International Journal of Engineering

Journal Homepage: www.ije.ir

Use of Quality Function Deployment for Gold Mining Feasibility Study (Case Study: Designing Explosive Storage Area)

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PAPER INFO

Paper history:
Received 03 January 2020
Received in revised form 20 March 2020
Accepted 20 March 2020

Keywords:
Engineering Design
Explosive Storage Area
Feasibility Studies
House of Quality
Quality Function Deployment

ABSTRACT

In the mining industry, at the beginning of development of a project, a consultant is assigned to build a design feasibility study to incorporate the client requirement, government regulation, and other inputs into the design. The consultant usually faces overwhelmed stages due to changes caused by the client and other stakeholders and has to repeat the process of inputting requirements into the design, which will cause delays for the projects. To enhance this design process and improve the quality, the use of " House of Quality (HoQ)" as part of Quality Function Deployment (QFD) was carried out. In this study it was attempted to improve the design of the Explosive Storage Area, which is the most complicated area where client expectations on the design are required, to meet the regulation. This study also aims to see how much time is saved during the design stages by using the HoQ. From the study, the technical importance rating of the containerized building showed the highest point (13%) followed by a radius between detonation and ammonium nitrate storage area (11%). The improvement design was developed and prioritized based on the rating from technical importance and the results of the design showed great satisfaction of the client. The duration of the design stage was also saved by almost 3 days of the normal design process without using QFD. This study showed the ability of QFD to enhance and assist during the design phase in the feasibility study, and resulted in great client satisfaction for the final product.

***doi**: 10.5829/ije.2020.33.05b.14*

1. INTRODUCTION

A feasibility study is an early analysis or assessment of a project before going ahead. It takes all relevant factors into the consideration, which includes: economic, technical, legal, social, and schedule considerations to ascertain a likelihood of completing a project successfully [1].

Feasibility study in a mining projects and industry is commonly conducted during their early-stage whether the projects are greenfield or brownfield due to their nature of the long term, high-cost investment, along with high-risk and uncertainty [2]. During these stages, the mining company will appoint a consultant to conduct a feasibility study on the project. The consultant will then gather all information that is required (i.e., technical, financial, schedule, risk) and create a final feasibility study report that summarizes whether the project is economical and technically feasible or requires some adjustment to meet the criteria [3]. The consultant will work closely with the client and tries as much as possible to get a certain amount of information and requirement. However, during this stage, the consultant should adjust the requirements based on regulation, supply chain, local content, social, and cultural issues [2, 3].

Designing for infrastructure is a part of the feasibility studies, along with mining exploration, mining development, and process design. Infrastructure inside the mine includes road and earthworks, camp and offices, substation and electrical distribution, explosive storage and mine facilities area, fuel distribution and storage, and tailing disposal and pipeline.

One of the critical areas in the gold mine is the explosive storage area. The explosive or magazine site should be stored and managed accordingly and ensure that the following items are met: (a) compliance with the regulations, (b) minimize the risk due to explosions, (c) prevent unauthorized personnel and risk of theft, (d) ease

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Please cite this article as: B. I. Saleh, W. Wahyudin, H. H. Purba, Use of Quality Function Deployment for Gold Mining Feasibility Study (Case Study: Designing Explosive Storage Area), International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 33, No. 5, (May 2020) 825-832

of access for the operation, and (e) maximize the lifetime of the explosive material storage which require a delicate design process due to the necessity to meet these requirements and also to satisfying other requirements that come from the client (i.e: cost, efficiency, etc.) [4].

Finalizing the design will be an overwhelming process where the consultant will input the design and functional requirements based on the interview from one user to another and repeating the process, which delays the project.

This study will use Quality Function Deployment (QFD) as a tool for translating the needs of customers/client into technical design and by then to reduce design errors and ensure that the important client specifications are prioritized.

QFD is a method for (a) developing a design quality where the final products are satisfying, and (b) translating the consumers' requirement into design targets and major quality points to be used throughout the production or manufacturing stage [5, 6]. According to the literature [7–9], the objectives of using QFD in a project are to (1) define design and specifications and achieve the highest level of customer requirements and satisfaction, (2) ensure the consistency between client needs and the product's measurable characteristics, (3) ensure consistency between the design/planning phase and the construction phase and (4) reduce the time to perform quality features, especially in the repeating process during design development. QFD can reduce issues that usually are raised between design and construction phases (including "constructability" problems and construction reworks).

