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# The Role of Integration QFDVA in New Product Design to Achieve World-Class Manufacturing

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**A B S T R A C T**

In the competitive economy of today, those companies are to succeed that can design efficiently and produce productions that would be preferred by its customers over those of their competitors and Those companies which desire to find for their performance a position in world-class should have the capability to quickly, efficiently and effectively respond to changes in global markets. So plans must be come up with which may satisfy customers' needs and lead to high-quality products that can compete with other companies. This paper aims at developing the way we can use QFD(quality function deployment) and VA(value analysis) tools both theoretically and in case study. Out of Iranian cars, Pride was chosen because of quality drawbacks it suffers from and then the combining process of QFDVA was applied to its bodywork. Finally, the research hypothesis was analyzed by developing and distributing a questionnaire. SPSS software was used for analyzing the data. Combining QFD and VA in product design obviated one of the executive problems in QFD, *i.e*, inability of the latter in recognizing all customer needs. The optimal value of the features of product design can be assessed by using the above-mentioned tools. Assessment of these features provides for allocating resources optimally to the recognized functions. One other finding of the research is that using QFDVA in new product design (NPD) improves the competitive status of the company in relation to its competitors in global market through improving designing and, consequently, decreasing the cost, increasing the quality and boosting sales. This paper provides some information for car industry and has some implications for defeating the competitors in the competition-ridden market of today.

**Keywords:** *Quality Function Deployment, value analysis, combined QFDVA, World-Class.*

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## 1. Introduction

In the industrial world of today the competitiveness of markets, the collapse of trade borders, the globalization of economy and, last but not least, the rise in customer expectations and customer demands have led economic institutions to pay more attention to customer satisfaction. Customers' demands have made organizations search for the demands of their customers either their explicit or implicit demands or concentrate from the planning level up to the operative level on providing for those demands. On the other hand, On the other hand,

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the ability to quickly adapt to the changes in customer needs and market requirements characterizes the world-class producers. As a result, one of the basic capabilities they emphasize is product design and dispatching the new goods to their customers in a quicker and better way than their competitors do. An organization enjoying such capability tends to grow faster and be more profitable than its competitors [1]. So, in order for the organization to remain in competition and survive, particularly in this day and age, it should continuously be engaged in creating values for its customers. This is not possible unless the organization recognizes the less-valued functions of its products. There are two factors involved in determining the value of functions of the products or functions of each one of product components by the customer: the cost and the value of the function a particular component fulfills. It is, therefore, possible to improve the products of an organization by recognizing, along with other factors, the functions and their values which influence decision-making in designing the product. Designing in accordance with customer expectations entails a clear plan so that the product would have the capabilities it should and be offered in an equal, or lesser, price than those offered by competitors [2]. To achieve this goal, it is necessary to combine tools like QFD and VA.

## 2. Literature Review

***Quality Function Development***

Quality Function Development (QFD) is an important product development method, dedicated to translating client requirements into activities to develop products and services [3]. QFD was introduced in 1972 at the Kobe shipyard of Mitsubishi Heavy Industrial Ltd. [4]. The concept further evolved through an application by the Quality Motor Company and its suppliers as well as through extensive research by the Quality Function Development Research Committee of the Japan Society for Quality Control. Major automobile companies such as General Motors and Ford Motor Co. and manufacturing companies such as 3M, Hewlett-Packard, and Texas Instruments introduced QFD to American industry in the early 1980s. [5].

***Value Analysis***

Value analysis is a structured and multidisciplinary process which tries to achieve the best value with the least life-time cost by analyzing project’s function [6]. The concept of value engineering was first developed in 1947 in General Electric Company (GE). After World War II, there was a shortage of construction materials, specifically metals. Consequently, product designs were to be modified so that the products could be produced with new, alternative materials and simultaneously fulfill the same functions they had fulfilled before. A seminar on value analysis was held a few years later in 1952 in General Electric Company during which different sections of the company became acquainted with the purposes and requirements of value analytic studies. The basis of society of American Value Engineers was formed with 1500 members in the late 1950s. Other countries including Japan, France, Italy, England and India gradually learned about this community and its activities. In the early 1960s, after introducing incentive methods in utilizing value analysis, it was also employed in manufacturing industry too. In recent years, the emphasis was on expanding the use of value analysis at the earlier stages of project (feasibility, primary design and expanded design) as well as on systematizing the consulting services for value analysis. These days it is so important that applying value analysis in the process of project implementation has turned into a compulsory rule and there are incentives predicted for it in respective bylaws in most countries [7].

***World-Class Manufacturing***

International competitors in world market have a tendency to position their performance on a world-class level, which is defined by the capability to respond quickly, efficiently and effectively to changes in market [8]. Schonberger was the first person to use the term, world-class production, in 1982. Hall, however, stated in 1983 that world-class production was an organization’s different operational method to implement a set of techniques. In 1990, Giffi included quality and customer as the primary focus of world-class production. According to Giffi, world-class production is supported by an assortment of strategies, production facilities, management approaches, organizational factors, human assets, technology, and performance measurement [9]. Greene presented in 1991 a basic definition of the companies which manufacture world-class productions: world-class producers are those companies that continuously undertake the best industrial operation on world class, that which know well their customers and supporters and are aware of their weaknesses and strengths as well as those of their competitors [8]. Therefore, an organization can reach the world-class production position when it can successfully create production capabilities for helping the company reach a persistent competitive advantage in areas as diverse as costs, quality, goods delivery, flexibility and innovation. This kind of organizations tends to optimize their workforce, facilities and systems; they, therefore, continuously analyze various organizations all over the world to model their activities on for different purposes [1].

## 3. Problem Definition

With competition getting more intense, manufacturers have realized that costs are a major factor in production. In organizations facing this intense competition, the price of the product is permanently under the effect of the market so that the competitive price of today might well cease to be so in the near future [10]. Consequently, car manufacturing companies can improve on their competitive status by lowering costs and enhancing quality, focusing on car design, including its bodywork, and catering toand satisfying the demands of their customers. So far, a great many studies have been conducted to achieve these goals in various manufacturing companies. These studies have drawn on QFD as a tool that translates customer needs into design features. The tool lends an insight into the voice of customers by distributing questionnaires, doing interviews, assessing and handling customers’ complaint, and then links them to engineering features of the product. As a result, it improves the design and quality of the product and stresses satisfying the customers’ demands and enhancing their satisfaction [2]. There are, however, some problems regarding the application of QFD, the most important of which is the failure in taking heed of all customer requirements. This will lead to the producing of a product which does not satisfy all customer demands [11]. So ways should be sought for to tackle this issue. Cavalca and Dedini [11] introduced the combined

QFDVA which is used in this paper for tackling the problem and then the combining process of QFDVA was applied to pride bodywork.

