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Develop QFD and AHP Models for Liquid Gas Valve for Product Developmen

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A B S T R A C T

This new methodology utilizes Quality Function Deployment (QFD) with Analytic Hierarchical Process (AHP) together for improving product planning stage, hence, the product development, because this stage precedes the manufacturing stage and is regarded as an important stage in the product development. The proposed methodology consists of two models; namely: (1) Curent QFD Model. (2) Current AHP Model. It was applied practically to demonstrate the models' applicability and suitability, and develop liquid Gas Cylinder Valve produced at Al-Ikhaa General Company (IGC) for Mechanical Industries. "Thus it was possible to find out the critical and important specifications for improving product planning which should be considered in product development". These specifications have high ranking and Scaled Value Technical Ratings (SVTR) of over (50%). SVTR have values as follows: (1) (1.0000) for Pad (H1), then (2) (0.9270) for piston (H4), (3) (0.9195) for gasket (H12), (4) (0.8236) for safety valve (H6), (5) (0.8156) for sealing 1 (H5), (6) (0.6935) for sealing 2 (H9), (7) (0.5441) for installing the regulator with valve (H10) and (8) (0.5220) for spring2 (H7). When applying AHP method, various results were obtained. Based on the final score of Al-Ikhaa Company, where the highest defects value was (45%) was reported in the production processes. Also, values of maintenance dismantling 23%, Product assemblage 12% and maintenance assemblage 9% of the Product values.

1. Introduction

The first of QFD matrices is named the House of Quality (HOQ), The main goal of HOQ is to translate the maintenance demands into product requirements. HOQ is a kind of conceptual map that provides the means for inter functional planning and communications [1].

"Another technique is AHP which is widely used to effectively handle both quantitative and qualitative data in different practical decision making problems". This method contains three main stages: first, constructing a pair-wise comparison matrix; second, synthesizing judgments; third, checking for consistency"[2].

This study aims at examining the applicability of Quality Function Deployment (QFD) and Analytical Hierarchy Process (AHP) to convert the expectations of the maintenance departments through the following objectives:

1- Identify the needs of maintenance and product design requirements through direct interviews, observation and data analysis.

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2- Quantify and prioritize the maintenance needs on the hierarchy diagram providing accurate ratio-scale priorities.
3- Classify the needs of the maintenance and prioritizing them. The requirements were then converted in to quality characteristics.
4- Thus in this case study, QFD augmented with the AHP can be successfully applied in the case and findings demonstrate that some solutions can be suggested for optimization of the product effectively.

2. Proposed Methodology Models

In formalizing and constructing the proposed methodology, which shown in Figures (1) and (2), the framework consists of two models. The condition (percentage of permitted change) in engineering specifications of current product should not exceed the percentage determined by the technical expert of QFD and AHP teams in the factory. This requires the development of the current product for the purpose of competition with similar products in other markets".

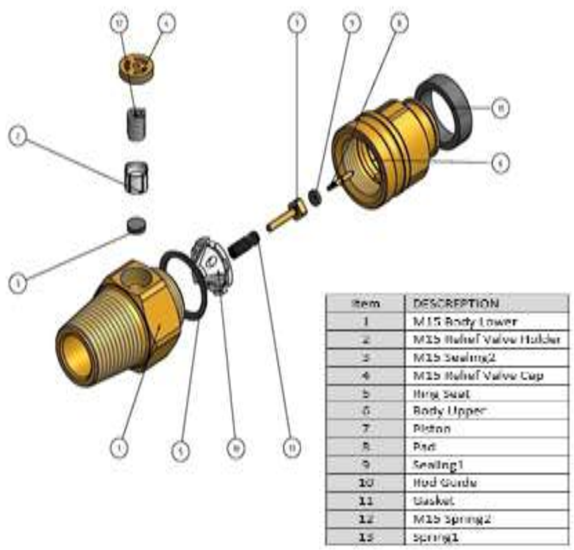

Figure 1. Valve parts assembly

Using models QFD and AHP, the first step is to compare with the foundation company (Al-Ikhaa) for product liquid gas cylinder valve.

QFD is to translate a desires of the customer (maintenance requirement) into product design or engineering characteristics, subsequently into parts characteristics, process plans, and production requirements associated with its manufacture. Ideally, each translation uses a chart, called (HOQ) [3, 4, 5].

AHP is a method to ranking the solutions to find the best one when two or more solutions are provided.

