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QUALITY AND RELIABILITY CORNER

Combined application of QFD and VA tools in the product design process

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Abstract *The aim of both value analysis (VA) and quality function deployment (QFD) is to reduce waste by avoiding redesign and providing optimal location of costs in general. To satisfy the consumer's most important needs, the VA prioritizes the increase in the cost of the product and not the subsequent price rise. QFD aims at generating clear engineering needs from consumer requirements thus, minimizing the reprojecting cost ("cost" should read "waste") and changes in the products. The existing common concepts between two design tools, QFD (the project tool) and VA (the product optimization tool) motivated this study. QFD establishes a link among parameters such as the consumer needs, engineering requirements and a comparative analysis of the consumer perception against that of rival companies. The VA prioritizes a rise in the aggregate value (perceived by the consumer) by optimization development and production costs. The proposed methodology is capable of integrating these two tools, integrating costs with product development ("for the consumer") for a joint analysis. This way it is possible to establish optimum cost values for each engineering requirement. It is also possible to evaluate the cost of each product function. Furthermore, the methodology provides a tool that supports decision making in product development and projects. This work evaluates the integrated use of the QFD and VA tools. Employing a survey that was carried out which intended to reveal the young male consumers' requirements concerning a sports bicycle.*

1. Introduction

The development of products for consumers requires a project or design that can identify the key benefits for consumers, the competitiveness of the product in question when compared with other market products, the development of the physical product itself, the marketing strategy involved, and a policy aimed at satisfying the key benefits. The process described above is called the core benefit proposition (CBP). The CBP states that a product is only worth manufacturing if it offers the same or even more benefits than its rival product (Hauser, 1993). The design process that develops the CBP is a conceptualized representation of the key decisions. Thus the team work should rely on it to make sure that the CBP does reveal the needs of the consumer. The design process studies the consumer's behavior acknowledging that the consumer's

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choice of a product depends on his perception and on the implicit benefits that attract him/her.

In order to reach the objectives mentioned above, some design tools can be combined and applied, such as quality function deployment (QFD) and value analysis (VA). QFD process quantifies customer explicit and implicit needs, relating them with engineering requirements. On the other hand, VA process establishes an optimal allocation of resources according to the importance level of product functions.

By the combined application of QFD and VA, here named QFDVA, it is possible to establish optimum cost values for each engineering requirement. It is also possible to evaluate the cost of each product function. Furthermore, the methodology provides a tool that supports decision making in product development and projects and enhance value of products.

Although this paper utilizes relevant statistical data, the application of this new tool prevails from statistical formality. The sequence of this paper presents the steps in which this method is based on.

2. Methodology development

2.1. Qualitative measures

Qualitative measures are rooted in the consumer's view point. Their role is not to identify the best strategy; on the contrary, qualitative measures raise questions about basic needs of consumers and their desires. As a result of that, decisions concerning products should be taken by open-minded people who are willing to listen to and learn from consumer (Hauser, 1993).

Therefore, it is important to carry out an exhaustive survey that covers all nuances and potential benefits. Qualitative surveys do not lead to any conclusive results, but they can be appropriated techniques when it comes to ensuring that the quantitative measure represent significant questions for the project development.

Herein, a group interview plan and a questionnaire are presented. They will serve as guidelines for the qualitative interview. Even though the questionnaire is not given directly to the interviewee, it is thoroughly filled in by the interviewer. The most common qualitative survey method used in industries is the group interview (Hauser, 1993). The method analyses three or four groups that are made up of three to four people. Each group discusses every aspect of a particular product. However, care should be taken not to allow the groups to be influenced by pre-conceived opinions, nor should its member's creativity and freedom of expression be affected Hauser (1993), Mitra (1998), Machado (1997). The interviews evaluated three groups of three individuals each. The interview took place from 22-27 October 2001 and the interview plan is shown in Table I.

2.1.1. Development of the questionnaire. A questionnaire should be elaborated carefully so that it is free from any kind of bias. Some representative considerations of the questionnaire development will be presented later on. The interviewees must be motivated to participate and they should be conscious of the important contributions (Hauser, 1993; Mitra, 1998; Machado, 1997; Bergquist and Abeysekera, 1996; Han *et al.*, 2001). A good questionnaire demands careful planning that should begin long before it is written down. When planning the questionnaire it is important to focus on administrative questions that need to be answered. These questions are the analytical techniques that should be used and the specific information that the techniques need, A block layout allows the project group of the new product to have a rational assessment of the questionnaire size. The group may determine whether or not it is necessary for the questionnaire to have various sections, making sure that all necessary information is obtained. The block layout also allows the project group to construct a smooth flow chart of answer for the questionnaire, checking the order of the questions (Hauser, 1993; Mitra, 1998; Machado, 1997; Bergquist and Abeysekera, 1996; Han *et al.*, 2001) (see Table II).

After the block layout is completed, accurate information for an analysis is obtained from groups being studied and also from past experience. The knowledge from past experience helps the elaboration and remaking of the questions. Some samples are used to compose the pre-test of the questionnaire. The interviewees are interviewed again about their answers to make sure that both the interviewee and the interviewer are thinking about the same situation when answering the questions.

2.2.Quantitative measures

Quantitative measures (personal interviews, survey by post or telephone) provide input for the analytical techniques utilized to identify specific strategy. For example, analytical techniques comprise the perceptions and preferences and offer a preliminary estimate of the buying attitudes (Hauser, 1993; Csillag, 1995; Moskowitz and Kim, 1997).

Furthermore, the records and the qualitative survey are used to understand semantic questions (which means if you are collecting the expected information from the questions submitted to the customers), while the quantitative approach is utilized to assess the consumer's attitudes and answers.

Block description	Objective	Technique
Presentation	Make it interesting and motivate interviewee	Motivation
Personal data	Data survey	Segmentation
General discussion	Preparation	Motivation
Instructions	Broaden minds Avoid "preconception"	
Guided discussion	Same as those in Table II	Questionnaire
Free comment	Deal with question not dealt with before	
The end		

Table I.
Group interview plan

Question	Objective
Do you cycle?	Verify the use of the equipment.
How many times have you cycled this year, this month or this week?	Analyze time intervals to establish an attitude
What is your reason for using bike?	Analyze rival products or alternative products
In your opinion, what market trademarks are the best?	Analyze rivals and establish attitudes
Have you ever bought a bike?	Analyzes frequency and market potential
What is the buying frequency?	Analyzes frequency and market potential
When you do not use a bike, what equipment do you use? And why?	Analyze rival products and alternative products
How much are you willing to pay for it?	Survey of demand
What do you like the least about them?	Survey of the necessities
What should be improved on it?	Survey of the necessities
What is lacking on it?	Survey of the necessities
What other functions do you consider important	Survey of the necessities
How much are you willing to pay for this new function?	Purchase ranking and limitation of the VA
Why would you not buy one?	Survey of the necessities, potential markets
Free comments	Deal with question that was not raised

Table II.
Questions for group interviews

As the development of the product takes place, by means of evaluations and refinement, the estimates become more precise and the emphasis shifts to quantitative measures (Hauser, 1993; Csillag, 1995; Moskowitz and Kim, 1997).

