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AN OBJECT-ORIENTED SOFTWARE DESIGN TOOL USING AUTOMATED HoQ AND AHP FOR TRACING AND PRIORITIZING SYSTEM REQUIREMENTS+

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ABSTRACT:

It has been widely acknowledged that software products should be developed based on customer requirements in order to achieve a high level of software quality and customer satisfaction. Tracing customer requirements and their impacts through the software development life cycle is not a well-explored area. In this paper, a framework is presented that uses quality function deployment (QFD) to trace customer requirements explicitly through various phases, such as requirements elicitation, analysis, and design in object-oriented software development, by assessing their impact on software artifacts of the next stages. QFD helps visualize the complete tracing from customer requirements to class designs. Degrees of impact are clearly calculated and presented in QFD automatically using a simple software (an excel sheet). The Analytical Hierarchy Process (AHP) is used to prioritize and calculate the importance index of customer requirements and their impact on design stages. In traditional QFD. the correlation between customer requirements and technical requirements is determined by the members of a design team using linguistic expressions (e.g. weak, average, and strong). These linguistic terms are then scaled into crisp values (e.g. 1-3-9) for the ranking of each alternative. This crisp assessment for correlation evaluation in QFD analysis has difficulty coping with uncertainty among design team members. Therefore, fuzzy sets are adapted in this paper. An object-oriented software design tool example is developed to illustrate and validate the framework.

KEY WORDS: Analytical hierarchy process (AHP), house of quality (HoQ), fuzzy sets, object-oriented software design, software quality function deployment (SQFD), traceability, customer requirements, system requirements, subsystem requirements, module requirements, remote sensing micro satellites.

CONCEPTION D'OUTILS LOGICIELS ORIENTEE-OBJET A L'AIDE DE AHP AUTOMATIQUE ET HOQ POUR DES RECHERCHES ET SYSTEME ORDRE DE PRIORITE

RÉSUMÉ :

Il a été largement reconnu que les produits logiciels devraient être développés en fonction des besoins du client afin d'atteindre un niveau élevé de qualité des logiciels et la satisfaction du client. Tracer les exigences des clients et de leurs impacts à travers le cycle de vie du développement logiciel n'est pas un endroit bien exploré. Dans cet article, un cadre est présentée que le déploiement de la fonction qualité (QFD) pour tracer les exigences du client explicitement par des phases diverses, telles que élicitassions des exigences, l'analyse et de conception dans le développement logiciel orienté objet, en évaluant leur impact sur les artefacts logiciels de la les prochaines étapes. QFD permet de visualiser la traçabilité complète des besoins des clients à des conceptions de classe. Degrés d'impact sont clairement calculés et présentées dans QFD automatiquement en utilisant un logiciel simple (une feuille Excel). L'analyse hiérarchique (AHP) est utilisé pour établir des priorités et calculer l'indice de l'importance des besoins des clients et de leur impact sur les stades de conception. En QFD traditionnels. la corrélation entre les exigences des clients et des exigences techniques est déterminé par les membres d'une équipe de conception en utilisant des expressions linguistiques (par exemple, faible, moyenne et forte). Ces termes linguistiques sont ensuite mis à l'échelle en valeurs nettes (par exemple 1-3-9) pour le classement de chaque solution. Cette évaluation nette pour l'évaluation de correspondance figurant à l'analyse QFD a du mal à faire face à l'incertitude chez les membres de l'équipe de conception. Par conséquent, sous-ensembles flous sont adaptés dans le présent document. Un exemple de logiciels orientés objet la conception d'outils est développée pour illustrer et valider le cadre.

MOTS CLES: processus de hiérarchie analytique (AHP), maison de qualité (Hoq), ensembles flous, la conception de logiciels orientés objet, déploiement de la fonction des logiciels de qualité (SQFD), la traçabilité, les exigences du client, la configuration système requise, les exigences du sous-système, les exigences de module, de la télédétection microsatellites.

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1. INTRODUCTION

Traditionally, traceability analysis provides linkages between requirements and design items. Although the linkage is necessary, it is not enough to develop software products with high customer satisfaction.

A tradeoff analysis that can be done to select a suitable requirements prioritization method and the results of trying one method, AHP, in a case study is described [1], [2]. AHP was developed by Thomas Saaty and applied to software engineering by Joachim Karlsson and Kevin Ryan in 1997 [3], [4], and [5]. AHP is a method for decision making in situations where multiple objectives are present. This method uses a pair-wise comparison matrix to calculate the relative importance of security software requirements. By using AHP, the requirements engineer can also confirm the consistency of the result. AHP can prevent subjective judgment errors and increase the likelihood that the results are reliable.

The limitations of QFD house of quality in its original form and also the advantages of automating it are identified [6]. The construction of the house of quality is simplified by creating it on Microsoft Excel. The standard format of the automated house of quality (AHOQ) created has been tested to be reusable and extendable for multiple applications. It saves time and effort as well as allows for automatic calculations of absolute and relative values.

A method for mapping and prioritizing customer requirements into functional features and technical modules to optimize market performance is introduced [7]. Although the quality of a product can be dramatically improved through a QFD exercise, the traditional crisp scoring approach has a major drawback. To overcome this problem, fuzzy scoring for linguistic terms is proposed. The implementation case of a low-end digital camera design shows that the result of the proposed fuzzy QFD model can reflect the certainty level of an evaluation term, which is designated for each correlation of customer requirements and technical requirements considered in design.

How different requirements have different impacts on design items are analyzed [8]. A design item that is impacted by more important requirements deserves more attention than a design item that is impacted by fewer important requirements. Otherwise, if more resources are given to design items with small impacts on the requirements, it is a waste of limited resources. It addresses the issue of requirements traceability by assessing the degrees of impact with the help of quality function deployment (QFD). QFD, which was developed more than 30 years ago in Japan, is a methodology that incorporates the voice of the customer into a product, and it is an excellent method for assuring that customers receive high quality products [9]. QFD is a process that transforms desires of the customer at all levels into the implementation of a product. Instead of focusing solely on defect prevention and elimination like traditional process improvement initiatives, QFD focuses on both minimizing the number of defects (customer dissatisfaction) and maximizing value (customer satisfaction). Software quality function deployment (SQFD) is the application of QFD to software production, which focuses on improving the quality of both the software development process and the product [10]. The ultimate goal is no longer zero-defect software, but rather good software that provides very high customer satisfaction. SQFD has been applied to the improvement of software quality focusing on three phases of the software development life cycle. It uses a set of house of quality (HoQ) matrices to translate customer requirements into system, subsystem, and class requirements.

This paper addresses the issue of requirements traceability by assessing the degrees of impact with the help of quality function deployment (QFD), House of Quality (HoQ). Analytical Hierarchy Process (AHP) is used for the purpose of prioritizing the customer requirements during implementing the House of Quality. The house of quality has been automated using an excel sheets thereby saving effort and time by using automated calculations. Besides, it gives the possibility of adding more customer or technical requirements to the HoQ matrix. Fuzzy sets and the concept of linguistic variables are adapted in this research. This model uses a four-phase set of house of quality (HoQ) matrices to translate customer requirements into system, subsystem, module and component requirements. An application example about developing an object oriented software tool for designing of a micro satellite system is used. The priorities resulting from the above has been used to prioritize the methods of design in the application program. The structure of classes corresponding to each phase has been shown.

2. A NEW METHODOLOGY

During the design and development phases, it is helpful to know what the most important design items are in terms of their correlation with the requirements. Thus, a priority assessment framework is provided to help find the important design items phase by phase. In this framework, HoQ incorporates customer requirements into multiple phases of the object-oriented software development life cycle, including system design, subsystem design, and module class design. There has been little research, however, on the traceability of customer requirements through object-oriented software developments. QFD seems to be a natural solution to this problem because it was developed to transform the voice of customer into designs. The advantage of using HoQ (from QFD) in this methodology is that it traces customer requirements from the very beginning to object module design. As a result, it is easier for both customers and developers to visualize which module is designed to reflect which set of requirements and to what extent these requirements are implemented. Based on the assessment result, limited resources can be allocated to more important design items and the resultant software product will achieve a higher level of customer satisfaction.

3. QFD METHODOLOGY FOR OBJECT-ORIENTED SOF WARE DEVELOPMENT; AN INTGRA-TED FRAMEWORK

An integrated framework (see Fig. (1)) for the application of QFD to object-oriented software development is developed. There are four phases in this development life cycle that this framework covers. They are:

Phase 1: Customer requirements are deployed to both the product functions and the quality factors of the whole system. The fuzzy sets are used in this phase instead of crisp numbers.

Phase 2: The product characteristics, which reflect the voice of customers, obtained from the previous phase are deployed into the important subsystem functions and subsystem constraints.

