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The Analysis of Project Delay Factors Using the Double-Roof House of Quality

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Abstract*— One of the biggest engineering concerns in the Middle East is the major delays in infrastructural projects which impact on both their quality and cost. A significant number of projects do not finish on time, are subject to cost overruns and are not completed to the specified quality. The Kingdom of Saudi Arabia (KSA) claims losses of the order of $ 40 Billion per annum as a result of these issues. Information on the factors contributing to project delays was studied. A literature review which determined the main project delay factors was first carried out. An online survey incorporating 66 of these was then developed with the purpose of identifying the most critical factors contributing to project delays. The survey was administered to over 200 specialists in the area of project engineering. This cohort included; Consultants, Business Owners, Project Directors, Project Engineers, Safety and Quality Managers and Contracting Managers. The resulting delay factors were ranked in order of priority based on a weighted index incorporating dimensions of Frequency and Severity. The non-linear relationships between 'customer attributes' and 'critical delay factors' in infrastructural projects was modeled using a 'House of Quality Tool 'with an innovative double roof. The method enabled the identification of the top 20 delay factors with respect to the following customer attributes; "Time, Cost, Quality, Safety and Environment". The highest ranked factors which impacted on all the customer attributes were; the shortage of technical professionals, unrealistic specified times and inadequate design and specification. The lowest ranked factors included; contractor cash flow problems and slow decision making by the client. The Double-Roof House of Quality Tools proved to be useful in determining and representing the relationships between 'customer attributes' and 'critical delay factors'. The next phase of the work is to model the non-linear nature of the relationship using Fuzzy Logic. The ultimate goal is to provide expert guidance on strategy with respect to the focus on delaying factors in major infrastructural projects. *(Abstract)

***Keywords*— Project Management, House of Quality, Quality Function Deployment, Integrated Weighted Index and Fuzzy Logic.**

I. Introduction

It is almost axiomatic of construction management that the project may be regarded as successful if the building is completed on time, within budget, and is of the desired quality. It is commonly said, however, that whereas two out of those three can often be achieved, because of the complexities involved in a construction contract, and in particular the many different trades and professions that are commonly involved.

Realistic construction time is now increasingly of the essence because it often serves as a crucial benchmark for assessing the performance of a project and the efficiency of the project organization. A fundamental specification of the construction contract is the project period or time of project execution, which is established prior to bidding. The successful execution of construction projects and keeping them within estimated cost and prescribed schedules depend on a methodology that requires sound engineering judgment).

Project completion for the owner means that he can make use of his new assets on time by habitation, renting, or selling. Any delay in project completion will disturb his/her plans. The client will not be able to make use of the property, and his/her business will be affected in almost all areas, especially finance. For the contractor, any delay in completion of the project gives rise to indirect overhead expenses and additional payments to the project staff and workforce. It also means that he will possibly be subjected to compensation claims. His next project might be cancelled as a result of delays in the present project, and loss of future opportunities will be made more likely by damage to his reputation and credibility. The consultants and all other parties involved will also lose if the project is delayed: they will at least lose time, which may mean losing money.

Despite the great effort that has been put into the evolution of construction project planning and control during the last four decades, delay is still a very common feature of construction projects in Saudi Arabia. These often result in adversarial relationships between construction stakeholders (clients, contractors, consultants, etc.): distrust, litigation, arbitration, cash-flow problems, and a general feeling of apprehension towards each other. In recent years, Saudi Arabia's construction enterprises increased greatly in many fields. According to recent analysis, the level of uncompleted projects reached to more than 40% which requires a strong attention [7]. Factors of delays differ from one country to another as well as the type and also the purpose the projects.

II. Materials and Methods

The analysis that has been used was divided into 3-stages. The 1st stage was concerned with identifying critical delay factors from the previous studies in the literature reviews. More than 300 different factors were collected and they have been grouped and filtered to 66 critical factors of delays. The 2nd stage involved an analysis of a survey that was administrated to 167 specialists from projects & engineering fields to prioritize the factors based on frequency and severity. The 3rd stage was based on using a newly developed tool inspired from the House of Quality. The new tool was named "Double Roof House of Quality [DRHOQ].

