school bus to compare to traditional diesel school bus. Results of case study showed that purchasing an electric school bus was consistently a net present benefit. Barfod et al. [4] proposed a composite decision support based on combining cost-benefit analysis with multi-criteria decision analysis for the assessment of economic as well as strategic impacts within transport projects. The outcome demonstrated that the proposed approach was valuable. Lin et al. [5] presented a hybrid electric vehicle(HEV) life-cycle private cost model that established to evaluate HEV market prospects in China compared with traditional internal combustion engine vehicles (ICEV). Results showed that technology's cost-competitiveness, compared with traditional ICEVs, is advantageous for these higher mileage vehicles. Trappey et al. [6] analyzed the internationalization process model developed by Johanson and Vahlne and derived two integer programming investment decision models that considered the risk attitudes of investment firms. The model could assist firms managers to handle the risks of their investments and to derive accurate investment strategies based on objectives and constraints.

Tzenga et al. [7] proposed that several types of fuels are considered as alternative-fuel modes, i.e., electricity, fuel cell (hydrogen), and methanol. It is found out that the hybrid electric bus is the most suitable substitute bus for Taiwan urban areas in the short and median term. Yavuz et al. [2]proposed a hierarchical hesitant fuzzy linguistic model that captures hesitant linguistic evaluations of multiple experts on multiple criteria for alternative-fuel vehicles. The results showed that an electric vehicle is the best fit for the considered scenarios. Zhao et al. [1] developed a life-cycle cost model to evaluate the lifetime cost of a vehicle. They found out that with central government subsidies, the BEV life-cycle private cost is about 1.4 times higher than internal combustion engine vehicles.

## 2. PROPOSED FRAMEWORK

This work developed the framework of an EV investment decision support system (EVIDSS). In the model base, fleet investment decision model and cost-benefit analysis model are included into the multi-criteria decision analysis module (See Fig. 1). Users can obtain an "suggested" optimal investment scale with fleet investment decision model, and then evaluate the economic feasibility of alternatives with cost-benefit analysis model. Furthermore, using multi-criteria decision analysis module, a manager could take into account two other aspects - environmental impact and fueling convenience, and to adjust alternatives. Decision-related information can be extracted from database, and the parameters could be adjusted in order to simulate different scenarios. Structure of EVIDDS is illustrated as below.

