# Application of Fuzzy Quality Function Deployment for Educational Buildings in Egypt

**Mostafa Khalifa, Hosam El Din Hosny, Ramy Fathy**

*Abstract*— **The construction industry has been one of the most important industries for the development of the Egyptian infrastructure and economy. The construction industry faces many challenges that affect it especially during the design phase. Many of these challenges arise from the changes in the economy ,technology, and user's dissatisfaction .This paper presents a systematic and operational approach to quality function deployment (QFD), a customer-driven quality management system for product development. After a comprehensive description of the relevant elements in house of quality (HOQ), the first and most influential of the QFD system, a 7-step model is proposed to help build such an HOQ. A number of scales are developed whose uses could help unify the various measurements in HOQ to avoid arbitrariness. Special attention is paid to the various subjective assessments in the HOQ process, and symmetrical triangular fuzzy numbers (STFNs) are suggested for use to capture the vagueness in people's linguistic assessments. Design phase has been regarded as an important phase to enhance overall performance in the construction industry. To achieve optimum designs, the design teams need to respond swiftly and efficiently to client requirements, but also to quickly and effectively exchange design and construction information. However, this process is not always easy due to the entrenched horizontal and vertical fragmentation in the industry. A thorough explanation is given to address the concepts, computations and implementations in the proposed HOQ model, followed by an illustrative example for designing an educational entity step by step all the relevant details with the purpose of facilitating the understanding and application of the QFD process.**

*Index Terms*— **Educational buildings, Total quality management, House of Quality (HoQ), Linear programming, Fuzzy, Quality Function Deployment (QFD), Egypt**

## I. INTRODUCTION

Egypt has the largest overall education system in the Middle East and North Africa and it has grown rapidly since the early 1990s. In recent years the Government of Egypt has accorded even greater priority in improving the education system. According to the Human Development Index (HDI), Egypt is ranked 123 in the HDI, and 7 in the lowest 10 HDI countries in the Middle East and Northern Africa, in 2009.

With the help of the World Bank and other multilateral organizations Egypt aims to increase access in early childhood to care and education and the inclusion of ICT at all levels of education, especially at the tertiary level. The government is responsible for offering free education at all levels. The current overall expenditure on education is about 12.6 percent as of 2007. Investment in education as a percentage of GDP rose to 4.8 in 2005 but then fell to 3.7 in 2007.

The Ministry of education is also tackling with a number of issues: trying to move from a highly centralized system to offering more autonomy to individual institutions, thereby increasing accountability. The personnel management in the education also needs to be overhauled and teachers should be hired on merit with salaries attached to the performance.

The design phase for construction industry is a critical stage to achieve client's requirements (Gargione, 1999). Since the design depends on the designers' experience, thus better decision making process during design stage of a project offers the potentials for designers to give clients better value-for money through designs (Yang et al., 2003).

Quality Function Deployment (QFD) can be used as a tool to prioritize important directions offering a potential for improvement according to what the customers' desires. Thus QFD provides the systematic method to support the process of design decision making (Yang et al., 2003).

The major objective of this paper is to apply QFD to improve the basic layout and basic specifications of educational entities in Egypt. To accomplish the objective, three logical steps are necessary. The first step is to obtain the users requirements. The second step is to obtain the technical specifications and features of the proposed entity toward satisfying the client's requirements. The third is to apply the QFD approach to enable the design team to prioritize and improve the quality of the layout design.

## II. LITERATURE REVIEW

### 2.1 A Glance at QFD

Yoji Akao has been credited with the initiation of the concept of QFD in the late 1960s (Chen and Chen, 2002). However, it was a dormant methodology until Kobe shipyards of Mitsubishi Heavy Industries applied QFD (Prasad, 1998, cited in Chen and Chen, 2002) as an integrated decision-making methodology.

Japan is internationally well known as a forerunner of the application of QFD. In the Japan, QFD reached its peak in the 1970s when Toyota Auto Body developed a quality table which is widely known as "the House of Quality (HOQ)" (Chen and Chen,2002). QFD was not formally introduced to the US and Europe until 1983 (Chen and Chen, 2002).

QFD is a method to: (1) develop a design quality aimed at satisfying the customer; and (2) translate the customer's demand into design targets and major quality assurance points to be used throughout the production stage (Akao, 1990, cited in Gargione, 1999). QFD is a methodology to convert the customer's desires into quality characteristics and to develop product design by systematically deploying the relationships of customer desires and product characteristics (Lee et al., 2000). QFD is a systematically way to transmit the customer's expectation to the level of the detailed operation (Yang et al., 2003). QFD uses a complex matrix titled House of Quality (HoQ) to translate

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customer's requirements into the prioritized level of major design solutions (Fig. 1).

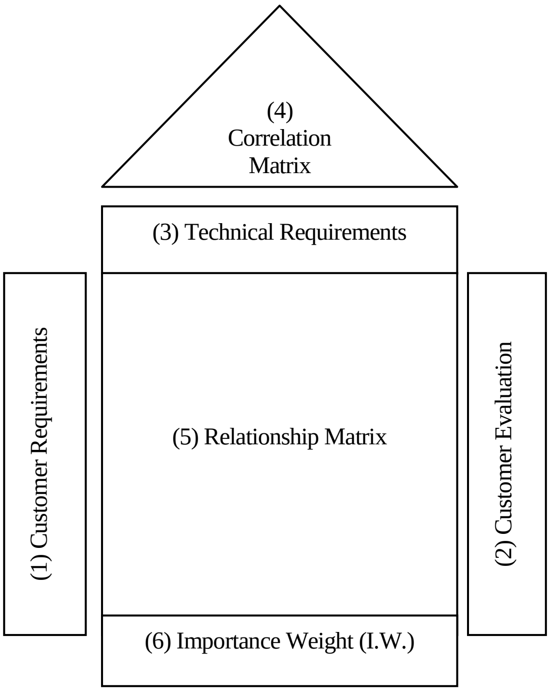


Figure. 1. The House of Quality (HOQ)

QFD is a powerful development methodology with a wide range of applications (Gargione, 1999). Many studies have been undertaken on the application of QFD to improve the quality of teaching (Lam and Zhao, 1998) and academic program (Pitman et al., 1996), to facilitate continuous product improvement with emphasis on the impact of organization learning on innovation (Govers, 2000, cited in Yang et al., 2003), to improve software quality (Erickkson and McFadden, 1993), to enhance the design quality of lithium battery (Halbleib et al., 1993), and to discover impacts of QFD utilization in the development of a non-destructive damage detection system for aerospace structures (Stubbs,1994).

