行政院國家科學委員會補助專題研究計畫成果報告

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執行期間：88 年 8 月 1 日至 89 年 7 月 31 日

計畫主持人：傅增棣

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行政院國家科學委員會專題研究計畫成果報告

機械設計之工程評估

Technical Evaluation of Mechanical Designs

計畫編號：NSC 89-2212-E-002-023
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Abstract

Owing to the development of new technology, the design goals of mechanical systems are normally sophisticated and varied. Much research in design evaluation has been devoted to devising quantitative and objective methods to systematically evaluate these design targets.

Using two types of scooters as the case study, a framework of whole-life cost evaluation is constructed. Quantitative relationships between the costs or benefits of system performance and their relevant design parameters are created. An evaluation chart is then formulated from the user's perspectives and used by design engineers. With the ability of considering the time factor, scoring procedures proposed in this project provide more technical and economic insights to the final design decision.

Keywords: Design evaluation, Cost-benefit analysis, Scooter

中文摘要

機械設計目標的本質，一般都具有多樣複雜之特性。因此，如何有系統地以客觀量化的方法，來檢討這些設計的目標，一直都是設計評估學中研究的重要課題。

本計畫係從使用者的觀點出發，以兩種截然不同的機車為案例研究，嘗試建立在其壽命週期當中，全車性能之成本效益與其設計參數間的關係。並以此為基礎，運用工程評估學的理論，建構量化之工程評估表，以供設計工程師在決策時之參考。此外，運用所建立的評分法則能夠考量時間因素的特性，設計者可以對評估結果作更深入之分析，而更有益於設計決策之週延。

關鍵詞：設計評估，成本效益分析，機車

1. Introduction

Evaluation is one of the most frequent activities in a typical design process [1,2]. It essentially determines the direction of design, which in turn will decide a majority part of the final product cost. According to a survey in the industry [3], it is estimated that 70~80% of product cost is fixed in the design process. As new technology emerges and the complexity of mechanical systems increases, evaluation of design becomes more important and sophisticated. Much effort has been put on the search for quantitative and objective methods for design evaluation in the field of design methodology [1,4,5,6,7,8].

Except for desired functions, the key to the success of a mechanical product is its cost. An economic analysis of a product can not only reveal the potential monetary gain/loss but also prevent the need of subjective weightings from getting into the evaluation process. However, most cost-benefit analyses of mechanical systems are mainly related to the manufacturing expenses [9,10]. Cost estimation attributed to design parameters is seldom discussed in the literature.

The aim of this project is attempted to build up links between design parameters and corresponding costs for system alternatives. Using two types of scooters as the case study, the process of a whole-life cost-effective design evaluation is constructed for design engineers.

2. Profiles of the case study

Owing to the mobility and relatively inexpensive in price, motorcycles uniquely prevail in many Asian countries. According to the Ministry of Transportation in Taiwan, ROC, the number of motorcycles has reached 10,550,000 by the end of 1998 in the island. They are the main transportation tool in people's daily life but also responsible for some 30~50% of air pollution from moving sources [11]. In order to ease this problem, the government has launched a series of campaigns since 1992 to promote electric motorcycles. It is required by the legislation that all motorcycle manufacturers in Taiwan have to achieve 2% of their total sales be powered by electricity before the end of 2000.

Electric motorcycles, like all other commercial goods, are economically driven. Although the authority can set favorite conditions in the beginning, the long-term survival of this product can only be guaranteed by its own profit. Electric motorcycles are new to the public. Most people, even heard of them, are seldom have experience in using [12]. Under this circumstance, evaluating by the public survey could sometimes be misleading. It is therefore hoped that the framework of a cost/benefit analysis proposed in this project can help more objectively reveal the best direction of development for the future.

3. The evaluation process

To facilitate the comparison, a two dimensional chart is constructed in the evaluation process. A typical evaluation chart requires three basic elements. They are described for the case of scooters as follows:

3.1 Alternative designs

Limited by current technology, the performance of electric motorcycles can only compete with that of 50cc petroleum scooters. Instead of investigating individual models, two sets of representative performance values for traditional petroleum scooters (PS) and electric scooters (ES) are used as the alternatives in evaluation. They are derived from typical models of 50cc petroleum scooters, and average values of five different models of new electric scooters in Taiwan [13].

3.2 Evaluation criteria

Evaluation criteria essentially reflect the evaluator's preference. In this project, the perspective of scooter users is applied. This is to acknowledge the fact that customers ultimately decide which product to purchase, and hence which design will be the most successful in a competitive market.