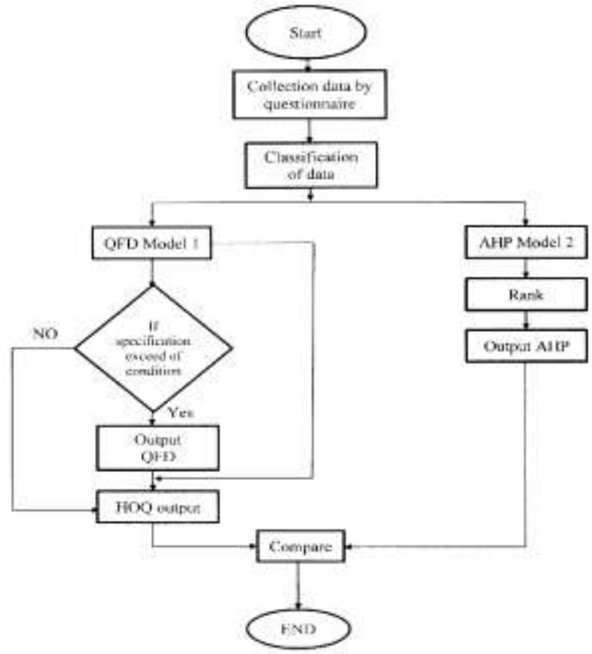

Figure 2. Flowchart of proposed methodology

This method was used because the situation of this study is composed of several alternatives"; the best of these alternatives to choose has been this method (AHP). Also, it is composed of several levels, towards the last level in the selection of the best alternatives [6, 7, 8,9].

3. Result Analysis and Desiccation

Data were collected from many different departments for IGC (production, maintenance, assemblage, engineering inspection, quality control, marketing department and planning department) through the interviews. The questionnaire was of 14 copies, each copy contains (12) questions given to managers, engineers, and technicians involved in maintenance. Response percentage to the questions was approximately (90%). The answers provide were analyzed using Excel Program Version (2016), QFD software and AHP software Version 15.

Percentage of change requirement allowed in current engineering specifications liquid gas cylinder valve should not exceed (±4%). This is determined by the technical expert in (IGC). The following models explain the implementation of the proposed methodology.

3.1 QFD Model No.1

In this model, there is a team of maintenance requirements including several persons, "every one of them represents one of the existing sections in the factory, starting with the design department and ending with the marketing department". This team is called the QFD team. A stepwise described algorithm of model No.1 is simply presented as flow chart in Figure (3):

Step1: Determine WHATs

No.	Quality dimensions	Maintenance needs	WHATs (W)
1	Performance	Ease of use during the filling. Ease of use during installation of cylinder regulator. No leakage of liquid gas. Attain the desired pressure. Effect of external and internal factors.	W1 W2 W3 W4 W5
1-A	Maintenance Features	Ease of maintenance. Quick maintenance. Maintenance efficiency .	W6 W7 W8
2	Reliability	Using for long time. Safety during filling, use and storage. Robust, wear resistant and corrosion.	W9 W10 W11
3	Conformance	Low cost and lightweight	W12

Step2,3: Determine scale system levels (1) for WHATs& Translate linguistic variables in scale system (1) to value numbers [10].

Linguistic variables	Symbol of linguistic variables	Value No.
Very Unimportant	VU	0
Quite Unimportant	QU	0.2
Unimportant	U	0.35
Semi important	SI	0.5
Moderately Important	MI	0.65
Important	I	0.8
Very Important	VI	1

Step4: Identify Relative Importance Ratings (RIR) a for each WHAT

Step5: Translate $(RIR)_A$ to Value Relative Importance Ratings $(VRIR)_A$

Step6: Calculate Average Value Relative Importance Ratings $(AVRIR)_A$ [4].

$$(AVRIR)_i = (1/K) * \sum_{MO=1}^{K} (VRIR)_i \ldots\ldots\ldots (1)$$

i=1,2,3………………., L

L=No. Of WHATs

MO=1, 2……………, K

K=No. of Maintenance requirement

Step7: Generate HOWs

	No.	Product Specifications (PS)	HOWs
Upper valve	1	Piston	H1
	2	spring1	H2
	3	Rod Guide	H3
	4	Pad	H4
	5	sealing1	H5
ower valve	1	safety valve	H6
	2	spring2	H7
	3	Relief valve holder	H8
	4	sealing2	H9
he upper nd lower part of society	1	Install the regulator with valve	H10
	2	Install the valve with the cylinder	H11
	3	Sealing upper	H12

Step8,9: Determine scale system (2) for strength relationship between HOWs and WHATs [10].