A. Methods of Analysis (Delay Factors) Ranking

Data collected from the survey was analyzed using descriptive statistical techniques [3]. An advanced and accurate analysis method was needed to arrange the large amount of data in a systematic, fast and reliable way. Google online survey Statistical Computing and Excel-Office were chosen to be used in this stage.

The respondents were asked to share their views for rating the factors of delays based on their frequency and severity weightings. The scales provided ranges from 1 to 4 as shown in Table I. However, in order to complete the quantitative measure of the frequency and the severity, it was decided to give an equal weight for both “Frequency & Severity”.

TABLE I. FREQUENCY AND SEVERITY WEIGHTING

Scale	Frequency	Severity
1	Never	No effect
2	Occasionally	Fairly severe
3	Frequently	Severe
4	Constantly	Very severe

The average score or the Index of frequency (FI) and severity (SI) for each delay factor was calculated by the following formula:

- **Equation-1** Frequency Index F.I.%

$$F.I. = \frac{\sum_{0}^{4} a_i n_i}{4N}$$

- **Equation-2** Severity Index S.I.%

a = constant expressing the weight assigned to each responses (ranges from 0 for No happen to 4 for Always), n = frequency of each response, N = total number of responses

$$S.I. = \frac{\sum_{0}^{4} a_i n_i}{4N}$$

a = constant expressing the weight assigned to each responses (ranges from 0 for No happen to 4 for Always), n = frequency of each response, N = total number of responses

The Important Index (*IMP. I*) was calculated by multiplying the S.I x F.I. The Important Weighted Index (*IWI*) was resulting by multiplying the *IMP.I.* x *m* as follow:

- **Equation-3** Important Index IMP.I.%

$$IMP.I. = F.I. \times S.I.$$

- **Equation 4** Importance Index of the category

$$IWI = AW * m$$

B. Top 20 Causes of Delays:

While,
m = The number of category causes / Total number of all causes

After the analysis, it was found that 12 factors out of top 20 were related to the contractors. The most important factor found was “shortage of technical professionals in the contractor organization” with important weight index (IWI) 53%. Table II indicates the top 20 factors of delays with their rankings. The general conclusion from these factors there is a shortage of the qualified technical staff and allocating them to the right positions. Improper technical studies, weak planning/ scheduling, losing safety roles, frequent changes in the scope and finally the poor communication between all parties are mostly the critical reasons behind projects delay.

