Use of Quality Function Deployment in Civil Engineering Capital Project Planning

Syed M. Ahmed, M.ASCE[1]; Li Pui Sang[2]; and Željko M. Torbica, M.ASCE[3]

Abstract: Capital project development is a complex process that takes many years to implement. The development of a capital project usually undergoes several rounds of design evolution, and as a result the basic and original customer's requirements may be easily sidetracked or may deviate from the client's objectives. Quality function deployment (QFD) is a tool that can be used to keep track of customers' requirements. The objective of this paper is to explore the applicability of QFD in the civil engineering capital project planning process by developing a QFD model with an application template for the process. To verify and demonstrate how the QFD model works, data are obtained from two real-life projects and fed into the template for back-analysis. The findings suggest that QFD can be successfully used in the capital project planning process as a road map to keep track of the original requirements, facilitate good communication across the hierarchy, and serve as a tool for evaluating project alternatives.

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Introduction

Improving customer satisfaction has been identified as one of the most important challenges facing businesses over the past decade. As industries and companies worldwide face increasing competition, slower growth rates, and price pressures, greater attention continues to be placed on customer satisfaction (Johnson and Fornell 1991). Private business entities are looking for magic ways to improve the quality of their products and services in order to survive in the keenly competitive world. The public sector is facing similar challenges regarding the quality of products and services provided, as one of its paramount responsibilities is to ensure that the community gets maximum value from the available resources [for example, Government (1999)].

Civil engineering capital projects, such as ports and airports, roads and highways, water supply and drainage systems, sewage, and other environmental schemes, are key assets of a country or city. Capital project development is a complex process that usually takes many years to implement. Due to the complexity of the development process, and after undergoing several rounds of design evolution, the basic and original customer's requirements may be easily sidetracked or may deviate from the client's objectives. Consequently, customer needs and functional requirements may remain unfulfilled. The major challenges encountered during the development process are how to identify and prioritize the customer requirements and how to maintain the requirements throughout the planning and design phases of capital projects.

Objectives of Study

The objective of this study is twofold: to explore the suitability of quality function deployment (QFD) in the planning and design of capital projects, and to propose a QFD application model that can be readily used in the planning and design process. To accomplish this objective, a four-stage research method has been adopted. First, we will review and discuss the principles, theory, and framework of the QFD technique; second, the civil engineering capital project planning process will be examined and analyzed; next, a QFD application model for the civil engineering project planning and design process will be developed; and finally, the validity of the proposed model will be tested using the data collected from two civil engineering capital projects.

Quality Function Deployment (QFD)

QFD focuses on the customer's needs and the prioritization of those needs to produce competitive quality products in the design phase. It is a systematic approach that maps the customer's needs into definable and measurable product and process parameters, using a series of matrices and other quantitative and qualitative techniques (Hauser and Clausing 1988; Akao 1990; Bicknell and Bicknell 1995). QFD is a powerful tool for consistent communication and for the transfer of information throughout the design or product development phases.

The overview of the QFD method presented here is a simplified approach that follows the framework of the integrated QFD approach of Bicknell and Bicknell (1995). The core of the QFD method is a matrix base commonly referred to as the ''house of quality'' (HOQ), a 2D matrix that displays customer's needs, also

[1]Assistant Professor, Dept. of Construction Management, Florida International Univ., 10555 W. Flagler St., Miami, FL 33174. E-mail: smahmed@eng.fiu.edu

[2]Engineer, Territory Development Dept., Hong Kong Government. E-mail: puisang@i-cable.com

[3]Assistant Professor, Dept. of Construction Management, Florida International Univ., 10555 W. Flagler St., Miami, FL 33174. E-mail: torbica@eng.fiu.edu

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J. Constr. Eng. Manage., 2003, 129(4): 358-368