## 4. Methodology

The methodology of this research is descriptive and it is a case study. Given the objective of the research which is to solve the issues surrounding the bodywork of Pride by applying the results of research, it is applied in nature. The research aims at improving a design and includes either confirming or rejecting a hypothesis. That is why inferential statistics was used for testing the hypotheses [12]. At first, Kolmogorov-Smirnov test was conducted to test the normality of data distribution, after approving which t-test was run for analyzing the research hypotheses. This research addresses the application of QFDVA tool to the designing of Pride's bodywork. The tool is used to determine the optimal value of each one of the engineering requirements and to evaluate each product function. Using this combined tool, therefore, one can produce a product in accordance with demands and needs of the customers and in a less expensive way [11].

## 5. Statistical Population and Sample

Since the opinion of experts is of great importance for QFDVA, the spatial scope of this research was the experts in the Center for Research and Innovation in Saipa Car Manufacturing Company and a group of customers who purchased Pride. The sample included 108 people. It should be noted that due to the specialized nature of the questions, the researcher was present to disambiguate the questions, if necessary, while customers were filling out the form.

## 6. Data Collection Tools

Given the issues above, two sets of data are needed for the present research, which we call data type I and data type II. The first type data was collected using field study and questionnaire methods (the latter having been distributed among a sample population). The second type was collected by using library research which includes library, magazines, journals, articles and dissertations as well as searching internet-based databases and consulting the documents on product standards. Similar cases and the recommendations of mentors were used in developing the questionnaire. The problems involved in this process were solved after submitting the questionnaire to some experts and obtaining their corrections on the questionnaire. Because of the specific structure and rationale questionnaires have, the researcher must be present when the experts read the questionnaire. This requirement rises from the necessity to elaborate on and disambiguate, if need be, the items in the questionnaire by the researcher.

## 7. Validity and Reliability

Validity refers to the fact that the questionnaire addresses and assesses the exact topic of research. Having been corrected by the designing experts in the Center for Research and

Innovation of Saipa Car Manufacturing Company and by the supervisor of the research, each one of the questionnaires was approved in terms of validity. The capacity of research tools to keep their reliability in time despite uncontrollable test conditions and the status of respondents indicated a minor mutability and a high stability. There is a variety of ways to test variability, the most effective of which is the calculation of Cronbach's alpha coefficient. The least acceptable value which indicates the reliability of research tools is 0.7. This value was estimated by SPSS. A questionnaire was designed to determine the relative importance of the recognized functions regarding Pride’s bodywork. The extent of importance customers place on each function is determined by using Mudge diagram and pair-wise comparison methods, an explanation of which came before the questionnaire. To prove the reliability of the questionnaire, Cronbach's alpha coefficient was calculated at 0.9815 which was larger than 0.7. This demonstrates that the questionnaire enjoys a plausible reliability. The next questionnaire was developed for creating a relationship matrix between the recognized functions and the features of product designing. Since the Cronbach's alpha was 0.9518 which is larger than 0.7, the reliability was proved. The last questionnaire was designed to help confirm or reject the hypotheses. This included 40 questions, 18 of which concerned the variable in the first sub-hypothesis, 7 were about the variable in the second sub-hypothesis and 15 concerned the third sub-hypothesis. These items were designed by using five-level Likert’s format (Strongly disagree, Disagree, neither agree nor disagree, Agree and strongly agree). In order to prove the reliability of questions, Cronbach’s alpha coefficients for each group of questions and for their entirety were estimated. The coefficients were 0.8614, 0.8381, 0.8574 and 0.8926 for the first group of questions (the first hypothesis), the second group (the second hypothesis), the third group (the third hypothesis) and the fourth group (the fourth hypothesis), respectively. These values indicate the high compatibility of data resulted from our questionnaire. They also signify that the questionnaire made for a high reliability of research.

## 8. Development of Combined QFDVA

Cavelca and Dedini [11] combined QFD and VA tools to produce QFDVA which is shown in Figure 1.

## 9. Theoretical Framework

The research proceeds thus:

1. Collecting primary data;
2. Putting together of the project team;
3. Collecting the explicit and implicit demands of customers, defining and categorizing the product functions;
4. Defining the scope of study;
5. Determining the relative importance of product functions;
6. Determining the engineering requirements;
7. Determining the relative costs of product functions;
8. Calculating the value index of the product;

9. Creating matrix of relationship between engineering requirements and product function;
10. Determining relative costs of customer needs;
11. Determining optimal costs of the engineering requirements;
12. Developing questionnaire on the basis of research hypothesis and then testing hypotheses