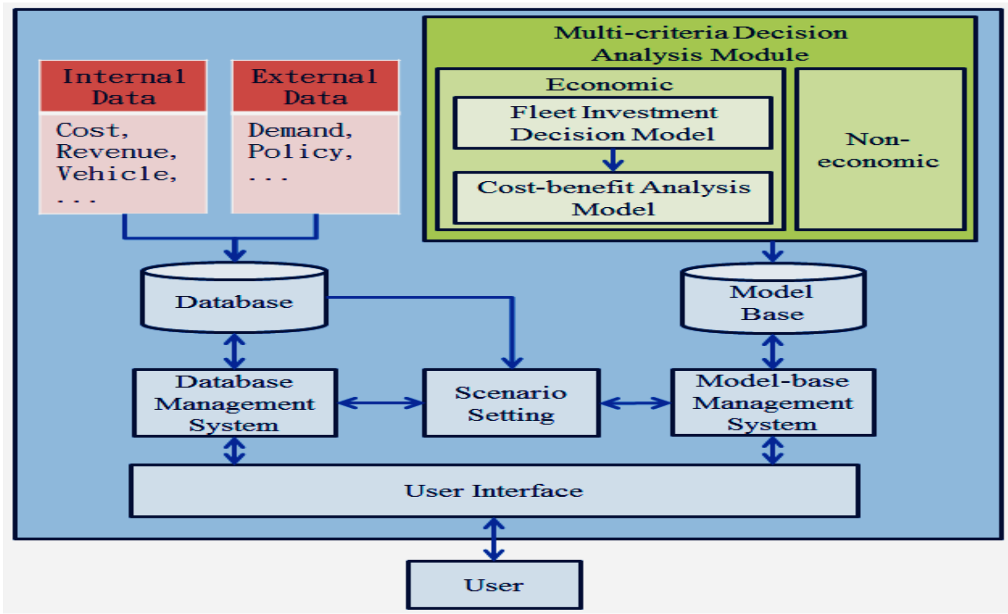


**Figure (1) Framework of EVIDSS**

**Table 1 Notations list of the fleet investment decision model**

| | |
|---|---|
| Sets | |
| $k$ | index of vehicle type, for example, EV and CV, $k = \{1, \dots, K\}$ |
| $n$ | index of vehicle, $n = \{1, \dots, N\}$ |
| $t$ | index of day, $t = \{1, \dots, T\}$ |
| $y$ | index of year, $y = \{1, \dots, Y\}$ |
| Decision variables | |
| $Iv_{n,k}$ | investment decision, decision to invest $n$ type $k$ vehicles |
| Parameters | |
| $Cost_{n,k}$ | total cost of investment of $n$ type $k$ vehicle |
| $Cost_{n,k,y}$ | cost of investment of $n$ type $k$ vehicle in year $y$ |
| $Cost_F$ | budget |
| $D_{t,y}$ | renting demand in year $y$ |
| $ER_{n,k}$ | expected revenue of decision to invest $n$ type $k$ vehicles |
| $i$ | discount rate |
| $LR$ | length of rent |
| $RR_k$ | rental rate of type $k$ vehicle |
| $R_{n,t,y}$ | amount of rented vehicle of day $t$ in year $y$, given investing $n$ vehicle |

### 2.1 Fleet investment decision model

A decision model for fleet investment based on Trappey and Shih (2008) and Trappey, Shih, and Trappey (2007) is proposed. This model is an integer program where the objective is to maximize the investor's profit. Variation of revenue and cost depends on vehicle type and amount of invested vehicles. After inputting the parameters and solving the problem, a "suggested" optimal investment scale would be provided. The model is expressed as follows. Notations list is shown in Table 1.

$$\text{Max } \pi = \sum_{n=1}^{N} \sum_{k=1}^{K} \{ER_{n,k} - Cost_{n,k}\} \times Iv_{n,k} \quad (1)$$

subject to

$$\sum_{n}^{N} (Cost_{n,k} \times Iv_{n,k}) \le Cost_F \quad , \forall k \ (2)$$

$$Cost_{n,k} = \sum_{y=1}^{Y} Cost_{n,k,y} / (1+i)^y \quad (3)$$

$$Iv_{n,k} = (0,1) \quad , \forall n, k \quad (4)$$

$$\sum_{n}^{N} Iv_{n,k} = 1 \quad , \forall k \quad (5)$$

The objective function (Equation 1) is the maximization of the profit for the investor. Constraint 2 represents that investment decision should be restricted by budget. Constraint 3 ensures that the total investment cost equals to the summation of discounted annual costs. Constraint 4 and Constraint 5 are to decide whether to invest or not, and to choose only one alternative for each vehicle type.

Since the case company is a travel agency intending to invest a fleet of EVs for local renting service, expected revenue depends on length of rent, rental price, and amount of rented vehicles. The expected revenue is calculated as follows.

$$ER_{n,k} = \frac{\sum_{y=1}^{Y} \sum_{t=1}^{T} R_{n,t,y} \times LR \times RR_k}{(1+i)^y} \quad , \forall n, k \quad (6)$$

The assumption is made that the company does not reserve vehicle, hence amount of rented vehicles is determined by fleet size and annual renting demand (constraint 7). Constraint 8 is to exclude the situation that index of day being zero or negative.

$$R_{n,t,y} = \min\{n - \sum_{t'=t-LR+1}^{t-1} R_{n,t',y}, D_{t,y}\} \quad ,\forall n,t,y \quad (7)$$

$$R_{n,0,y}, R_{n,-1,y}, R_{n,-2,y}, \ldots = 0 \quad ,\forall n,y \quad (8)$$

**2.2 Cost-benefit analysis model**

As to the Cost-benefit analysis model, cost of EV is composed of two categories of cost - implementation cost which is involved with initial investment and operation cost which depends on usage of resources and equipment. The cost structure of EV fleet investment is constructed as shown in Figure 2. Notations list is shown in Table 2.

**2.2.1 Implementation Cost**

- EV acquisition cost

Price of EV and commodity tax of EV compose EV acquisition cost, and should be multiplied by the amount of EV purchased. Because of tax exemption provided by government, there is no taxation caused by purchasing EV until 2017. The calculation of EV acquisition cost is as follows.

$$C_{EV} = (P_{EV} + T_{EVC}) \times N_{EV} \quad (9)$$

- Charging pile acquisition cost

The amount of charging piles is determined by charging demand. Charging demand could be computed by amount of EV purchased, average mileage per day, and electric power consumption rate of EV as shown in equation 10. To calculate electric power consumption rate, battery capacity is divided by maximum mileage of EV, shown as equation 11.

$$D_{char} = N_{EV} \times M_{AVG} \times CR_{EV} \quad (10)$$

$$CR_{EV} = CP_B \div M_{max} \quad (11)$$

According to the standard of announced by Industrial Development Bureau, MOEA, of Taiwan, there are three level of charging demand, expressed as table 4.

