# APPLICATION OF QFD FOR ENABLING ENVIRONMENTALLY CONSCIOUS DESIGN IN AN INDIAN ELECTRIC CAR MANUFACTURING ORGANIZATION

**Gopinath Rathod[1,a], S. Vinodh[2,b] and U. R. Madhyasta[3,c]**

[1]*Mechanical Engineering Department, Basaveshwar Engineering College, Bagalkot, India.*

[2]*Production Engineering Department, National Institute of Technology, Tiruchirappalli, India.*

[3]*Research and Development Department, REVA Electric Car Co. (P) Ltd, Bangalore, India.*
*Email: [a]gopinath.rathod@gmail.com, [b]vinodh_sekar82@yahoo.com, [c]urm@revaindia.com*

Increasing competition among the manufacturing organizations recognizes environmental consciousness as an important concept for surviving in the competitive world. Environmental friendliness has becoming the need of contemporary product design scenario. Many design tools are available for evaluating a product's impact on environment. Quality function deployment (QFD) is a tool that analyzes the functions of a product that could be used at early product development stage. A sustainable product will impart little impact on the environment during its life cycle. In this context, QFD for environment (QFDE) has been used in this research paper. QFDE consists of four phases. QFDE phases I and II are concerned with the identification of components that are focused on product design considering both environmental and traditional requirements. QFDE phases III and IV enables the design engineers to examine the possibility of design improvements for components and determining the improvement effect of design changes. This article reports a case study on the application of QFDE to components of electric car being manufactured by an Indian electric car manufacturing organization.

*Keywords:* Quality Function Deployment, Product design, Environmentally Conscious Quality Function Deployment, Design for environment.

## 1. INTRODUCTION

With growing awareness of environmental issues from global warming to local waste disposal, organizations and government face increasing pressure to reduce the environmental impacts involved in the production and consumption of goods and services. With the question of sustainable development posed as a key concern in developed societies and for all major organizations, the automotive industry is facing a new economic, technological and political environment [2]. Today, hybrid and electric vehicles are hit in the market because of the combination of engineering and environmental performance. Recently, resource optimization (energy and material) and environmental issues in the product development context are taken very seriously by both the general public and government agencies. These activities urge governments and companies alike to set up environmental friendly production technologies, which aim to avoid harmful emissions into air, water and soil [4]. However, these environmentally conscious designed products have not been achieved a favorable position in the marketplace as expected even though they appear to be more environmental friendly and economical. This may be due that they are focused solely on environmental impact analysis without regard for customer needs and technical requirements. Dr. Yoji Akao is regarded as the father of QFD who has contributed a widely used definition of QFD. QFD provides the means for translating the consumer

*Research into Design — Supporting Sustainable Product Development*. *Edited by* Amaresh Chakrabarti

ISBN: 978-981-08-7721-7

needs to appropriate technical requirements for each stage of a product/process development cycle [1]. It helps in the development of customer friendly and high quality products. QFD is an excellent management tool that enables the teams to focus on the needs of the customers for enabling product design. In this concern, quality function deployment for environment (QFDE) has been developed to aid a product design team in considering environmental concerns since QFD is a proven quality systems tool to achieve total customer satisfaction. Without QFDE, designers would not grasp the relation between requirements from environment and customers, and then are more likely to generate harmful side effects on customer requirements. In this context, QFDE has been applied to an electric vehicle in this research paper.

## 2. LITERATURE REVIEW

Zhang *et al.* [8] have introduced a new methodology Green Quality Function Deployment-II), for product development or improvement. They integrated LCC into QFD matrices and suggested the deployment of quality, environmental and cost requirements throughout the entire product development process to evaluate different product concepts. Masui *et al.* [5] have presented a novel methodology for applying QFD for environmentally conscious design in the early stage of product development. The authors have developed this methodology by incorporating environmental aspects into QFD to handle the environmental and traditional product quality requirements simultaneously. Kaebernick *et al.* [3] have presented the integration of environmental requirements into every single stage of product development from the very beginning, leading to a new paradigm for sustainable manufacturing. Byggeth and Hochschorner [2] have presented a concept of handling trade-offs in Eco-design tools for sustainable product development and procurement to prescribe design alternatives, assess environmental impacts or to compare environmental improvement alternatives. Rao [6] has presented three multiple attribute decision-making methods for evaluation of environmentally conscious manufacturing programs for producing a given product. Sakao [7] has proposed the application of quality engineering in the early phase of environmentally conscious design.