2.2.1. Results

(1) *Demography and revenue*. The survey was focussed only on male customers (sportsmen) between age of 19 and 25, whose may not necessarily have an income, but that are affordable to expend at about R$ 900,00 per month.

(2) *Survey results (consumer preferences)*. After a series of four guided interviews, the consumer needs had to satisfy the following requirement:
   - be ergonomic: knees, dorsum, hands and seats. Those who were interviewed believe that an ergonomic aspect improves riding performance;
   - change gear easily and maintain the performance level: on an uphill road, power reduction may occur if gear is not engaged easily;
   - have tool box;
   - have carrier: to carry supplies, tool box, spare chain or chain-clips;
   - have a flask of water;
   - have a pedal with clip;

- be versatile: capable of being used on highways, in cities, or on dusty roads;
- hands should not slip even when the gauntlet is wet;
- have front suspension: improve the grips and reduce arm fatigue;
- colors: blue, black, red, orange, or metallic tones;
- not have stickers that attract attention;
- have long intervals between gear speeds, the gear wheel does not necessarily need to have a lot of cogs, in fact most interviewees preferred fewer gears to a longer interval between gear speed;
- have an on board computer to control distance, time, global location, velocity, etc.;
- have a guide to tracks and services;
- allow easy maintenance: wheels, seats and tires;
- be light;
- have style;
- have a tire repair kit;
- strong frame;
- be durable even in severe weather conditions;
- make little noise;
- brakes that require very little effort.

(3) *Sales boosters*:

- Strong: style, trademark, ergonomics.
- Medium: improvement of damping system to reduce impact effects on riders during irregular tracks.

2.2.2. Quantitative surveys. The survey focussed on three groups of three individuals each and took place between 19-22 November, 2001. Their purpose was to quantify the relative importance of each function of the equipment (see 2.5.3 – Mudge diagram) and also that of its deployed functions.

The functions in a Fast diagram are ranked in a Mudge diagram and must be the "What" input (implicit requirements) in a QFD diagram. However, it is not always clear how to relate directly the information from Fast and Mudge diagrams to engineering requirements in QFD diagram. In these situations, the functions must be deployed again to allow the relation process. These deployed functions must be ranked again, but only with respect to the original functions, so that they are not compared in a Mudge diagram again.

The quantitative survey process was divided into two parts. The first part was dedicated to the elaboration of the diagram of Mudge (Csillag, 1995; Miles, 1972), which compares the relative importance of each function. It is important to keep in mind that even though the consumer compares the functions, in reality he is comparing the level of importance of the function for his personal satisfaction.

The second part of the survey quantifies the function deployment of the diagram of Mudge for the engineering requirements. This was done using the ranking questionnaire because the Mudge diagram is too extensive and laborious for the consumer.

2.3. QFD

The QFD technique helped generate the following secondary functions that need to be quantified as well as the form that was used (see Table III).

QFD is a planning tool that focuses on the quality project of a product or a service by incorporating consumer requirements. It is a systematic approach that involves multidiscipline teams that address the entire development cycle of a product (Mitra, 1998; Machado, 1997; Dedini and Cavalca, 1997; Machado *et al.*, 1997). QFD reduces the cycle time of the product in each functional area, from its conception to product and sale. Considering projections of the product and its elements, such as manufacturing feasibility and resources limitations, QFD significantly reduces the reprojecting time (Mitra, 1998; Machado, 1997; Dedini and Cavalca, 1997; Machado *et al.*, 1997).

Function	Secondary function	Preference (%)
A	Have attractive texture	50
	Have attractive color	50
B	Should suit the perineum anatomy	65
	Should suit the gluteal anatomy	35
C	Have comfortable pedals	50
	Have a good pedal grip	50
J	Decelerate the front wheel	80
	Apply front wheel brakes without much effort	20
K	Decelerate the rear wheel	80
	Apply rear wheel brakes without much effort	20
N	Have tool box	25
	Have carrier	40
	Have flask	10
	Have a guide to tracks and services	10
	Have an onboard computer	15
O	Reduce impact acceleration	50
	Reduce impact amplitude	50
Q	Have comfortable handles	25
	Have shock-absorbing seat	35
	Make little noise	15
	Offer an ergonomic trunk inclination	25

Table III. The deployment of secondary functions

In Figure 1, the "objective" describes both the purpose of the QFD as well as its scope in order to avoid unnecessary complexities. "Requirements and needs" points out the characteristics/features the customer expects from the product/service. "Engineering requirements" gives the "technical translation" of the customer needs and, finally, the "relationship matrix" gives how these design parameters are related to each other (strong, medium or weak relation) using a numerical scale.

Therefore, one or more customer needs can be related to one or more engineering requirement, although a one to one correlation is a preferable design. A weighing process between "requirements and needs" and the "relationship matrix" generates the "customer analysis" as well as between "Engineering requirements" yields the "Technical analysis" (Moskowitz and Kim, 1997)

The next step is to determine the consumer needs detailed in section 2.2. The requirements are listed in the column of the "what", and they represent the individual characteristics of the product or service. The next step is to quantify each one of the requirement listed.

It is important to point out that most functions of a product may not be mentioned by the consumer during the survey. This is due to the fact that such functions are viewed as inherent parts of the product in question. In this case the functional approach described in 2.5.1 proves to be an appropriate tool for completing the list of requirements of the consumer. The consumer's requirement list does not include handlebars. This seems to suggest a bicycle without handlebars. However, it is impossible to imagine a bicycle without any steering. Therefore, this reminds us that some implicit functions should not be left out when using QFD.