In order to have a complete evaluation for both systems, the criteria have to cover various aspects of scooters, which may include opinions from the users [14~20], purposes of systems (air pollution and noise reduction), and issues which have significant difference between alternatives (range and refueling time). A set of eight criteria was then selected for the evaluation of scooters as listed in Table 1:

Table 1. Evaluation criteria and design parameters

Evaluation criteria	Unit	Relevant design parameters
Maximum speed	km/hr	Maximum horse power, weight, front sectional area
Operation cost	NT$	Fuel consumption, regular replacements, part costs
Price	NT$	List price
Maintenance cost	NT$	Non-expected component failures
Air pollution	g/km	Engine or power plant emission
Noise	dB(A)	Motor/engine or tire noise
Gradability	degree	Weight, maximum torque
Refueling cost	NT$	Time to refuel, time value, range (battery capacity, motor efficiency)

In this table, fuel economy along with other regular replacements, such as spark plug, battery, etc. are included in the criterion of operation cost. The component failure rates are considered in terms of maintenance cost to reveal its economic effect. Hill climbing and acceleration are united under the criterion of gradability. For the issue of refueling time, it means the time of refueling gasoline for PS and charging batteries for ES, respectively. For the criterion of refueling cost in this table, it estimates the overall cost to users by taking account of both the refueling time and range.

3.3 Scoring procedures

The procedures aim to provide each alternative with an overall score for evaluation. The approach applied is essentially a whole-life cost-benefit analysis using currency as the common index for summation in the evaluation chart. It is attempted to link the costs (economic issues) with corresponding design parameters (technical issues). A summary of these links is also shown in Table 1. In this way, costs to users are possibly perceived by the design engineers and then incorporated in their design considerations.

For each criterion, the cost or benefit (indicated by a negative or positive sign) for each system is assessed for a typical lifetime. Using PS as the datum, the sum of all relative costs or benefits constitutes a basis for the decision-making and further analysis.

Individual calculations for all criteria are described below:

(a) Maximum speed

According to the survey in [21], the accepted level of maximum speed for scooter users is 63.68km/hr. For each 1km/hr increase of this speed, people are willing to pay (WIP) NT$579 more. The cost or benefit of PS or ES in this criterion can then be calculated by:

$$V = (X\text{-accepted level})*WIP \qquad (1)$$

In which, V is the user perceived cost or benefit in the unit of NT dollars, and X represents the maximum speed in km/hr for PS or ES [13].

(b) Operation cost

This criterion accounts for the costs of fuel or electricity, transmission oil, fuel tax for PS, regular replacements of spark plug, filter, and batteries. Calculations were based on the data from [12, 13, 21, 22] and lead to an average cost per kilometer. In particular, fuel efficiency for PS is 21.2km/l and 36.4Wh/km for ES under the driving mode of ECE47, respectively.

According to [22], it is found that 50cc scooters are generally used for seven years, 5.3 days per week, and 7.1km per day in average. The total system lifetime for scooters in terms of distance can then be estimated as 13,697km.

(c) Price

They are average values of the listed prices for various models of PS and ES from [13,23].

(d) Maintenance cost

For PS, it can be acquired directly from a survey in [22]. However, for a new product like ES, the duration of use is not long enough for accurate estimation. Its value was then calculated from records of a test-ride campaign for a year [12].

(e) Air pollution

The main pollutants emitted by PS are CO and HC+NOx. Being difficult to be perceived by human senses, their costs to users are hard to evaluate. The only occasion of possible extra cost for PS riders is the risk of being fined by the authority if the amount of pollutants emitted from their scooters exceeds that permitted by the law. According to records in [24], the average percentage of scooters being fined by the authority among those examined is about 11.86%. Under current penalty of NT$3,000 and assuming the condition of scooters is good in the first two years of lifetime, the potential cost of using PS in the rest five years is NT$1,752. In contrast, ES users have no worry about this pollution cost.

(f) Noise

Research in [25,26] indicates that noise has little effect on the performance of people in non-calculating work, such as riding a scooter. In particular, there is no record of scooter riders being fined for excess noise by the government. Although it is important in the environment protection, under current circumstances, no real cost or benefit of noise is incurred to either PS or ES users.

(g) Gradability

Average values of gradability for a typical PS and ES are derived from [13]. The accepted reference and WIP values can be calculated from the scooter specification [23] as 17.4deg and NT$719/deg, respectively. By substituting these values into Equation (1), the perceived costs or benefits for PS and ES are obtained.