## 3. CASE STUDY

The application of QFD for enabling environmentally conscious design has been illustrated in this section.

### 3.1. About the case company

The case study was conducted in an Electrical Vehicle Manufacturing (EVM) organization located in Bangalore, Karnataka, India. EVM was established to manufacture environment-friendly and cost-effective electric vehicles.

### 3.2. Identification of Environmental voice-of-customer (VOC) and environmental engineering metrics (EM)

Gathering and analyzing the environmental VOCs is critically important in QFD in order to provide customer-oriented products. The environmental VOCs may come from a wide variety of sources, such as surveys, focus groups, interviews, trade shows, complaints, and even expert opinions. It is essential to capture the marketing needs from the customers' perspective. To further consider environmental EMs, the requirements of environmental EMs should be identified as well. To summarize environmental VOCs as well as environmental EMs systematically, a house-of-quality can be constructed. This section describes what kind of VOCs and EMs should be considered from the environmental point of view through a whole product life cycle, and integrates those environmental items into a set of feasible environmental VOCs and EMs, and their correlation factors. The voice of recyclers and government regulations are treated as environmental VOCs and were expressed by means of engineering terms as environmental EMs.

## 3.3. Identifying the target for design improvements

### 3.3.1. QFDE phase I

Phase I describes the application of QFD to the design of electric vehicle. Table 3.1. shows the deployment of VOC to EM. Generally VOC items are weighted based on a market survey to reveal the "customer weights". A rating of "9" indicates that it is very important, "3" indicates it is important and "1" indicates it is relatively important. The degree of importance of environmental VOC is dependent on the concept of product life cycle. The mapping points between VOC items and EM items are indicated by means of numbers indicating both factors called "relational strength" determined by the designer. Similar to the weighting of VOC item, "9" indicates a strong relationship, "3" indicates a medium relationship and "1" indicates certain strength. Here, at the mapping points between the environmental VOC items and environmental EM items, the values of relational strength are provided for the designer to enable decision making. The total of the sum multiplied by "customer weights" and "relational strength" is the "raw score" for each EM item. "Relative weight" for each item is obtained by dividing the raw score by the sum of the raw score.

### 3.3.2. QFDE phase II

Phase II is concerned with the deployment of EM items to product components. The relative importance of each product component is obtained in a similar manner as phase I. As shown in Table 4.1., it is found that "Battery charger,", "Energy Management System", "AC Motor" and "AC Motor Controller" are the important components.

## 3.4. Evaluation method of design improvement

In this section, a method to evaluate the effects of design changes for parts or components on environmental aspects are introduced in phases III and IV of QFDE.

### 3.4.1. QFDE phase III

In phase III, the effect of a set of design changes on EM items is estimated. In general, design engineers can make several alternative plans. There are two options for design engineers to decide their focus. One method originates from target VOC. Another method is examining the most important components

**Table 1.** QFDE Phase I of Electric vehicle.

| | Engineering Metrics | | | | | |
|---|---|---|---|---|---|---|
| | Customer weights | High torque AC induction motor | 350 Amp microprocessor based with regenerative braking | High frequency switch mode type battery charger | Microprocessor based battery management system | Power train performance |
| Easy to drive, Fully automatic drive (No clutch and no gear) | 3 | 3 | 3 | 3 | 9 | 9 |
| Easy to charge at home or office | 9 | | | 9 | 9 | |
| Less power consumption | 9 | 9 | 3 | 3 | 9 | 9 |
| Speed up to 80 Km/hr | 9 | 9 | 3 | | 3 | 9 |
| Better slope negotiation | 9 | | 3 | | 3 | 3 |
| **Raw Score** | | 171 | 90 | 117 | 243 | 216 |
| **Relative Weight** | | 0.204 | 0.107 | 0.139 | 0.290 | 0.258 |