The engineering requirements or design requirements reveal the characteristic that the consumer hopes to find in the new product,

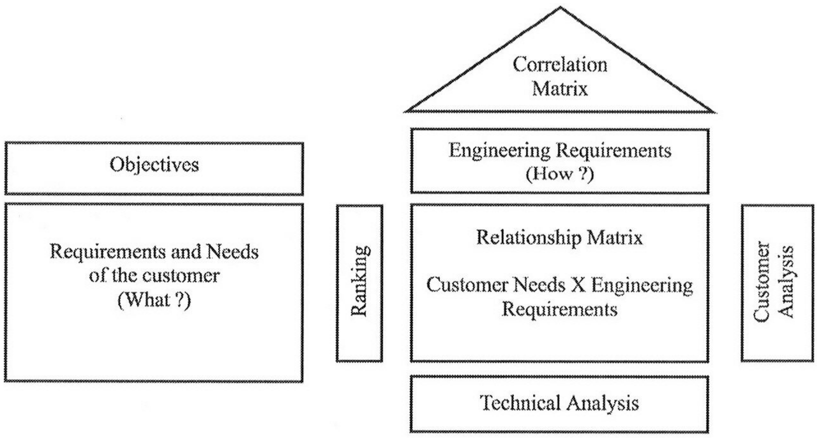

Figure 1.
QFD basic structure

translating the consumer needs into technical language (Dedini and Cavalca, 1997; Machado *et al.*, 1997; Moskowitz and Kim, 1997). If necessity is derived from a use function, the engineering requirements will be related to a unit of measure. And if necessity is derived from an aesthetic function, the engineering requirement will be related to a special characteristic that may or may not be explicitly related to a unit of measure but it will certainly be related to a clear engineering requirement. The design requirements considered in the QFD are listed in Figure 2.

The relationship matrix links the consumer needs with the design requirements. For each time of requirement of the consumer, the kind of existing relationship should be checked for such a requirement, against all the project requirements. The relationship can be very important, important or a little important, normally corresponding to a ranking of 5, 3 and 1, respectively (Mitra, 1998; Machado, 1997).

2.4. VA

The functional approach proposed by the VA can be defined as the determination of the essential nature of a purpose, considering that all objects or all actions exist for a purpose (Csillag, 1995; Miles, 1972; Fang and Rogerson,

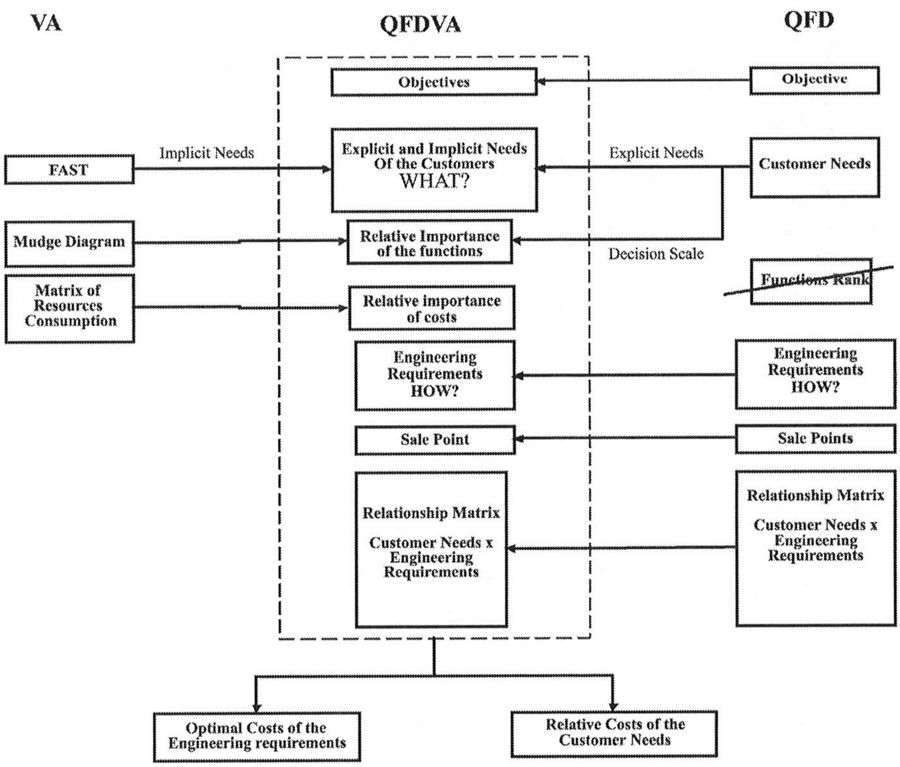

Figure 2.
The composition of the QFDVA process

1999). It is necessary to go through a semantic process to carry out a functional approach, since function should always be defined by two words: a verb (acting on something) and a noun (an object on which a verb acts). The function is the object of an action or an activity to be fulfilled, observing the obtained results. On the other hand, action is the method used to carry out such an objective (Csillag, 1995; Miles, 1972; Fang and Rogerson, 1999). Considering such an approach, the functions are divided into two main groups: use functions and aesthetic functions.

A function defined by a verb and by a measurable noun is called a use function. And it establishes quantitative relations (Csillag, 1995; Miles, 1972; Fang and Rogerson, 1999). All branches of Figure 3, except branch A, illustrate this. A function defined by a verb and by a non-measurable noun is called an aesthetic function. And it establishes qualitative relations (Csillag, 1995; Miles, 1972; Fang and Rogerson, 1999). The branch of A in Figure 3 shows this kind of function.

A primary function determines the identity of a product. It defines parameters to achieve the design tasks. In other words, it is a function for which the product is projected. For example, the basic function of a watch is to measure time (Csillag, 1995; Miles, 1972; Fang and Rogerson, 1999). It is important to point out that the primary function of a product is closely related to its use. Secondary functions support the design and help visualize the product and correspond to way the manufacture chooses to carry out the functions (Csillag, 1995; Miles, 1972; Fang and Rogerson, 1999).

2.5. The comparative method

Value analysis aims at offering the user the function performance which is an essential part of the price determination. It makes sure that it guarantees a price that the consumer is will to pay, the minimum price. Two universes coexist in this sentence. The first one refers to the supplier and the second one to the user (Csillag, 1995; Miles, 1972; Fang and Rogerson, 1999).

The method consists in obtaining the functions of the product from the Fast diagram (item 2.5.1). It also develops the resource consumption matrix and the Mudge diagram to obtain a comparative diagram ("compare"). The diagram compares the cost of the functions and its relative importance (Csillag, 1995; Miles, 1972; Fang and Rogerson, 1999).

2.5.1. Fast diagram. The Fast diagram is a technique to analyze system functions, made up of a basic function from which secondary functions are continuously derived, until a detailed and convenient setup is obtained. The setup may have use function or aesthetic functions. Figure 3 shows a Fast diagram for a bicycle.

This technique consists in a breakdown of the basic design function. When applied to a project, it builds a block diagram with the whole deployment of product functions, allowing their organization and hierarchy level among them.