TABLE II. TOP 20 FACTORS OF DELAYS

.	Factor Category	Discription	F.I.		S.I.		IWI	Risk Order	Points
			Rate	%	Rate	%	Overall %		
13	Contractor - PM	13. Shortage of technical professionals in the contr	2.9	73.08%	2.9	71.79%	52.47%	1	65
9	Contractor - MP	9. Shortage of manpower (skilled, semi-skilled, unsk	2.7	66.67%	3	75.00%	50.00%	2	64
22	Contractor - PM	22. Ineffective planning & scheduling of the project	2.6	66.03%	3	75.64%	49.94%	3	63
19	Contractor - PM	19. Loose safety rules & regulations within the cont	2.7	68.59%	2.9	72.44%	49.68%	4	62
21	Contractor - PM	21. Improper technical studies by the contractor du	2.6	65.38%	3	75.64%	49.46%	5	61
53	Early plan & Design	53. Changes in the scope of the project	2.6	64.74%	2.9	73.72%	47.73%	6	60
20	Contractor - PM	20. Poor qualifications of contractor's tech. staff as	2.6	65.38%	2.9	72.44%	47.36%	7	59
14	Contractor - PM	14. Contractor's poor coordination with parties' inv	2.5	62.82%	3	74.36%	46.71%	8	58
45	Client	45. Slow decision making by the client's organizatio	2.5	62.18%	2.9	73.72%	45.84%	9	57
54	Early plan & Design	54. Ambiguities, mistakes, and inconsistencies in sp	2.5	61.54%	3	74.36%	45.76%	10	56
15	Contractor - PM	15. Slow preparation of changed orders requested	2.6	66.03%	2.8	69.23%	45.71%	11	55
10	Contractor - MP	10. Low skill of manpower	2.6	64.10%	2.8	71.15%	45.61%	12	54
24	Contractor - PM	24. Ineffective control of project progress by the co	2.5	63.46%	2.9	71.79%	45.56%	13	53
59	Gov. Regulation	59. Gov. tendering system of selecting the lowest b	2.6	65.38%	2.8	69.23%	45.27%	14	52
38	Consultant	38. Inadequate design specifications	2.4	60.26%	3	75.00%	45.19%	15	51
39	Consultant	39. Poor contract management	2.5	62.18%	2.9	71.79%	44.64%	16	50
42	Client	42. Delay in the settlement of contractor claims by	2.5	63.46%	2.8	69.87%	44.34%	17	49
29	Contractor - PF	29. Cash flow problems faced by the contractor	2.4	59.62%	3	74.36%	44.33%	18	48
25	Contractor - PM	25. Inefficient quality control by the contractor	2.5	62.82%	2.8	70.51%	44.30%	19	47
41	Client	41. Unrealistic contract duration	2.5	61.54%	2.9	71.79%	44.18%	20	47

C. Top 10 (highest severity) Factors of Delays:

One of the important things to know after identifying the top 20 factors of delays, the factors that have high severity in order to give an alerts in the last chapter about what should be avoided or at least not to elevate their impacts to the major undertaken projects.

TABLE III. TOP 10 (HIGHEST SEVERITY) FACTORS OF DELAY

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No.	Factor Category	Discription	F.I. Rate	F.I. %	S.I. Rate	S.I. %	IWI Overall %	Risk Order	Points
22	Contractor - PM	22. Ineffective planning & scheduling of the project	2.6	66.03%	3.03	75.64%	49.94%	3	63
21	Contractor - PM	21. Improper technical studies by the contractor du	2.6	65.38%	3.03	75.64%	49.46%	5	61
28	Contractor - PF	28. Difficulties in financing the project by the contra	2.3	57.05%	3.03	75.64%	43.15%	25	41
9	Contractor - MP	9. Shortage of manpower (skilled, semi-skilled, unsk	2.7	66.67%	3.00	75.00%	50.00%	2	64
38	Consultant	38. Inadequate design specifications	2.4	60.26%	3.00	75.00%	45.19%	15	51
14	Contractor - PM	14. Contractor's poor coordination with parties' inv	2.5	62.82%	2.97	74.36%	46.71%	8	58
54	Early plan & Design	54. Ambiguities, mistakes, and inconsistencies in sp	2.5	61.54%	2.97	74.36%	45.76%	10	56
29	Contractor - PF	29. Cash flow problems faced by the contractor	2.4	59.62%	2.97	74.36%	44.33%	18	48
53	Early plan & Design	53. Changes in the scope of the project	2.6	64.74%	2.95	73.72%	47.73%	6	60
45	Client	45. Slow decision making by the client's organizatio	2.5	62.18%	2.95	73.72%	45.84%	9	57

As shown in the table III above that highest severity index (S.I.%) is 76% and most of the participants admitted that the difficulties in financing the project by contractor is the highest concern and has a big influence in delaying any project. The second one is the improper technical studies by contractor during the bidding and followed by the ineffective planning & scheduling by contractor.

D. Top 10 (highest frequency) Factors of Delays:

Describing the critical factors of delays was giving the impacts based on both the severity and frequency and in this part will be talking about the factors that are mostly repeated in general projects and all parties are facing them in their daily projects. Eight factors out of 10 are related to the contactors and they seem to be a chronic and the projects mangers suffer for getting them repeated and seen every time particularly in the execution stage.