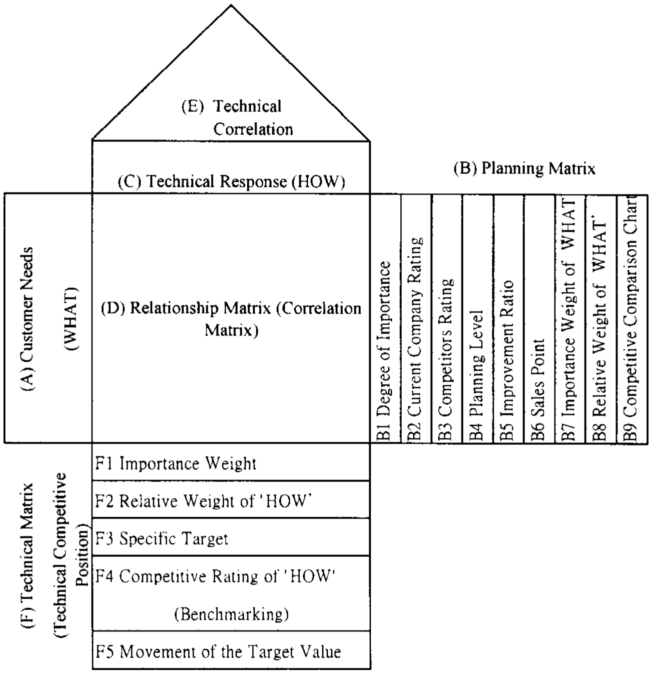


Fig. 1. Sections of house of quality (HOQ)

referred to as the "what," and the organization's technical responses to these needs, also referred to as the "how." Each of the customer needs for the "what" can be cross-checked against the related design and product response elements of the "how." The core matrix of QFD or HOQ is illustrated in Fig. 1.

QFD starts with a structured list of customer wants and needs (customer needs, or "what"). A relative degree of importance is assigned to each of the customer's needs, which are then tabulated according to the relative importance ranking order. The planning matrix section is a competitive analysis of a product or service performance against the performance of competitors' products and services with respect to each individual customer need. This section may contain one or more of the following subsections: (B1) degree of importance, (B2) current company rating, (B3) competitors' rating, (B4) planning level, (B5) improvement ratio, (B6) sales point, (B7) importance weight of customer needs, (B8) relative weight of customer needs, and (B9) competitive comparison chart.

To define the relative degree of importance of each of the structured customer needs, this study uses a 1 to 5 point scale that assigns a ranking of 5 to the most important needs and 1 to the least important needs. The technical response section ("how") formulates a structured set of technical responses that are directly related to the customer needs outlined in the "what" section. The relationship matrix shows the extent to which individual technical responses support the fulfillment of each customer need.

The following measures are used in this study to quantify the strength of each relationship: 9 (very strong), 5 (moderate), 3 (weak), and 0 or blank (no relationship). The technical correlation section measures the interaction between the technical responses and provides an early recognition of whether any technical response is positively or negatively correlated with other technical response.

A four-point scale (strongly positive, positive, negative, and strongly negative) is usually adopted for this purpose. Technical responses exhibiting negative relationships are traded off to find the best compromise, and strong positive relationships are studied

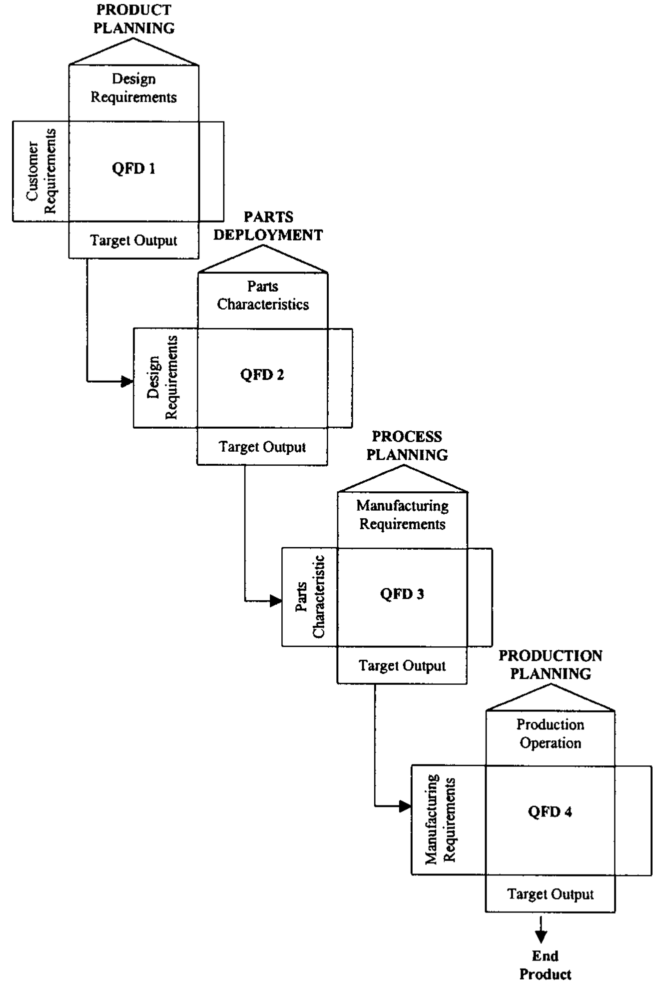


Fig. 2. Chain of QFD matrices

to prevent duplication of effort. The technical matrix section represents the technical responses in computed rank ordering and usually contains one or more of the following subsections: (F1) importance weight, (F2) relative weight of technical response, (F3) specific target, (F4) competitive rating of technical performance, and (F5) movement of the target value.