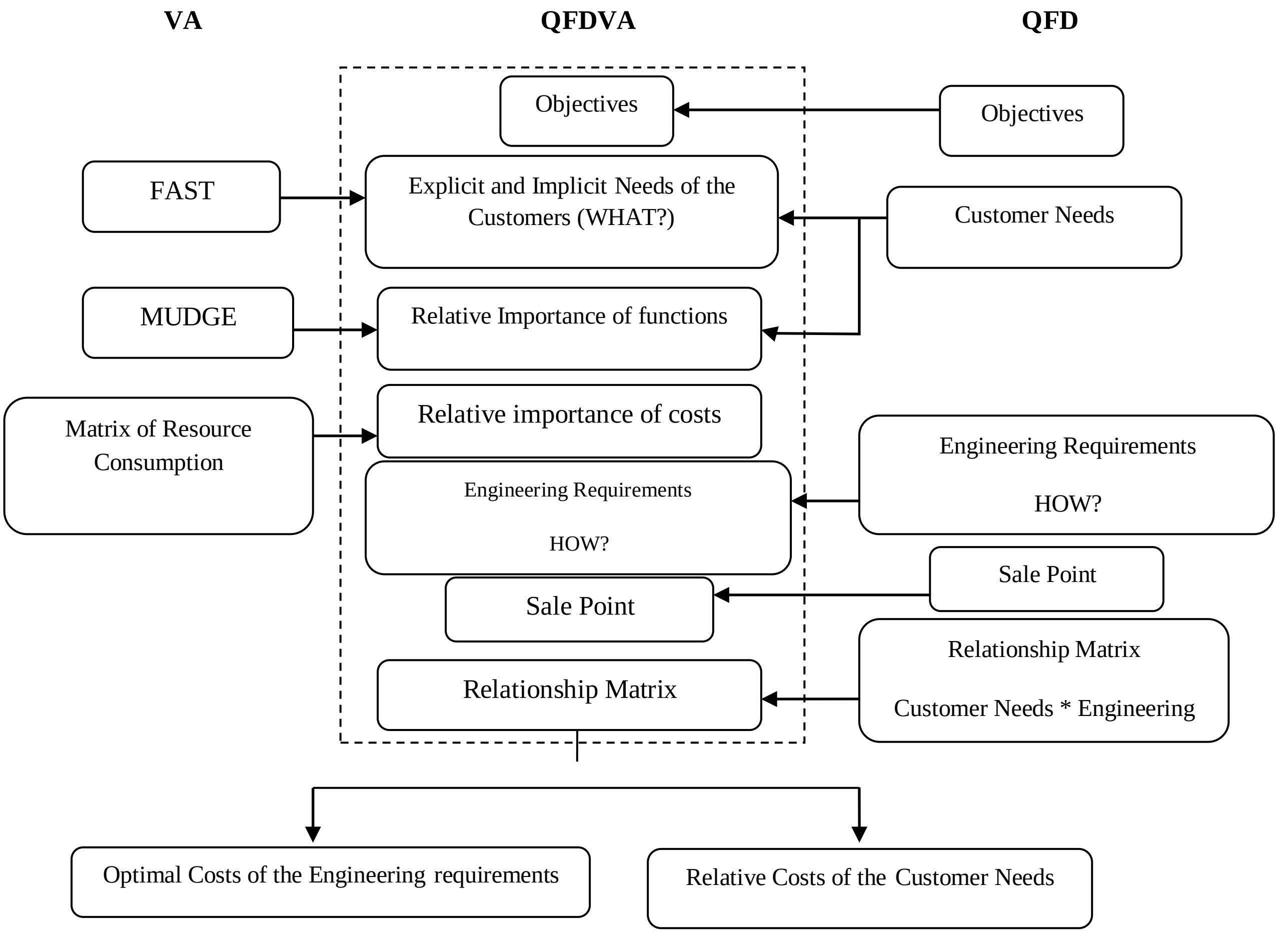


**Figure 1.** The composition of the QFDVA process [11]

## 10. Application of QFDVA to the Bodywork of PRIDE

***Stage 1: Collecting the Primary Data***

The bodywork of car is a pertinent issue in car beauty and its dynamic features. The bodywork, on the other hand, affects car's other features including its capacity, dimensions, weight, efficiency, fuel consumption and, finally, its price. In designing the bodywork, these parameters are kept in view: good appearance, resistance against corrosion, proper driver's view, high safety, reduction of wind noise, easy manufacturing, easy sale, low manufacturing expenses, desirable quality, being manufactured in a short time and meeting customer satisfaction [13]. The present research was conducted only on the bodywork design phase which included parts like the bumpers, windshield and mirrors. The vehicle under discussion was first produced in 1986 by Japan's Mazda car manufacturers under the name Mazda 121. The production lasted until 1993. In North America, Pride was promoted and distributed under the name Ford Festiva by Ford Company. Having been manufactured between 1987 and 2000 in South Korean Kia Motors, the car was transferred to Iran in 2001 to be manufactured by Saipa.

***Stage 2: Putting Together of the Project Team***

The project team is constituted of experts of car bodywork designers in the Center for Research and Innovation in Saipa Manufacturing Company. The team, composed of 19 people, conducts research by brainstorming.

***Stage 3: Collecting the Explicit and Implicit Demands of Customers, Defining and Categorizing the Product Functions***

A questionnaire in open format, aimed at customers, was used in this stage to collect the data about customer needs concerning bodywork design of Pride and to determine the point of sale. The function regarding the bodywork of the car was defined in view of the needs learned about in the polling. The relevant FAST diagram (Function Analysis System Technique) was drawn accordingly.

Drawing FAST diagram is regarded as the basis of function analysis stage. The first step in drawing such diagrams is to find the main function from among those defined in the previous stage. In developing it, a question is of great importance: "How do the main functions work?" Answer to this question is supposed to be one of the secondary functions. Therefore, a second function is inserted to the right hand of the main function, which indicates that the main function is the corollary of the second one. The question is asked in the following steps, albeit in a different way: this time the second function which had led to the main function comes under question. It is noteworthy that in answering the latter, it may be the case that the proper answer lies in one or more lower-level secondary functions. The question and the logical answer to it, therefore, lead to a multilayered function tree. The functional hierarchy proceeds down to the most basic functional levels in the area under study [14]. In the FAST diagram drawn for Pride(Figure2), the main function was improving the bodywork design of the bodywork which ranks higher than other functions. Secondary functions were defined on lower levels of research scope. The point of sale is an indication of the extent of customer satisfaction with each requirement. That is to say, for example, how the fulfillment of one requirement would satisfy the customer. To determine this extent, numbers 1 and 2 were used. Number 1 indicates that the fulfillment of the requirement in question does not have any effect on customer satisfaction. Larger values signify that the fulfillment of a certain requirement makes for more customer satisfaction. The ratio used in some sources is shown in the format of 1, 1.2, and 1.5 which indicates these, respectively:

1. The fulfillment of the pertinent requirement does not have an effect on customer satisfaction (like primary and basic needs).

2. The fulfillment of the pertinent requirement leads to customer satisfaction (like functional needs).
3. The fulfillment of the pertinent requirement leads to remarkable customer satisfaction (like evocative and emotive needs) [15].