No.%	linguistic variables	Symbol of linguistic variable
0	No Effect	NE
1	Very Weak	VW
2	Weak	W
3	Moderate	M
4	High	H
5	Very High	VH

Step10: Determine matrix of strength relationship between HOWs and WHATs

Step11: Translate linguistic variables in relationship matrix to value numbers

Step12: Calculate Value Technical Ratings (VTR), Normalized Value Technical Ratings (NVTR) $_A$ [11].

$$(\mathbf{VTR})_{jA} = \sum_{i=1}^{L} (\mathbf{AVRIR})_{iA} * \mathbf{RV}_{ij} \ \ldots\ldots. \ (2)$$

$$(\mathbf{NVTR})_{jA} = (\mathbf{VTR})_{jA} \Big/ \sum_{j=1}^{p} (\mathbf{VTR})_{jA} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

- RV = Relationship Value between HOWs & WHATs

- j = 1, 2, ………., p

- p = No. of HOWs

Step13: Calculate (SVTR) a to find ranking of HOWs in original manufacture (A)

$$(SVTR)_{jA} = (VTR)_{jA} / \max.(VTR)_{jA} \ldots\ldots\ldots\ldots\ldots(4)$$

Figure 3. Steps of current QFD model-1

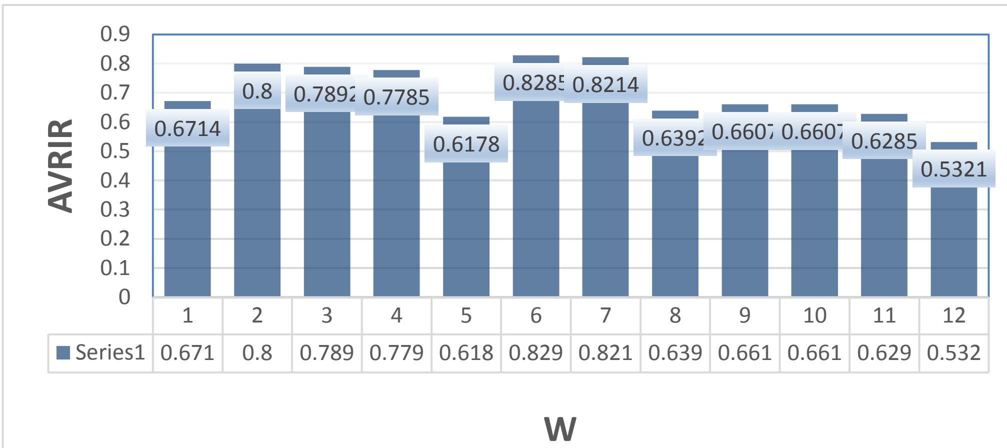

Figure 4. (AVRIR)A for each WHAT in manufacture (A)

The engineering specifications of the product are identified for model -1 by QFD team, such as, performance, features, conformance, reliability of system (valve), and sub systems related to it.

The central matrix of HOQ was constructed as shown in Step (8, 9), which represent the influence of each HOW (H) of the product on each maintenance requirement WHAT (W) by using the new scale system (2).

From step 12, 13

The value numbers that represent the linguistic variables by scale system (2) are used to construct the Relationship Value (RV) of central matrix for HOQ.

From step (12, 13):

Calculate (VTR, NVTR, SVTR) A for each engineering specification by equations (2, 3, 4) respectively. The results highest defects value is shown in Table (1) (SVTR).

Table 1. (VTR, NVTR, SVTR)A for current manufacture A in current value model

H	VTR	NVTR	SVTR
1	5.9903	0.1308	1
2	2.7184	0.0593	0.9270
3	1.2546	0.0274	0.9195
4	5.5535	0.1213	0.8236
5	4.8860	0.1067	0.8156
6	4.9339	0.1077	0.6935
7	3.1272	0.0683	0.5441
8	2.5576	0.0558	0.5220
9	4.1547	0.0907	0.4538
10	3.2594	0.0712	0.4269
11	1.8320	0.0400	0.3058
12	5.5082	0.1203	0.2094

Based on the results in Table (1), the ranking of HOWs is shown in Table (2).

Table 2. Ranking of HOWs for model-1

No.	Ranking of HOWs	Scaled Value Technical Rating (SVTR)
1	H1	1
2	H4	0.9270
3	H12	0.9195
4	H6	0.8236
5	H5	0.8156
6	H9	0.6935
7	H10	0.5441
8	H7	0.5220
9	H2	0.4538
10	H8	0.4269
11	H11	0.3058
12	H3	0.2094

Based on Table (2), (H1) (pad) are considered one of the most important engineering specifications of the product, which has great effects on achieving the maintenance staff desires, and subsequently increases the sales of this product. For this reason, care should be taken by the designer of this (H1). The importance of other engineering specifications from the designer view is illustrated in Table (2).

chy of objectives. This involves identifying the goal, criteria, (sub-criteria) and alternatives. Figure (5) shows the hierarchy of AHP tree.