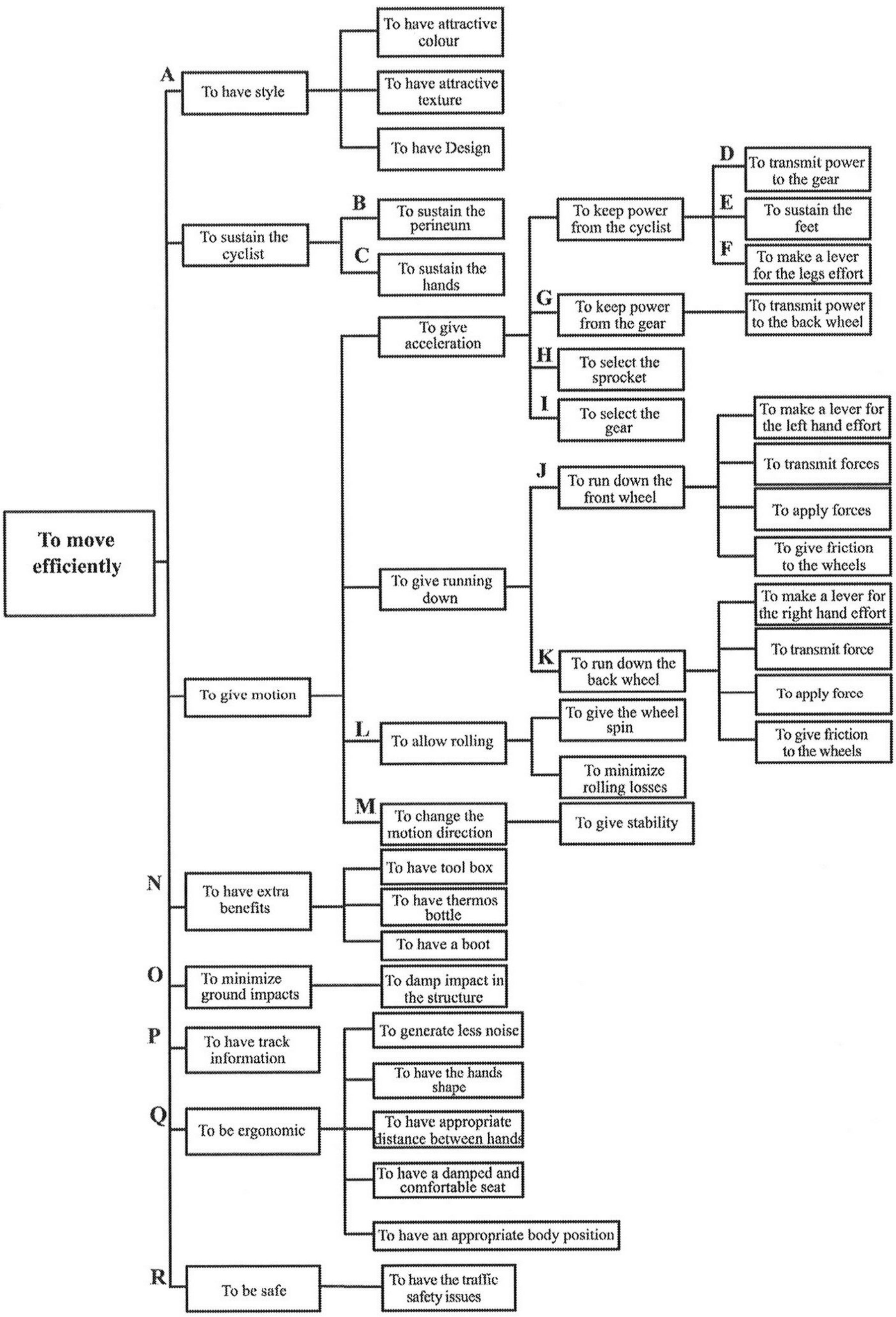

Figure 3.
Fast diagram for a bicycle

With this point of view, the basic (primary) function of a bicycle studied here is to move efficiently even in irregular tracks.

To get this purpose, the first level of secondary functions (Figure 3) consists of "Use" functions related to performance, dynamics, ergonomics and safety. There is an aesthetic function related to style. In sequence, the secondary functions are successively deployed until more detailed levels, until some redundant functions appeared, indicating the closure of the process.

*2.5.2. Resource consumption matrix.*The resource consumption matrix (Table IV) has components (by row) and functions obtained from the Fast diagram (by column). The main purpose of the matrix is to divide the cost of the components among its functions, since each component may be associated with one or more functions in a product. And so the cost of each function will be estimated, considering the matrix division. For comparison purposes, cost is transformed into a percentage in the graph "compare".

2.5.3. Mudge diagram. The Mudge diagram is a numerical evaluation of the importance level of the function. This technique compares all the possible combinations of the functions, two by two. It determines which one of them is most important as it ranks them (Csillag, 1995).

The importance level is defined by ranking the most important function of each pair into levels 1, 2 or 3 (these levels are the weights given to the importance level). Afterwards, the sum of all ranks for each function is evaluated and written in a "Total" column, corresponding to its function row. The sum of all functions value gives the total value of the product, corresponding to 100 per cent of relative importance. In this way, the relative importance can be evaluated for each function separately.

After the comparison and the evaluation procedures, the scores will reveal the relative importance of each function. The functions were evaluated by three different groups. Figure 4 shows a diagram for a bicycle elaborated according to group 1.

The complete procedure is applied to several interviewed groups (groups 1, 2 and 3) and an average is calculated for the final product analysis (Figure 5).

In Figure 5 the profiles of groups 1, 2 and 3 are sufficiently close to the average profile evaluated from the Mudge diagrams, indicating a convergence among the groups of customers interviewed.

The Mudge diagram can still be used to compare the profiles of consumers. For example, when the curves are very different, they suggest that there are other profiles to be considered. And this may led to the development of other types of products (Figure 5).