TABLE IV. TOP 10 (HIGHEST FREQUENCY) FACTORS OF DELAY

No.	Factor Category	Discription	F.I. Rate	F.I. %	S.I. Rate	S.I. %	IWI Overall %	Risk Order	Points
13	Contractor - PM	13. Shortage of technical professionals in the contra	2.9	73.08%	2.87	71.79%	52.47%	1	65
19	Contractor - PM	19. Loose safety rules & regulations within the cont	2.7	68.59%	2.90	72.44%	49.68%	4	62
9	Contractor - MP	9. Shortage of manpower (skilled, semi-skilled, unsk	2.7	66.67%	3.00	75.00%	50.00%	2	64
22	Contractor - PM	22. Ineffective planning & scheduling of the project	2.6	66.03%	3.03	75.64%	49.94%	3	63
15	Contractor - PM	15. Slow preparation of changed orders requested	2.6	66.03%	2.77	69.23%	45.71%	11	55
21	Contractor - PM	21. Improper technical studies by the contractor du	2.6	65.38%	3.03	75.64%	49.46%	5	61
20	Contractor - PM	20. Poor qualifications of contractor's tech. staff ass	2.6	65.38%	2.90	72.44%	47.36%	7	59
59	Gov. Regulation	59. Gov. tendering system of selecting the lowest b	2.6	65.38%	2.77	69.23%	45.27%	14	52
53	Early plan & Design	53. Changes in the scope of the project	2.6	64.74%	2.95	73.72%	47.73%	6	60
10	Contractor - MP	10. Low skill of manpower	2.6	64.10%	2.85	71.15%	45.61%	12	54

Table IV above shows the top 10 factors that are frequently appear as they go day after day. The most frequent factor is shortage of technical professionals in the contractor's organization. Lose safety rules & regulation is ranked the 2nd in the contractor's organization followed by shortage of the general staff skills from high to low. Ineffective planning & scheduling, Slow preparation of change orders during bedding time, improper technical studies and poor qualification for staff assigned to the project by contractor are ranked respectively the 4th , 5th , 6th and 7th.

III. *Double Roof House of Quality*

House of Quality is a diagram, whose structure resembles that of a house which aids in determining how a product or service is living up to customer needs. Although quite intricate, it is capable of storing a lot of information and comparing large amounts of data used for defining the relationship between customer desires and the firm/product capabilities.[1] It is a part of the quality function deployment (QFD) and utilizes a planning matrix to relate what the customer wants to how a firm (that produces the products or service) is going to meet those wants. It looks like a house with a "correlation matrix" as its roof, customer wants versus product features as the main structure, competitor evaluation as the porch, etc. It is based on "the belief that products should be designed to reflect customers' desires and tastes".[4] It also is reported to increase cross functional integration within organizations using it, especially between marketing, engineering and manufacturing. The basic structure is a table with "Whats" as the labels on the left and "Hows" across the top. The roof is a diagonal matrix of "Hows vs. Hows" or What's vs Whats and the body of the house is a matrix of "Whats vs. Hows". Both of these matrices are filled with indicators of whether the interaction of the specific item is a strong positive, a strong negative, or somewhere in between. Additional annexes on the right side and bottom hold the "Whys" (market research, etc.) and the "How Muches". Rankings based on the Whys and the correlations can be used to calculate priorities for the Hows.

House of Quality analysis can also be cascaded, with "Hows" from one level becoming the "Whats" of a lower level; as this progress the decisions get closer to the engineering & manufacturing details. The double-roof concept has been developed in the research so that it can consider both Hows vs. Hows and Whats vs. Whats especially if the relations are strong and effective between them. This is kind of concept is very new and innovative since nothing found in the previous studies have investigated the relations between the technical delay factors. The fig. 1 below shows the both roofs, the 1st roof is fixed in the top of the structure to reflect the relation between the customers attributes. The 2nd roof is fixed in the left side of the structure to reflect as well the inter-relations between the top 20's factors of delays.