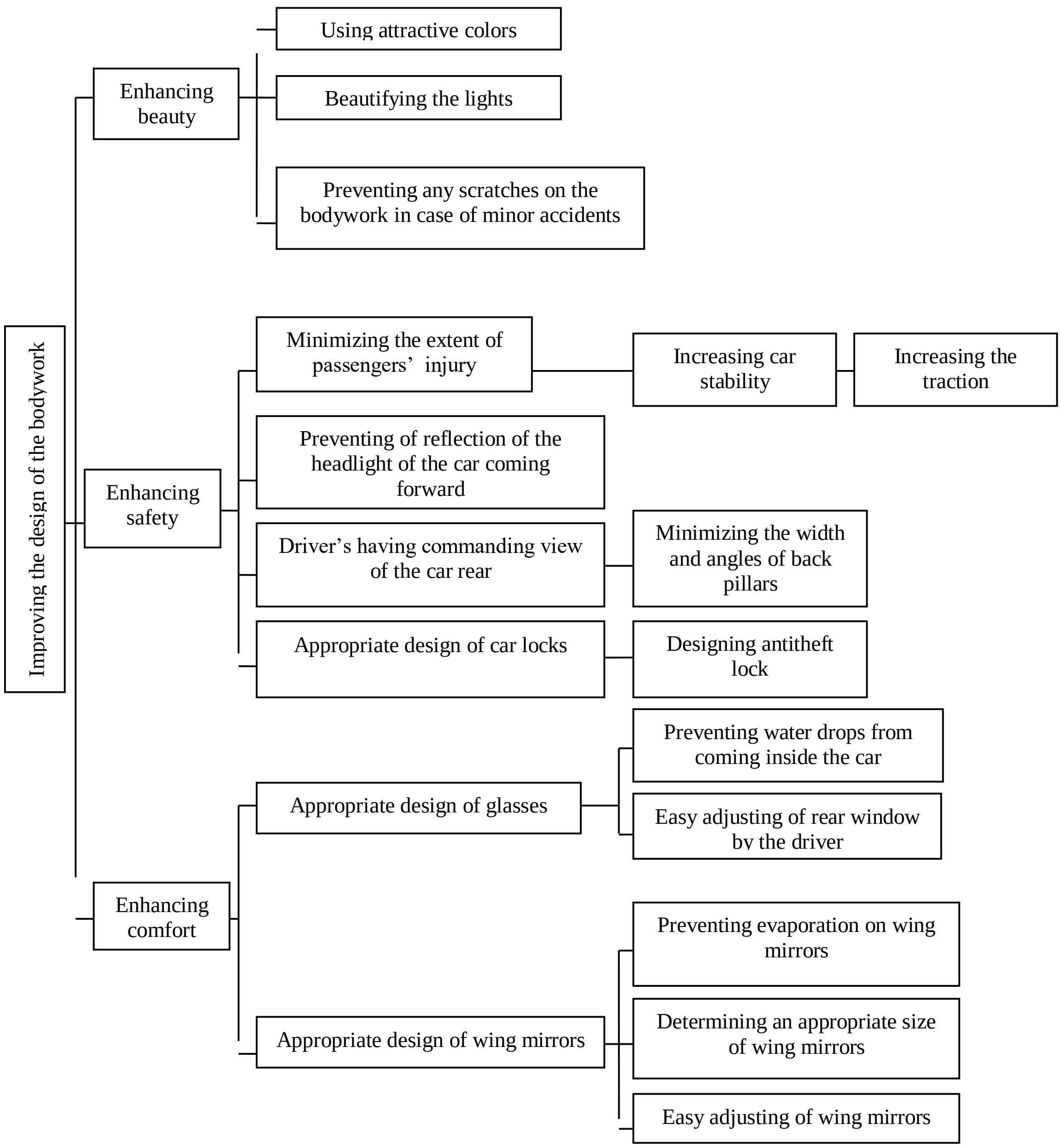


**Figure 2.** Fast diagram for the pride bodywork

***Stage 4: Defining the Scope of Study***

Drawing on FAST diagram, the scope of study was defined on the basis of the most appropriate functions regarding the car bodywork—those functions that would lead to any improvement in Pride's design, given time and budget limitations.

***Stage 5: Determining the Relative Importance of Product Functions***

Mudge method which is a pair-wise comparisons one was used in this stage to determine the relative importance of each function of the pride bodywork. This relative importance had been drawn in FAST diagram [11]. To determine the relative importance, a questionnaire was developed and distributed in the sample population. In the diagram, all combinations were compared in pairs and the score of each function was determined. A sample of completed Mudge diagram is shown in Figure3. Afterwards, a diagram for all median lines of completed diagrams is drawn (Figure 4). In comparing the functions in pairs if they enjoy the following conditions:

- They have the same importance
- They have meagre difference in their importance
- They have average difference in importance
- They have major difference in importance

Then the weights of 0, 1, 2 and 3 will be used for the mentioned comparisons. Afterwards, the sum of all weights is calculated for each function and is inserted into the sum column of each function. The importance of each function is determined in this way. In this method, the relative importance of each function can be calculated separately [11]. Each function includes one or more minor functions as well. Having determined the relative importance of the first level of functions regarding the bodywork and given the extent of importance determined for the first level function, the QFD/VA team was asked to establish the extent of priority for fulfilling each one of functions developed before. The final results of this priority- setting were inserted in the third column of the quality house of completed QFDVA.

***Stage 6: Determining the Engineering Requirements***

At this stage, the design and technical features to satisfy the needs of customers will be addressed. To do this, the features of design (with the recognized functions included) were determined, given the opinion of design team and brainstorming sessions. These features include:

1. Regarding the response to the function of increasing the beauty of the bodywork, these points were made:
    - Using fancy colours for the bodywork instead of usual water-based paint much in vogue currently.
    - Installing LED lights instead of the currently used ones on the product.
    - Designing new style for the lights to enhance the beauty of view.
    - Applying a lacquer coating over the paint to prevent scratch on the outer surface in case any minor accident happens.
2. Regarding the response to the function of higher traction, these points were made:
    - Using tyres with specific tread for increasing the contact of tyres with the earth, which makes for higher stability of car in sharp road turns.

- Installing a spoiler on the trunk.

3. Regarding the response to the function of preventing light reflection, this point was made:
   - Using layered safety glass produce by Nanotechnology which prevents the annoyance of driver's eye.
4. Regarding the response to having a commanding view of the rear, this point was made:
   - Minimizing the width and angles of the back pillars.
5. Regarding the response to an appropriate design of wing mirrors:
   - Installing automatic wing mirror for the easy handling by the driver.
   - Installing a defroster for preventing evaporation on glasses particularly in cold weather.
   - Designing mirrors in appropriate and standard size to provide a better view of car rear.
6. Regarding the response to the function of easy handling of the rear window by the driver, this point was made:
   - Installing an electrical elevator.
7. Regarding the response to the function of appropriate design of door locks, this point was made:
   - Designing and installing antitheft lock for enhancing driver's comfort and security
8. Regarding the response to the function of preventing water drops from coming in the car when windshield wipers work, this point was made:
   - Using hose on the wipe. Engineering requirements are inserted in the top part of the completed QFDVA(Figure 11)

***Stage 7: Determining the Relative Costs of Product Functions***

Having determined the relative importance of functions, the research now addresses their relative costs. To do this, the resource consumption matrix was drawn [11]. The devices relevant to, and fulfilling, each one of the recognized functions must be determined prior to drawing this matrix. These devices were recognized in the course of an interview with QFD/VA team in The Centre for Research and Innovation in Saipa Manufacturing Company. The average expenses needed for drawing the matrix of consumed resources were estimated during this meeting. The cost of each function and the price of functions are shown in percentage at the bottom of Figure 6.

***Stage 8: Calculating the Index Value of the Product***

From customer's perspective, value depends on product function and the price of other products available in the market, which is calculated thus:

$$\text{Value as defined by the customer} = \frac{\text{Function \%}}{\text{Price\%}} = \frac{\text{Desirability}}{\text{Price\%}} = \frac{\text{Importance of value}}{\text{Cost \%}} \quad (1)$$

| | | | | | | | | Total | % |
|---|---|---|---|---|---|---|---|---|---|
| A | $B_3$ | $C_3$ | 0 | $E_1$ | $F_2$ | $A_1$ | $H_2$ | 1 | 2/2 |
| | B | 0 | $B_2$ | $B_2$ | $B_2$ | $B_3$ | $B_2$ | 14 | 30/4 |
| | | C | $C_2$ | $C_2$ | $F_1$ | $C_2$ | $C_2$ | 11 | 23/9 |
| | | | D | $E_1$ | $F_2$ | $D_1$ | $H_1$ | 1 | 2/2 |
| | | | | E | $F_2$ | $G_1$ | 0 | 2 | 4/3 |
| | | | | | F | $F_2$ | $F_2$ | 11 | 23/9 |
| | | | | | | G | $H_2$ | 1 | 2/2 |
| | | | | | | | H | 5 | 10/9 |
| | | | | | | | | 46 | 100 |