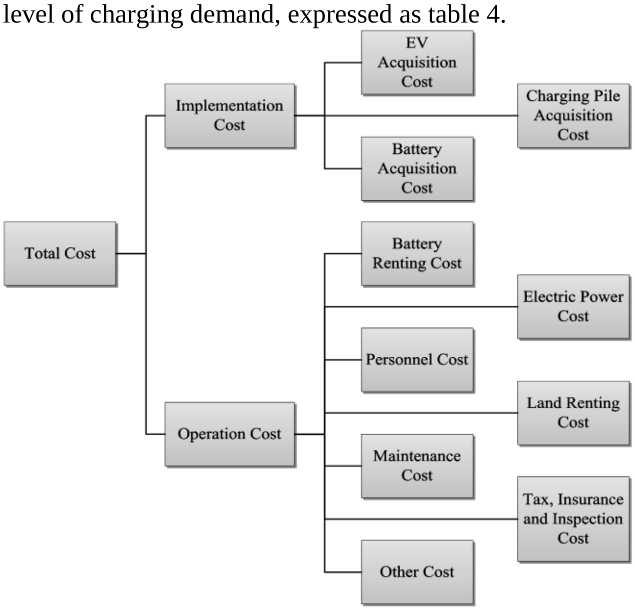


**Figure (2) Cost structure of EV**

**Table 2 Notations list of the cost-benefit analysis model**

| | |
|---|---|
| **Sets** | |
| $v$ | $v = 1$ for rated voltage of 110V/AC and rated current of 16A<br>$v = 2$ for rated voltage of 220V/AC and rated current of 32A<br>$v = 3$ for rated voltage of 220V/AC and rated current of 80A |
| **Parameters** | |
| $C_{BR}$ | battery renting cost per year |
| $C_{char}$ | charging pile acquisition cost |
| $C_{EV}$ | EV acquisition cost |
| $C_{EVinsp}$ | inspection fee of EV per year |
| $C_{EVinsu}$ | insurance fee of EV per year |
| $C_{EVM}$ | maintenance cost of EV per year |
| $C_{EVTII}$ | tax, insurance and inspection cost of EV per year |
| $C_{LR}$ | land renting cost per year |
| $C_{pers}$ | personnel cost per year |
| $CP_B$ | battery capacity |
| $CR_{EV}$ | electric power consumption rate of EV |
| $D_{char}$ | total charging demand |
| $D_{char,v}$ | charging demand of level v |
| $H_{char}$ | available charging time per day |
| $M_{AVG}$ | average mileage per day |
| $M_{max}$ | maximum mileage of EV |
| $N_B$ | amount of battery purchased |
| $N_{char,v}$ | amount of level v charging pile purchased |
| $N_{EV}$ | amount of EV purchased |
| $P_{char,v}$ | price of level v charging pile |
| $P_{EV}$ | price of EV |
| $P_{EVM}$ | price of maintenance of EV |
| $POW_{char,v}$ | charging power of level v charging pile |
| $R_B$ | battery rent per year |
| $R_{OC}$ | operations center rent per year |
| $R_{PL}$ | parking lot rent per year |
| $RT_{vac,v}$ | vacancy rate of level v charging pile |
| $S_{dr}$ | salary of drivers per year |
| $S_{ad}$ | salary of administrators per year |
| $S_{cons}$ | salary of consultants per year |
| $T_{EVC}$ | commodity tax of EV |
| $T_{EVL}$ | annual license tax of EV per vehicle |
| $T_{EVF}$ | annual fuel tax of EV per vehicle |
| $TM_{EVM}$ | time of EV maintenance per year |

**Table 4 Classification of Different EV Charging Modes**

| Type | Charging Demand Type | Rated Voltage | Rated Current | Applicable Place |
|---|---|---|---|---|
| Level 1 | Slow demand | 110V AC | 16A | Home, Working place |
| Level 2 | Regular demand | 220V AC | 32A、80A | Shopping mall, Parking lots |
| Level 3 | Urgent demand | not defined | not defined | Charging stations, Highway service areas |