## 2.2 Applications of QFD in Construction

Gargion (1999) reported that the application of QFD has Focused on different ways, such as a hypothetical renovation of apersonal computer workroom (Mallon and Muligan, 1993), integrating of the customer's requirements in an industrialized Housing component (Amarcost et al., 1994), and determining the design characteristics of the internal layout of a building apartment (Serpell and Wagner, 1997), testing the applicability of QFD to construction involving companies from different backgrounds (Huovila et al., 1997).

Other studies of the implementation of QFD in construction have been reported, such as to examine the awareness and applicability of QFD methodology in design/build contracts (Low and Yeap, 2001), to improve layout and features of a middle-class apartment unit (Gargione, 1999), to incorporate customer demands into the design process (Stehn and Bergström, 2002), to establish prioritized order of consumer requirements in low-cost flats (Abdul-Rhman et al., 1999), to propose a model that can be readily used in the planning and design process of capital projects (Ahmed et al., 2003). In the US, Arditi and Lee (2003) proposed the use of the HoQ for clients to assess service quality performance prior to setting up a working relationship with a construction company. In Gaza strip ,Palestine , Jannat Allahham (2010) proposed an application of design an appropriate vocational educational facility using FQFD.

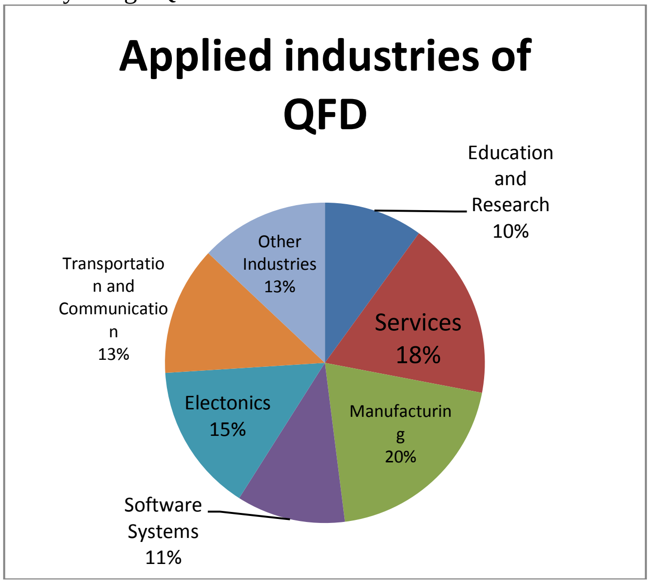


Fig. 2.1: Percentage of Publications in Functional Fields of QFD [Chan and Wu, 2002].

## III. Research Method

### 3.1 Conceptual Research Framework

Since QFD originated from the manufacturing industry, QFD approach must be fine-tuned in accordance with the requirements of the construction industry. This study adopted the methodology presented by Gargione (1999) and Yang et al. (2003) as a conceptual research framework to develop the implementation of QFD for improving the design of an educational entity. The research framework, consisting of seven steps, is introduced in the "case study" section through application to a real educational entity project (A.A.S.T.).

### 3.2 Applying Fuzzy Numbers in the QFD System

Since customer opinions are the inherently imprecise, the Triangular fuzzy number is integrated into HOQ to capture the degree of importance of each customer requirement to the proposed entity.

The computational procedure for fuzzy numbers in the QFD System is adapted from Yang et al. (2003). According to Yang et al. (2003), this procedure consists of three steps: (1) assigning linguistic terms; (2) translating the linguistic terms into triangular fuzzy numbers (Fig. 3); and (3) computing an average triangular fuzzy number from the triangular fuzzy numbers. Details of above steps can be found in Yang et al. (2003). Moreover, a detailed procedure for using fuzzy numbers and functions is available in Quan (2006).

## IV. Case Study

The study used the Construction and Building department of the Arab Academy of Science And Technology And Maritime Transport, Cairo branch. The whole building of the college of engineering consists of four stories. This study focuses on the two stories of the construction and building department.

### 4.1 Step 1: Determining The Customer's Requirements

This research determines a total of 15 customer requirements that were collected from the literature and interviews with experts who are aware of the user's needs.
Table 4.1. Shows the customer requirements.

Table 4.1. The Determined Customer Requirements

| **Factors collected from the literature review** |
|---|
| 1. Existence of clean drinkable water |
| 2. Fresh air |
| 3. Noiseless |
| 4. temperature controlled year round |
| 5. No accidents and incidents |
| 6. Clearly see visual and take notes |
| **Factors derived from interviews** |
| 1. Comfortable seats |
| 2. Easy and quick access to tools in labs and workshops |
| 3. No dead viewing areas |
| 4. Appropriate space like: Enough area , Equipment |
| 5. The availability of educational aids |
| 6. The availability of suitable library in terms of size |
| 7. The availability of required number of labs and workshops |
| 8. The existence of private rooms for each department faculty suitable in terms of size |
| 9. Existence of adequate bathrooms for boys and girls. |

Step 2: Questionnaire design

In order to calculate the customer importance weights a closed-ended questionnaire was used for its advantages such as: it is easy to ask and quick to answer, they require no writing by either respondent or interviewer, and their analysis is straight Forward (Naoum, 1998).The size of the sample required from the population was determined based on statistical principles for this type of exploratory investigation to reflect a confidence level of 95%.

For populations that are large, Cochran (1963:75) developed the Equation to yield a representative sample for proportions.

This study used probability sampling technique for infinite population to calculate the required sample size (respondents). The calculations were based on confidence level 95%, and a desired level of precession +/- 7% (Cochran (1963:75)). The Sample Size was computed as per the following equation:

$$SS = \frac{Z^2 \text{ x } (p) \text{ x } (1-p)}{C^2} \qquad (1)$$

Where SS = Sample Size, Z = Z-values (Cumulative Normal Probability), the equivalent Z-value for a 95 percent confidence level is (1.96), P is equal to (20%) according to the number of answers (five answers) for each question, but since 50% is the critical case percentage in the calculation of sample size, the value used for P in the equation is 0.5, and C = desired level of precession , expressed as decimal (0.07 = +/- 7 percentage points)

Therefore:

$$SS = \frac{(1.96)^2 \text{ x } (0.5) \text{ x } (1-0.5)}{(0.07)^2} = 196$$

The required number of respondents is not less than 196 respondents. However, the target number of questionnaire recipients shall consider a percentage of about 40% of no response to the questionnaire, thereafter, the target number of questionnaire recipients will be as follows

196 X (1+40%) = 275 respondents. (2)

After the effort done to send the questionnaire and collect the experts opinions, the questionnaire responses were analyzed though two stages validity test and reliability test. First stage, testing the questionnaire validity was performed statistically using the criterion-related validity test (Pearson test). The internal consistency of the questionnaire was measured using a scouting sample of sixteen questionnaires. It measured the correlation coefficients between each paragraph in one field and all the field. Table 4.2. Shows the correlation coefficient and p-value for each field paragraph.