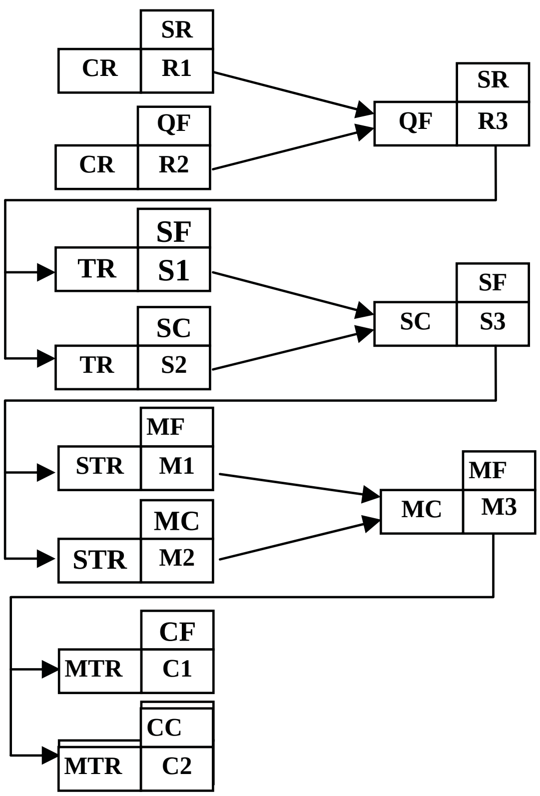
Phase 3: The most important functions and constraints of the modules are identified. The subsystem characteristics from the previous phase are deployed to these functions and constraints.

Phase 4: Module functions and module constraints are deployed into component functions and component constraints in this phase.

In order to provide traceability, the final outputs from each phase are used as the inputs for the next phase matrices. In this manner, customer requirements are incorporated into the whole system.

There are three types of matrices used in this framework to help in reflecting traceability, namely, quality house of quality (Q-HoQ), functional house of quality (F-HoQ), and the design point analysis matrix. Quality and functionalities are the two major issues affecting the degree of customer satisfaction. Thus, this paper tries to relate customer requirements with each one of the two using HoQs. The HoQ relating customer requirements with the quality factors is given the name Q-HoQ; similarly, the HoQ relating customer requirements with the functionalities is given the name F-HoQ. The design point analysis matrix is then used to combine the quality factors and functionalities, both of which now have weight values reflecting the impacts from the customer requirements.

In Figure 1, the matrices R2, S2, M2 and C2 are Q-HoQs; the matrices R1, S1, M1 and C1 constitute F-HoQs; and the matrices R3, S3 and M3 are of the type of design point analysis matrix. The customer requirements serve as an input into R1 (F-HoQ) and R2 (Q-HoQ) requirement elicitation matrices. The results of these two requirements elicitation matrices serve as inputs for the R3 matrix. Results of the R3 matrix are used to combine the product functions and quality factors into one set of subsystem-level requirements, which are carried over to Phase 2 of the development life cycle where similar steps are taken.



Phase 1: Requirements Elicitation Phase

CR=Customer Requirements
SR=System Requirements
QF=Quality Factors

Phase 2: Subsystem Design Phase

TR=SR+QF (From previous phase)
TR=Technical Requirements
SF=Subsystem Functions
SC=Subsystem Constraints

Phase 3: Module Design Phase

STR=SF+SC (From previous phase)
STR=Subsystem Technical Requirements
MF=Module Functions
MC=Module Constraints

Phase 4: Component Design Phase

MTR=MF+MC (From previous phase)
MTR=Module Technical Requirements
CF=Component Functions
CC=Component Constraints

4. CLASS DIAGRAM

The design phases of the object oriented software system will be reflected on the class diagram [11] as shown in Fig. (2). It shows the systems and subsystem classes, similarly module and component classes can represented. The instant variables of the system class are objects of the subsystems classes. The instant variables of the subsystem class are objects of the module classes. The methods of each module class are executed according to the weighted priorities of each module function and module constraint in the application program.

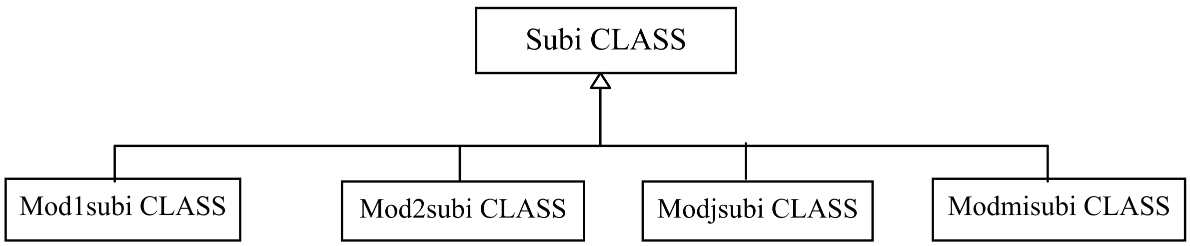


Fig. (2): Class diagrams

//System class
public class system implements requirement_documments
{
//subi is the class of subsystem I, msubi is object from this class
private sub1 msub1;
private sub2 msub2;
. . .
private subi msubi;
. . .
private subn msubn;
}
//Object of the system class can be created by the constructor as follows
//class constructor
System (sub1 msub1, sub2 msub2, …. Subn msubn){ }
//methods of system class { } }

//Subsystem class
public class sub1 implements csub1{
//misubj is the class of module i in subsystem j, mimsubj is object from this class.
private m1sub1 m1msub1;
private m2sub1 m2msub1;
.
.
private misub1 mimsub1;
.
.
private mnsub1 mnmsub1;
//Object of the subsystem class can be created by the constructor as follows
//class constructor
Sub1(m1sub1 m1msub1, m2sub1 m2msub1,…. mnsub1 mnmsub1){ }
//methods of sub1 {} }

5. TYPES OF MATRICES

5.1 The Q-Hoq Matrix (R2/S2/M2)

The structure of the Q-HoQ matrix is shown in Fig.(3).

The most important components of a Q-HoQ are:

- ***Requirements***: They are identified from customer statements or are obtained from the previous phase.
- ***Importance***: The importance column in the matrix accommodates a list of importance ratings (real values between 1 and 9) for the requirements entered. Importance ratings can be achieved using the Analytical Hierarchy Process (AHP) Technique (Figs.(4),(5)).

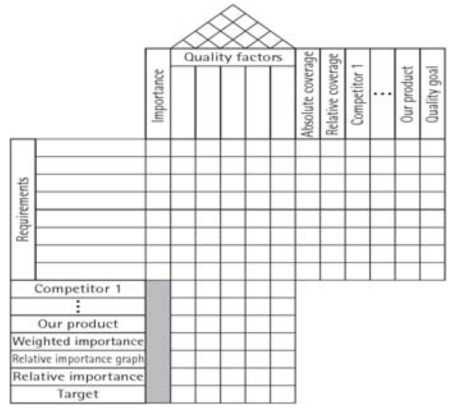


Fig.(3): The Q-HoQ Matrix

With respect to " "	Importance (or Preference) of one Sub-Criterion over another																		
Questions	Criteria	Absolute	Intermediate	Very Strong	Intermediate	Strong	Intermediate	Weak	Intermediate	Equal	Intermediate	Weak	Intermediate	Strong	Intermediate	Very Strong	Intermediate	Absolute	Criteria
		9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	

Fig. (4): A Questionnaire form for deciding on the importance index of the customer requirements

Consistency Check - Eigenvector Method																						
	A	B	C	D	E	F	G	H		I	J	K	L	M	N	O	P	Q	R	S	T	
		CR-1	CR-2	CR-3	CR-4	CR-5	CR-6	CR-7		SR-1	SR-2	SR-3	SR-4	SR-5	SR-6	SR-7	SR-8	SR-9	Score	Product	Ratio	
1	CR-1	1								1	0	0	0	0	0	0	0	0	0.1111	#VALUE!	#VALUE!	
2	CR-2		1							0	1	0	0	0	0	0	0	0	0.1111	#VALUE!	#VALUE!	
3	CR-3			1						0	0	1	0	0	0	0	0	0	0.1111	#VALUE!	#VALUE!	
4	CR-4				1					0	0	0	1	0	0	0	0	0	0.1111	#VALUE!	#VALUE!	
5	CR-5					1				0	0	0	0	1	0	0	0	0	0.1111	#VALUE!	#VALUE!	
6	CR-6						1			0	0	0	0	0	1	0	0	0	0.1111	#VALUE!	#VALUE!	
7	CR-7							1		0	0	0	0	0	0	1	0	0	0.1111	#VALUE!	#VALUE!	
										1	1	1	1	1	1	1	1	1	1	CI	#VALUE!	
																				CI/RI	#VALUE!	