(h) Refueling cost

The time spent on each refueling process of scooters consists of two parts. One is for the trip to the station if needed, and the other is time for refueling gasoline or electricity. On the other hand, the number of times to refuel required by a scooter during its lifetime is determined by the range. This is equal to the length of lifetime in kilometer divided by the corresponding range.

According to estimation in [12], it takes six minutes in average for a PS to refuel in a gas station. By considering the density of gas stations in Taiwan being 0.05 station per km square [27], and assuming an average driving speed of 30km/hr, it is found that 2.52min in average is required for a scooter on its route to the station.

Average values of range for PS and ES are calculated from [13] under a constant speed of 30km/hr. For an ordinary employee in Taiwan, the average salary per hour is NT$215 [28]. However, not all scooter users are working, a factor of 0.63 [22] is applied on this time value. Thus, the refueling cost can be calculated as follows:

V=(number of times to refuel in the lifetime)
* (refueling time) * (time value) (2)

4. Whole life cost evaluation of scooters

Various conditions for the possible ways of charging ES have been proposed in the literature [12,16,21] due to the problem of batteries. A survey of ES users in Taiwan [21] indicated that the first three favorite methods were charging at home, battery exchange, and charging at stations. Effects of these charging schemes on the performance of ES against various criteria are summarized in Table 2 along with that of PS for comparison. In this table, attributes of air pollution and noise possess two values for each system. They represent the amounts of permitted CO and HC+NOx, and noise levels of scooters during idle and acceleration [12], respectively. Details for the difference of these schemes are discussed below:

Table 2. Performance levels of scooters

Attributes	Unit	PS	ES1	ES2	ES3
Maximum speed	km/hr	65	52.8	52.8	52.8
Operation cost	NT$/km	1.06	3.925	1.986	1.54
Price	NT$/km	36,000	58,500	58,500	58,500
Maintenance cost	NT$/year	1,693	2,821	2,821	2,821
Air pollution	g/km	3.5/2.0	0/0.0492	0/0.0492	0/0.0492
Noise	dB(A)	99/72	0/62.7	0/62.7	0/62.7
Gradability	degree	18	14.2	14.2	14.2
Refueling time	minute	6	15	408	10
Range	km	150	61.7	61.7	61.7

(a) Charging at stations

Figures in the column of ES1 in Table 2 denote the performance of relevant attributes for ES with batteries charged at stations. In this case, batteries belong to the scooter user, and the user has to pay NT$80 and spends 15min in average for each fast charging [21]. The operation cost is then estimated as NT$3.925/km. If the density of charging stations is the same as that of gas stations nowadays, the refueling cost can be calculated by following Equation (2).

(b) Charging at home

This is denoted as ES2 in Table 2. Most performance levels are the same as ES1 except for the operation cost and refueling time. Since ES is designed to fit household sockets, the operation cost for charging at home is down to NT$1.986/km under current electricity tariff of NT$2.5/degree. On the other hand, although the charging time takes about 6.8hr (408min) long in average [13], it assumes no extra cost to the user if considering the time is spent when this user is normally off work.

(c) Exchanging batteries at stations

In this exchange scheme (ES3), the company owns batteries for ES. It will take only 10min for ES users to replace and pay NT$60 for each exchange in a battery station [21]. Thus, the operation cost would reduce to NT$1.54/km under ECE47 driving mode [13]. The refueling cost is then calculated according to Equation (2).

Table 3 shows results of the whole life cost evaluation for PS and various conditions of ES. Columns under “B/C” are estimated benefits/costs for each alternative according to the scoring procedures described before. Values in columns of “Rel. B/C” are obtained by subtracting those of PS (the datum) from various ES schemes. Summing up these figures yields the total relative costs or benefits in the bottom row. They indicate the amounts of more cost to the customer for the whole lifetime if an ES is purchased instead of a PS.

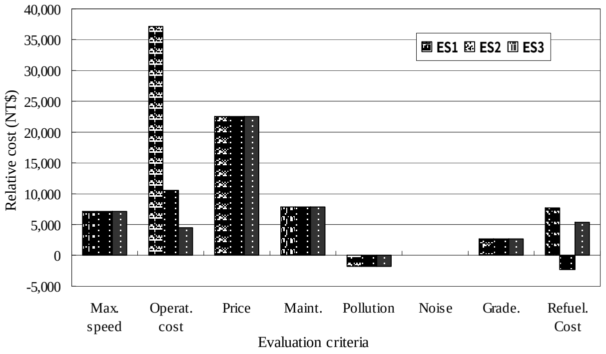

Figure 1. Profiles of evaluation criteria

Figure 1 is the profiles of relative costs or benefits for different ES schemes against all evaluation criteria. The signs of cost and benefit are reversed here for the ease of reading.