**Table 2.** QFDE Phase II of Electric vehicle.

| | | Component Characteristics of Electric car | | | | | |
|---|---|---|---|---|---|---|---|
| Engineering Metrics | Phase I relative weight | AC motor | AC motor controller | Single reduction gear box | Battery pack | Battery charger | Energy Management System |
| High torque AC induction motor | 0.204 | 9 | | 3 | | | |
| 350 Amp microprocessor based with regenerative braking | 0.107 | | 9 | 3 | | | 3 |
| High frequency switch mode type battery charger | 0.139 | | | | 9 | 9 | 9 |
| Microprocessor based battery management system | 0.290 | | 3 | 3 | 9 | 9 | 9 |
| Power train performance | 0.258 | 9 | 9 | 3 | | 3 | |
| **Raw Score** | | 4.158 | 4.155 | 2.577 | 3.861 | 4.635 | 4.182 |
| **Relative Weight** | | 0.176 | 0.176 | 0.109 | 0.163 | 0.196 | 0.178 |

identified in phase II. Table 3 shows example of phase III. Here, priority has been assigned to the environmental aspects and the design improvement plan has been set mainly from the viewpoint of the environment. The two design options proposed with consideration of the results of Phase I and phase II include the following combinations of components and EMs.

Option I: AC motor controller should have 350 Amp microprocessor based with regenerative braking.
Battery pack should have a high frequency switch mode type battery charger.

Option II: Battery charger should be integrated with a microprocessor based battery management system.
Microprocessor based battery management system should operate in coordination with energy management system.

**Table 3.** QFDE Phase III of Electric vehicle for option I.

| | | Component Characteristics of Electric car | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Engineering Metrics | Phase I relative weight | AC motor | AC motor controller | Single reduction gear box | Battery pack | Battery charger | Energy Management System | Score | Improvement rate of EM |
| High torque AC induction motor | 0.204 | | | | | | | 0 | 0.00 |
| 350 Amp microprocessor based with regenerative braking | 0.107 | | 9 | | | | | 9 | 0.60 |
| High frequency switch mode type battery charger | 0.139 | | | | 9 | | | 9 | 0.33 |
| Microprocessor based battery management system | 0.290 | | | | | | 0 | 0 | 0.00 |
| Power train performance | 0.258 | | | | | | | 0 | 0.00 |

**Table 4.** QFDE Phase IV of Electric vehicle for option I.

| | Engineering Metrics | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Customer weights | High torque AC induction motor | 350 Amp micro-processor based with regenerative braking | High frequency switch mode type battery charger | Micro-processor based battery management system | Power train performance | Improvement rate of customer requirement | Improvement rate of customer requirement |
| Easy to drive, Fully automatic drive (No clutch and no gear) | 3 | 3 | 3 | 3 | 9 | 9 | 0.034 | 0.103 |
| Easy to charge at home or office | 9 | | | 9 | 9 | | 0.018 | 0.165 |
| Less power consumption | 9 | 9 | 3 | 3 | 9 | 9 | 0.009 | 0.0845 |
| Speed up to 80 Km/hr | 9 | 9 | 3 | | 3 | 9 | 0.008 | 0.075 |
| Better slope negotiation | 9 | | 3 | | 3 | 3 | 0.022 | 0.200 |
| Improvement rate of EM | | 0.00 | 0.60 | 0.33 | 0.00 | 0.00 | | **0.6275** |

**Table 5.** QFDE Phase IV of Electric vehicle for option II.

| | Engineering Metrics | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Customer weights | High torque AC induction motor | 350 Amp micro-processor based with regenerative braking | High frequency switch mode type battery charger | Micro-processor based battery management system | Power train performance | Improvement rate of customer requirement | Improvement rate of customer requirement |
| Easy to drive, Fully automatic drive (No clutch and no gear) | 3 | 3 | 3 | 3 | 9 | 9 | 0.060 | 0.181 |
| Easy to charge at home or office | 9 | | | 9 | 9 | | 0.030 | 0.272 |
| Less power consumption | 9 | 9 | 3 | 3 | 9 | 9 | 0.016 | 0.148 |
| Speed up to 80 Km/hr | 9 | 9 | 3 | | 3 | 9 | 0.007 | 0.068 |
| Better slope negotiation | 9 | | 3 | | 3 | 3 | 0.020 | 0.181 |
| Improvement rate of EM | | 0.00 | 0.00 | 0.00 | 0.545 | 0.00 | | **0.850** |

### 3.4.2. QFDE phase IV

The objective of phase IV is to translate the effect of design changes on EM into environmental quality requirements. A Tables 4 and 5 shows an example of phase IV for electric vehicle. In these tables, the value of customer weight and relational strength between VOC items and EM items are the same as shown in phase I (Table 3.1.). The improvement rate for EM items obtained in phase III are shown at the bottom of Tables 4 and 5.