QFD is not just a prioritization tool, but is also a deployment tool. The deployment process is generally referred to as the four-phase approach (Sullivan 1986), whose four elements may vary depending upon application and can be (1) program planning, (2) product design, (3) process planning, and (4) process control planning. The process continues until each objective is refined to an actionable level (Slabey 1990). Fig. 2 shows the chain of QFD matrix application in a simplified manufacturing process.

Civil Engineering Capital Project Development Process

In this section we will discuss the civil engineering capital project planning process and the various phases involved in the process. Civil engineering capital projects, irrespective of type, size, and complexity, go through a typical development life cycle that can be divided into two stages: planning and design, and construction and implementation. During the planning and design stage, the owner's concept of a project is converted into a finished design.

J. Constr. Eng. Manage., 2003, 129(4): 358-368

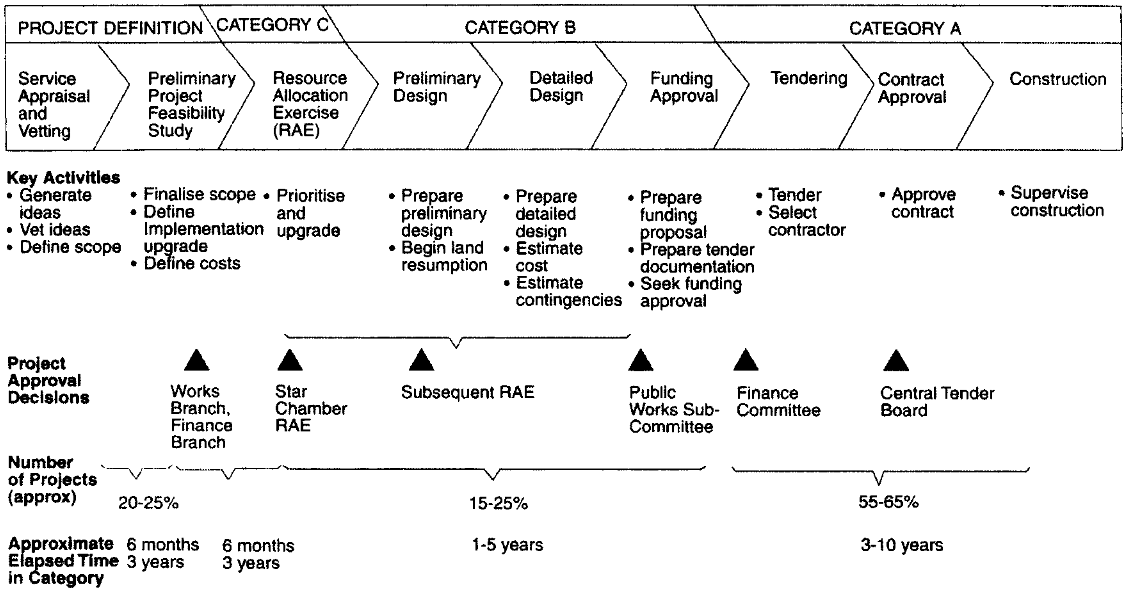


Fig. 3. Project delivery process in PWP system

This conversion process includes planning, design, and possibly the preconstruction procurement. The term project planning is used here to represent both the planning and design of a project. The construction and implementation phase includes the following subphases: bidding (tendering), construction and procurement, startup commissioning, operation, and final disposal of the project. The subphases may be sequential where completion of one subphase is followed by the start of the succeeding subphase, or there may be some overlapping between subphases. Also, some of the subphases may be combined with others, or not performed at all on a given project.

In this study we use the Hong Kong government's procedures and practices, called the Public Works Program (PWP) system, as a generic model to illustrate the project planning process (EACSB 1990; Crow 1996). The project development process in any other country, as well as in the private sector, will follow a similar path. Fig. 3 illustrates the project delivery process used by the Hong Kong government (Crow 1996).

This study is concerned with the application of QFD in the planning and design stage. Four development phases for civil engineering capital project planning can be identified as follows: project requirement, feasibility study, preliminary design, and detailed design. Each of these four successive phases involves transactions between a customer and a supplier and produces a distinct deliverable. The term phase customer is used here to describe the customer in one particular phase that will take up the role of the client in the respective phase. Similarly, the phase supplier is the counterpart to a phase customer who provides the service in the respective phase. Also, each phase deliverable provides expanded and refined information about the potential civil engineering capital project.