This study will focus on designing the explosive storage area during the feasibility stages. This study was conducted in Indonesia for a gold mining project.

2. LITERATURE REVIEW

2. 1. QFD (Definition and History) QFD was first conceived in Japan in the late 1960s after World War II. During this time, the automotive industries were emerging but still produced low–quality products. Then, influenced by Deming and other quality management specialists who came to Japan, Japan Engineers start to improve their quality process and methods.

During that time the Japanese auto industry was in a rapid growth phase. Continually new models were developed and improved. To meet the situation Yoji Akao and Shigeru Mizuno developed a method to improve the design of products. On the basis of their work in 1978 jointly, they published the first book on the method QFD: Quality Function Deployment: A Company-Wide Quality Approach [5, 10]. The Quality Function Deployment is a translation from Japanese words "hinshitsu kino tenkai" that in literal translation means deploying the attributes/features of a product/service accepted by customers throughout the relevant department of a company [11].

2. 2. House OF Quality (HoQ) House of Quality (HoQ) was given this name because of the shape of triangular, which looks like a roof (Figure 1). It was introduced by Hauser and Clausing with the purpose that HoQ is to transform the "Customer Requirements and Needs" into "Engineering and Technical Characteristics" and assign values as a target for the product. HoQ is also described as a matrix that correlates between understanding the customer requirement and prioritizing the engineering and technical requirement. Cooperation between all departments (i.e., engineering, marketing, manufacturing, etc.) is very crucial for building the HoQ. This will lead to a greater new or improved product success and more profits for the company [12, 13].

Customer needs/ requirements show the "voice of customers" that can be obtained using interviews or surveys. Performance measures show the improvement of technical requirements. Design/technical requirements section shows the technical requirements for the design; it shows how to achieve the customer needs. The engineering measures (located in the below section of the house) indicate the relatives' measurement and target value. The roof of the house indicates the positive and negative relationships between the technical requirements. The body of HoQ shows the correlation between customer needs and technical requirements [5, 12, 13].

2. 3. QFD Use in Design for Construction and Infrastructure QFD was most often used in the automotive and manufacturing industries. However, the method used to incorporate the voice of the customer into a new development of the product did not restrict this method for the development of the design for construction [14]. Some studies [12] used QFD to monitor the quality of the concrete mix in the project. Other research [8] showed how QFD can be applied in

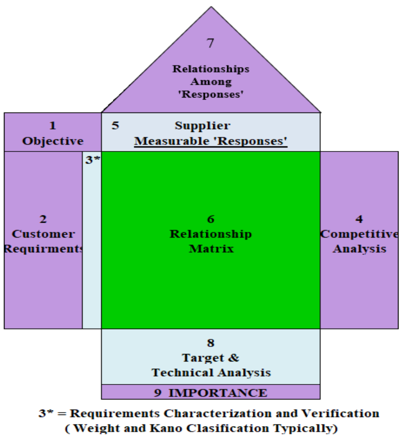

Figure 1. House of Quality [12]

the housing projects to facilitate marketing decisions. In the engineering phase, some works [15, 16] used the QFD to design the house to fulfill the requirements from the customers, and in another study [17] QFD was used for design of integrated Building Information Management (BIM).

3. METHODS

The first phase is gathering the information and requirement from the client-side and regulatory side ("What"). Methods that are going to be used are as follow: (a) asking and interviewing in a focus group that consists of project technical manager, engineering manager, safety, legal and commercial from client-side and also invites the government side as a regulatory input, (b) some of the subtopics that will be interviewed in the focus groups are regulation, safety & security, capacity, operation, fixtures, and cost efficiency and (c) design draft (called: revision 0.0) is given to the focus group along with the design from previous projects and vendor design as benchmarks or comparisons.

After capturing the "What" list from the client, other brainstorming methods are implemented internally with the design and engineering team; this is a process to develop the technical requirement of the design " How."