In the case of ES1, the operation cost and price are more significant than others, which show that they are the main sources of difference between ES and PS. On the other hand, air pollution and noise possess the least amount. This indicates that, though their reduction is beneficial to the whole society, they incur neither monetary benefit to ES users nor significant penalty to PS users under current situations. The true benefit of ES over PS on these issues can only be realized by more restricted policy of air pollution and noise by the government, or people’s awareness and willing to pay for the reduction.

For charging at home in ES2, the first two significant items are still price and operation cost. In particular, operation cost has dramatically reduced by the low household electricity price and becomes the second highest.

Price is still the most significant criterion in ES3. However, the second one becomes maintenance cost. There is no increase of maintenance cost, but with a further reduction of operation cost by not possessing batteries to the user.

Among all three schemes, the most favorite is charging at home (ES2) which has the lowest relative cost to PS. The second one is exchanging batteries (ES3), but difference between them is only NT$1,438 during the whole lifetime. The third one is charging at stations.

5. Further discussions

Except for the above variations, the government also subsidizes each ES purchaser a certain amount of money, depending on the achievement of ES models.

Table 3. A whole-life cost evaluation chart for scooters

Evaluation criteria	PS	ES1		ES2		ES3	
	B/C (+/-)	B/C (+/-)	Rel. B/C	B/C (+/-)	Rel. B/C	B/C (+/-)	Rel. B/C
Maximum speed	764	-6,300	-7,064	-6,300	-7,064	-6,300	-7,064
Operation cost	-16,619	-53,761	-37,142	-27,202	-10,583	-21,093	-4,474
Price	-36,000	-58,500	-22,500	-58,500	-22,500	-58,500	-22,500
Maintenance cost	-11,851	-19,747	-7,896	-19,747	-7,896	-19,747	-7,896
Air pollution	-1752	0	1752	0	1752	0	1752
Noise	0	0	0	0	0	0	0
Gradability	467	-2,265	-2,732	-2,265	-2,732	-2,265	-2,732
Refueling cost	-2,276	-10,043	-7,767	0	2,276	-7,547	-5,271
Sum	datum		-83,349		-46,747		-48,185

This essentially reduces the price of ES up to an average amount of NT$24,000 [13]. By taking this advantage into account, a summary of the total relative costs of ES to PS for all cases under investigation is presented in Table 4.

Table 4. Total relative costs for investigated cases

Cases	Total Rel. cost (ES-PS)	
	No subsidy	with subsidy
Charging at stations (ES1)	-83,349	-59,349
Charging at home (ES2)	-46,747	-22,747
Exchanging batteries (ES3)	-48,185	-24,185

According to this table, the most favorite condition of ES is charging at home with subsidy. This is due to the highest criterion of price is cut to a small amount by the subsidy. The remaining deficit is mainly from the operation and maintenance cost.

The second choice is exchanging batteries with subsidy. Differing little from the best solution, it could be a good substitute particularly in views of the convenience of refueling and difficulty of access to the ground floor socket in most urban areas. On the other hand, the worst case of ES is charging at stations without subsidy. This is because of its high operation cost, price, and maintenance cost.

Therefore, the deficit of using ES is mainly from the short range (affecting operation and refueling cost), price, battery maintenance (maintenance cost). Most of them can be attributed to the limitation of batteries. The improvement of battery technology is then the key to the survival of ES in the market.

The cost of gradability does not cause much trouble in the competition of ES with PS. This is out of expectation from the general public but consistent with comments by those who had experience in using ES both from Taiwan [12] and Japan [29].

ES is particularly reputed by its silence in operation. However, owing to the habit of using PS, people tend to be unaware of its power starting and passing by silently, and then feel a little unsafe [12,29].

In Table 3, costs of criteria on operation, maintenance, air pollution, and refueling are all dependent upon the length of lifetime. Differences between PS and ES on these issues will increase with the increase of scooter lifetime. The evaluation is then more complete by the ability of including the time factor in the process.

6. Conclusions

A whole-life cost-effective evaluation chart for various ES charging schemes has been devised for the selection of favorite policy on ES from the user's point of view.

According to the evaluation, the most favorite condition of using ES is found to be charging at home with subsidy. A good substitute of it is the exchanging scheme, and the worst case for ES is charging at stations without subsidy.