Fig. (5): Analytical hierarchy process for prioritizing customer requirements

• ***Quality factors***: The quality factors columns in the matrix accommodate a list of quality factors that contribute to the satisfaction of the requirements. Quality factors specify the desired quality attributes that need to be considered during the development of a particular software product, such as reliability, understandability, and so on.

• ***Correlation***: The degree of impact of a quality factor on the satisfaction of a requirement is entered in a correlation matrix cell (the intersection of the quality factor and the requirement). Seven levels of impact are used to fill these cells. The fuzzy set is used to implement this correlation (Fig. (6)). Most researchers use special fuzzy numbers, such as triangular fuzzy numbers, trapezoidal fuzzy numbers, and R-L fuzzy numbers, to satisfy the need of modeling fuzzy problems. For simplicity, the most commonly used trapezoidal fuzzy numbers are used for necessary illustrations in this paper (Fig. (7)). The proposed fuzzy QFD model provides the ability for changing the level of linguistic certainty for the problem by altering the proposed linguistic certainty index. That is, selecting different spreads of fuzzy numbers will reveal different levels of linguistic certainty (Fig. (8)). A fuzzy number with a wider spread possesses a more ambiguous decision-making condition where the design team is uncertain with the evaluation. Conversely, a fuzzy number with a shorter spread represents a more clear and confident decision-making environment.

$$\mu_{\tilde{A}}(x)=\begin{cases} l(x) & for \quad x\in(\alpha,\beta) \\ 1 & for \quad x\in[\beta,\gamma] \\ r(x) & for \quad x\in(\gamma,\delta) \\ 0 & otherwise \end{cases}$$

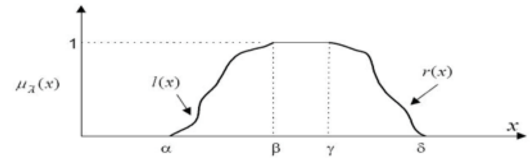


Fig. (6): A typical graph of a fuzzy number described by the equation above

The membership function of a trapezoidal fuzzy number will be:

$$\mu_{\tilde{A}}(x)=\begin{cases} (x-\alpha)/(\beta-\alpha) & for \quad x\in[\alpha,\beta] \\ 1 & for \quad x\in[\beta,\gamma] \\ (x-\delta)/(\gamma-\delta) & for \quad x\in[\gamma,\delta] \\ 0 & for \quad x\in(-\infty,\alpha) \ and \ x\in(\delta,\infty) \end{cases}$$

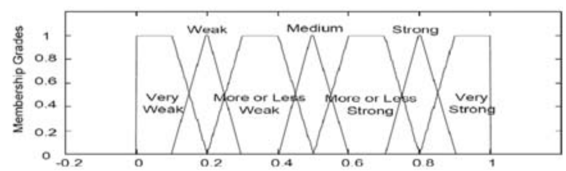


Fig. (7): Linguistic terms for correlation

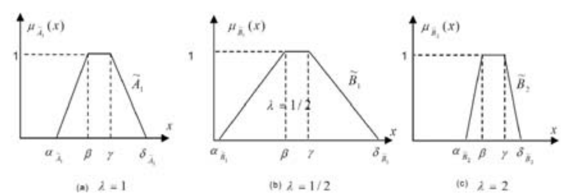


Fig. (8): Different fuzzy numbers revealing different linguistic certainty levels

• ***Absolute coverage***: The absolute coverage of a requirement is examined against its corresponding quality factors in the matrix. For each requirement X, across all quality factors, Y is calculated as:

$$ABS\_Coverage(X_i) = \sum_{k=1}^{\#\_Quality\_Factors} Correlation(X_i, Y_k)$$

(Equation 1)

• ***Relative coverage***: The relative coverage of a requirement is examined against those of all requirements. For each requirement X, the relative coverage is calculated as:

$$REL\_Coverage(X_i) = \frac{ABS\_Coverage(X_i)}{\sum_{k=1}^{\#\_Requirements} ABS\_Coverage(X_k)} \times 10$$

(Equation 2)

The relative coverage ensures that a high-priority customer requirement receives coverage proportional to its priority.

• ***Weighted and relative importance***: For each quality factor X, across all requirements Y, the weighted importance value can be calculated from the importance values of the requirements and the correlation values between this quality factor and all requirements as follows:

$$Weighted\_IMP(X_i) = \sum_{k=1}^{\#\_Requirements} Correlation(Y_k, X_i) \times IMP(Y_k))$$

(Equation 3)

With all the weighted importance values calculated, the relative importance value of a quality factor X can be obtained as follows:

$$REL\_IMP(X_i) = \frac{Weighted\_IMP(X_i)}{\sum_{k=1}^{\#\_Quality\_Factors} Weighted\_IMP(X_k)} \times 10$$

(Equation 4)

- ***Target:*** The development targets are set for one's product.
- ***Roof:*** The roof contains the tradeoffs between the quality elements. A plus sign (+) is used to indicate a positive relation and a minus sign (-) to indicate a negative relation. If improving the satisfaction of one quality factor will harm another, a negative relation exists between the two.

For instance, if the fault tolerance requires more safety checking and recovering calculation, it will very likely sacrifice the efficiency of the system. Thus, fault tolerance and efficiency are negatively related. Conversely, if one quality factor improves another, there is a positive relation.

5.2The F-HoQ Matrix (R1/S1/M1)

The structure of the F-HoQ matrix is shown in Fig. (9).

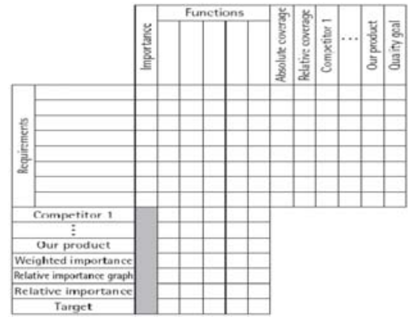


Fig. (9): The F-HoQ matrix

It differs from the Q-HoQ by not having the roof, because the functions are implementation independent. Hence, negative correlations among them are rare. In addition, the F-HoQ deploys requirements to functions instead of quality factors. The calculations of the absolute and relative coverages for the requirements and the weighted and relative importance values for the functions are similar to Equations 1 to 4 used in the Q-HoQ.

5.3 Design Point Analysis Matrix (R3/S3)

The structure of the design point analysis matrix is shown in Fig. (10).

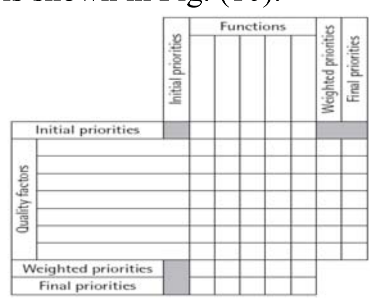


Fig.(10): The design point analysis matrix

It is used to integrate functions and quality factors by examining their impacts on each other. The aim is to produce technical requirements for the next phase so that the original customer requirements are traced along the design of the system components. Following is a list of the components in the design point analysis matrix:

- ***Quality factors and functions***: These are obtained from the Q-HoQ and F-HoQ matrices.
- ***Initial priorities:*** These are obtained from the relative importance values calculated in the Q-HoQ and F-HoQ matrices.
- ***Correlation***: The degree of importance of a quality factor on a function is entered in a correlation matrix cell (the intersection of the quality factor and the function) using crisp values. Three levels of impact are used to fill these cells (as shown in Table (1)).

Table (1): Correlation between requirements/quality factors and functions

◎	Strong	9
○	Medium	3
▽	Weak	1

- ***Weighted priorities***: For each quality factor X and each function Y, the weighted priority can be calculated from the initial priority values and the correlation values as follows:

$$Weighted\_P(X_i) = \sum_{k=1}^{\#\_functions} (Init\_P(X_i) \times Correlation(X_i Y_k) \times Init\_P(Y_k)) \quad \text{(Equation 5)}$$

$$Weighted\_P(Y_i) = \sum_{k=1}^{\#\_Quality\_Factors} (Init\_P(Y_i) \times Correlation(Y_i X_k) \times Init\_P(X_k)) \quad \text{(Equation 6)}$$

- ***Final priorities***: For each quality factor X and each function Y

$$Final\_P(X_i) = \frac{Weighted\_P(X_i)}{\sum_{k=1}^{\#\_Quality\_Factors} Weighted\_P(X_k)} \times 10 \quad \text{(Equation 7)}$$

$$Final\_P(Y_i) = \frac{Weighted\_P(Y_i)}{\sum_{k=1}^{\#\_Functions} Weighted\_P(Y_k)} \times 10 \quad \text{(Equation 8)}$$

These final priorities are calculated for traceability purpose. They reflect the level of satisfaction of the original set of customer requirements.