The QFD matrix that is going to be used is HoQ is based on a published work [18] excel template. The HoQ method follows: (a) client and regulatory requirements "Whats" that were developed from the discussion will be inputted into the matrix to show the degree of importance (customer importance) and input during the focus group meeting from the scale 1-10 (lowest-highest). The design benchmarks weight is also input from the scale 1-5 (lowest to highest) based on their compliance with "Whats." (b) The functional requirements "How" based on the brainstorming method are inputted into the matrix. The "roof side of the matrix" is developed to see if there is an effect (positive, negative, or no effect) between the functional requirements. (c) The target values are input as value to achieve the required standard. The directional improvements "How" are filled based on the target value (to maximize, is on target, or to minimize). (d) The last one is to develop the QFD correlation matrix. This matrix is the center of QFD and links "What" and "Hows." The scale of the relationship is based on strong, moderate, and weak relationships. There should be no empty cells (no relationship) in this matrix.

After the result of relative weight and importance of weight is obtained, the design team then implements and develops a new design accordingly. The new design will then be presented to the focus group team for the final design product. All the durations for those stages are recorded and highlighted.

4. RESULTS AND DISCUSSIONS

4. 1. Customer Requirement "What", Degree of Importance and Benchmarking

The requirement from the client and regulatory-side, customer degree of importance and benchmarking are shown as follows; The requirement from the client and regulatory- side, customer/degree of importance and benchmarking are shown in Table 1. According to the result of customer requirements in Table 1, the highest priorities (customer importance) for the design are compliance with regulation and efficiency. The fixtures (i.e., cable optics, dustproof materials) somehow don't show high numbers of importance because the client does not think that it will

TABLE 1. Customer requirement " What", degree of importance and benchmarking

No	Weight Chart	Relative Weight	Customer Importance (1 -10)	Subtopic	Customer Requirements (Explicit and Implicit) "What"	Design Benchmarks (1- 5 scale)		
						Design Draft (Revision 0)	Using previous project design	Vendor #1: Design Data
1	|||	6%	9	Regulation	Comply with regulations from the government for the length and radius to other building especially for detonation and explosive storage	2	2	4
2	|||	6%	9		Comply with regulations from the government for the length and radius to other main facilities	2	2	2
3	|||	6%	9		Embankment surround the area	2	2	2
4	|||	6%	9		Comply with regulations from the government for the type and standard	3	3	3
5	||	5%	8	Building Capacity	The building should hold maximum storage based on the operation	2	3	2
6	||	5%	7		efficient size of building	1	2	3
7	||	4%	6		Watchtower to oversee the surrounding	1	1	1

8	||	4%	6	Security and Safety	A Fire hydrant with water system separate	1	1	1
9	|	3%	4		CCTV inside and outside building	1	1	1
10	|	3%	4		Gate and fences for entrance	2	3	4
11	||	5%	7		High fences that surround the area	2	2	2
12	||	5%	8	Operation	wide road (two lines)	2	2	2
13	||	4%	6		waterline for operation using sufficient water tank	2	3	1
14	||	4%	6		The parking lot for light vehicles and maneuver point for trucks	3	2	1
15	|	3%	4	Fixtures	Genset for backup	1	3	2
16	|	2%	3		Dust proof lighting	2	2	2
17	||	4%	6		Cable optics for networks	2	2	2
18	||	5%	7		Main fire extuingisher	2	2	1
19	||	5%	8	Eficiency	Using low cost material for building	2	2	4
20	||	5%	8		Easy install / construct	3	3	4
21	||	4%	6		Cut & fill material can be used as embankment or other	3	3	2
22	||	5%	7		The materials are easy to procure and deliver	2	2	3