Table 4.2. Pearson Coefficient between each Paragraph in Field and Whole Fields.

| | Item | Pearson correlation coefficient | P-value | Significance |
|---|---|---|---|---|
| 1 | Fresh Air | 0.420 | 0.051 | * |
| 2 | No Dead Viewing Area | 0.365 | 0.051 | * |
| 3 | Noiseless | 0.599 | 0.007 | ** |
| 4 | Temperature Controlled Year Round | 0.633 | 0.003 | ** |
| 5 | No Accidents and Incidents | 0.404 | 0.050 | * |
| 6 | Clearly See the Visual Information | 0.609 | 0.006 | ** |
| 7 | Easy and Quick Access to Tools | 0.30 | 0.012 | * |
| 8 | Comfortable Seats | 0.461 | 0.036 | * |
| 9 | Appropriate Space Like: Enough Area and Equipment. | 0.158 | 0.028 | * |
| 10 | The availability of educational aids | 0.666 | 0.002 | * |
| 11 | The availability of suitable library in terms of size | 0.83 | 0.000 | ** |
| 12 | The availability of required number of labs and workshops | 0.609 | 0.006 | ** |
| 13 | Existence of clean drinkable water | 0.30 | 0.012 | * |
| 14 | The existence of private rooms for each department faculty suitable in terms of size. | 0.461 | 0.036 | * |
| 15 | Existence of adequate bathrooms for boys and girls | 0.666 | 0.002 | * |

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

From Table 4.2, it can be seen that the p-values for each paragraph are less than 0.05 or 0.01, so the correlation coefficients of this field are significant at α = 0.01 or α = 0.05. So, it can be said that the paragraphs of this field are consistent and valid to measure what they were set for.

Second, the reliability test was repeated to the same sample used in validity test on two occasions. The scores obtained were compared by computing a reliability coefficient. Two tests were performed on the sample the half split method and Cronbach's coefficient alpha. The results of these tests were as follows:

1. Half Split Method: The Pearson correlation coefficient between the means of odd questions and even questions of each field of the questionnaire was calculated. Then, it was corrected using Spearman Brown correlation coefficient of correction. The corrected correlation coefficient (Consistency coefficient) is computed according to the following equation:

Corrected correlation coefficient = $2r/(r+1)$

Where, r the Pearson correlation coefficient which equals 0.9471.

The normal range of corrected correlation coefficient is between 0.0 and + 1.0. The corrected correlation coefficients value equals 0.9728 and the significant ($\alpha$ ) equal 0.000 which is less than 0.05 so the corrected correlation coefficients are significant at $\alpha = 0.05$. It can be said that According to the Half Split method that the questionnaire is reliable.

2. Cronbach's Coefficient Alpha: This method was used to measure the reliability of the questionnaire between each field and the mean of all fields of the questionnaire. The normal range of Cronbach's coefficient alpha value is between 0.0 and + 1.0, and the higher values reflect a higher degree of internal consistency. The Cronbach's coefficient alpha equals 0.6944. Therefore, Cronbach's coefficient result ensures the reliability of the questionnaire.

Step 3: Customer Importance Weights

The proposed educational entity (A.A.S.T) teachers and students were asked to specify the importance of their requirements as "very unimportant", "unimportant", "moderate", "important", and "very important". Where "very unimportant" has (0, 1, 2) as a score, while "very important" has (8, 9, 10) as a score. Then, the total score that each requirement was calculated by multiplying the number of times score was repeated by the score value. After that, this total score was divided by the total number of customers to obtain the relative importance (RI). The relative importance index (RII) was calculated to determine the ranks of the listed customers' requirements using the following expression:

Relative importance index = $\Sigma$ W/A , (Iyer and Jha, 2005)
Where $\Sigma$ W = the relative importance of each requirements
A = the highest weight (A = 10 in this research)

The relative importance and the relative importance indexes of the customer requirements were obtained using SPSS (Decoursey, 2003). Table 4.3 shows the relative importance and the relative importance indexes of the requirements from the viewpoint of teachers and Table 4.4 shows the relative importance and the relative importance indexes of the requirements from the viewpoint of students.

Table 4.3: Relative Importance and Relative Importance Indexes of Educational Entity (A.A.S.T) Requirements from Academic staff' Point of View

| Customer Requirements | R.I. | R.I.I. |
|---|---|---|
| Existence of drinkable clean water | 8.91 | 0.89 |
| Fresh Air | 8.99 | 0.90 |
| No Accidents and Incidents | 8.76 | 0.88 |
| The availability of educational aids | 9.0 | 0.90 |
| No dead viewing areas | 8.97 | 0.90 |
| Noiseless | 8.00 | 0.80 |
| Temperature controlled year round | 8.62 | 0.86 |
| Clearly see the visual information and take notes | 9.11 | 0.91 |
| Easy and quick access to tools in labs and workshops | 8.24 | 0.82 |
| Appropriate Space like: Enough Area, Equipment and Furniture | 9.01 | 0.90 |
| Comfortable colorful seats | 9.00 | 0.90 |
| The existence of private rooms for each department faculty suitable in terms of size | 8.29 | 0.83 |
| Existence of adequate bathrooms for boys and girls | 8.49 | 0.85 |
| The availability of suitable library in terms of size and equipment | 9.19 | 0.92 |
| The availability of the required number of qualified and secured laboratories and workshops | 9.00 | 0.90 |

Table 4.3: Relative Importance and Relative Importance Indexes of Educational Entity (A.A.S.T) Requirements from students Point of View

| Customer Requirements | R.I. | R.I.I. |
|---|---|---|
| Existence of drinkable clean water | 9.00 | 0.90 |
| Fresh Air | 9.01 | 0.90 |
| No Accidents and Incidents | 8.36 | 0.84 |
| The availability of educational aids | 8.91 | 0.89 |
| No dead viewing areas | 9.02 | 0.90 |
| Noiseless | 7.80 | 0.78 |
| Temperature controlled year round | 9.00 | 0.90 |
| Clearly see the visual information and take notes | 8.87 | 0.89 |
| Easy and quick access to tools in labs and workshops | 7.99 | 0.80 |
| Appropriate Space like: Enough Area, Equipment and Furniture | 9.03 | 0.90 |
| Comfortable colorful seats | 9.01 | 0.90 |
| The existence of private rooms for each department faculty suitable in terms of size | 8.61 | 0.86 |
| Existence of adequate bathrooms for boys and girls | 8.39 | 0.84 |
| The availability of suitable library in terms of size and equipment | 9.12 | 0.91 |
| The availability of the required number of qualified and secured laboratories and workshops | 8.03 | 0.80 |

It has been noticed that, the RII for both teachers and students were nearly the same as shown in Table 4.2 and 4.3. The customer requirement with highest score was "No Dead Viewing Area" because the customers need intense light in the educational entity. "Noiseless" was the customer requirement with lowest score from students and teachers point of view because they do not care about noise or they be accustomed to it in the entity as they are in an open campus.