**Figure 3.** A Mudge diagram completed by a member of sample population

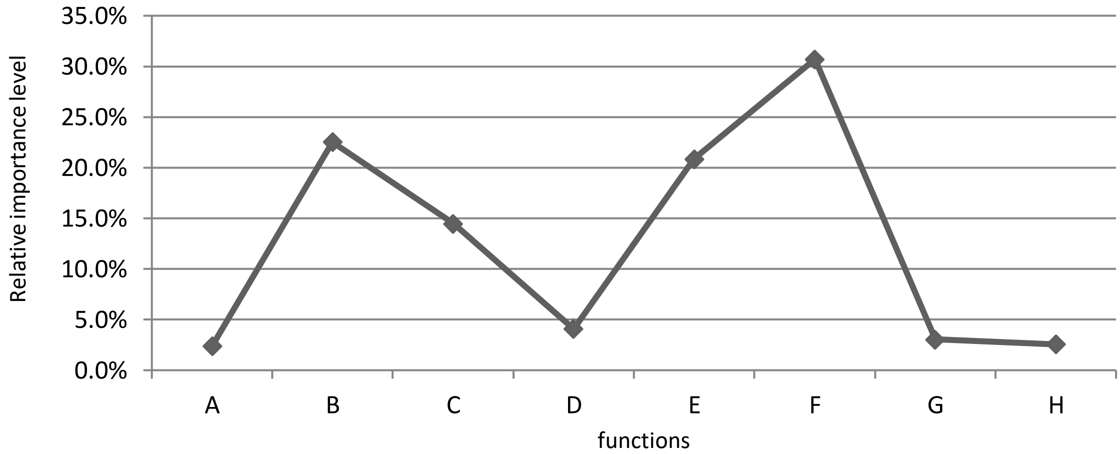


**Figure 4.** The median line of Mudge diagrams completed by all samples

| **Main function** | **First-level secondary functions** | **Second-level secondary functions** | **Relative importance level(%)** | |
|---|---|---|---|---|
| **Improving the design of the bodywork** | Enhancing the beauty of bodywork**(A)** | Using attractive colors | 2.4% | o.84% |
| | | Beautifying the lights | | 1.08% |
| | | Preventing any scratches on the bodywork in case of minor accidents | | 0.48% |
| | Minimizing the extent of passengers' injury**(B)** | Increasing car stability | 22.5% | 22.5% |
| | Preventing of reflection of the headlight of the car coming forward**(C)** | Preventing of reflection of the headlight of the car coming forward | 14.5% | 14.5% |
| | Driver's having a commanding view of the car rear**(D)** | Minimizing the width and angles of back pillars | 4.1% | 4.1% |
| | Appropriate design of wing mirrors**(E)** | Preventing evaporation on wing mirrors | 20.9% | 7.32% |
| | | Determining an appropriate size for wing mirrors | | 6.27% |
| | | Easy adjusting of wing mirror | | 7.32% |
| | Appropriate design of car locks**(F)** | Designing antitheft lock | 30.7% | 30.7% |
| | Easy adjusting of rear window by the driver**(G)** | Easy adjusting of rear window by the driver | 3.0% | 3.0% |
| | Preventing water drops from coming inside the car**(H)** | Preventing water drops from coming inside the car | 2.6% | 2.6% |

**Figure 5.** The relative importance of functions

Having determined the value of functions in the bodywork of Pride, the question rises as to which function must be singled out for making improvement on the structure and doing further research. If the functions amount up to just a few, the selection will be simpler and the possibility of improvement in all functions will increase. If not, improvement will be something unobtainable unless the best function is selected through a reliable index. Value index is the best touchstone for choosing functions for making improvement on. Therefore, those functions that attract less proportion of importance or involve high cost percentages are the best options. For example, those functions whose value is less than 1 are most likely to improve the whole value of the product [13]. The value index for Functions A to H is calculated in Figure 7 : out of the eight first-level secondary functions presented for the bodywork of Pride, function A, D and G might attract more attention of the manufacturer use to being less than 1 in value index. This would lead the manufacturer to find solutions to enhance the value index of those functions for enhancing the whole value of the product.

| Functions / Components | A | B | C | D | E | F | G | H | Total |
|---|---|---|---|---|---|---|---|---|---|
| LED headlights | 3.1$ | | | | | | | | 3.1$ |
| LED backlights | 3.1$ | | | | | | | | 3.1$ |
| Tires with specific treads | | 102$ | | | | | | | 102$ |
| Lights with new style | 14.3$ | | | | | | | | 14.3$ |
| Using fancy colors | 81.6$ | | | | | | | | 81.6$ |
| Electrical elevator for the backdoor glasses | | | | | | | 18.4$ | | 18.4$ |
| Pillars with new style | | | | 81.6$ | | | | | 81.6$ |
| Installing a spoiler on trunk | | 16.3$ | | | | | | | 16.3$ |
| Antitheft lock | | | | | | 14.3$ | | | 14.3$ |
| Layered safety glass produce by Nanotechnology | | | 40.8$ | | | | | | 40.8$ |
| Installing electrical wing mirror | | | | | 12.2$ | | | | 12.2$ |
| Wing mirrors with standard size | | | | | 3.1$ | | | | 3.1$ |
| Using defroster | | | | | 8.2$ | | | | 8.2$ |
| Using hose on the windshield wipers | | | | | | | | 1.2$ | 1.2$ |
| Applying lacquer cover | 204$ | | | | | | | | 204$ |
| Total | 306.1$ | 118.3$ | 40.8$ | 81.6$ | 23.5$ | 14.3$ | 18.4$ | 1.2$ | 604.2$ |
| **Relative importance of costs** (%) | 50.66 | 19.59 | 6.75 | 13.51 | 3.88 | 2.36 | 3.05 | 0.2 | 100 |

**Figure 6.** Resource consumption matrix

***Stage 9: Creating Relationship Matrix between Engineering Requirements and Product Functions***

At this stage, the extent of effect each one of the design requirements has on functions pertaining to the bodywork of the car is determined by distributing a questionnaire. 1, 3 and 5 are used for showing the extent of relation among the designing features and car functions. Here 1, 3, 5 and empty box indicate weak relationship, medium strength relationship and strong relationship, respectively [11]. Finding of this stage is inserted in the middle part of QFDVA matrix (Figure 11).

***Stage 10: Determining Relative Costs of Customer Needs***

The following equation was used at this stage to calculate the relative optimal value of customer needs [11]:

$$\mathrm{Requirement}_i = \left(\sum_{j=1}^{n} M(i,j)\right).\mathrm{PV}_{(i)}\ .\mathrm{IR}_{(i)} \quad (2)$$

Where:

M is the relationship matrix

IR is the relative importance (%) of function (first column of consumer importance in Figure)

PV is the scale point (Figure 11)

The calculations done at this stage are inserted in the right hand of quality house of QFDVA (Figure 11). It is noteworthy that the diagram of relative optimal value of customer needs was drawn by the help of the results of this stage (Figure 9).

| First-level secondary functions | Relative Importance of functions | Relative importance of costs | Value index from customer perspective |
|---|---|---|---|
| Enhancing the beauty of bodywork**(A)** | 2.4% | 50.66% | 0.047 |
| Minimizing the extent of passengers' injury**(B)** | 22.5% | 19.59% | 1.148 |
| Preventing of reflection of the headlight of the car coming forward**(C)** | 14.5% | 6.75% | 2.148 |
| Driver's having a commanding view of the car rear**(D)** | 4.1% | 13.51% | 0.303 |
| Appropriate design of wing mirrors**(E)** | 20.95 | 3.88% | 5.386 |
| Appropriate design of car locks**(F)** | 30.7% | 2.36% | 13.008 |
| Easy adjusting of rear window by the driver**(G)** | 3.0% | 3.05% | 0.984 |
| Preventing water drops from coming inside the car**(H)** | 2.6% | 0.20% | 13.00 |