6. ANAPPLICATION EXAMPLE

The design of a remote sensing micro-satellite system, through which customers requirements are deployed through the design process, was chosen as an example to illustrate the QFD methodology for object-oriented software development. A number of requirements were elicited. From these requirements, the system design starts with a number of major system functionalities as well as system constraints. Figs. (11) - (13) were constructed for the requirements elicitation phase. When it moves to the subsystem design phase, the system functionalities and constraints become the subsystem requirements from which the subsystem constraints and functionalities are listed. Figs. (14) - (16) were constructed for this phase. Finally; the subsystem constraints and functionalities are used to develop module-level functionalities and constraints. Figs. (17) and (18) were developed for the module design phase. Following is an explanation of the HoQs constructed in the three design phases.

6.1 Phase 1: Customer Requirements System Requirements

The Q-HoQ shown in Fig. (11) and the F-HoQ shown in Fig. (12) were developed to deploy the system- level requirements to the system-level product functions and quality factors, respectively. In both figures, the requirements are listed in rows. Fig. (13) is the design point analysis matrix used to analyze the correlation between the quality factors and the functionalities and to integrate them.

Table (2) shows requirements, functions and constraints which have been investigated by the customers and design team at different phases of design of the microsatellite.

Table (2): Requirements, functions and constraints at different phases of design of the microsatellite

	Customer Requirements		System Requirements		Subsystem Functions			Module Functions		
Functional Requirements	CR1	Image Quality (S/N)	SR1	Orbit altitude	SF1	MBEI	Acquire reflected Earth radiation energy & Transform it to electric signals	MF1	MBEI	Optical System
	CR2	Resolution	SR2	Orbit inclination	SF2		Amplify & Transform to digital code	MF2		CCD
	CR3	Location Accuracy	SR3	Scanner aperture size	SF3		Digital Processing & adding service information	MF3		SPE
	CR4	Coverage	SR4	Scanner field of view	SF4	PLCDHS	Receive and store in MMU, image info (MBEI) and commands & annotation info (PCDHS)	MF4	PLCDHS	CDAU
	CR5	Imaging Capacity	SR5	Scanner MTF	SF5		Form & transfer output frames information to X-band	MF5		MMU
	CR6	Responsiveness	SR6	MMU size	SF6	CSS	Receive commands & data files from GCS	MF6	CSS	S-band Tx
	CR7	Lifetime	SR7	OB Data processing	SF7		Transmit acknowledgement, TM, and data files to GCS	MF7		S-band Rx
			SR8	Average & peak power	SF8		Transmit image video data to GDRS	MF8		S-band AFD
			SR9	Data rates	SF9	GPS	Receive, navigating signals from GPS constellation & Measure current satellite navigation parameters	MF9		X-band Tx
			SR10	S/N ratios	SF10		Send current motion parameters, GPS second mark, GPS TMI to PCDHS	MF10		X-band AFD
			SR11	Stabilization	SF11	PCDHS	Receive, protect, switch and distribute power	MF11	GPS	GPS-NSR
			SR12	Pointing accuracy	SF12		Control work of PCDHS & PLCDHS	MF12		GPS-AFD
			SR13	Slew rate	SF13		TMI collection, processing & transfer	MF13	PCDHS	PCDHS-CPDB
			SR14	Max roll angle	SF14		OTS handling	MF14		OBC
			SR15	Transmitter power	SF15		Form annotation information for PLCDHS	MF15		PCDHS-CCU
			SR16	G/T, Rx sensitivity	SF16	ADCS	attitude determination	MF16		PCDHS-CM
			SR17	Staffing	SF17		pointing accuracy at normal and standby modes	MF17		PCDHS-TM Module
					SF18		Realization of program rotations	MF18	ADCS	ADCS Sensors
					SF19	PSS	Generate, store, provide and control power	MF19		ADCS Actuators
					SF20	TSS	Temperature maintenance for OB equipment	MF20	PSS	Solar Arrays
					SF21	Structure	Provide required relative attitude of subsystems & units of satellite	MF21		Battery
					SF22	GCS	Generate & transmit commands	MF22		PCU
					SF23		Receive & process acknowledgment and telemetry	MF23	GCS	GCS-Tx
					SF24		Process measured satellite navigation parameters	MF24		GCS-Rx
					SF25		Forecast satellite motion parameters	MF25		FCC-PPS
					SF26		Measure mismatch between OB and ground time scales	MF26		FCC-CSS
					SF27	GDRS	Receive, demodulate, decode X-band radio signal	MF27		FCC-Navigation
					SF28		Preliminary processing of video information	MF28		FCC-TM Processing
					SF29		Information archiving	MF29	GDRS	GDRS-Rx
								MF30		GDRS Processing
Quality Factors			QF1	Availability	SC1		Subsystem Redundancy	MC1		Cold & hot Redundancy
			QF2	Level of security	SC2		Subsystem Reliability	MC2		(m/n) majority voting
			QF3	Operation Effectiveness	SC3		Satellite Access Control	MC3		S-band access keys
					SC4		Parts, Materials and Processes Program	MC4		Module Reliability

Tables (3), and 4 shows how to calculate the importance index for customer requirements using the Analytical Hierarchy process and also a consistency check using the method of Eigen Vectors.

Table (3): A Questionnaire for estimating the preference of one customer requirement to another

With respect to " "	Importance (or Preference) of one Sub-Criterion over another																		
Questions	Criteria	Absolute	Intermediate	Very Strong	Intermediate	Strong	Intermediate	Weak	Intermediate	Equal	Intermediate	Weak	Intermediate	Strong	Intermediate	Very Strong	Intermediate	Absolute	Criteria
		9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
1	Image Quality (S/N)															x			Resolution
2	Image Quality (S/N)													x					Location Accuracy
3	Image Quality (S/N)								x										Coverage
4	Image Quality (S/N)							x											Imaging Capacity
5	Image Quality (S/N)				x														Responsiveness
6	Image Quality (S/N)			x															Lifetime
7	Resolution								x										Location Accuracy
8	Resolution							x											Coverage
9	Resolution						x												Imaging Capacity
10	Resolution					x													Responsiveness
11	Resolution				x														Lifetime
12	Location Accuracy							x											Coverage
13	Location Accuracy						x												Imaging Capacity
14	Location Accuracy					x													Responsiveness
15	Location Accuracy				x														Lifetime
16	Coverage								x										Imaging Capacity
17	Coverage							x											Responsiveness
18	Coverage						x												Lifetime
19	Imaging Capacity								x										Responsiveness
20	Imaging Capacity							x											Lifetime
21	Responsiveness								x										Lifetime

Table (4): The AHP method for calculation of Customer Requirements importance index

	A	B	C	D	E	F	G	H
		CR-1	CR-2	CR-3	CR-4	CR-5	CR-6	CR-7
1	CR-1	1	1/7	1/5	2	3	6	7
2	CR-2	7	1	2	3	4	5	6
3	CR-3	5	1/2	1	3	4	5	6
4	CR-4	1/2	1/3	1/3	1	2	3	4
5	CR-5	1/3	1/4	1/4	1/2	1	2	3
6	CR-6	1/6	1/5	1/5	1/3	1/2	1	2
7	CR-7	1/7	1/6	1/6	1/4	1/3	1/2	1

Consistency Check - Eigen value / Eigenvector Method

	A	B	C	D	E	F	G	H		I	J	K	L	M	N	O	P	Q	R
		CR-1	CR-2	CR-3	CR-4	CR-5	CR-6	CR-7		SR-1	SR-2	SR-3	SR-4	SR-5	SR-6	SR-7	Score	Product	Ratio
1	CR-1	1.00	0.14	0.20	2.00	3.00	6.00	7.00		0.0707	0.0551	0.0482	0.1983	0.2022	0.2667	0.2414	0.15466236	1.1682	7.5532
2	CR-2	7.00	1.00	2.00	3.00	4.00	5.00	6.00		0.4949	0.3857	0.4819	0.2975	0.2697	0.2222	0.2069	0.33697921	2.9441	8.7368
3	CR-3	5.00	0.50	1.00	3.00	4.00	5.00	6.00		0.3535	0.1928	0.2410	0.2975	0.2697	0.2222	0.2069	0.25480558	2.2115	8.6792
4	CR-4	0.50	0.33	0.33	1.00	2.00	3.00	4.00		0.0354	0.1286	0.0803	0.0992	0.1348	0.1333	0.1379	0.10707179	0.7824	7.3071
5	CR-5	0.33	0.25	0.25	0.50	1.00	2.00	3.00		0.0236	0.0964	0.0602	0.0496	0.0674	0.0889	0.1034	0.06993834	0.5073	7.2532
6	CR-6	0.17	0.20	0.20	0.33	0.50	1.00	2.00		0.0118	0.0771	0.0482	0.0331	0.0337	0.0444	0.0690	0.04532685	0.3226	7.1161
7	CR-7	0.14	0.17	0.17	0.25	0.33	0.50	1.00		0.0101	0.0643	0.0402	0.0248	0.0225	0.0222	0.0345	0.03121587	0.2247	7.1978
										1	1	1	1	1	1	1	1	CI	0.115320
																		CI/RI	0.087363