Thus, the average of students RII and teachers RII was calculated from:
Average Students RII = RII * 133/196
Average Teachers RII= RII * 63/196
Then, the importance weight of each customer requirements was determined from the expression:
Importance weight = average (RII / Σ RII) * 100%.
Average RII and importance weight for customer requirements are shown in Table 4.4.

Table 4.7 shows the final relative importance indexes of customer requirements

Table 4.4: Average RII and Importance Weight for Customer Requirements of the proposed educational entity (A.A.S.T).

| Customer Requirements | R.I. | R.I.I. |
|---|---|---|
| Existence of drinkable clean water | 0.90 | 6.87 |
| Fresh Air | 0.90 | 6.89 |
| No Accidents and Incidents | 0.85 | 6.52 |
| The availability of educational aids | 0.89 | 6.84 |
| No dead viewing areas | 0.90 | 6.89 |
| Noiseless | 0.79 | 6.02 |
| Temperature controlled year round | 0.89 | 6.80 |
| Clearly see the visual information and take notes | 0.90 | 6.87 |
| Easy and quick access to tools in labs and workshops | 0.81 | 6.18 |
| Appropriate Space like: Enough Area, Equipment and Furniture | 0.90 | 6.89 |
| Comfortable colorful seats | 0.90 | 6.89 |
| The existence of private rooms for each department faculty suitable in terms of size | 0.85 | 6.51 |
| Existence of adequate bathrooms for boys and girls | 0.84 | 6.46 |
| The availability of suitable library in terms of size and equipment | 0.91 | 6.99 |
| The availability of the required number of qualified and secured laboratories and workshops | 0.83 | 6.37 |

Step 4: Design Requirements

Based on literature, each design requirement satisfies at least one of the customer requirements as shown in Table 4.5

Table 4.5. The Determined Design Requirements

| **Factors collected from the literature review** |
|---|
| 1. Classroom orientation |
| 2. Ceiling height |
| 3. Ceiling type |
| 4. Window type |
| 5. Window distance from the floor |
| 6. Window dimensions |
| 7. Entrance & exit doors dimensions |
| 8. Emergency door dimensions |
| 9. Number of air conditions |
| 10. Teaching space area |
| 11. Practical space area |
| 12. Floor type |
| 13. Number of seats |
| 14. Seat type |
| 15. Lamps type |
| 16. Wall finishing type |
| 17. Teachers room area |
| 18. labs and workshops area |
| 19. library area |
| 20. wall insulation |
| 21. tables type |
| 22. electrical outlets number |
| 23. board dimensions |
| 24. board type |
| 25. board distance from floor |
| 26. computer + LCD |
| 27. safety equipment type |
| 28. fire alarm system |
| 29. fire extinguisher number |
| 30. first aid kit |
| 31. hot water |
| 32. cold water |
| 33. seating area |
| 34. number of sinks |
| 35. number of tables |

Step 5: Relationship Matrix:

The strength of the relationships between customer requirements and design requirements by using a scale of fuzzy variables: strong, medium, and weak as shown in Table 4.6 (Zaim and Sevkli, 2002). Relationships are conducted through interviews with experts in designing the educational buildings in Egypt.

Table 4.6. The Determined Design Requirements

| Customer Requirement | Design Requirement | Grade |
|---|---|---|
| Fresh Air | Class room Orientation | S |
| | Ceiling Height | M |
| | Ceiling Type | W |
| | Windows Type | S |
| | Windows Distance from the Floor | S |
| | Windows Dimensions | S |
| | Entrance and Exit Doors Dimensions | S |
| | Emergency Door | W |

| | | |
|---|---|---|
| | Dimensions | |
| | Number of Air Conditions | S |
| | Teaching space area | M |
| | Practical space area | M |
| Easy and Quick access to tools | Floor type | S |
| | Practical Area | S |
| Comfortable seats | Floor type | S |
| | Number of seats | S |
| | Seats type | S |
| No Dead Viewing Area | Classroom orientation | W |
| | Ceiling height | M |
| | Ceiling type | S |
| | Windows type | S |
| | Windows distance from floor | S |
| | Windows dimensions | S |
| | Entrance and exit door dimensions | W |
| | emergency door dimensions | W |
| | Lambs type | S |
| | Floor type | W |
| | Wall finishing type | S |
| | Teachers room area | S |
| | Labs and workshop area | S |
| | Teaching space area | S |
| | Practical space area | S |
| | Library area | S |
| Noiseless | Ceiling height | S |
| | Ceiling Type | S |
| | Windows Type | S |
| | Windows Distance from the Floor | S |
| | Windows Dimensions | S |
| | Entrance and Exit Door Dimensions | S |
| | Emergency door dimensions | W |
| | Floor type | M |
| | Wall finishing type | S |
| | Wall insulation | S |
| Temperature Controlled Year Round | Classroom orientation | S |
| | Ceiling height | M |
| | Ceiling type | M |
| | Windows type | S |
| | Windows distance from floor | S |
| | Windows dimensions | S |
| | Entrance and exit door dimensions | S |
| | Emergency door dimensions | W |
| | Wall finishing type | S |
| | Teaching space area | S |
| | Walls insulation | S |
| Appropriate Space like: Enough Area, Equipment and Furniture | Roof Height | M |
| | Roof Type | M |
| | Windows Type | M |
| | Windows Distance from the floor | M |
| | Windows Dimensions | M |
| | Lamps Type | S |
| | Floor Type | S |
| | Tables Type | S |
| | Wall Finishing Type | M |
| | Electrical outlet numbers | S |
| | Practical Space Area | M |
| Clearly See the Visual Information | Classroom Orientation | S |
| | Roof Height | M |
| | Roof Type | M |
| | Windows Type | M |
| | Windows Distance from the Floor | W |
| | Windows Dimensions | W |
| | Lamps Type | S |
| | Number of Seats | S |
| | Seats Type | S |
| | Board Dimension | S |
| | Board Type | S |
| | Board Distance from the Floor | S |
| | (Computer +LCD) | M |
| | Teaching Space Area | S |
| No Accidents And Incidents | Roof Height | S |
| | Roof Type | S |
| | Windows Type | M |
| | Windows Distance from the Floor | M |
| | Windows Dimensions | M |
| | Entrance and Exit Door Dimensions | M |
| | Emergency Door Dimensions | S |
| | Floor Type | S |
| | Type of Seats | M |
| | Tables Type | M |
| | Safety Equipment Types | S |
| | Fire Alarm System | S |
| | Fire Extinguishers Number | S |
| | First Aid Kit | S |
| | Wall Finishing Type | S |
| | Electrical Outlets Number | S |
| | Practical Space Area | S |
| The existence of private rooms for each department faculty staff | Seats Type | S |
| | Seats Number | S |
| | Tables Type | M |
| | Tables Number | M |
| | (Computer +LCD) | S |
| The Availability of the required number of Qualified labs and Workshops | Seats Type | M |
| | Seats Number | M |
| | Tables Type | M |
| | Tables Number | M |
| | (Computer +LCD) | S |
| | Walls Isolation | S |
| | Electrical Outlet Number | S |
| Existence of adequate bathrooms for boys and girls | Cold Water | S |
| | Hot Water | S |
| | Sinks Number | S |
| Existence of | Cold Water | S |