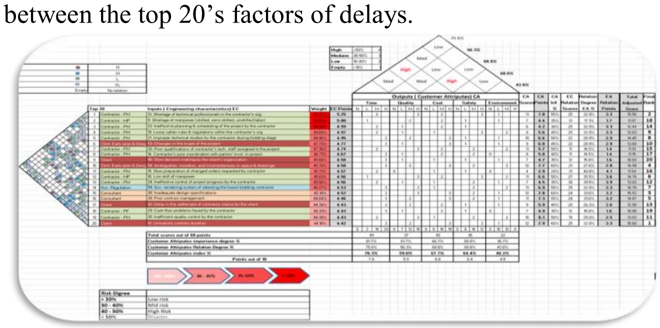

Figure 1. Double Roof House of Quality

Single-roof house of quality described the both relations between Hows and Whats relations in the main structure i.e. "0, l, 2 and 3" while the 2nd relations have been built in the top roof between the Whats vs. Whats i.e. "nothing, low, Medium and high".

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Fig. 2 below shows how the customer attributes such as time, cost, quality, safety and environment have inter-relations between each one of them. Hence, relation degrees have been interpreted in each one of them based on expert's opinions and decisions that was called for this purpose.

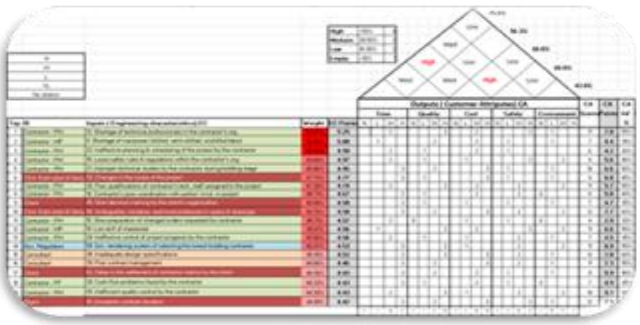

Figure 2. First -Roof House of Quality

The left fixed roof represented all relations between the Engineering Characteristics or the top 20's critical factor of delays. The degree of relations where described as follows:

- No-relation
- Very-low
- Low
- Medium
- High

The total number of relations was 361 relations were interpreted to points that reflect how each factor of delays interacts or getting influenced by others. An (engineering degree index) was created to represent this kind of relations by giving an independent weight for each factor of delay. The range of degree was (17% to 41%). Figure-3 below shows the degree of relations between all factors of delays.

Figure 3. Second Roof House of Quality

Total numbers of relations reached to 477 relations, 361 out of them were relations between factors of delays and a 100 for relations between factors of delays vs. customer attributes and the last 16 were for customer attributes among each other.

IV. Results

As a result of the three stages of analysis, table v. below shows clearly how the ranking of the factors got changed and how the additional weights that have been created by the influence of house of quality contributed to further adjustments in order to give a more rational for the proper ranking of each critical factor. As example factor-1 "shortage of technical staff" changed from R-1 to R-2 and F-15 "Inadequate design specification changed from R-15 to R-3.