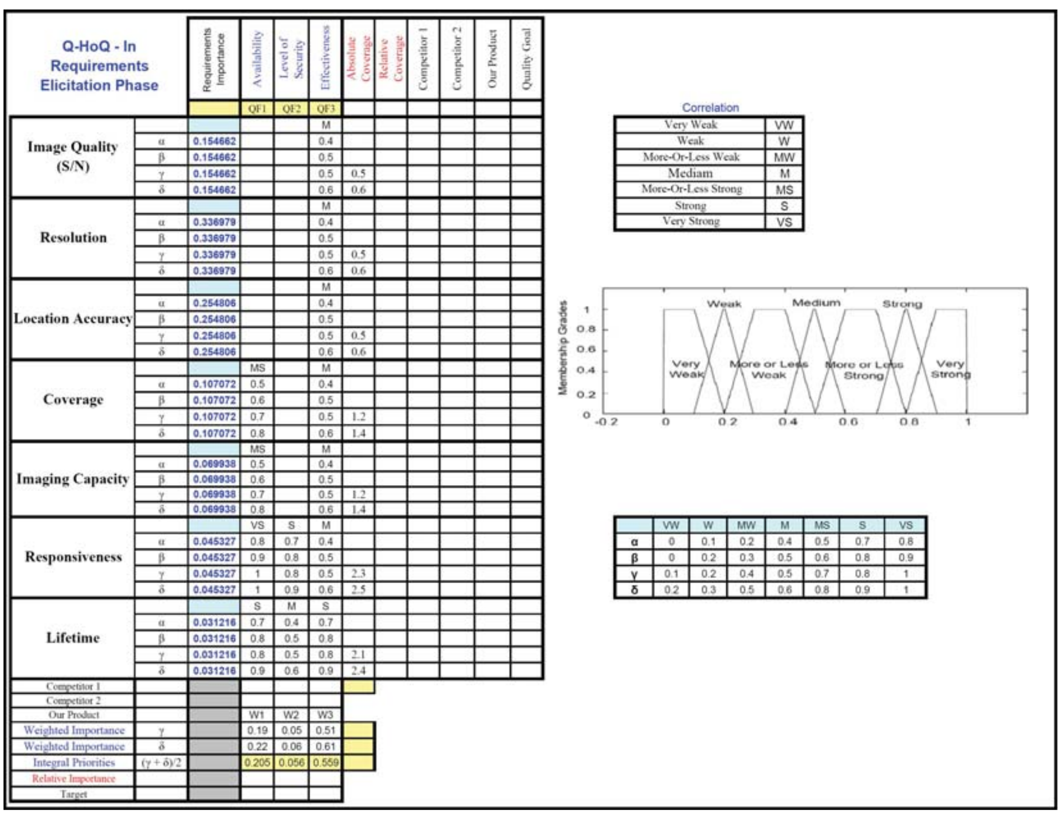


Fig. (11): Q-HoQ in requirements elicitation phase -

F-HoQ - In Requirements Elicitation Phase		Requirements Importance	Orbit altitude	Orbit inclination	Scanner aperture size	Scanner field of view	Scanner MTF	MMU size	OB Data processing	Average & peak power	Data rates	S/N ratios	Stabilization	Pointing accuracy	Slew rate	Max roll angle	Transmitter power	G/T, Rx sensitivity	Staffing	Absolute Coverage	Relative Coverage	Competitor 1	Competitor 2	Our Product	Quality Goal
			SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17						
Image Quality (S/N)											S	VS					S	S							
	α	0.154662									0.7	0.8					0.7	0.7							
	β	0.154662									0.8	0.9					0.8	0.8							
	γ	0.154662									0.8	1					0.8	0.8		3.400					
	δ	0.154662									0.9	1					0.9	0.9		3.700					
Resolution			S	MS	VS		S				M														
	α	0.336979	0.7	0.5	0.8		0.7				0.4														
	β	0.336979	0.8	0.6	0.9		0.8				0.5														
	γ	0.336979	0.8	0.7	1		0.8				0.5									3.800					
	δ	0.336979	0.9	0.8	1		0.9				0.6									4.200					
Location Accuracy			W	W						S		W	S	VS											
	α	0.254806	0.1	0.1						0.7		0.1	0.7	0.8											
	β	0.254806	0.2	0.2						0.8		0.2	0.8	0.9											
	γ	0.254806	0.2	0.2						0.8		0.2	0.8	1						3.200					
	δ	0.254806	0.3	0.3						0.9		0.3	0.9	1						3.700					
Coverage			VS	M	W	S		S		W	MS		S		S	S									
	α	0.107072	0.8	0.4	0.1	0.7		0.7		0.1	0.5		0.7		0.7	0.7									
	β	0.107072	0.9	0.5	0.2	0.8		0.8		0.2	0.6		0.8		0.8	0.8									
	γ	0.107072	1	0.5	0.2	0.8		0.8		0.2	0.7		0.8		0.8	0.8				6.600					
	δ	0.107072	1	0.6	0.3	0.9		0.9		0.3	0.8		0.9		0.9	0.9				7.500					
Imaging Capacity					W	S		VS	VS	MS	S		M		M	S									
	α	0.069938			0.1	0.7		0.8	0.8	0.5	0.7		0.4		0.4	0.7									
	β	0.069938			0.2	0.8		0.9	0.9	0.6	0.8		0.5		0.5	0.8									
	γ	0.069938			0.2	0.8		1	1	0.7	0.8		0.5		0.5	0.8				6.300					
	δ	0.069938			0.3	0.9		1	1	0.8	0.9		0.6		0.6	0.9				7.000					
Responsiveness						W		M	S	S	S	W	M	W	M				S						
	α	0.045327				0.1		0.4	0.7	0.7	0.7	0.1	0.4	0.1	0.4				0.7						
	β	0.045327				0.2		0.5	0.8	0.8	0.8	0.2	0.5	0.2	0.5				0.8						
	γ	0.045327				0.2		0.5	0.8	0.8	0.8	0.2	0.5	0.2	0.5				0.8	5.300					
	δ	0.045327				0.3		0.6	0.9	0.9	0.9	0.3	0.6	0.3	0.6				0.9	6.300					
Lifetime			S						M	W							S	M	S						
	α	0.031216	0.7						0.4	0.1							0.7	0.4	0.7						
	β	0.031216	0.8						0.5	0.2							0.8	0.5	0.8						
	γ	0.031216	0.8						0.5	0.2							0.8	0.5	0.8	3.600					
	δ	0.031216	0.9						0.6	0.3							0.9	0.6	0.9	4.200					
Competitor 1																									
Competitor 2																									
Our Product			W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17						
Weighted Importance	γ		0.45	0.34	0.37	0.15	0.27	0.18	0.12	0.32	0.46	0.21	0.35	0.26	0.14	0.14	0.15	0.14	0.06						
Weighted Importance	δ		0.51	0.41	0.39	0.17	0.30	0.19	0.13	0.37	0.53	0.24	0.39	0.27	0.17	0.16	0.17	0.16	0.07						
Integral Priorities	$(\gamma + \delta)/2$		0.484	0.375	0.381	0.162	0.286	0.186	0.126	0.342	0.495	0.230	0.371	0.266	0.154	0.150	0.158	0.149	0.065						
Relative Importance																									
Target																									