**Figure 7.** The value index of functions

| Customer needs | Sum of ith row in the relationship matrix | Sale point | Relative importance level of functions | *Optimal relative costs of customer needs* | Mode(%) |
|---|---|---|---|---|---|
| Using attractive colors | 8 | 1.2 | 0.0084 | 0.081 | 0.94 |
| Beautifying the lights | 10 | 1.5 | 0.0108 | 0.162 | 1.89 |
| preventing any scratches on the bodywork in case of minor accidents | 8 | 1.5 | 0.0048 | 0.0576 | 0.67 |
| Increasing car stability | 10 | 1.5 | 0.225 | 3.375 | 27.64 |
| Preventing of reflection of the headlight of the car coming forward | 7 | 1.5 | 0.145 | 1.5225 | 17.72 |
| Minimizing the width and angles of back pillars | 5 | 1.5 | 0.041 | 0.3075 | 3.58 |
| Preventing evaporation on wing mirrors | 5 | 1.5 | 0.0732 | 0.549 | 6.39 |
| Determining an appropriate size for wing mirrors | 5 | 1.2 | 0.0267 | 0.3762 | 4.38 |
| Easy adjusting of wing mirror | 5 | 1.5 | 0.0732 | 0.549 | 6.39 |
| Designing antitheft lock | 5 | 1.5 | 0.307 | 2.3025 | 26.80 |
| Easy adjusting of rear window by the driver | 5 | 1.2 | 0.03 | 0.18 | 2.09 |
| Preventing water drops from coming inside the car | 5 | 1 | 0.026 | 0.13 | 1.51 |
| Total | | | | 8.592 | 100 |

***Stage 11: Determining Optimal Costs of the Design Requirements***

At this stage, the relative optimal value of each design feature of car bodywork was evaluated given the relative importance of function values and the matrix of relationships. The equation is as follows [11]:

$\text{Engineering Cost}_j = \left(\sum_{i=1}^{n} M(i,j)\right).IRC_i$ (3)

Where:

M is the relationship matrix

IR is the relative importance of the cost for function (second column of consumer importance in Figure 11.

**Figure 8.** The relative optimal value of customer needs

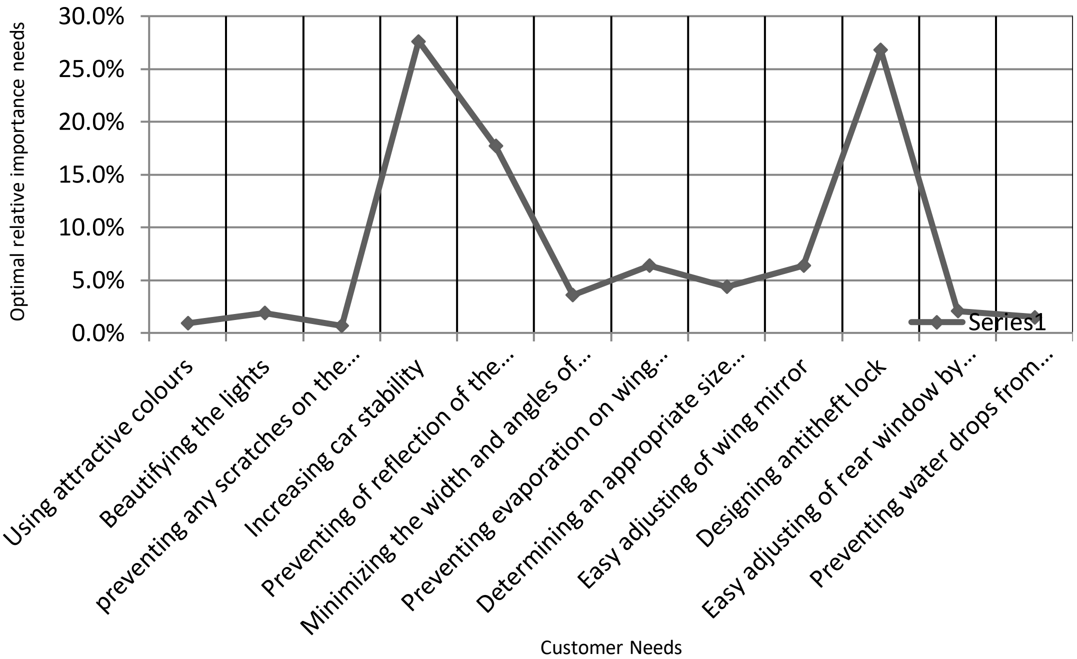


**Figure 9.** Importance of the customer needs

The diagram of relative value of engineering requirements was drawn by the help of the results of this stage (Figure 10). Having determined the optimal value of designing requirements of the bodywork, information was provided in the form of feedback for the optimal allocation of resources to functions and devices and for proper investment. The quality house of completed QFDVA is shown in Figure 11.

***Stage12: Developing Questionnaire on The Basis of Research Hypotheses, Doing Calculations, Statistical Analysis and the Analysis of Hypothesis***

Every manufacturing company can gain competitive advantage in face of its competitors in global markets through concentrating on one of the factors including decreasing costs, increasing product quality, innovation, flexibility, etc. The present research aimed at demonstrating how Saipa Manufacturing Company can improve on the product quality, decrease the costs and consequently increase the sale and reach a better competitive status over its competitors in world-class. To show these, a hypothesis and three sub-hypotheses were developed:

The main hypothesis: The application of QFDVA tool in product design leads to a superior competitive status in world-class.

Sub-hypothesis A: The application of QFDVA tool in product design leads to an enhancement in product quality.

Sub-hypothesis B: The application of QFDVA tool in product design leads to an increase in sale.

Sub-hypothesis C: The application of QFDVA tool in product design leads to a decrease in costs.