Since DC interface has not be defined yet in practice, this work could only take level 1(110V/AC, 16A) and level 2(220V/AC, 32A; 220V/AC, 80A) into consideration, which is presented as $D_1$, $D_2$, and $D_3$, shown as equation 12. The amount of level v charging pile purchased is determined by charging demand of level v, charging power of level v charging pile, available charging time per day, and vacancy rate of level v charging pile, calculated as equation 13. After figuring out the amount of each charging pile, the total cost of charging piles could be calculated accordingly.

$$D_{char} = \sum_{v=1}^{3} D_{char,v} \qquad (12)$$

$$N_{char,v} = \frac{D_{char,v}}{POW_{char,v} \times H_{char} \times (1 - RT_{vac,v})} \quad \forall v \qquad (13)$$

$$C_{char} = \sum_{v=1}^{3} P_{char,v} \times N_{char,v} \qquad (14)$$

### 2.2.2 Operation cost

- Battery renting cost

Instead of spending valuable resources on battery acquisition initially, the “separation between vehicle and battery” model is performed by purchasing vehicle and renting battery. A company should pay rent for battery every year, and the cost of battery renting is calculated as follows.

$$C_{BR} = R_B \times N_B \qquad (15)$$

- Personnel cost

Personnel cost consists of drivers’ salaries, administrators’ salaries, and consultants’ salaries, which is calculated by the unit of annual wage.

$$C_{pers} = S_{dr} + S_{ad} + S_{cons} \qquad (16)$$

- Land renting cost

Land renting cost consists of operations center rent and parking lot rent, which is calculated by the unit of annual rent.

$$C_{LR} = R_{OC} + R_{PL} \qquad (17)$$

- Maintenance cost

Maintenance of EV varies from different vehicle structure and different amount of components and parts. Maintenance cost of EV depends on price, frequency, and amount of vehicle, calculated as follows.

$$C_{EVM} = P_{EVM} \times TM_{EVM} \times N_{EV} \qquad (18)$$

- Tax, insurance and inspection cost

Annual tax is composed of license tax and fuel tax. A company is suggested to purchase 4 kinds of essential insurances. According to Directorate General of Highways of Taiwan, inspection of commercial vehicle which age below 5 years should be re-inspected once a year, while that of commercial vehicle which age above 5 years should be re-inspected twice a year. Total cost calculation is as follows.

$$C_{EVTII} = (T_{EVL} + T_{EVF} + C_{EVinsu} + C_{EVinsp}) \times N_{EV} \qquad (19)$$

### 2.2.3 Economic benefit

Economic benefit is referred to as the income caused by operation and subsidy. Should a travel agency is intending to invest a fleet of EVs for local renting service, its revenue is calculated using the model in previous section. The subsidy of IDB, MOEA is no more than 49% of total budget.

## 3. CONCLUSION

After an interview of the top manager of a real case, EVIDSS was designed and problem parameters were also inputted. The simulation could be performed to examine the potential benefits and costs.

The simulation results demonstrated that using EVIDSS can assist the managers to find better alternatives (see table 3). Although profitability of EV alternative was still lower than that of CV alternative, but the government subsidy could off-set the differences. Note that EV alternative’s profitability was improved using EVIDSS. Models provided in this work are quite useful for managers in asking “what-if” questions during the decision process – though our interface is still quite primitive to be commercial.

**Table 3. Simulation results**

| **Simulation Outputs** | | | | | |
|---|---|---|---|---|---|
| | | **without EVIDSS** | | **using EVIDSS** | |
| | | **EV** | **CV** | **EV** | **CV** |
| **Net Present Value** | **mean (thousand NTD)** | 39,325 | 74,931 | 59,668 | 81,389 |
| | **standard deviation** | 1260.7 | 1185.3 | 9,996.6 | 10,515.7 |
| **Benefit-Cost Ratio** | **mean** | 1.04 | 1.09 | 1.08 | 1.11 |
| **Internal Rate of Return** | **mean** | 10.12% | 13.59% | 13.13% | 15.13% |
| Payback Period | mean (year) | 8.87 | 7.80 | 7.72 | 7.32 |

This work constructs a framework of a decision support system, EVIDSS, to assist government policy makers or top managers of a company to make better decision in regarding to EVs investment projects. Details of the model is presented and a preliminary system is developed. The proposed EVIDSS integrates related cost variables and a fleet investment decision model which can evaluate the economic feasibility of alternatives by cost-benefit analysis are implemented. A case study is used to illustrate the usefulness of EVIDSS. Using this EVIDSS, a top manager can make a better decision during the process and improving the cost-benefit ratio thereafter.

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