## 3.5. Evaluation of design for environment options

The improvement effect for the VOCs with their weights was calculated for each design from environment perspective through phases III and IV. In this case study, the scores **0.6275** and **0.850** are obtained for options I and II, respectively and it has been concluded that *option II* is found to be the best for electric vehicle.

## 4. DISCUSSIONS

The options developed in this case study were the outcomes of phase II of QFDE. Option I lists the traditional design requirements for an electric vehicle by considering product performance as a key requirement. Option I is developed without considering the priority order of the result of phase II of QFDE where as option II is developed according to the priority order resulted from phase II of QFDE. Option II lists the environmentally conscious design requirements for an electrical vehicle by considering both product and environmental performance as a key requirements. Thus when evaluating the options I and II, option II found to be best for electric vehicle which is treated as a most important environmentally conscious design option. This case study presented QFDE as an important tool to identify the components that are focused on product design considering both environmental and traditional requirements and to examine the possibility of design improvements for components and determining the improvement effect of design changes in the early stage of product development. The limitations of QFDE are: generating concrete solutions totally depends on the designers in spite of some suggestions derived from Phases I and II; giving discrete numbers to two matrices. Future improvements include the application of QFDE to the stage of developing new products.

## 5. CONCLUSIONS

The introduction of environmental requirements into the product development process at all stages of a product's life enables the EMV to bring environmentally conscious electric vehicle. QFDE has been developed by incorporating environmental aspects (VOC and EM) into QFD to handle both environmental and traditional product quality requirements together to be used in the early stage of production design for enabling sustainability [5]. Design engineer can identify the components that should be given more importance in electric vehicle in order to make it more environmentally friendly by the help of QFDE phases I and II. QFDE phases III and IV were used to analyze which design changes among the formed design options of electric vehicle are most effective with regard to environmental improvement. The design options generated by QFDE enable the organization to bring environmentally conscious product.

## REFERENCES & ESSENTIAL BIBLIOGRAPHY

1. Akao, Y. and Mazur, G.A., "The leading edge in QFD: past, present and future", *International Journal of Quality & Reliability Management*, Vol. 20 No. 1, pp. 20–35, 2003.
2. Byggeth, S. and Hochschorner, E., "Handling trade-offs in Ecodesign tools for sustainable product development and procurement", *Journal of Cleaner Production*, Vol. 14 No. 15–16, pp. 1420–1430, 2006.
3. Kaebernick, H. Kara, S. and Sun, M., "Sustainable product development and manufacturing by considering environmental requirements", *Robotics and Computer Integrated Manufacturing*, Vol. 19 pp. 461–468, 2003.

4. Kuo, T. Wu and H. Shieh, J., "Integration of environmental considerations in quality function deployment by using fuzzy logic", *Expert Systems with Applications*, Vol. 36 No. 3, pp. 7148–7156, 2009.
5. Masui, K. Sakao, T. Kobayashi and M. Inaba, A., "Applying Quality Function Deployment to environmentally conscious design", *International Journal of Quality & Reliability Management*, Vol. 20 No. 1 pp. 90–106, 2003.
6. Rao, R.V., "Evaluation of environmentally conscious manufacturing programs using multiple attribute decision-making methods", *Journal of Engineering Manufacture*, Vol. 222(B) pp. 441–451, 2008.
7. Sakao, T., "A QFD-centered design methodology for environmentally conscious product design", *International Journal of Production Research*, Vol. 45 No. 18–19, pp. 4143–4162, 2007.
8. Zhang, Y. Wang, H. P. and Zhang, C., "Green QFD-II: a life cycle approach for environmentally conscious manufacturing by integrating LCA and LCC into QFD matrices", *International Journal of Production Research*, Vol. 37 No. 5, pp. 1075–10910, 1999.