TABLE V. FACTORS OF DELAYS ADJUSTED RANKING

Delay Factors		EC wight %	CA inf. %	EA relation %	Total Adjusted score	Rank
13. Shortage of technical professionals in the contractor's org.	STP-C	[illegible]	55%	32.9%	15.56	2
9. Shortage of manpower (skilled, semi-skilled, unskilled labor)	SMPALL-C	50.00%	35%	17.1%	11.07	18
22. Ineffective planning & scheduling of the project by the contractor	IEPS-C	[illegible]	30%	32.9%	12.44	14
19. Loose safety rules & regulations within the contractor's org.	LSRR-C	49.68%	45%	32.9%	13.83	9
21. Improper technical studies by the contractor during bidding stage	IMTS-C	49.46%	50%	28.9%	14.45	8
53. Changes in the scope of the project	CSP-O	47.73%	45%	28.9%	13.68	10
20. Poor qualifications of contractor's tech. staff assigned to the project	PQS-C	47.36%	55%	14.5%	11.91	15
14. Contractor's poor coordination with parties' invol. in project	PCAP-C	46.71%	40%	14.5%	11.15	17
45. Slow decision making by the client's organization	SDM-O	45.84%	35%	15.8%	10.83	20
54. Ambiguities, mistakes, and inconsistencies in specs & drawings	AMSD-O	45.76%	60%	27.6%	14.99	4
15. Slow preparation of changed orders requested by contractor	SPCO-C	45.71%	20%	40.8%	11.54	16
10. Low skill of manpower	LSMP-C	45.61%	55%	35.5%	14.76	6
24. Ineffective control of project progress by the contractor	IECPP-C	45.56%	35%	39.5%	13.03	12
59. Gov. tendering system of selecting the lowest bidding contractor	GTLB-O	45.27%	55%	32.9%	14.70	7
38. Inadequate design specifications	IDS-E	45.19%	60%	31.6%	15.52	3
39. Poor contract management	PCM-E	44.64%	55%	31.6%	14.87	5
42. Delay in the settlement of contractor claims by the client	DSC-O	44.34%	45%	26.3%	12.99	13
29. Cash flow problems faced by the contractor	CFP-C	44.33%	35%	15.8%	10.95	19
25. Inefficient quality control by the contractor	IEQC-C	44.30%	50%	25.0%	13.03	11
41. Unrealistic contract duration	URCD-O	44.18%	60%	32.9%	15.60	1

The ranking for the critical delay factors were completely reordered after the realization of all influenced factors as discussed before. The contribution of all relations "EC weight, EC-Index and CA-Index" have been formulated to the total adjusted weight. The highest score was giving the 1st rank and the lowest was considered the last. Figure-4 below gives the three different indexes influences with each critical factor of delay.

IV. *Discussions*

Most of the previous studies were concerned about finding the critical factors of delays by using different methods and techniques. Some of them have done further analysis assuming all factors have linear relations but in fact and after detailed analysis, it has been found that most of the factors have non-linear relations with customer attributes and even among each other. Here in this research, the critical delays factors have been evaluated thoroughly in many workshops to find wither these relations got influenced by other factors or not in order to give sensitive weights that reflects the reality.

This research has a unique principle of considering the effects between all delay factors which represented around 477 different degrees of relations which helped to create three additional indexes that have recharged the complete rankings. In the fig. 4 below shows how the top 20's factors of delays are influenced by the expert ratings, other factors of delays and customer attributes such as time, cost and quality.

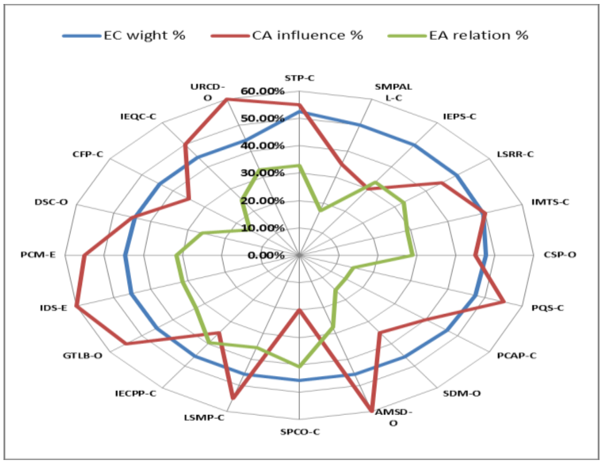

Figure 4. All Indexes Relations With Factors Of Delay

The final adjusted ranking has shown that the unrealistic time duration that is usually planned at the very beginning of the project is the main reason of delayed followed by shortage of professional in the contractor organization. The inadequate design and specification by consultant was ranked as a 3rd critical factor. Figure 4 gives full details of ranking for the top factors of delays from highest to lowest.

Acknowledgment

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About Author (s):

I hope to continue building my acting career and work more in projects that fulfill my artistic thirst