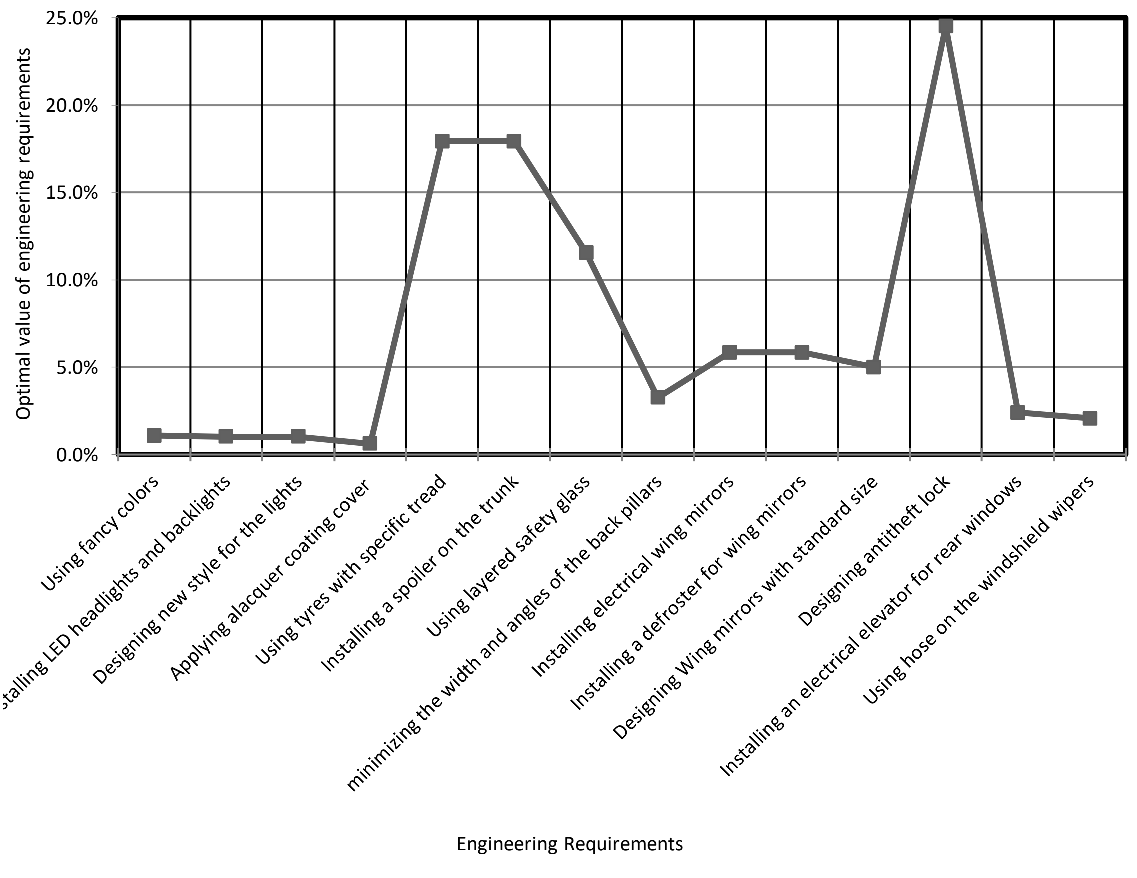


**Figure 10.** Optimal costs of the engineering requirements

| | Using attractive colors | Beautifying the lights | Preventing any scratches on the bodywork in case of minor accidents | Increasing car stability | Preventing of reflection of the headlight of the car coming forward | Minimizing the width and angles of back pillars | Preventing evaporation on wing mirrors | Determining an appropriate size for wing mirrors | Easy adjusting of wing mirror | Designing antitheft lock | Easy adjusting of rear window by the driver | Preventing water drops from coming inside the car | | Weight | Mode (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mode (%) | 0.94 | 1.89 | 0.67 | 27.6 | 17.7 | 3.58 | 6.39 | 4.38 | 6.39 | 26.8 | 2.09 | 1.51 | 100 | | |
| Weight | 0.081 | 0.162 | 0.058 | 3.375 | 1.523 | 0.308 | 0.549 | 0.376 | 0.549 | 2.303 | 0.18 | 0.13 | 8.592 | | |
| Sale point | 1.2 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.2 | 1.5 | 1.5 | 1.2 | 1.0 | | | |
| Total | 8 | 10 | 8 | 10 | 7 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 78 | 6.276 | 100 |
| Using hose on the windshield wipers | | | | | | | | | | | | 5 | 5 | 0.130 | 2.071 |
| Installing an electrical elevator for rear windows | | | | | | | | | | | 5 | | 5 | 0.150 | 2.390 |
| Designing antitheft lock | | | | | | | | | | 5 | | | 5 | 1.536 | 24.459 |
| Designing Wing mirrors with standard size | | | | | | | | 5 | | | | | 5 | 0.3136 | 4.995 |
| Installing a defroster for wing mirrors | | | | | | | 5 | | | | | | 5 | 0.3660 | 5.832 |
| Installing electrical wing mirrors | | | | | | | | | 5 | | | | 5 | 0.366 | 5.832 |
| width and minimizing the angles of the back pillars | | | | | | 5 | | | | | | | 5 | 0.2050 | 3.267 |
| Using layered safety glass produce by Nanotechnology | | | | | 5 | | | | | | | | 5 | 0.7250 | 11.552 |
| Installing a spoiler on the trunk | | | | 5 | | | | | | | | | 5 | 1.1250 | 17.926 |
| Using tyres with specific tread | | | | 5 | | | | | | | | | 5 | 1.1250 | 17..926 |
| Applying a lacquer coating cover | 3 | | 5 | | | | | | | | | | 8 | 0.0384 | 0.612 |
| Designing new style for the lights | | 5 | | | 1 | | | | | | | | 6 | 0.0648 | 1.033 |
| Installing LED headlights and backlights | | 5 | | | 1 | | | | | | | | 6 | 0.0648 | 1.033 |
| Using fancy colors | 5 | | 3 | | | | | | | | | | 8 | 0.0672 | 1.071 |
| Customer importance (%) | %0.84 | %1.08 | %0.48 | %22.5 | %14.5 | %4.1 | %7.32 | %6.27 | %7..32 | %30.7 | %3.0 | %2.6 | Total | Weight | Mode (%) |
| | | %2.4 | | %22.5 | %14.5 | %4.1 | | %20.9 | | %30.7 | %3.0 | %2.6 | | | |
| | | A | | B | C | D | | E | | F | G | H | | | |

**Figure 11.** The quality house of completed QFDVA for pride

***The Results of Kolmogrov-Smirnov Test for Sub-Hypothesis A***

Firstly, to find out if data collected by questionnaire has normal distribution, Kolmogrov-Smirnov test is used. This test is run to investigate the claim regarding the distribution of data of a quantitative variable [12]. The statistical assumptions are proposed this way:

***H0:*** Data distribution is normal ***H1:*** Data distribution is not normal

Since the significant value is 0.396 and is larger than 5 percent, H0 is confirmed and the claim of data distribution normality regarding the variable of sub-hypothesis A is accepted.

***T-Test for Sub-Hypothesis A***

The statistical assumptions in sub-hypothesis A are:

$\mathrm{H}_0 = \mu \geq 3$ $\mathrm{H}_1 = \mu < 3$

Where $\mu$ indicates the mean of variable (Quality) in sub-hypothesis A. Since the questionnaire makes use of Likert scale, in running t-test in SPSS, the test value is taken to be equal to the mean of 1 to 5, i.e. 3. The results of t-test are shown in the form of two outputs ($\propto = 0.05$)

| | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| mean1 | 108 | 4.3903 | .17211 | .01656 |

**Figure 12.** Descriptive statistics of the variable in sub-hypothesis A

| | Test Value = 3 | | | | | |
|---|---|---|---|---|---|---|
| | T | Df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| mean1 | 83.947 | 107 | .000 | 1.39031 | 1.3575 | 1.4231 |

**Figure 13.** The results of t-test for the data of hypothesis A

Given the results of the descriptive test which calculated the mean at 4.3903 that is larger than 3, it is obvious that most respondents who answered the questions regarding the variable of sub-hypothesis A mostly opted for "strongly agree". The standard deviation turned out to be 0.17211 which is an indication of this variable's low scatter. This, however, should be proved by inferential statistics (assumption test or confidence interval).