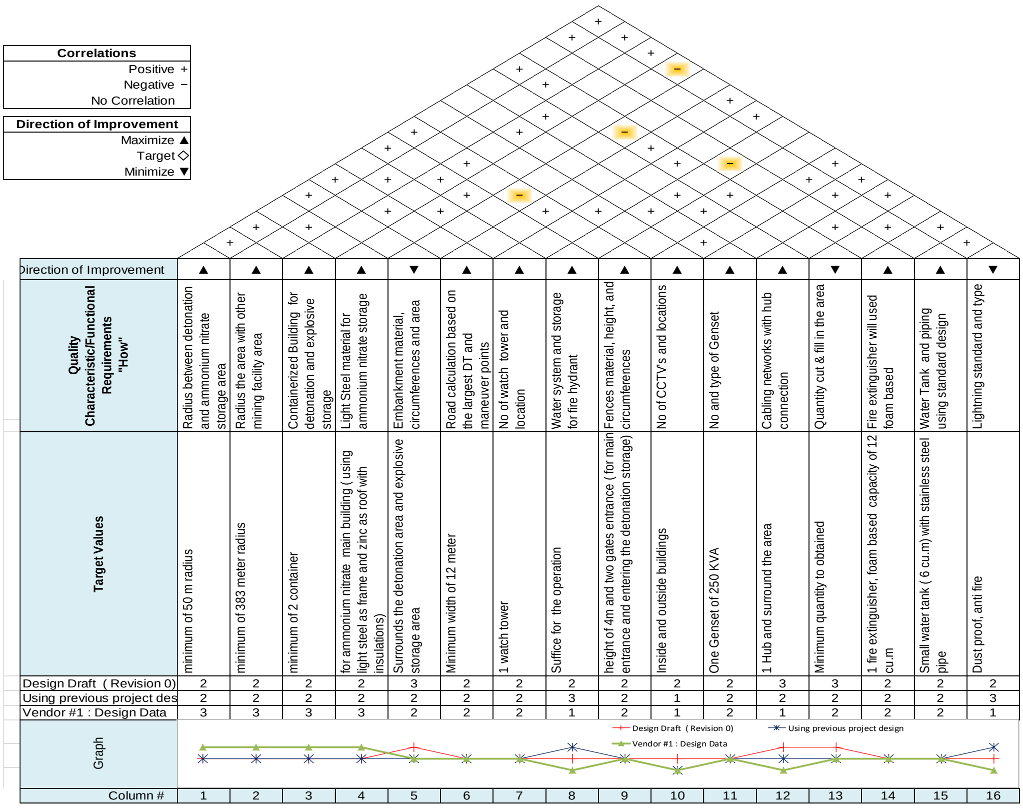

Figure 2. Functional requirement, correlation matrix, direction of improvement, target values and measurement evaluation

be a prioritize item and can be changed accordingly in the future. An explosive storage area is considered to have a high number of government regulations that need to comply, especially for the radius of the area inside the vicinity and with other facilities, but on the other hand, the client also requires to use low-cost material and easy to construct materials. Proposed vendor design mostly met the customer requirement" What," while design revision 0.0 and previous project design mostly did not meet.

4. 2. Functional Requirement Matrix ("How's"), Direction of Improvement, Correlation Matrix, Target Values, and Measurement Evaluation After developing the customer requirement and benchmarking the design, another process is developing the functional requirement matrix ("How's") with the direction of improvement and correlation matrix, as shown in Figure 2. The target values are set to show what is the target that needs to be achieved as reference. The revision 0.0 design requires improvements to achieve the targeted values. The increase is for the radius of the length between the detonation area, and with another mining facility since it did not reach the targeted value. Some of the designs (i.e., embankment and cut & fill area) need to reduce to achieve minimum quantity.

Measurement evaluation between revision 0.0, previous project design, and vendor proposed design for the functional requirements was also developed to be used as complementary information and benchmarks. As seen in Figure 2, all designs show not very good value on satisfying the target values. The correlation matrix for functional requirements was also developed (using the roof), this will be used to assist the design team in seeing the positive and negative correlations between the functional requirements during the improvements.

4. 3. QFD Correlation Matrix The QFD correlation matrix was developed to see the correlation between customer needs ("what") and functional requirements ("How"), as seen in Figure 3. The relative