| | | |
|---|---|---|
| Drinkable Clean Water | Hot Water | W |
| The Availability of Educational aids | Board Dimensions | S |
| | Board Distance From Floor | S |
| | Board Type | S |
| | Electrical Outlet Number | M |
| The Availability of Suitable Library | Seats Type | S |
| | Seats Number | S |
| | Tables Type | S |
| | Tables Number | S |
| | (Computer +LCD) | S |
| | Walls Isolation | M |
| | Seating Area | S |
| | Electrical Outlet Number | S |

It is clear from table 4.4, the customer requirement “No Dead Viewing Area” of the proposed educational entity is affected by room area. When the room area is enough for practical application, the dead viewing areas will decrease. So, this relation was assigned a grade "S" to indicate this strong relationship. Also, the customer requirement “No Dead Viewing Area " is affected by the lamps type. Whenever the lamps equipped with all lightening needs, the dead viewing areas will decrease. Since the lamps type is important for the view in the room, so this relation was assigned a grade "S" to indicate this strong relationship.

Step 6: Individual Rating of Design Requirements

The ranges of importance weight were derived from calculated importance weight and predetermined uncertainty value and it is considered as an importance weight with moving boundaries. The boundaries of the importance weight of the customer requirements are at 0.5 as a truth value for convenience (Kahraman et al., 2004). For example the importance weight of the customer requirement "Fresh Air" was calculated and had a score of 6.89 in the traditional QFD approach, but in the FQFD approach the importance weight was calculated in the range of 6.88 to 6.92. Table 4.7 shows the ranges of the importance weight for the customer requirements for the proposed educational entity.

Then, the individual rating is calculated from the equation:

$$\text{Individual rating} = \sum_{j}^{n} A_{ij} * X_j$$

Where Aij is a symmetrical triangular fuzzy number (TFN) as illustrated in Table 4.8.
Where Xj is ranges of importance weight.
Table 4.9 and 4.10 shows the individual ratings for all the design requirements.

Table 4.7: Rating of Importance Weight for Customer Requirements.

| Customer Requirements | Rating | |
|---|---|---|
| | From | To |
| Existence of drinkable clean water | 6.86 | 6.89 |
| Fresh Air | 6.88 | 6.92 |
| No Accidents and Incidents | 6.50 | 6.54 |
| The availability of educational aids | 6.83 | 6.86 |
| No dead viewing areas | 6.88 | 6.92 |
| Noiseless | 5.94 | 6.10 |
| Temperature controlled year round | 6.79 | 6.81 |
| Clearly see the visual information and take notes | 6.83 | 6.89 |
| Easy and quick access to tools in labs and workshops | 6.11 | 6.23 |
| Appropriate Space like: Enough Area, Equipment and Furniture | 6.88 | 6.92 |
| Comfortable colorful seats | 6.88 | 6.92 |
| The existence of private rooms for each department faculty suitable in terms of size | 6.49 | 6.54 |
| Existence of adequate bathrooms for boys and girls | 6.43 | 6.49 |
| The availability of suitable library in terms of size and equipment | 6.88 | 7.04 |
| The availability of the required number of qualified and secured laboratories and workshops | 6.33 | 6.41 |

Table 4.8: Triangular Fuzzy Number

| Fuzzy Variables | Triangular Fuzzy Number (TFN) |
|---|---|
| Strong Relation (S) | (0.6-1.0) |
| Moderate Relation(M) | (0.3-0.7) |
| Weak Relation(W) | (0-0.4) |

For example, the individual rating for the design requirement ‘‘ceiling type’’ was calculated as follows:
ΣA*X = (0.0*6.88; 0.4*6.92) + (0.3*6.83; 0.7*6.89) + (0.6*6.50; 1.0*6.54) + (0.6*6.88; 1.0*6.92) + (0.6*5.94; 1.0 *6.10) + (0.3*6.79; 0.7*6.81) + (0.3*6.88; 0.7*6.92)
= (17.74; 36.76)

Table 4.9: Individual Rating of Design Requirements for the proposed educational entity

| Design Requirements | Individual Rating | |
|---|---|---|
| | From | To |
| Classroom orientation | 12.30 | 23.39 |
| Ceiling height | 17.77 | 42.31 |
| Ceiling type | 17.74 | 36.76 |
| Window type | 22.56 | 41.00 |
| Window distance from the floor | 19.91 | 38.93 |
| Window dimensions | 20.51 | 38.93 |
| Entrance & exit doors dimensions | 13.72 | 27.18 |
| Emergency door dimensions | 3.90 | 17.24 |
| Number of air conditions | 4.13 | 6.92 |
| Teaching space area | 10.27 | 18.57 |
| Practical space area | 17.89 | 31.45 |
| Floor type | 17.60 | 33.65 |
| Number of seats | 18.15 | 31.88 |
| Seat type | 20.10 | 36.46 |
| Lamps type | 12.35 | 20.73 |
| Wall finishing type | 8.23 | 13.81 |
| Teachers room area | 4.13 | 6.92 |
| labs and workshops area | 14.13 | 6.92 |
| library area | 4.13 | 6.92 |

| | | |
|---|---|---|
| wall insulation | 14.10 | 24.25 |
| tables type | 12.10 | 23.00 |
| electrical outlets number | 18.00 | 31.71 |
| board dimensions | 8.20 | 13.66 |
| board type | 4.10 | 6.89 |
| board distance from floor | 8.20 | 13.66 |
| computer + LCD | 13.87 | 24.81 |
| safety equipment type | 3.90 | 6.54 |
| fire alarm system | 3.90 | 6.54 |
| fire extinguisher number | 3.90 | 6.54 |
| first aid kit | 3.90 | 6.54 |
| hot water | 0 | 8.02 |
| cold water | 7.95 | 13.29 |
| seating area | 4.13 | 7.04 |
| number of sinks | 3.86 | 6.49 |
| number of tables | 7.98 | 16.11 |