Fig. (12): F-HoQ in requirements elicitation phase

Design Point Analysis Matrix - In Requirements Elicitation Phase			Initial Priorities	Orbit altitude	Orbit inclination	Scanner aperture size	Scanner field of view	Scanner MTF	MMU size	OB Data processing	Average & peak power	Data rates	S/N ratios	Stabilization	Pointing accuracy	Slew rate	Max roll angle	Transmitter power	G/T, Rx sensitivity	Staffing	Weighted Priorities	Final Priorities
				SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8	SR9	SR10	SR11	SR12	SR13	SR14	SR15	SR16	SR17		
Initial Priorities				0.484	0.375	0.381	0.162	0.286	0.186	0.126	0.342	0.495	0.230	0.371	0.266	0.154	0.150	0.158	0.149	0.065		
Availability		QF1	0.205						W	S	S	S		W		W	W	MS	M	S		
	α		0.205						0.1	0.7	0.7	0.7		0.1		0.1	0.1	0.5	0.4	0.7		
	β		0.205						0.2	0.8	0.8	0.8		0.2		0.2	0.2	0.6	0.5	0.8		
	γ		0.205						0.2	0.8	0.8	0.8		0.2		0.2	0.2	0.7	0.5	0.8	0.2418	
	δ		0.205						0.3	0.9	0.9	0.9		0.3		0.3	0.3	0.8	0.6	0.9	0.2868	
	$(\gamma + \delta)/2$																				0.2643	
Level of Security		QF2	0.056	W	W					W	W	M						MS	M	VS		
	α		0.056	0.1	0.1					0.1	0.1	0.4						0.5	0.4	0.8		
	β		0.056	0.2	0.2					0.2	0.2	0.5						0.6	0.5	0.9		
	γ		0.056	0.2	0.2					0.2	0.2	0.5						0.7	0.5	1	0.0427	
	δ		0.056	0.3	0.3					0.3	0.3	0.6						0.8	0.6	1	0.0546	
	$(\gamma + \delta)/2$																				0.0487	
Effectiveness		QF3	0.559			M	M	MS	M	M	M	MS	MS		W			M	M			
	α		0.559			0.4	0.4	0.5	0.4	0.4	0.4	0.5	0.5		0.1			0.4	0.4			
	β		0.559			0.5	0.5	0.6	0.5	0.5	0.5	0.6	0.6		0.2			0.5	0.5			
	γ		0.559			0.5	0.5	0.7	0.5	0.5	0.5	0.7	0.7		0.2			0.5	0.5		0.8456	
	δ		0.559			0.6	0.6	0.8	0.6	0.6	0.6	0.8	0.8		0.3			0.6	0.6		1.0011	
	$(\gamma + \delta)/2$																				0.9233	
Weighted Importance	γ			0.005	0.004	0.107	0.045	0.112	0.060	0.057	0.156	0.289	0.090	0.015	0.030	0.006	0.006	0.073	0.061	0.0143		
Weighted Importance	δ			0.008	0.006	0.128	0.054	0.128	0.074	0.067	0.184	0.329	0.103	0.023	0.045	0.009	0.009	0.086	0.073	0.0156		
Integral Priorities	$(\gamma + \delta)/2$			0.0068	0.0053	0.1172	0.0497	0.1201	0.0667	0.0623	0.1696	0.3091	0.0963	0.0190	0.0372	0.0079	0.0077	0.0795	0.0670	0.0150		
Final Priorities																						

Fig. (13): DPAM in requirements elicitation phase

6.2 Phase 2: System Requirements

Q-HoQ - In Subsystem Design Phase

	Requirements Importance	Subsystem Redundancy (SC1)	Subsystem Reliability (SC2)	Satellite Access Control (SC3)	Parts, Materials and Processes Program (SC4)	Absolute Coverage	Relative Coverage	Competitor 1	Competitor 2	Our Product	Quality Goal
Orbit altitude	0.0068		1			1	0.1				
Orbit inclination	0.0053		1			1	0.1				
Scanner aperture size	0.1172				1	1	0.1				
Scanner field of view	0.0497				1	1	0.1				
Scanner MTF	0.1201		1			1	0.1				
MMU size	0.0667	3			1	4	0.4				
OB Data processing	0.0623	1	3	9	3	16	1.5				
Average & peak power	0.1696	3	3	3	1	10	0.9				
Data rates	0.3091		3	1	3	7	0.6				
S/N ratios	0.0963	1	3		3	7	0.6				
Stabilization	0.0190		1			1	0.1				
Pointing accuracy	0.0372		1			1	0.1				
Slew rate	0.0079		1			1	0.1				
Max roll angle	0.0077		1			1	0.1				
Transmitter power	0.0795	1	1		3	5	0.5				
G/T, Rx sensitivity	0.0670		3		3	6	0.5				
Staffing	0.0150				9	9	0.8				
Availability	0.2643	9	9		3	21	1.9				
Level of Security	0.0487			9		9	0.8				
Effectiveness	0.9233	3	3		1	7	0.6				
Competitor 1						110					
Competitor 2											
Our Product		W1	W2	W3	W4						
Weighted Importance		6.096	7.545	1.817	4.097	19.555					
Relative Importance		3.1172	3.8584	0.9291	2.0952						
Target											

Correlation		
◎	Strong	9
○	Medium	3
▽	Weak	1

Fig. (14): Q-HoQ in subsystem design phase

F-HoQ - In Subsystem Design Phase

	Requirements Importance	Acquire reflected Earth radiation energy & Transform it to electrical signals	Amplify & Transform to digital code	Digital Processing & adding service information	Receive and store in MMU, image info (MBEI) and commands & annotation info (PCDHS)	Form & transfer output frames information to X-band	Receive commands & data files from GCS	Transmit acknowledgement, TM, and data files to GCS	Transmit image video data to GDRS	Receive, navigating signals from GPS constellation & Measure current satellite navigation parameters	Send current motion parameters, GPS second mark, GPS TMI to PCDHS	Receive, protect, switch and distribute power	Control work of PCDHS & PLCDHS	TMI collection, processing & transfer	OTS handling	Form annotation information for PLCDHS	attitude determination	pointing accuracy at normal and standby modes	Realization of program rotations	Generate, store, provide and control power	Temperature maintenance for OB equipment	Provide required relative attitude of subsystems & units of satellite	Generate & transmit commands	Receive & process acknowledgment and telemetry	Process measured satellite navigation parameters	Forecast satellite motion parameters	Measure mismatch between OB and ground time scales	Receive, demodulate, decode X-band radio signal	Preliminary processing of video information	Information archiving	Absolute Coverage	Relative Coverage	Competitor 1	Competitor 2	Our Product	Quality Goal
		MBEI			PLCDHS		CSS			GPS		PCDHS					ADCS			PSS	TSS	Str	GCS					GDRS								
		SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF10	SF11	SF12	SF13	SF14	SF15	SF16	SF17	SF18	SF19	SF20	SF21	SF22	SF23	SF24	SF25	SF26	SF27	SF28	SF29						
Orbit altitude	0.0068	9							1	3					1		1					1	1	1		1		1			20.00	0.40				
Orbit inclination	0.0053	1								1							1									1					4.00	0.08				
Scanner aperture size	0.1172	3																													3.00	0.06				
Scanner field of view	0.0497	3																				1									4.00	0.08				
Scanner MTF	0.1201	3																													3.00	0.06				
MMU size	0.0667				9	1	1		1																						12.00	0.24				
OB Data processing	0.0623		1	9	3	3		1	3	1	1		3	9	3	9	3			1	1		3	3							57.00	1.15				
Average & peak power	0.1696	1	1	1	1	1	1	1	1	1	1	9	3	1	1	1	1	1	3	9	1		1	1	1				3	3	49.00	0.99				
Data rates	0.3091				3	3	3	3	9	3	3		1	1						1	1		3	3	3		1	3	3	3	50.00	1.01				
S/N ratios	0.0963	1	9			1		1	1	1	1		1	1		1				1	1		1	1	1		1	3	3	3	33.00	0.67				
Stabilization	0.0190									3								3	1			3				9					19.00	0.38				
Pointing accuracy	0.0372								1	1							3	9				9				9					32.00	0.65				
Slew rate	0.0079								1	3								1	9							1					15.00	0.30				
Max roll angle	0.0077								1									1	9			1				1					13.00	0.26				
Transmitter power	0.0795						3						3		3					3	1		3					3			19.00	0.38				
G/T, Rx sensitivity	0.0670							3	3															3			3	3			15.00	0.30				
Staffing	0.0150																						9	9	3	9	3	3	9	9	54.00	1.09				
Availability	0.2643	1	3	3	1	1	3	1	1	1		3	3	3	1		1	1	1	3			3	1	1		1	3	3		43.00	0.87				
Level of Security	0.0487						9	3															9	3							24.00	0.48				
Effectiveness	0.9233			1	3	3			3	1		1	1	1	1			1	1				1	1			1	3	3		26.00	0.53				
Competitor 1																															495.00					
Competitor 2																																				
Our Product		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29						
Weighted Importance		1.458	1.892	2.447	4.918	4.481	2.633	1.867	6.596	2.587	1.256	3.243	3.056	2.852	1.789	0.827	0.745	1.765	1.856	3.026	0.717	0.456	3.915	3.057	1.503	0.669	1.839	5.270	5.423	1.860	74.00					
Relative Importance		0.1970	0.2556	0.3306	0.6647	0.6056	0.3559	0.2523	0.8914	0.3496	0.1697	0.4382	0.4130	0.3854	0.2418	0.1117	0.1006	0.2385	0.2508	0.4089	0.0969	0.0616	0.5291	0.4131	0.2030	0.0903	0.2485	0.7122	0.7328	0.2514						
Target																																				