In the table above, the value of statistic t is 83.947 and degree of freedom 107. As SPSS can test equivalence claim only in terms of significance, to make judgments about claims in terms of $\leq$or $\geq$, high and low limits must be used [12]. In the t-test above, the high limit is 1.4231 and the low 1.3575, both of which are positive. It can be concluded that the mean is larger than 3. Moreover, the average difference of sample from the value under test is 1.39031 (($\bar{x} - \mu = 1.39031$). The 95 percent confidence distance between the two is 4.3575 and 4.4231. Based on these values, the confidence interval for "the population mean" may be written thus:

$$1.3575 \leq \mu - 3 \leq 1.4231 \rightarrow 4.3575 \leq \mu \leq 4.4231$$

Therefore, the null assumption H0: $\mu \geq 3$ is proved and the alternative assumption is rejected. That is to say, on the level of 95 percent confidence, the application of QFDVA to product design causes an increase in quality.

***The Results of Kolmogrov-Smirnov Test for Sub-Hypothesis B***

The statistical assumptions of Kolmogrov-Smirnov test for sub-hypothesis B are:

***H0:*** Data distribution is normal ***H1:*** Data distribution is not normal

Since the significant value is 0.076 and is more than 5 percent, H is confirmed and the claim to the normality of data distribution in the variable of sub-hypothesis B is accepted.

***T-Test of Sub-Hypothesis B***

The statistical assumptions in sub-hypothesis B are:

$H_0 = \mu \geq 3$ $H_1 = \mu < 3$

The results of t-test are shown in the form of two outputs ($\propto = 0.05$). Where $\mu$ indicates the mean of variable (Sale) in sub-hypothesis B.

| | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| mean2 | 108 | 4.4202 | .28216 | .02715 |

**Figure 14.** Descriptive statistics of the variable in sub-hypothesis B

| | Test Value = 3 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| mean2 | 52.308 | 107 | .000 | 1.42019 | 1.3664 | 1.4740 |

**Figure 15.** The results of t-test for the data of hypothesis B

Given the results of the descriptive test which calculated the mean at 4.4202 that is larger than 3, it is obvious that most respondents who answered the questions regarding the variable of sub-hypothesis B mostly opted for "strongly agree". The standard deviation turned out to be 0.28216 which is an indication of this variable's low scatter. This, however, should be proved by inferential statistics. In the second output, the value of statistic t is 52.308 and degree of freedom 107. In the t-test above, the high limit is 1.4740 and the low 1.3664, both of which are positive. It can be concluded that the mean is larger than 3. Confidence interval for the mean of the population can be obtained by using the method implemented in hypothesis A:

$$1.3664 \leq \mu - 3 \leq 1.4740 \rightarrow 4.3664 \leq \mu \leq 4.4740$$

Therefore, on the confidence level of 95%, the null assumption H0 is proved and the alternative assumption is rejected. That is to say, on the level of 95 percent confidence, the application of QFDVA to product design causes an increase in sale.

***The Results of Kolmogrov-Smirnov Test for Sub-Hypothesis C***

The statistical assumptions of Kolmogrov-Smirnov test for sub-hypothesis C are:

***H0:*** Data distribution is normal ***H1:*** Data distribution is not normal

Since the significant value is 0.478 and is more than 5 percent, H is confirmed and the claim to the normality of data distribution in the variable of sub-hypothesis C is accepted.

***T-Test of Sub-Hypothesis C***

Statistical assumptions (H1 and H0) for sub-hypothesis C are as follows:

$H_0 = \mu \geq 3$ $H_1 = \mu < 3$

The two outputs on the next page show the results of descriptive and inferential statistics obtained by using SPSS ($\propto = 0.05$).

| | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| mean3 | 108 | 4.4068 | .19290 | .01856 |

**Figure 16.** Descriptive statistics of the variable in sub-hypothesis C

| | Test Value = 3 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| mean3 | 75.789 | 107 | .000 | 1.40677 | 1.3700 | 1.4436 |

**Figure 17.** The results of t-test for the data of hypothesis C

Given the descriptive statistics, the mean value of sample is 4.4068 which are larger than value considered (3). It indicates that most respondents marked “Strongly agree” in the pertinent questions. Since standard deviation is 0.19290, it can be concluded that the variable in sub-hypothesis C has fairly low scatter—a point which needs further confirmation by inferential statistics. Since the claim is not in the form of an equation, the low and high limit obtained in the second output is used for either supporting or rejecting the claim. The high limit and low limit are 1.4436 and 1.3700, respectively, both of which are positive. The mean of sample, therefore, is larger than 3, which leads to the confirming of the claim. Further, the confidence interval is as follows:

$$1.3700 \leq \mu - 3 \leq 1.4436 \rightarrow 4.3700 \leq \mu \leq 4.4436$$

Given the results, then, it can be concluded that H0 is supported and the other one is rejected. Moreover, on the confidence level of 95 percent, it is safe to state that the application of QFDVA in product design leads to lessening costs. Given the three sub-hypotheses A, B and C, it can be concluded that the main research hypothesis is supported. That is to say, on the confidence level of 95 percent, it can be stated: "The application of QFDVA tool in product designing causes the product to reach a better competitive status in world-class".

## 11. Conclusions

Today all managers desire to have dynamic and flexible organizations which keep abreast of the rapid changes in the global markets. That is to say, they have to lessen the expenses to an extent that they can compete with, and resist, whatever price their competitors set for their products and be so innovation-driven that their goods and services would enjoy novelty, providing services in the best quality possible. The managers, therefore, must use some techniques like QFD to achieve their ends, i.e., the highest quality and value analysis for decreasing costs. Applying QFD and VA tools simultaneously, the present research elaborated on each one of the tools separately and jointly, both theoretically and in case study, to enhance the capacity and overcome their weaknesses. QFD ensures that the product is properly designed and VA ensures that the proper designing is undertaken in the best way possible (involving the least expenses). Since there are so many commonalities between the two methods, assimilating them will lead to their cross-fertilization. The most important question brought up when designing a proper product is "What is the best way to allocate resources to maximizing customer satisfaction?" Answer to this question is manifold in aspect which QFDVA undertakes the best. All in all, the purpose of QFDVA method is to recognize and cater for all explicit or implicit customer needs and also to allocate resources properly so that the value customers think of increase and production costs decrease. This will lead in turn to more profitability. Furthermore, given that the hypotheses were confirmed, the application of combined QFDVA tool in new product designs results in success and in a better competitive advantage in relation to the competitors in the world-class. This success is a result of enhancing quality, lessening costs and increasing sales.

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