The design requirements are organized in a descending order of priority and the cumulative percentage of design requirements is calculated to use the Pareto principle, which states that 20% of the design requirements achieve 80% of the importance percentage to find the critical design requirements of the educational entity. Table 4.10 shows the cumulative percentage of design requirements in descending order.

Table 4.10: Cumulative Individual Rating of Design Requirements for the proposed educational entity

| Design Requirements | Individual Rating | |
|---|---|---|
| | From | To |
| number of sinks | 6.49 | 0.89 |
| first aid kit | 13.03 | 1.81 |
| fire extinguisher number | 19.57 | 2.71 |
| fire alarm system | 26.11 | 3.61 |
| safety equipment type | 32.65 | 4.52 |
| board type | 39.54 | 5.48 |
| labs and workshop area | 46.46 | 6.44 |
| number of air conditions | 53.38 | 7.39 |
| library area | 60.30 | 8.36 |
| seating area | 67.34 | 9.33 |
| hot water | 75.36 | 10.44 |
| cold water | 88.65 | 12.29 |
| board dimensions | 102.31 | 14.18 |
| board distance from floor | 115.97 | 16.07 |
| teachers room area | 129.78 | 17.99 |
| number of tables | 145.89 | 20.22 |
| emergency doors dimensions | 163.13 | 22.61 |
| teaching space area | 181.70 | 25.18 |
| lamps type | 202.43 | 28.06 |
| tables type | 225.43 | 31.25 |
| classroom orientation | 248.82 | 34.49 |
| wall insulation | 273.07 | 37.85 |
| Computer + L.C.D | 297.88 | 41.29 |
| entrance and exit door dimensions | 325.06 | 45.06 |
| wall finishing type | 356.29 | 49.39 |
| practical space area | 387.74 | 53.75 |
| electrical outlet number | 419.45 | 58.14 |
| number of seats | 451.33 | 62.56 |
| floor type | 484.98 | 67.23 |
| seat type | 521.44 | 72.28 |
| ceiling type | 558.20 | 77.38 |
| windows dimensions | 598.13 | 82.92 |
| **windows distance from floor** | **638.06** | **88.45** |
| **windows type** | **679.06** | **94.13** |
| **Ceiling Height** | **721.37** | **100.00** |

By knowing the cumulative percentage, the most important design requirements to satisfy Customer requirements in the educational entity were determined. The most critical design requirements which contributed to the success of the proposed educational entity design were: "windows distance from the floor"; "windows type"; "ceiling height". So, the " Ceiling Height " was determined to be the most important design requirements in the proposed educational entity design, because it has a maximum percentage and the highest score. The major output of analysis is the HOQ for the proposed educational entity shown in Table 4.12.

Step 7: Target Values for Design Requirements

Based on results from interviews with experts, teachers and students, the target values of design requirements were determined as shown in Table 4.11.

Table 4.11: Target Values for Educational Entity A.A.S.T Design Requirements.

| Design Requirements | Target Values |
|---|---|
| Classrooms Orientation | North |
| Ceiling Clear Height (m) | 3.5 |
| Ceiling Type | Paneled Beams |
| Windows Type | Sliding Aluminum With Sun Reflecting |
| Windows Distance from the Floor (m) | 1.00 |
| Windows Dimensions (W*H) (m2) | 1.5*1.5 |
| Dimensions of Door for Entrance and Exit (W*H) (m*m) | 2.5*2.5 |
| Dimensions of Emergency Door (W*H) (m2) | 1.5*2.5 |
| Number of Exhaust Fans with 3 Horsepower | 2 |
| Type of Lamps | Fluorescent |
| Type of Floor | Silent Wooden |
| Number of Seats per Classroom | 20 |
| Seats Type | Solid Wood Armchair |
| Tables Type | Appropriate study table |
| Board Dimensions (W*H) (m2) | 2*2 |
| Board Type | Smart Board |
| Board Distance from the Floor (m) | 1.20 |
| Electrical Outlets Number | 15 |
| Safety Equipment Types in labs and Workshops | Safety Glasses or Face Shield, Shop Apron, Cap, Gloves |
| Fire Alarm System | Sound and Visual |

| | |
|---|---|
| Fire Fighting Systems | Available |
| Fire Fighting Type | Water Sprinkles |
| First Aid Kit | Available |
| Wall Finishing Type | Soft Plastic Paint on Plaster |
| Wall Insulation | Noise and Temperature |
| Academic Staff Room Area (m2) | 25 |
| (Computer +LCD) | Available |
| Classroom Area (m2) | 49 |
| Library Area (m2) | 120 |
| Toilets number per floor | 4 |
| Windows Area per Classroom Area | 1/6 |
| Hot Water | Available |
| Cold Water | Available |
| Sink Number per Classes | 1 |

V. MODEL DEVELOPMENT

A zero–one goal programming is a decision tool since it can handle multiple objectives and seeks to minimize the total deviation from the desired goals. This property of zero–one goal programming enables us to incorporate multiple goals including FQFD, cost budget and maintainability into the product design process. The weighted goal programming model considers all the goals simultaneously by forming an achievement function that minimizes the total weighted deviation from all the goals stated in the model.

A model has been developed to identify the main design requirements of the higher educational facility according to many conditions that achieve most customer requirements. To develop the model, the following steps have been used:

Step (1): Determine the relative weight of higher educational entity design requirements using FQFD as in Table 4.13.