*2.5.4. Compare graph.*The Compare graph compares the relative costs (obtained from the resources consumption matrix) with the relative importance (obtained from the intermediate line of the Mudge diagram) (see Figure 6). The more the function line gets closer to the cost line, the better the cost is allocated

Table IV.
Resource consumption matrix for a bicycle

Components	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Total
Frame	10.00	5.00	6.00									30.00		5.00		7.00	7.00		70.00
Front suspension	5.00														65.00		10.00		80.00
Front chamber												2.30			0.30		0.20		2.80
Back chamber												2.30			0.30		0.20		2.80
Front tire	1.30											7.50					0.50		9.30
Back tire	1.30											7.50					0.50		9.30
Front wheel frame	2.30											3.40							5.70
Back wheel frame	2.30											3.40							5.70
Front spokes	1.50											2.30							3.80
Back spokes	1.50											2.30							3.80
Front spokes protection	0.10											0.40							0.50
Back spokes protection	0.10											0.40							0.50
Front ball bearing												10.30							10.30
Back ball bearing												10.30							10.30
Front break shoes	0.20									1.30									1.50
Back break shoes	0.20										1.30								1.50
Front V Brake	0.50									4.60									5.10
Back V Brake	0.50										4.60								5.10
Front horse-shoe break cable										0.18									0.18
Back horse-shoe break cable											0.22								0.22
Front cable conduit										0.21									0.21
Back cable conduit											0.28								0.28
Pedals	2.00			3.40	1.50												1.50		8.40
Pedal clippers	2.00			3.40	3.00														6.10
Pedals crank	2.00			10.00	2.00	6.00						12.70					5.00		37.70
Indexed front gear				2.50				2.40					3.00						7.90

(continued)

Table IV.

Components	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Total
Saddled central motion				10.75		10.75													21.50
Indexed chain							4.50					5.45							9.95
Indexed back gear							5.40		10.80										16.20
Saddle	3.00	9.30													3.00		4.00		19.30
Saddle support		3.00																	3.00
Saddle locker		1.50																	1.50
Front gear gauntlet	2.00		3.50					13.00									4.50		23.00
Back gear gauntlet	2.00		3.50						13.00								4.50		23.00
Reflector kit																		1.20	1.20
Brake light	1.00																	8.90	9.90
Front lights	3.00																	20.00	23.00
Rear-view mirror	0.30																	3.20	3.50
Handle bar	0.60		0.90										2.00				1.10		4.60
Handle bar support	2.50												12.10						14.60
Direction motion													2.90						2.90
Couple of gauntlets	0.20		1.30										0.30				0.70		2.50
Frame bag	1.00													7.00					8.00
Repair kit														1.50					1.50
Thermos Bottle (750ml)	1.60													7.00					8.60
Bottle support	1.05													2.10					3.15
Onboard computer	2.50													30.00					32.50
Electronic alarm																		12.00	12.00
Total	53.55	18.80	15.20	30.05	6.50	16.75	9.90	13.00	26.20	6.29	6.40	100.55	20.30	52.60	68.60	7.00	39.70	45.30	537.88
Percentage	10.00	3.50	2.80	5.60	1.20	3.10	1.80	2.40	4.90	1.20	1.20	18.70	3.80	9.80	12.80	1.30	7.40	8.40	100.00

Note: Table of Prices (JFC Comércio de Peças para Bicicletas LTDA)
Source: Bergquist and Abeysekera (1996)

Group: 1

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Total	%
A	B3	C3	D3	D1	A1	G2	H2	I2	J2	K1	L3	M2	N2	O2	A2	Q3	R2	3	1.2%
B		B1	D2	B1	F2	G2	H2	I2	J1	K1	L3	M1	B2	O1	B2	Q2	B2	11	4.3%
C			D2	E1	F2	G3	H2	I2	J1	K1	L2	M2	C2	O1	C2	Q1	C1	8	3.1%
D				D1	D1	D1	H2	I2	J1	K1	D1	D2	D1	O1	D1	Q1	D1	17	6.6%
E					E2	E1	H2	I2	E1	E1	L2	F1	E2	O1	E2	Q2	E2	13	5.1%
F						F1	H1	I2	F2	K1	L2	F2	F2	F2	F2	E1	F3	19	7.4%
G							H1	I2	G1	G1	G1	M1	G2	G1	G2	Q1	G2	17	6.6%
H								H3	H1	K1	H1	M1	N2	H2	P2	Q1	H2	21	8.2%
I									I1	K2	I1	M1	N3	I1	I2	Q1	I2	21	8.2%
J										J2	L1	J1	J2	O1	J2	Q1	R3	12	4.7%
K											L2	K2	K2	K1	K2	Q1	K1	16	6.3%
L												L2	L3	O1	L2	Q1	R3	22	8.6%
M													M1	M1	M3	Q3	M1	14	5.5%
N														O3	O3	Q1	R3	7	2.7%
O															O2	Q1	O1	17	6.6%
P																Q1	R3	2	0.8%
Q																	Q1	22	8.6%
R																		14	5.5%
																		256	100.0%

Figure 4.
Mudge diagram for group 1

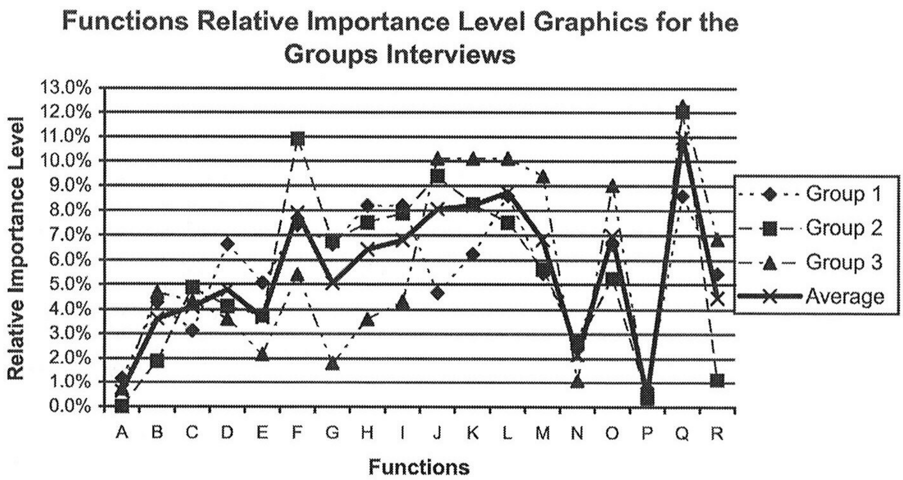

Figure 5.
Graph ranking of the importance level of the function for the interviewed group

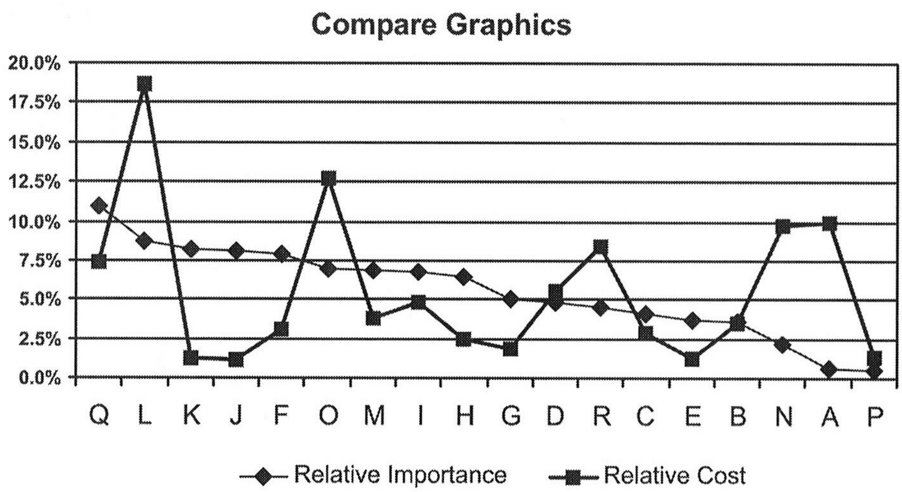

Figure 6.
The Compare graph for a bicycle

to the function, so the product value rises. Consequently, the consumer will be able to perceive the improvement in the product value.