3.2.1 Creation of the Hierarchy: (GIC) to produce liquid gas cylinders valves

The first step in the process is to determine the criteria for the decision in the form of a hierarchy of objectives. This involves identifying the goal, crite-

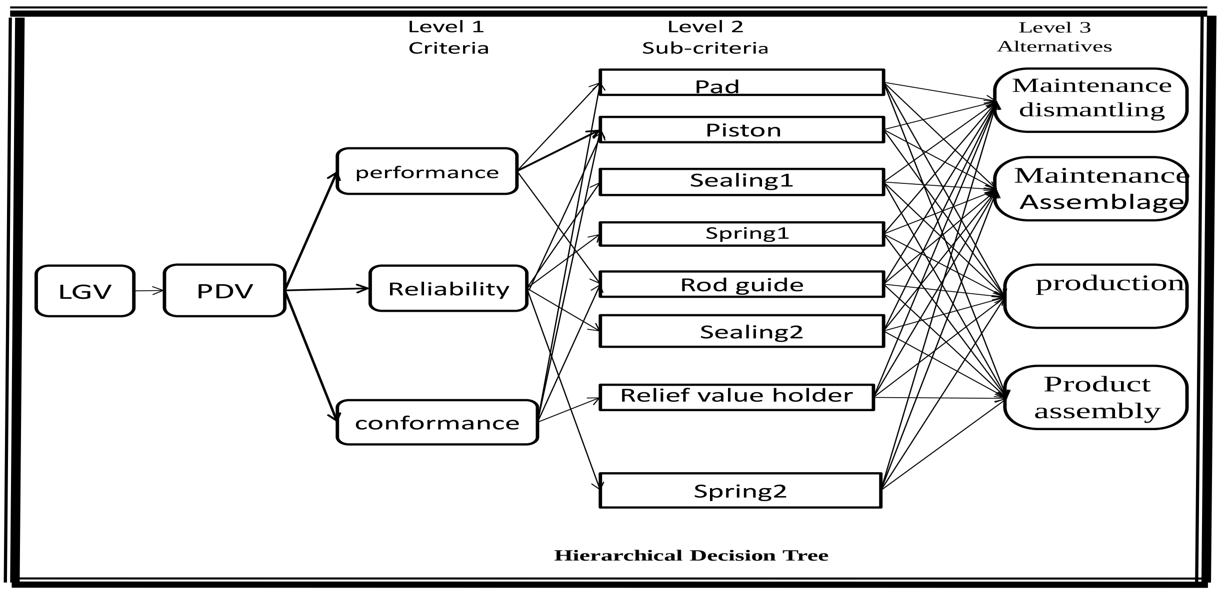

Figure 5. Hierarchical Decision Tree

3.2 Model-2: Analytic Hierarchy Process (AHP) Model

The proposed methodology to find the problem in the production of the (IGC) is to produce liquid gas cylinders' valves that are composed of two main stages: (1) problem definition, and (2) AHP computation.

The first step in the process is to determine the criteria for the decision in the form of a hierarchy

$$P = (p_{ij})_{n \times n} = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{pmatrix} \quad \ldots\ldots\ldots(5)$$

where:

Pij is the importance degree of the ith factor compared to the jth factor.

The matrix is normalized by dividing the values in each column by the sum of the column (P Normalized). An approximate for w max is calculated for each row by calculating the average of the rows of the normalized matrix using the equations (6), (7), (8), and (9):

The following formula is used and the elements of matrix P are normalized.

ria, (sub-criteria) and alternatives. Figure (6) shows the hierarchy of AHP tree.

The normalized priority vector is calculated by dividing the original priority vector by its sum. The pairwise comparison matrix (P) is formed by using equation (3-16).

$$P_{ij\ Norm.} = \frac{P_{ij}}{\sum_{k=1}^{n} P_{kj}}, \quad i, j = 1,2..,n \quad \ldots (6)$$

Then, normalization matrix, can be acquired

$$PNorm. = (P_{ijNorm.})\ n \times n \quad \ldots\ldots\ldots\ldots (7)$$

Aggregating the elements of the same line/row of normalization matrix PNorm., we can get:

$$W_{i\ Norm.} = \sum_{j=1}^{n_{Norm}} P_{ij} \quad , j = 1, 2 \ldots, n \quad ..(8)$$

The weights vector W = (w1, w2, …, wn) is then found through the following formula:

$$W_i = \frac{Wi_{\text{Norm}}}{\sum_{k=1}^{n_{\text{Norm}}} W\,k}, \quad i= 1, 2….., n \qquad ….\ (9)$$

The maximum value λmax is computed as follows:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{PW)i}{Wi} \qquad …….(10)$$

where *n* is the dimension of the comparison matrix.