Table 4.13: Relative Weight of Educational Entity Design Requirements Using FQFD.

| Design Requirements | Relative Weight | Variables |
|---|---|---|
| Classroom Orientation | 0.0324 | X1 |
| Ceiling Height | 0.0587 | X2 |
| Ceiling Type | 0.0510 | X3 |
| Windows Type | 0.0568 | X4 |
| Windows Distance From Floor | 0.0554 | X5 |
| Windows Dimensions | 0.0554 | X6 |
| Dimensions Of Doors of Entrance And Exit | 0.0377 | X7 |
| Dimensions Of Emergency Door | 0.0239 | X8 |
| Number of Air Conditions per Class | 0.0096 | X9 |
| Types Of Lamps | 0.0287 | X10 |
| Type Of Floor | 0.0466 | X11 |
| Number Of Seats | 0.0442 | X12 |
| Seats Type | 0.0505 | X13 |
| Tables Type | 0.0319 | X14 |
| Board Dimensions | 0.0189 | X15 |
| Board Type | 0.0096 | X16 |
| Board Distance From Floor | 0.0189 | X17 |
| Electrical Outlets Number | 0.0440 | X18 |
| Safety Equipment Type | 0.0091 | X19 |
| Fire Alarm System | 0.0091 | X20 |
| Fire Extinguishers Number | 0.0091 | X21 |
| First Aid Kit | 0.0091 | X22 |
| Wall Finishing Type | 0.0433 | X23 |
| Wall Insulation | 0.0336 | X24 |
| Teachers Room Area | 0.0191 | X25 |
| Computer + LCD | 0.0344 | X26 |
| Labs And Workshops Area | 0.0096 | X27 |
| Numbers of Tables | 0.0233 | X28 |
| Teaching Space Area | 0.0257 | X29 |
| Practical Space Area | 0.0436 | X30 |
| Library Area | 0.0096 | X31 |
| Cold Water | 0.0184 | X32 |
| Hot Water | 0.0111 | X33 |
| Number Of Sinks | 0.0090 | X34 |
| Seating Area | 0.0098 | X35 |

Step (2): Determine the relative weight of higher educational entity design requirements with respect to additional design goals like cost and maintainability using AHP method. The analytic hierarchy process (AHP) method is a well-known technique that decomposes a problem into several levels in such a way that they form a hierarchy. Each element in the hierarchy is supposed to be independent, and a relative ratio scale of measurement is derived from pair wise comparisons of the elements in a level of the hierarchy with respect to an element of the preceding level. In AHP, the relative importance values are determined using pair wise comparisons with a scale of 1–9, where a score of 1 indicates equal importance between the two elements and 9 represents the extreme importance of one element compared to the other one. Table 4.14 shows the relative weight of cost goal and Table 4.15 shows the relative weight of the maintainability goal.

Table 4.14: Relative Weight of Educational Entity Design Requirements Using Cost

| Design Requirements | Relative Weight | Variables |
|---|---|---|
| Classroom Orientation | 0.0038 | X1 |
| Ceiling Height | 0.0536 | X2 |
| Ceiling Type | 0.0589 | X3 |
| Windows Type | 0.0354 | X4 |
| Windows Distance From Floor | 0.0278 | X5 |
| Windows Dimensions | 0.0307 | X6 |
| Dimensions Of Doors of Entrance And Exit | 0.0333 | X7 |
| Dimensions Of Emergency Door | 0.0343 | X8 |
| Number of Air Conditions per Class | 0.0502 | X9 |
| Types Of Lamps | 0.0082 | X10 |
| Type Of Floor | 0.0485 | X11 |
| Number Of Seats | 0.0135 | X12 |
| Seats Type | 0.0145 | X13 |
| Tables Type | 0.0202 | X14 |
| Board Dimensions | 0.0049 | X15 |
| Board Type | 0.0053 | X16 |

| | | |
|---|---|---|
| Board Distance From Floor | 0.0076 | X17 |
| Electrical Outlets Number | 0.0353 | X18 |
| Safety Equipment Type | 0.0161 | X19 |
| Fire Alarm System | 0.0491 | X20 |
| Fire Extinguishers Number | 0.0415 | X21 |
| First Aid Kit | 0.0041 | X22 |
| Wall Finishing Type | 0.0337 | X23 |
| Wall Insulation | 0.0331 | X24 |
| Teachers Room Area | 0.0425 | X25 |
| Computer + LCD | 0.0404 | X26 |
| Labs And Workshops Area | 0.0425 | X27 |
| Numbers of Tables | 0.0159 | X28 |
| Teaching Space Area | 0.0425 | X29 |
| Practical Space Area | 0.0425 | X30 |
| Library Area | 0.0417 | X31 |
| Cold Water | 0.0067 | X32 |
| Hot Water | 0.0090 | X33 |
| Number Of Sinks | 0.0101 | X34 |
| Seating Area | 0.0429 | X35 |

Table 4.15: Relative Weight of Educational Entity Design Requirements Using Maintainability

| Design Requirements | Relative Weight | Variables |
|---|---|---|
| Classroom Orientation | 0.0040 | X1 |
| Ceiling Height | 0.0056 | X2 |
| Ceiling Type | 0.0066 | X3 |
| Windows Type | 0.0346 | X4 |
| Windows Distance From Floor | 0.0095 | X5 |
| Windows Dimensions | 0.0096 | X6 |
| Dimensions Of Doors of Entrance And Exit | 0.0081 | X7 |
| Dimensions Of Emergency Door | 0.0081 | X8 |
| Number of Air Conditions per Class | 0.0081 | X9 |
| Types Of Lamps | 0.0189 | X10 |
| Type Of Floor | 0.0538 | X11 |
| Number Of Seats | 0.0498 | X12 |
| Seats Type | 0.0484 | X13 |
| Tables Type | 0.0452 | X14 |
| Board Dimensions | 0.0540 | X15 |
| Board Type | 0.0547 | X16 |
| Board Distance From Floor | 0.0533 | X17 |
| Electrical Outlets Number | 0.0324 | X18 |
| Safety Equipment Type | 0.0479 | X19 |
| Fire Alarm System | 0.0142 | X20 |
| Fire Extinguishers Number | 0.0292 | X21 |
| First Aid Kit | 0.0540 | X22 |
| Wall Finishing Type | 0.0247 | X23 |
| Wall Insulation | 0.0247 | X24 |
| Teachers Room Area | 0.0122 | X25 |
| Computer + LCD | 0.0320 | X26 |
| Labs And Workshops Area | 0.0122 | X27 |
| Numbers of Tables | 0.0470 | X28 |
| Teaching Space Area | 0.0122 | X29 |
| Practical Space Area | 0.0122 | X30 |
| Library Area | 0.0122 | X31 |
| Cold Water | 0.0490 | X32 |
| Hot Water | 0.0479 | X33 |
| Number Of Sinks | 0.0438 | X34 |
| Seating Area | 0.0122 | X35 |

Step (3): Calculate the relative weight of all determined goals considered in the design of the proposed educational facility using AHP method. Table 4.16 shows the relative weight of all goals.