The best way to evaluate the product value is to determine how close the relative cost curves (manageable) is from the customer requirement curve (unmanageable). Naturally each different position of the linear graph points depreciates the product value. This may not be due to resources waste or the lack of their use. Therefore the global value index, IGV, can easily be used to evaluate the product value using the equation below:

$$IGV = 1 - \sum_{f=1}^{n} ABS(RC_f - RN_f) \quad (1)$$

where:

RC is the relative cost (%) of the function f,

RN is the relative needs (%) of the function f

2.6. Integrating the QFD and the VA

2.6.1. The Fast diagram and consumer needs/requirements. When the QFD and the VA are used, a very interesting fact is observed: the Fast diagram generates functions that are rarely mentioned by the consumers. This fact occurs because VA allows the deployment of the product into use functions (explicit and implicit) and aesthetic functions. However, all functions are essential for one reason or another and have costs that have to be taken into account. Therefore, when the consumer needs for the QFD were being obtained, no essential function was left out.

2.6.2. The importance of the needs (QFD) and the Mudge diagram (VA). To compute the costs, the ranking column of the QFD is replaced with the relative importance level of the VA, as a "Ranking of the functions" in Figure 7. The VA ranking is used to evaluate the "Optimal relative costs of the needs" when applying equation (2).

In reality the needs costs in QFDVA matrix are the costs of functions weighted by the relationship matrix and by sale point proposed by the equation below:

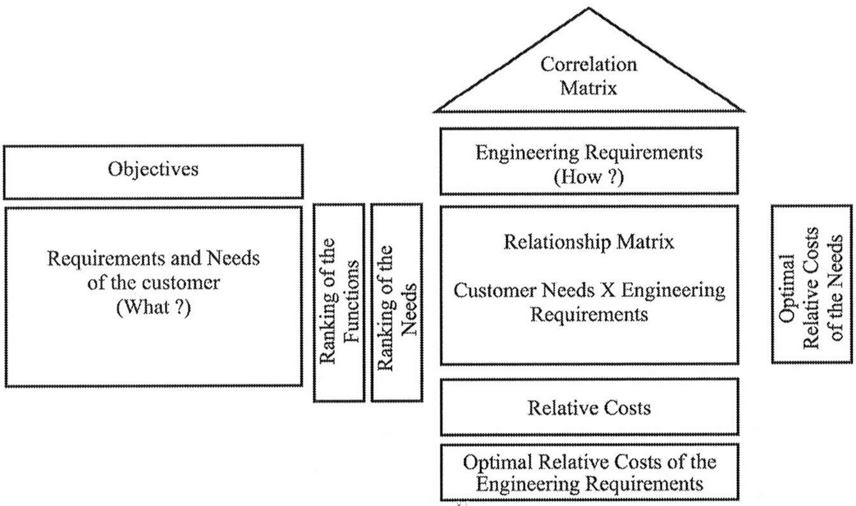

Figure 7.
The structure of QFDVA

$$Requirement_i = \left(\sum_{j=1}^{n} M(i,j)\right) \cdot PV(i) \cdot IR(i) \qquad (2)$$

where:

- M is the relationship matrix
- IR is the relative importance (%) of function f (first column of consumer importance in Figure 8)
- PV is the sale point (Figure 8)

Otherwise, the optimal engineering costs in QFDVA diagram are calculated by manipulating the new line of the relative importance of the cost, adding up the correspondent column of the relationship matrix.

$$EngineeringCost_j = \left(\sum_{i=1}^{n} M(i,j)\right) \cdot IRC(i) \qquad (3)$$

where:

- M is the relationship matrix
- IR is the relative importance of the cost for function f (second column of consumer importance in Figure 8 and last row of relationship matrix)

2.6.3. Adding the relative importance of the costs of the QFD. To compute the cost, a new line with relative importance of the costs was added to the QFD immediately after the relationship matrix. From the relationship matrix information, it is possible to quantify the connectivity between the engineering requirements and the costs relationship that will offer the highest product value achieved by optimizing the engineering costs.

*2.6.4. Relationship matrix function.*The relationship matrix does not vary much in relation to the conventional QFD. The score is the same as the one that is normally used and the construction is identical. Its new purpose is to weight the cost for each engineering requirement and for each cost of needs, according to equations (2) and (3) mentioned previously.

2.6.5. Quality function deployment with value analysis. The quality function deployment with value analysis (QFDVA) process can be summarized as shown in Figure 2.

The basic structure of QFD diagram in maintained except for function rank, which is cut off in the new structure of QFDVA. Fast diagram provides the input of implicit functions with the customer needs obtained from the questionnaire. The Mudge diagram gives the relative importance of the