Relationships	
Strong	●
Moderate	○
Weak	▽

Row #	Weight Chart	Relative Weight	Customer Importance (1 -10)	Maximum Relationship	Subtopics	Customer Requirements (Explicit and Implicit) "What" / Quality Characteristic/Functional Requirements "How"	Radius between detonation and ammonium nitrate storage area	Radius the area with other mining facility area	Containerized Building for detonation and explosive storage	Light Steel material for ammonium nitrate storage	Embankment material, circumferences and area	Road calculation based on the largest DT and maneuver points	No of watch tower and location	Water system and storage for fire hydrant	Fences material, height, and circumferences	No of CCTV's and locations	No and type of Genset	Cabling networks with hub connection	Qunatity cut & fill in the area	Fire extinguisher will used foam based	Water Tank and piping using standard design	Lightning standard and type
1		6%	9	9	Regulation	Comply with regulations from the government for the length and radius to other building especially for detonation and explosive storage	●	●	○		○				○	○						
2		6%	9	9		Comply with regulations from the government for the length and radius to other main facilities	●	●			○				○	○						
3		6%	9	9		Embankment surround the area	▽	○			●					○						
4		6%	9	9		Comply with regulations from the government for the type and standard	●	●	○	○											○	○
5		5%	8	9	Building Capacity	Building should hold as maximum storage based on the operation			●	○		○					○	○		○		○
6		5%	7	9		Efficient size of Building	▽	▽	●	○		○			○		○	○				
7		4%	6	9	Security and Safety	Watchtower to oversee the surrounding	○			○	▽		●									
8		4%	6	9		Fire hydrant with water system separate	▽							●			○			○	●	
9		3%	4	9		CCTV inside and outside building	▽		○	▽						●						
10		3%	4	9		Gate and fences for entrance	▽	○			○				●							
11		5%	7	9		High fences that surround the area	▽				○				●				○			
12		5%	8	9	Operation	Wide Road (two lines)	○	○			▽	●							○			
13		4%	6	3		Water line for Operation using suificient water tank	○	○												○		
14		4%	6	9		Parking lot for Light Vehicles and maneuver point for Trucks	▽		○			●							○			
15		3%	4	9	Fixtures	Genset for backup											●					
16		2%	3	9		Dust proof lighting																●
17		4%	6	9		Cable optics for networks										○		●				
18		5%	7	9		Main fire extuingisher								○						●		
19		5%	8	9	Eficiency	Using low cost material for building		▽	●	○		▽	○				○	○	●		○	
20		5%	8	9		Easy install / construct			●	▽	○		○					○				○
21		4%	6	9		Cut & fill Material can be used as embannkmet or other	○	▽			○	●							●			
22		5%	7	9		The materials are easy to procure and delivered			●	●		▽		○			●	▽	▽		○	●
						Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
						Technical Importance Rating	248	235	290	129	152	163	69,4	65,3	118	91,8	127	105	133	83,7	85,7	112
						Relative Weight	11%	11%	13%	6%	7%	7%	3%	3%	5%	4%	6%	5%	6%	4%	4%	5%
						Weight Chart																

Figure 3. QFD correlation matrix, importance rating and relative weight of functional requirement ("How's")

weight and importance of weight for functional requirements were developed to determine the level of importance of design requirements.

To calculate the technical importance rating, the relationship that is measured as a strong relationship is 9 points, moderate is 3 points, and weak is 1 point. The technical importance rating is then calculated by the following formula (Equation (1)) as follows:

$$Technical\ importance\ rating = \sum_{i=1}^{n} R_i\ d_i \qquad (1)$$

where R_i = relative weight for customer importance and d_i is functional relationship requirement and customer importance across the vector of functional requirement column.

The technical importance rating and relative weight will be used to set the priority of the design requirement. The first priority is to increase the capacity and No's of the containerized building for storage, then the radius of the length of detonation and ammonium nitrate storage area, and continues following the rank from the relative weight. The following is reconsider also based on compliance to regulate also use low cost and easy to install is the high rank of customer needs.

4. 4. Design Improvement for Explosive Storage Area

After obtaining the importance weight and relative weight of technical requirement, it will be possible to develop the design improvement table to be implemented in the new layout, as seen in Table 2.

The design improvement and solutions were based on the priority, and also reconsider the correlation between the functional requirements. The revision drawing (called revision 1.0) then developed and submitted to the client. There was no further comments from the client for the updated design and stated that it met their criteria.

Durations of design stages are summarized and compared with the normal design durations without using QFD, as shown in Table 3.

Total duration of design stages using QFD was only 12 days compared to without QFD of 15 days. The duration differs in how much revision is being submitted to the client, where using QFD only 1-time revision is required and gets approval from the client.