Correlation		
◎	Strong	9
○	Medium	3
▽	Weak	1

Fig. (15): F-HoQ in subsystem design phase

Design Point Analysis Matrix - In Subsystem Design Phase

Subsystem	SF	Function	Initial Priorities	Subsystem Redundancy (3.1172)	Subsystem Reliability (3.8584)	Satellite Access Control (0.9291)	Parts, Materials and Processes Program (2.0952)	Weighted Priorities	Final Priorities
MBEI	SF1	Acquire reflected Earth radiation energy & Transform it to electric signals	0.1970		3			2.28	0.1342
	SF2	Amplify & Transform to digital code	0.2556		1		3	2.59	0.1526
	SF3	Digital Processing & adding service information	0.3306		1		3	3.35	0.1974
PLCDHS	SF4	Receive & store in MMU, image information from MBEI and commands & annotation information from PCDHS	0.6647	3	3		3	18.09	1.0648
	SF5	Form & transfer output frames information to X-band	0.6056		1		3	6.14	0.3616
CSS	SF6	Receive commands & data files from GCS	0.3559	3	1	9	3	9.91	0.5836
	SF7	Transmit acknowledgement, TM, and data files to GCS	0.2523	3	1	9	3	7.03	0.4138
	SF8	Transmit image video data to GDRS	0.8914	3	1		3	17.38	1.0231
GPS	SF9	Receive, navigating signals from GPS constellation & Measure current satellite navigation parameters	0.3496	3				3.27	0.1924
	SF10	Send current motion parameters, GPS second mark, GPS TMI to PCDHS	0.1697	3			3	2.65	0.1562
PCDHS	SF11	Receive, protect, switch and distribute power	0.4382	3	3		3	11.92	0.7020
	SF12	Control work of PCDHS & PLCDHS	0.4130	3	1		3	8.05	0.4740
	SF13	TMI collection, processing & transfer	0.3854		1		1	2.29	0.1351
	SF14	OTS handling	0.2418				3	1.52	0.0895
	SF15	Form annotation information for PLCDHS	0.1117		1		3	1.13	0.0667
ADCS	SF16	attitude determination	0.1006	3	1		1	1.54	0.0907
	SF17	pointing accuracy at normal and standby modes	0.2385	3	1		3	4.65	0.2737
	SF18	Realization of program rotations	0.2508		3		3	4.48	0.2637
PSS	SF19	Generate, store, provide and control power	0.4089	3	3		3	11.13	0.6550
TSS	SF20	Temperature maintenance for OB equipment	0.0969		9		1	3.57	0.2100
Str	SF21	Provide required relative attitude of subsystems & units of satellite	0.0616		9		3	2.53	0.1488
GCS	SF22	Generate & transmit commands	0.5291	1	1	3	9	15.14	0.8914
	SF23	Receive & process acknowledgment and telemetry	0.4131	1	1		3	5.48	0.3225
	SF24	Process measured satellite navigation parameters	0.2030		3		3	3.63	0.2135
	SF25	Forecast satellite motion parameters	0.0903				3	0.57	0.0334
	SF26	Measure mismatch between OB and ground time scales	0.2485				3	1.56	0.0920
GDRS	SF27	Receive, demodulate, decode X-band radio signal	0.7122		1		3	7.22	0.4253
	SF28	Preliminary processing of video information	0.7328		1		3	7.43	0.4376
	SF29	Information archiving	0.2514	3	1			3.32	0.1955
								169.9	

Requirement	Importance	Weighted Priorities	Final Priorities
Subsystem Redundancy	3.1172	45.34	2.6690
Subsystem Reliability	3.8584	55.92	3.2921
Satellite Access Control	0.9291	6.56	0.3862
Parts, Materials and Processes Program	2.0952	62.05	3.6528
		169.9	

Fig. (16): DPAM in subsystem design phase

6 .3 Phase 3: Subsystem Requirements

Q-HoQ - In Module Design Phase

	Requirements Importance	MC1 Cold & hot Redundancy	MC2 (m/n) majority voting	MC3 S-band access keys	MC4 Module Reliability	Absolute Coverage	Relative Coverage	Competitor 1	Competitor 2	Our Product	Quality Goal
Acquire reflected Earth radiation energy & Transform it to electric signals	0.1342	1	1		3	5	0.27				
Amplify & Transform to digital code	0.1526	3			3	6	0.32				
Digital Processing & adding service information	0.1974	3			3	6	0.32				
Receive and store in MMU, image info (MBEI) and commands & annotation info (PCDHS)	1.0648	3	1		3	7	0.38				
Form & transfer output frames information to X-band	0.3616				3	3	0.16				
Receive commands & data files from GCS	0.5836	3		9		12	0.65				
Transmit acknowledgement, TM, and data files to GCS	0.4138	3			3	6	0.32				
Transmit image video data to GDRS	1.0231	3			3	6	0.32				
Receive, navigating signals from GPS constellation & Measure current satellite navigation parameters	0.1924	3			1	4	0.22				
Send current motion parameters, GPS second mark, GPS TMI to PCDHS	0.1562	1			3	4	0.22				
Receive, protect, switch and distribute power	0.7020				3	3	0.16				
Control work of PCDHS & PLCDHS	0.4740	3	3		1	7	0.38				
TMI collection, processing & transfer	0.1351	3			3	6	0.32				
OTS handling	0.0895	1				1	0.05				
Form annotation information for PLCDHS	0.0667				3	3	0.16				
attitude determination	0.0907	3			1	4	0.22				
pointing accuracy at normal and standby modes	0.2737	3	9		3	15	0.81				
Realization of program rotations	0.2637	3			3	6	0.32				
Generate, store, provide and control power	0.6550	1	9		9	19	1.03				
Temperature maintenance for OB equipment	0.2100				1	1	0.05				
Provide required relative attitude of subsystems & units of satellite	0.1488				3	3	0.16				
Generate & transmit commands	0.8914			3		3	0.16				
Receive & process acknowledgment and telemetry	0.3225				1	1	0.05				
Process measured satellite navigation parameters	0.2135				3	3	0.16				
Forecast satellite motion parameters	0.0334				3	3	0.16				
Measure mismatch between OB and ground time scales	0.0920				3	3	0.16				
Receive, demodulate, decode X-band radio signal	0.4253				3	3	0.16				
Preliminary processing of video information	0.4376				3	3	0.16				
Information archiving	0.1955	3				3	0.16				
Subsystem Redundancy	2.6690	9				9	0.49				
Subsystem Reliability	3.2921	3	3		3	9	0.49				
Satellite Access Control	0.3862			9		9	0.49				
Parts, Materials and Processes Program	3.6528				9	9	0.49				
Competitor 1						185	10				
Competitor 2											
Our Product		W1	W2	W3	W4						
Weighted Importance		50.11	20.86	11.40	68.82	151.2					
Relative Importance		3.315	1.379	0.754	4.552	10.00					
Target											