		costumer importance		metallic paint	special coloring	distance to the fingers	front seat edge	back seat edges	chain strength	pedal area	pedals-feet friction	length of the pedal lever	sprocket strength	belt distance	distance for gear displacement	front shoes force	front breaks force	rear shoes force	rear break forces	shaft rotation	handle torque	number of tools	carrier volume	maintenance time for consumption	information of the support book	type of electronic device	front spring stiffness	front damping	book information	hands distance	elasticity of the seat	noise level	hands-seat distance	necessary tissues	Summ	PV	Costumer weight	Costumer mode
A	have attractive texture	0,6%	0,32%	5	3																														8	1,5	0,038	0,4%
	have attractive color		0,32%	3	5																														8	1,5	0,038	0,4%
B	have hands format	3,6%	3,62%			5																									1				6	1,0	0,217	2,2%
C	suit the perineum anatomy	4,1%	2,67%				5	1																											6	1,0	0,160	1,7%
	suit the gluteal anatomy		1,44%				1	5																											6	1,0	0,086	0,9%
D	transmission of gear power	4,8%	4,80%						5	3	3	1	5																						17	1,0	0,815	8,4%
E	have comfortable pedals	3,7%	1,83%							5	3																								8	1,0	0,147	1,5%
	have a good pedal grip		1,83%							3	5																								8	1,0	0,147	1,5%
F	improve the legs force	7,9%	7,91%				1	1		3	3	5	3				3																		19	1,0	1,503	15,5%
G	transmit power from sproket	5,1%	5,07%						5				5																						10	1,0	0,507	5,2%
H	select sprocket	6,4%	6,44%											5	1																				6	1,5	0,580	6,0%
I	select gear	6,8%	6,81%											1	5																				6	1,5	0,613	6,3%
J	decelerate the front wheel	8,1%	6,45%													5	3																		8	1,0	0,516	5,3%
	apply front wheel breaks without m		1,61%															5																	5	1,0	0,081	0,8%
K	decelerate the rear wheel	8,2%	6,57%													3	5																		8	1,0	0,525	5,4%
	apply rear wheel breaks without m		1,64%																5																5	1,0	0,082	0,8%
L	give rolling to the wheels	8,7%	8,74%						3				1							5															9	1,0	0,787	8,1%
M	change motion direction	6,8%	6,83%																		5														5	1,0	0,342	3,5%
N	have tool box	2,1%	0,54%																			5	3												8	1,0	0,043	0,4%
	have carrier		0,86%																			3	5												8	1,0	0,069	0,7%
	have flask		0,21%																					5											5	1,0	0,011	0,1%
	have a guide to tracks and services		0,21%																						5										5	1,0	0,011	0,1%
	have an on board computer		0,32%																							5									5	1,0	0,016	0,2%
O	reduce impact acceleration	7,0%	3,49%																								5	1			3				9	1,2	0,377	3,9%
	reduce impact amplitude		3,49%																								1	5			3				9	1,2	0,377	3,9%
P	have tracks information	0,5%	0,51%																										5						5	1,0	0,025	0,3%
Q	have ergonomy to the arms	11,0%	2,74%			3															3									5					11	1,5	0,452	4,7%
	have shock-absorbing seat		2,74%																												5				5	1,5	0,206	2,1%
	make little noise		2,74%																													5			5	1,5	0,206	2,1%
	offer an ergonomic trunck inclinatio		2,74%			3						3									1												5		12	1,5	0,493	5,1%
R	offer safety	4,5%	4,5%																															5	5	1,0	0,224	2,3%
	Summ			8	8	11	7	7	13	14	14	9	14	6	6	8	11	5	5	5	9	8	8	5	5	5	6	6	5	5	12	12	5	5	237		9,694	100,0%
				0,3%	0,3%	3,6%	2,7%	1,4%	4,8%	1,8%	1,8%	7,9%	5,1%	6,4%	6,8%	6,5%	1,6%	6,6%	1,6%	8,7%	6,8%	0,5%	0,9%	0,2%	0,2%	0,3%	3,5%	3,5%	0,5%	2,7%	2,7%	2,7%	2,7%	4,5%				
			weight	0,025	0,025	0,399	0,187	0,101	0,623	0,257	0,257	0,712	0,71	0,387	0,409	0,518	0,177	0,328	0,082	0,437	0,615	0,043	0,069	0,011	0,011	0,016	0,209	0,209	0,025	0,137	0,329	0,329	0,137	0,224	7,996888			
			mode	0,3%	0,3%	5,0%	2,3%	1,3%	7,8%	3,2%	3,2%	8,9%	8,9%	4,8%	5,1%	6,5%	2,2%	4,1%	1,0%	5,5%	7,7%	0,5%	0,9%	0,1%	0,1%	0,2%	2,6%	2,6%	0,3%	1,7%	4,1%	4,1%	1,7%	2,8%	100%			

Figure 8.
QFAAV – relationship matrix (detail)