TABLE 2. Design improvement and solutions

No	Technical Requirements	Technical Importance Rating	Relative Weight	Design Improvement and Solutions
1	Containerized building for detonation and explosive storage	289.8	13%	Adding the quantity container using 20' feet - 4 nos
2	Radius between detonation and ammonium nitrate storage area	247.6	11%	Increasing the radius, 50'm
3	Radius the area with other mining facility area	234.7	11%	Increase the radius to other facilities, move to a new area
4	Road calculation based on the largest DT and maneuver points	163.3	7%	Widening the road to 12'm and create a maneuver point using large parking lots
5	Embankment material, circumferences, and area	152.4	7%	Reduce the Embankment only surrounds the detonation and high explosive storage using an excess of cut & fill from road
6	Quantity cut & fill in the area	133.3	6%	Changing some location to minimize cut & fill
7	Light Steel material for ammonium nitrate storage	128.6	6%	Using light steel and zinc alum roof - increase the size
8	No and type of genset	126.5	6%	Upgrade to 250 KVA
9	Fences material, height, and circumferences	118.4	5%	Upgrade the height of the fences and using two gates
10	Lighting standard and type	112.2	5%	Reduce to dust-proof material and using anti-fire materials
11	Cabling networks with hub connection	104.8	5%	Increase the quantity and terminal hub
12	No of CCTV's and locations	91.8	4%	Increase the numbers for outside and inside the building
13	Water tank and piping using standard design	85.7	4%	Increase the quantity for piping and size
14	The fire extinguisher will be used foam-based	83.7	4%	Increase in size
15	No of watchtower and location	69.4	3%	Adding one watchtower in the detonation storage area
16	Water system and storage for fire hydrant	65.3	3%	Increase size and quantity for piping

TABLE 3. Duration using QFD *vs* duration without QFD

No	Design Phase	Duration - using QFD (in days)	Duration - without QFD (in days)
1	Create design	1	1
2	Design submission to client	1	1
3	Brainstorming for design with client	5	2
4	Revision design #1	3	4
5	Revision design #1-Submission	1	1
6	Client review	0	1
7	Revision design #2	0	3
8	Revision design #2-Submission	0	1
9	Client approval	1	1
	Total Duration	**12**	**15**

5. CONCLUSIONS

Customer requirement "What" shows that the highest priority is from the compliance of regulation and efficiency (within an average of 9 and 7). The benchmarking for design against customer requirement shows the low result for design revision 0.0 (with the lowest result in compliance with the regulation). From the technical importance rating, containerized building shows the highest percentage (13%) followed by radius between detonation and ammonium nitrate storage area (11%). The technical importance rating then reordered to prioritize the design improvement and solutions. The durations of design also accelerated to almost three days. It indicates that QFD shows great assistance during the design state in feasibility studies. Further research is to combine the QFD with risk assessment of the design using Design Failure Mode and Effect Analysis (DFMEA) method.

6. ACKNOWLEDGMENTS

The authors would like to thank and show gratitude to the University of Mercu Buana for given the opportunity to do the research and to other lecturers for valuable inputs and comments during the research.

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Persian Abstract

چکیده

در صنعت معدن، در ابتدای توسعه یک پروژه، یک مشاور برای مطالعه امکان سنجی در نظر گرفته می‌شود تا نیاز مشتری، مقررات دولتی و سایر مسائل را در طرح بگنجاند. مشاور معمولاً به دلیل تغییراتی که توسط مشتری و سایر ذینفعان ایجاد می شود با مراحل پر پیچ و خمی روبرو است و مجبور است روند وارد کردن الزامات به طرح را تکرار کند که این امر باعث تاخیر در پروژه ها خواهد شد. برای بهبود این روند طراحی و بهبود کیفیت، استفاده از "خانه کیفیت (HoQ)" به عنوان بخشی از استقرار عملکرد کیفیت (QFD) انجام شد. در این مطالعه سعی شده است تا طراحی منطقه ذخیره سازی انفجاری، به عنوان پیچیده ترین منطقه ای که انتظارات مشتری در طراحی مورد نیاز است، بهبود یابد تا مطابق آیین نامه باشد. این مطالعه همچنین قصد دارد که بررسی کند با استفاده از HoQ چقدر در زمان مراحل طراحی صرفه جویی می‌شود. براساس این مطالعه، اهمیت فنی ساختمان کانتینر شده بالاترین نقطه را (۱۳٪) در رتبه بندی نشان داد و بعد از آن شعاعی که بین انفجار و محل ذخیره نیترات آمونیوم (۱۱٪) وجود دارد. طراحی بهبودیافته براساس اهمیت فنی تهیه و اولویت بندی شده و نتایج حاصل از طراحی، رضایت زیاد مشتری را نشان داد. مدت زمان طراحی نیز تقریباً به اندازه سه روز روند طراحی عادی و بدون استفاده از QFD ذخیره شد. این مطالعه توانایی QFD در تقویت و کمک در مرحله طراحی را در مطالعه امکان سنجی نشان می‌دهد و باعث رضایت مشتری از محصول نهایی می‌شود.