Finally, a consistency check is applied by computing the consistency ratio (CR)

CR= CI/RI   me be ≤0.10 …………… (11)

where RI is the random index. The values of RI, which change with variations in the dimensions, are shown in Table (3). CI is the consistency index, and can be computed by

CI= (λmax-n)/ (n-1) ……………….. (12)

when CR 0.10, it means that the consistence of the pairwise comparison matrix is acceptable.

Table (3) the random consistency index

Dimension	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

The comparison needs to be repeated for each column of the matrix, i.e. independent judgments must be made over each pair. Suppose that after all the comparisons are made, the matrix A includes only exact relative weights.

Multiplying the matrix by the vector of weights w= (w1, w2…, wn) yields:

$$AW=\begin{bmatrix} a11 & a12 & \dots & a1n \\ a21 & a22 & \dots & a2n \\ \vdots & \vdots & \vdots & \vdots \\ an1 & \dots & \dots & ann \end{bmatrix} \begin{bmatrix} w1 \\ w2 \\ \vdots \\ wn \end{bmatrix} = \begin{bmatrix} w1/w1 & w1/w2 & \cdots & w1/wn \\ w2/w1 & w2/w2 & \vdots & w2/wn \\ \vdots & \vdots & & \vdots\ \vdots \\ wn/w1 & \cdots & \cdots & wn/wn \end{bmatrix} \begin{bmatrix} w1 \\ w2 \\ \vdots \\ wn \end{bmatrix} = n \begin{bmatrix} w1 \\ w2 \\ \vdots \\ wn \end{bmatrix}$$

Table (4) shows the final results that the highest percentage of problems found in the production process (alternatives with respect to sub-criteria), based on that will be selection of preferred alternative in the Robust Design for AL-IKHAA Company. Because of the highest scoring was (0.4512).

Table 4. Hierarchy of Alternative/ AL-IKHAA Company

Score of LGV by using (AHP)

	1	2	3	4	5	6	7	8		
Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	∑ wi/n	score
M1	0.079	0.125	0.101	0.123	0.176	0.413	0.319	0.421	0.080	0.2328
M2	0.065	0.070	0.113	0.127	0.176	0.078	0.064	0.077	0.073	0.0904
P1	0.827	0.825	0.365	0.672	0.176	0.334	0.872	1.127	0.194	0.4512
P2	0.331	0.246	0.114	0.127	0.176	0.449	0.251	0.415	0.088	0.1247
									0.150	
									0.131	
									0.127	
									0.156	

Where the criteria of:

(C_1)Piston	(C_2) Pad	(C_3) Rod Guide
(C_4) Relief Valve Holder	(C_5)Spring1	(C_6) Spring2
(C_7) Sealing1	(C_8) Sealing2	

And so on for all sub-criteria.
M1: maintenance dismantling M2: maintenance assemblage
P1: Production P2: Product assemblage

4. Conclusions

The conclusions of this research regarding the use of QFD and AHP to improve the product and get a robust design during the planning phase are":

1. QFD and AHP can be used to develop a framework for the new process of product development. Furthermore, maintenance needs should be related product development to increase the product's competitiveness.

2. A hybrid approach is proposed as a modification to the QFD. This proposed method depends on the cooperation between the maintenance and the design procedure in addition to applying the principles of QFD and AHP together to develop a new product, so that it can compete with the similar products besides satisfying the customer in original market.

3."The benefits of the proposed methodology help to find out the critical and important specifications for improving product planning which should be considered in product development stage".

4. The application gives clear results that the change of design of pad and piston as well as the improvement of gasket, safety valve, sealing1, sealing2, installing the regulator with valve and spring2 would help the designers to develop new products in order to compete in the Iraqi market.

5. Obtaining real values for the critical specifications which are pad (1.000), piston (0.9270), gasket (0.9195), safety valve (0.8236), sealing1 (0.8156), sealing2 (0.6935), install the regulator with valve (0.5441) and spring2 (0.5220). They can be used by the designers to design new competitive valve product.

Based on the results obtained, it is recommended that as extension of the current research to get more accurate specifications for new developed product as a future research project.

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