Correlation		
◎	Strong	9
○	Medium	3
▽	Weak	1

Fig. (17): Q-HoQ in module design phase

F-HoQ - In Module Design Phase	Requirements Importance	Optical System	CCD	SPE	CDAU	MMU	S-band Tx	S-band Rx	S-band AFD	X-band Tx	X-band AFD	GPS-NSR	GPS-AFD	PCDHS-CPDB	OBC	PCDHS-CCU	PCDHS-CM	PCDHS-TM Module	ADCS Sensors	ADCS Actuators	Solar Arrays	Battery	PCU	GCS-Tx	GCS-Rx	FCC-PPS	FCC-CSS	FCC-Navigation	FCC-TM Processing	GDRS-Rx	GDRS Processing	Absolute Coverage	Relative Coverage	Competitor 1	Competitor 2	Our Product	Quality Goal
		MBEI			PLCDHS		CSS					GPS		PCDHS					ADCS		PSS			GCS						GDRS							
		MF1	MF2	MF3	MF4	MF5	MF6	MF7	MF8	MF9	MF10	MF11	MF12	MF13	MF14	MF15	MF16	MF17	MF18	MF19	MF20	MF21	MF22	MF23	MF24	MF25	MF26	MF27	MF28	MF29	MF30						
Acquire reflected Earth radiation energy & Transform it to electric signals	0.1342	9	9																1	3	1	1	1									25	0.35				
Amplify & Transform to digital code	0.1526			9																	1	1	3									14	0.20				
Digital Processing & adding service information	0.1974			9																	1	1	3									14	0.20				
Receive and store in MMU, image info (MBEI) and commands & annotation info (PCDHS)	1.0648				9	9															1	1	1									21	0.30				
Form & transfer output frames information to X-band	0.3616				9																1	1	1									12	0.17				
Receive commands & data files from GCS	0.5836							9	9												1	1	1	9								30	0.42				
Transmit acknowledgement, TM, and data files to GCS	0.4138						9		9												3	3	3		3							30	0.42				
Transmit image video data to GDRS	1.0231									9	9										3	3	3							3		30	0.42				
Receive, navigating signals from GPS constellation & Measure current satellite navigation parameters	0.1924											9	9								1	1	1									21	0.30				
Send current motion parameters, GPS second mark, GPS TMI to PCDHS	0.1562											9									1	1	1									12	0.17				
Receive, protect, switch and distribute power	0.7020													9							3	3	3									18	0.25				
Control work of PCDHS & PLCDHS	0.4740														9	9					3	3	3									27	0.38				
TMI collection, processing & transfer	0.1351						3											9			1	1	1									15	0.21				
OTS handling	0.0895											3	3		3																	9	0.13				
Form annotation information for PLCDHS	0.0667													1	3	1					1	1	1									8	0.11				
attitude determination	0.0907																		9		1	1	1									12	0.17				
pointing accuracy at normal and standby modes	0.2737																		3	9	3	3	3									21	0.30				
Realization of program rotations	0.2637																			9	3	3	3									18	0.25				
Generate, store, provide and control power	0.6550																				9	9	9									27	0.38				
Temperature maintenance for OB equipment	0.2100	3	1				1			1					3							9										18	0.25				
Provide required relative attitude of subsystems & units of satellite	0.1488	9							3		3		3						9		1											28	0.39				
Generate & transmit commands	0.8914							3	3															9		9						24	0.34				
Receive & process acknowledgment and telemetry	0.3225						3		3																9				9			24	0.34				
Process measured satellite navigation parameters	0.2135																										1	9				10	0.14				
Forecast satellite motion parameters	0.0334																									1	1	9				11	0.15				
Measure mismatch between OB and ground time scales	0.0920																								1	3	3	3				10	0.14				
Receive, demodulate, decode X-band radio signal	0.4253																													9	3	12	0.17				
Preliminary processing of video information	0.4376																														9	9	0.13				
Information archiving	0.1955																														3	3	0.04				
Subsystem Redundancy	2.6690			3	3		3	3		3		3			3	3	3	3	3	3	1	1	1									39	0.55				
Subsystem Reliability	3.2921		1	1	1	1	1	1	3	1	3	3	3		3	3	3	3			3	3	3	3	3	1	1	1	1	9	9	68	0.96				
Satellite Access Control	0.3862						3	9	3															9	3							27	0.38				
Parts, Materials and Processes Program	3.6528	3	3	1	3	3	3	3	1	3	1	1	1	3	3	3	3	3	3	3	3	3	3	1	1					3	3	64	0.90				
Competitor 1																																##	10				
Competitor 2																																					
Our Product		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30						
Weighted Importance		14.14	15.67	18.10	35.10	23.83	28.72	33.66	27.75	31.68	23.18	24.94	15.98	17.34	34.21	33.17	28.84	30.06	22.08	24.20	42.13	43.87	42.68	30.28	18.92	11.62	3.82	5.79	6.19	47.48	46.39	781.8					
Relative Importance		0.181	0.200	0.232	0.449	0.305	0.367	0.431	0.355	0.405	0.297	0.319	0.204	0.222	0.438	0.424	0.369	0.384	0.282	0.310	0.539	0.561	0.546	0.387	0.242	0.149	0.049	0.074	0.079	0.607	0.593	10.00					
Target																																					

Correlation		
◎	Strong	9
○	Medium	3
▽	Weak	1

Fig. (18): F-HoQ in module design phase

Resultant Priorities of Module Functions and module constraints

Table (4): shows the resultant calculated importance or priorities of different module function and module constraints of micro-satellite systems.

Table (4): module functions priorities

No	Mod Fn	Function	Priority	Priority Weighted
1	MF30	GDRS Processing	0.623	0.5497059
2	MF29	GDRS-Rx	0.601	0.5302941
3	MF21	Battery	0.531	0.4685294
4	MF22	PCU	0.514	0.4535294
5	MF20	Solar Arrays	0.508	0.4482353
6	MF4	CDAU	0.490	0.4323529
7	MF14	OBC	0.449	0.3961765
8	MF7	S-band Rx	0.440	0.3882353
9	MF15	PCDHS-CCU	0.435	0.3838235
10	MF17	PCDHS-TM Module	0.397	0.3502941
11	MF23	GCS-Tx	0.395	0.3485294
12	MF16	PCDHS-CM	0.382	0.3370588
13	MF6	S-band Tx	0.381	0.3361765
14	MF8	S-band AFD	0.362	0.3194118
15	MF5	MMU	0.338	0.2982353
16	MF11	GPS-NSR	0.327	0.2885294
17	MF19	ADCS Actuators	0.324	0.2858824
18	MF9	X-band Tx	0.312	0.2752941
19	MF18	ADCS Sensors	0.294	0.2594118
20	MF24	GCS-Rx	0.254	0.2241176
21	MF3	SPE	0.232	0.2047059
22	MF13	PCDHS-CPDB	0.226	0.1994118
23	MF2	CCD	0.214	0.1888235
24	MF12	GPS-AFD	0.214	0.1888235
25	MF10	X-band AFD	0.201	0.1773529
26	MF1	Optical System	0.197	0.1738235
27	MF25	FCC-PPS	0.152	0.1341176
28	MF28	FCC-TM Processing	0.083	0.0732353
29	MF27	FCC-Navigation	0.074	0.0652941
30	MF26	FCC-CSS	0.050	0.0441176
No	Mod Ct	Function	Priority	Priority Weighted
1	MC4	Module Reliability	4.642	0.5461176
2	MC1	Cold & hot Redundancy	3.209	0.3775294
3	MC2	(m/n) majority voting	1.386	0.1630588
4	MC3	S-band access keys	0.763	0.0897647

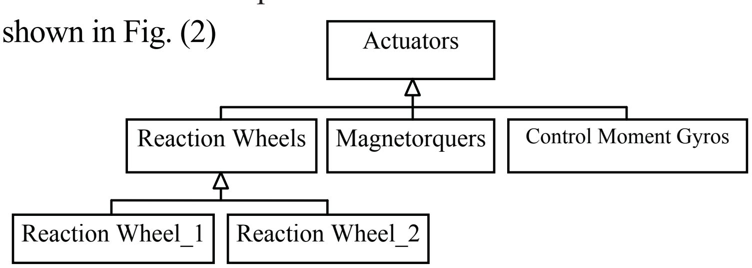
The methodology can be extended to the fourth phase of system design (Component Phase). In this case, the priorities of component functions and component constraints can be identified.

<u>Example:</u> // the ADCS is sub1 as shown in Fig. (2)

Module of subsystem ADCS

Components of Actuator Module (Association)

Different variants of RW (Inherited from RW)



ACRONYMS

MBEI	Multiband Earth Imager	AFD	Antenna Feeder Device
CCD	Charge Coupled Devices	S-Tx	S-Band Transmitter
MTF	Modulation Transfer Function	S-Rx	S-Band Receiver
SPE	Signal Processing Equipment	X-Tx	X-Band Transmitter
PLCDHS	Payload Command and Data Handling Subsystem	NSR	Navigation Signal receiver
CDAU	Configuration and Data Acquisition Unit	GCS	Ground Control Station
MMU	Mass Memory Unit	GDRS	Ground Data Reception Station
PCDHS	Platform Command and Data Handling Subsystem	FCC	Flight Control Center
CCU	Configuration Control Unit	FCC-PPS	Flight Control Center, Payload Scheduling Subsystem
CPDB	Control and Power Distribution Block	FCC-CSS	Flight Control Center, Control Subsystem
CM	Command Module	FCC-NAV	Flight Control Center, Navigation Subsystem
TM	Telemetry Module	FCC-TM	Flight Control Center, Telemetry Processing Subsystem
OBC	On Board Computer	PCU	Power Conditioning Unit
CSS	Communication Subsystem	PMP	Parts, Materials and Processes

7. CONCLUSION

It has been commonly acknowledged that customer requirements are essential in software development to achieve a high level of software quality and customer satisfaction. There are a few methodologies, however, that deal with the traceability of customer requirements through impact analysis throughout the software design process into the design items. The paper proposed a framework that integrates object-oriented software design, which has been a popular paradigm for software development with QFD. The paper major contribution is making the customer requirements traceable from requirements analysis, to system design, subsystem design, and module design so that both customers and software developers can clearly identify whether the important requirements are implemented, and how they are implemented in system design, subsystem design, and module design. In addition, through the methodology, the important requirements can be traced to prioritized design items. With the help of the methodology introduced in this paper, the weights of the requirements and their impacts on the design items are calculated. Design items reflecting more impacts from more important requirements deserve more attention and more resources from software developers. When resources are limited and the choice has to be made on which design items to select for implementation, those with high priority values should be selected. With these design items implemented better, a higher level of customer satisfaction can be achieved than the other design alternatives because more important and more influential requirements have been implemented in the software product before the others. One of the limitations of previous methodologies is that the assignment of correlation values can be arbitrary and can affect the accuracy of the final results. This problem is solved through using the principles of the Fuzzy set theory and through the collaboration of stakeholders during the assignment of correlation values. Each correlation value should be assigned with consensus from all participating stakeholder representatives. This will, to a great extent, remove the possible bias. In addition, the extra cost spent on the calculation of impact relationships is not negligible when the number of requirements and design items becomes large.

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