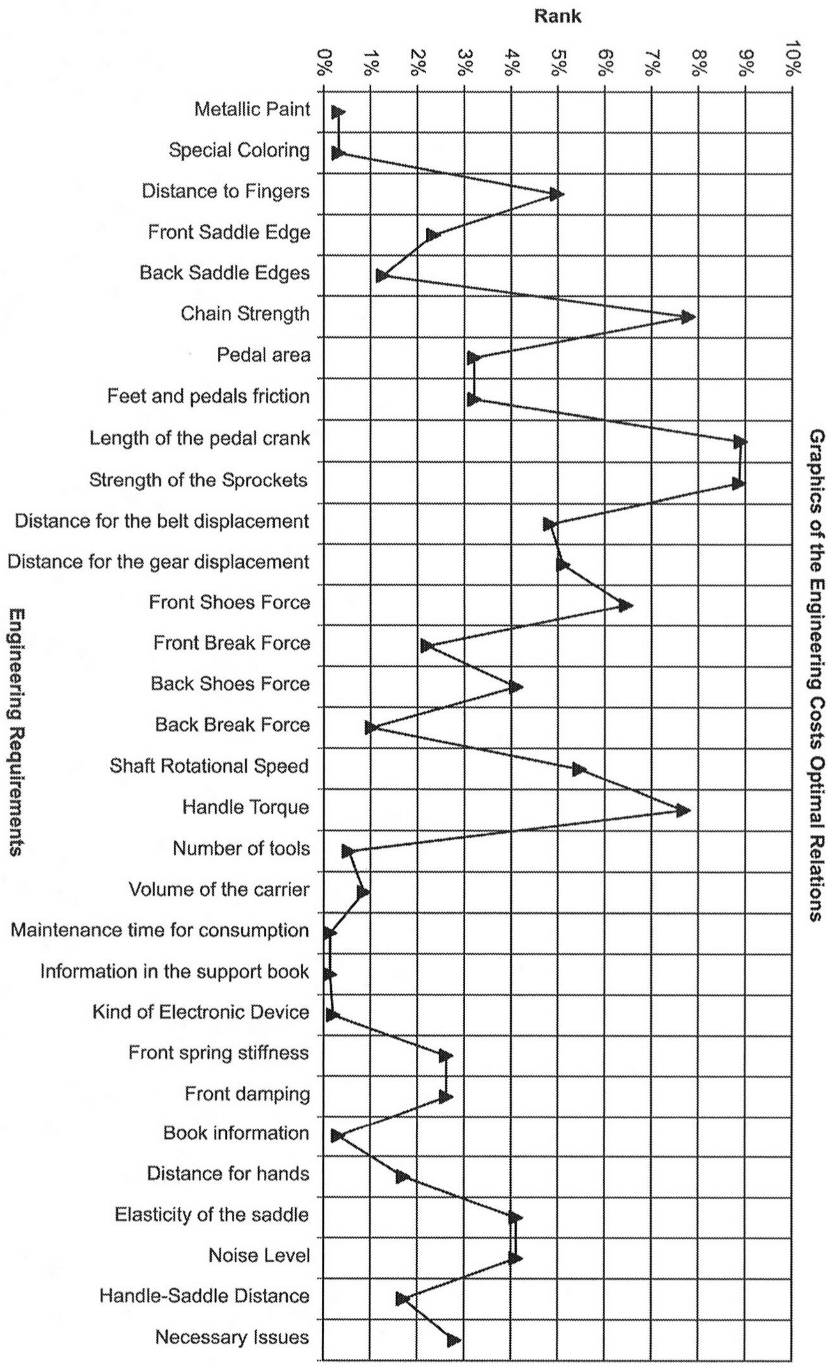

Figure 9.
QFDVA – optimal cost × engineering requirements (detail)

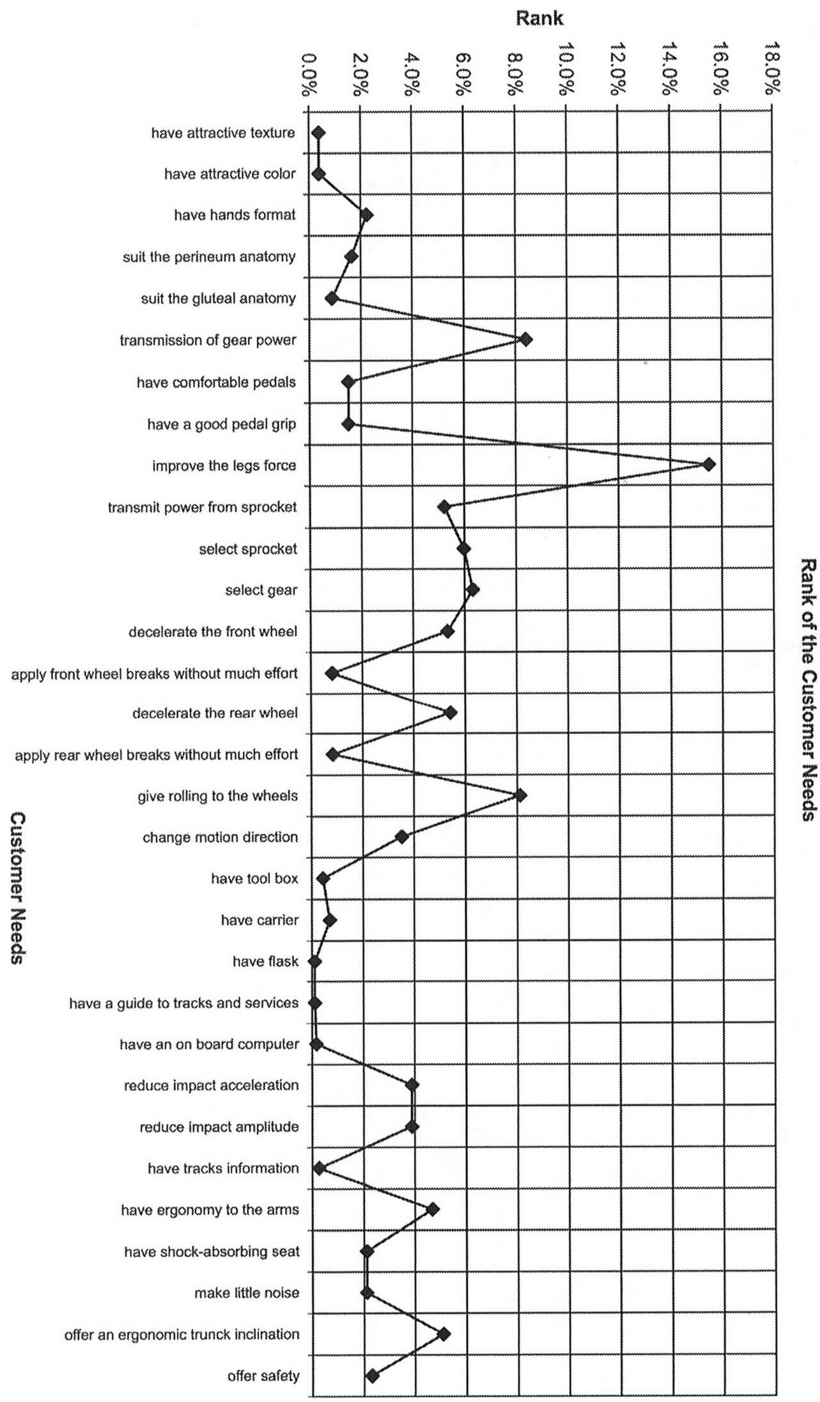

Figure 10.
QFDVA – importance of the customer needs (detail)

functions in the new QFDVA diagram. Finally, the matrix of resource consumption introduces the relative importance of costs.

The results of the QFDVA are presented in Figure 8. This application considers the Fast diagram information (Figure 3) to complete the customer needs in first and second columns (functions A to R). The relative importance obtained by the Mudge diagram is positioned in first column of customer importance in Figure 8. The second column of customer importance results from the initial functions deployment mentioned in section 2.2.2. The relative importance of costs is evaluated by equation (3) and gives information to the matrix of resource consumption (VA) in order to feedback the resources location for functions and components. The last line of the chart shows the normalized values that generate the graph of the optimum engineering costs (Figure 9). And the last column shows the normalized values that generate the graph of the importance of the needs (Figure 10).

Conclusion

The joint use of the QFD and the VA is deemed essential when developing products. The quality function deployment with value analysis (QFVA) is the new tool obtained from the fusion of the QFD and the VA. The QFDA aims at fulfilling consumer requirements and supplying financial decision parameters that are based on company formal engineering terms.

When developing a regular product, it is difficult to answer the question: what is the best way to allocate the available resources in order to guarantee maximum consumer satisfaction? This question involves diverse aspects that should be considered and that can answered by QFDVA.

First, this method quantifies and qualifies each one of the implicit and explicit requirements acquired. Then it arranges them as unique engineering requirements with their interrelationship, fulfilling all the consumer requirements according to their ranking. Finally, we have a clear picture of the importance of each consumer need. Also, we can determine the optimum allocation of engineering resources for project.

This kind of analysis is more appropriate when a consumer of a certain product becomes more exigent and critical of the product. That is, when the differentiation level of a product matters to him.

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