**Table 4.16**: Relative Weight of for All Determined Design Goals.

| **Goals** | **Relative Weights** |
|---|---|
| FQFD | 0.2224 |
| Cost | 0.7011 |
| Maintainability | 0.0765 |

Step (4): Formulate and solve the zero–one goal programming model to identify the proposed educational facility design requirements to be considered in the designing process. The general form of the ZOGP model employed in the decision framework is as follows:

MIN 0.2224$d_{1n}$+0.6961$d_{2p}$ +0.0790$d_{3n}$

Subject to

0.0324x1 + 0.0587x2 + 0.0510x3 + 0.0568x4 + 0.0554x5 + 0.0554x6 + 0.0377x7 + 0.0239x8 + 0.0096x9 + 0.0287x10 + 0.0466x11 + 0.0442x12 + 0.0505x13 + 0.0319x14 + 0.0189x15 + 0.0096x16 + 0.0189x17 + 0.0440x18 + 0.0091x19 + 0.0091x20 + 0.0091x21 + 0.0091x22 + 0.0433x23 + 0.0336x24 + 0.0191x25 + 0.0344x26 + 0.0096x27 + 0.0233x28 + 0.0257x29 + 0.0436x30 + 0.0096x31 + 0.0184x32 + 0.0111x33 + 0.0090x34 + 0.0098x35+ $d_{1n}$ - $d_{1p}$ =1 (FQFD)

0.0038x1 + 0.0536x2 + 0.0589x3 + 0.0354x4 + 0.0278x5 + 0.0307x6 + 0.0333x7 + 0.0343x8 + 0.0502x9 + 0.0082x10 + 0.0485x11 + 0.0135x12 + 0.0145x13 + 0.0202x14 + 0.0049x15 + 0.0053x16 + 0.0076x17 + 0.0353x18 + 0.0161x19 + 0.0491x20 + 0.0415x21 + 0.0041x22 + 0.0337x23 + 0.0331x24 + 0.0425x25 + 0.0404x26 + 0.0159x27 + 0.0425x28 + 0.0425x29 + 0.0425x30 + 0.0417x31 + 0.0067x32 + 0.0090x33 + 0.0101x34 + 0.0429x35 + $d_{2n}$ - $d_{2p}$= 1 (Cost)

0.0040x1 + 0.0056x2 + 0.0066x3 + 0.0346x4 + 0.0095x5 + 0.0096x6 + 0.0081x7 + 0.0081x8 + 0.0081x9 + 0.0189x10 + 0.0538x11 + 0.0498x12 + 0.0484x13 + 0.0452x14 + 0.0540x15 + 0.0547x16 + 0.0533x17 + 0.0324x18 + 0.0479x19 + 0.0142x20 + 0.0292x21 + 0.0540x22 + 0.0247x23 + 0.0247x24 + 0.0122x25 + 0.0320x26 + 0.0122x27 + 0.0470x28 + 0.0122x29 + 0.0122x30 + 0.0122x31 + 0.0490x32 + 0.0479x33 + 0.0438x34 + 0.0122x35 + $d_{3n}$ - $d_{3p}$ = 1 (Maintainability)

End

**Table 4.17:** Relative Weight of for All Determined Design Goals.

| Ratio | Objective Function For Cost |
|---|---|
| 0.2 | 0.1488 |
| 0.4 | 0.0932 |
| 0.6 | 0.0504 |
| 0.8 | 0.0202 |
| 1.0 | 0.0000 |

**Table 4.18:** Zero–One Goal Programming Solutions of higher Educational Facility Design Requirements.

| Cost Ratio | Variable Selected |
|---|---|
| 0.2 | Except X2,X3,X7,X8,X9,X10,X12,X15,X19, X21,X22,X24,X25,X26,X27,X28,X29 ,X31, X32,X33 |
| 0.4 | Except X2,X7,X8,X9,X10,X15,X19,X21,X22 , X24,X25,X27,X28,X31,X33 |
| 0.6 | Except X8,X10,X15,X19,X21,X22,X24,X25, X27,X33 |
| 0.8 | Except X21,X22,X24,X27 |
| 1.0 | All variables |

As shown in Table 4.18, when the right hand of the cost goal equal 1 in the model, all variables (design requirements) can be satisfied in the design process to achieve the most customer requirements. But, when the right hand of the cost goal less than 1 (the percentage of this goal is enough for all design requirements), some of design requirements are satisfied in the design process to achieve the most customer requirements. As in Table 4.18, the objective function is lowest when the ratio equal 1 of the right hand of the model for cost goal that means, when the cost is ideal and real, the deviation is minimum. Figure 4.11 shows the objective function for every ratio of the right hand of the cost goal in the model. So, this model describes the design method, which may be used to assess the designers to strengthen the design process and to be easily extended for real-world applications. So, the results of this chapter clearly indicate that all higher educational facility design requirements are satisfied in the designing process when the cost goal is ideal.

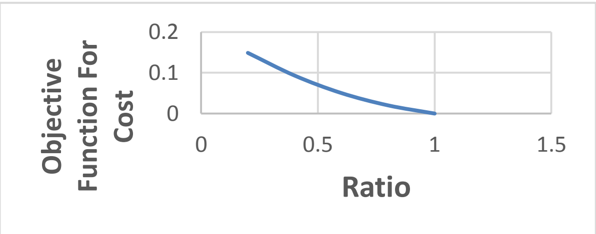


**Figure 4.11:** Results of Zero–One Goal Programming.

## VI. Conclusion And Recommendations

### 5.1 Conclusions

- The main objective of this research was to design an appropriate educational entity using FQFD.
- FQFD is a valuable and very flexible tool for design. The practical applications of FQFD mentioned illustrate that it can be utilized in different ways and can be adapted to solve a great number of design problems.
- FQFD supports the customer requirements in the educational entity (WHATs) and the design requirements (HOWs).
- Customer voice was evoked through interviews and from literature reviews that would affect on educational entity conceptual design.
- A set of design requirements were proposed to satisfy the needs and their relationship with each of customer requirements agreed.
- Design requirements were ranked through FQFD method to guide the design of educational entity.
- . The three most important design requirements of educational entity were: windows dimensions, windows type and windows distance from the floor.
- From the comparison between the case study and the results of the research, FQFD has made a successful experiment with more objectivity.

### 5.2 Recommendations

- Future studies can be pursued on developing a computerized intelligent decision support system for group decision making environment.
- Future studies and much better research are needed to demonstrate its usefulness in the detail design, procurement and construction phases as well.
- FQFD can be employed in any stage of the project.
- The FQFD process appears suitable for fast-track design/build contracts.

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