Those that have been in the first three significant criteria in the evaluation are price, operation cost, maintenance cost, and maximum speed.

Battery technology is the key to the competitiveness of ES, which affects significant criteria of operation cost, price, maintenance cost, and refueling cost.

Real benefits of air pollution and noise for ES depend on people's awareness and government regulations. In current status, the benefit of ES over PS on these issues is marginal.

Evaluation with the scoring procedures proposed in this project can reveal economic consequences to the relevant users, and incorporate the effect of lifetime into design considerations. More insights can then be acquired in the process of evaluation.

References

[1] Pahl, G. and Beitz, W., *Engineering Design*, The Design Council, London, 1988.

[2] Pugh, S., *Total Design*, Addison-Wesley, 1990.

[3] Sheldon, D.F., Perks, R., Jackson, M., Kiles, B.L. and Holland, J., *Designing for whole life costs at the concept stage*, J. of Engineering Design, 1(2), pp. 131-145, 1990.

[4] Kahne, S., *A procedure for optimizing development decisions*, Automatica, 11, pp. 261-269, 1975.

[5] Satty, T.L., *The Analytic Hierarchy Process*, McGraw-Hill, 1980.

[6] Baas, S.M. and Kwakernaak, H., *Rating and ranking of multi-aspect alternatives using fuzzy sets*, Automatica, 13, pp. 47-58, 1977.

[7] Suh, N.P., *The Principles of Design*, Oxford University Press, 1990.

[8] Cziulik, C. and Driscoll, J., *Conceptual design evaluation based on function metrics*, Proc. International Conference on Engineering Design, Tampere, Finland, pp. 411-416, 1997.

[9] Apgar, H.E. and Daschbach, J.M., *Analysis of design through parametric cost estimation techniques*, International Conference of Engineering Design, W. E. Eder, ASME, Boston, pp. 759-766, 1987.

[10] Sheldon D.F., Huang, G.Q. and Perks, R., *Design for cost: past experience and recent development*, J. of Engineering Design, 2(2), pp. 127-139, 1991.

[11] 於幼華，*台北市綜合發展計畫中有關公害防治問題之未來展望*，民國七十九年六月。

[12] 行政院環境保護署，*電動機車示範運行計畫 86 年 8 月－87 年 6 月研究報告*，民國八十七年六月。

[13] 行政院環境保護署，*發展電動車行動紀要*，民國八十五年。

[14] 陳光華，*輕型機車購買行為及行銷策略之研究*，中國文化大學企業管理研究所碩士論文，民國七十年六月。

[15] 謝振峰，*速克達機車的購買行為研究*，東吳大學管理學研究所碩士論文，民國八十年六月。

[16] 邱怡璋，*電動機車之潛在需求與敘述性偏好模糊修正模式之研究*，交通大學交通運輸研究所碩士論文，民國八十三年六月。

[17] 陳志民，*機車消費者購買行為之研究*，東海大學企管研究所碩士論文，民國八十四年六月。

[18] 馬台渝，*電動機車之市場需求及其對經濟、能源與環境影響之研究*，交通大學交通運輸研究所碩士論文，民國八十四年六月。

[19] 朱盈年，*聯合分析法在購買機車產品之應用研究*，大葉工學院事業經營研究所碩士論文，民國八十四年六月。

[20] 洪啟勝，*台灣中北部地區機車消費者購買行為之研究*，大葉工學院事業經營研究所碩士論文，民國八十五年六月。

[21] 張承邦，*電動機車使用特性與購買行為之研究*，交通大學交通運輸研究所碩士論文，民國八十六年六月。

[22] 交通部統計處，*台灣地區機車使用狀況調查報告*，民國八十七年六月。

[23] 摩托車雜誌社，*摩托車*，第 175 期，民國八十八年十二月。

[24] 台北市環境保護局，*台北市政府環境保護局年報*，民國八十八年。

[25] 游以德譯，*環境保護*，國立編譯館，民國七十八年。

[26] Bell, P. A., *Effects of noise and heat stress on primary and on subsidiary task performance,* Human Factors, Vol. 20, No.6, 1978.

[27] 行政院公平交易委員會，*八十七年七月加油站業市場結構調查結果提要分析*，公平交易季刊第七卷第三期，民國 88 年 7 月。

[28] 行政院勞工委員會統計處，*勞動統計指標-勞動條件*，民國八十九年。

[29] 財團法人日本電動車輛協會，*平成五年度電動機車試乘調查報告書*，平成六年三月。