Project Requirement Phase

The objective of the project requirement phase is to develop a clear definition of the end product a client is looking for. It starts with a client who faces a problem and needs a solution. For example, the traffic is too busy at a local road junction where a bridge is required to find a route across the junction. The phase customer is the policy secretary and client department in the PWP system, or the business department of a private entity in the case of a privately financed project. The phase supplier, in response to the tasks received from the phase customer, develops and evaluates alternative project concepts. The engineering or operation department within the client organization usually does this. In the PWP system, the product of this phase is the client project brief. In the private sector, the deliverable of this phase will have different names but will still be similar in content and serve the same purposes. The phase deliverable will become and remain a proxy requirement for the next phase.

Feasibility Study Phase

Like the project requirement phase, the feasibility study may be, and usually is, carried out internally. In the PWP system, the customer and the supplier remain the same as in the previous phase, that is, the appropriate policy secretary and the works department. The phase deliverable for this phase is the preliminary project feasibility study report.

During the first two phases, the customer needs and wants are initiated (project requirement phase) and then subjected to validation (feasibility phase). Up to this point, it is the business or policy side of the client that speaks. The value-adding actions in the following phases (preliminary and detailed design) are engineering in nature, and customer and supplier roles are fulfilled by engineering entities, either by the owner's in-house design/engineering team or by an outside consultant.

Preliminary Design Phase

After the project is determined to be feasible for meeting the client's business objectives, the client will give a green light to proceed with a preliminary design. In the PWP system, the role of phase customer is now undertaken by the works department, and the role of phase supplier by the consultant or the in-house design/engineering group. The preliminary engineering design deliverables are quite substantial and will undergo a series of partial submittals, reviews, and further refinements in collaboration with the customer. When approval by the customer (the client) is obtained and funding is available, the project scope is considered

J. Constr. Eng. Manage., 2003, 129(4): 358-368

finalized. The detailed design then proceeds, and the approved deliverables of the preliminary design phase will constitute the basis for the detailed design phase.

Detailed Design Phase

The main objective of the detailed design is to produce a set of contract documents for the contractor to follow during construction of the project. At the completion of the preliminary design phase, the design of a project may be 40% or so complete. The preliminary-to-detailed design interface involves only the further refinement of the same design work performed in the preceding phase. Up to this stage, the results of all related studies, such as the environmental impact assessment, traffic impact assessment, and drainage impact assessment, are obtained, as required in Hong Kong. Statutory approvals will be obtained as well. The detailed design will finalize the project design close to 100%, and the remainder, if any, would be items that require initial construction to commence before they can be finalized. Such items are not usually planned, but simply happen. It must be noted that the consultant involved in the preliminary design phase may not be the same one used in the detailed design phase, but the phase customer and phase supplier relationship remains the same as that in the preliminary design phase. By completing the detailed design phase, the planning and design phase in the development of a civil engineering capital project ends.

Customer and Supplier Role in Planning Process

As the project planning process proceeds, it can be seen that the entities of the customer and supplier change from phase to phase. All the customers and suppliers across the sequential phases are termed the phase customer and phase supplier. Note that phase customers are not the same entities as the end users, who are usually the general public, which enjoys the use of a capital project when it is constructed. End users usually pay for the project indirectly, either through taxes or through toll or ticket payments for the tunnel or bridge users, for example.

If the design of a project does not meet the end users' expectations, they may just turn their backs and choose not to use that service. If this happens, the client (owner) of the project may suffer a loss for developing an undesired project. Understanding that the end users' needs are crucial to the success of a capital project, all necessary measures should be taken to ensure that these needs are fully addressed and maintained throughout the entire process of the project planning and design. A phase supplier, however, is generally more concerned with the needs of the corresponding phase customer than with the needs of the end users. After all, it is the phase customer who directly pays the phase supplier for the services provided. Therefore, it is necessary for the project client to take initiatives in identifying the end users' needs and to maintain the focus on these needs throughout the four phases of the project planning and design process.

Based on the observations and analysis of different phases in the project planning process, a model is proposed depicting the four sequential phases, the phase deliverables, and the change of the phase customer–phase supplier roles. The model is shown in Fig. 4.

Each phase seems to follow a similar flow path of development. Fig. 5 shows the typical flow chart of a phase in the project planning process that describes the customer-supplier relationship, major activities, and main inputs and outputs of the phase.

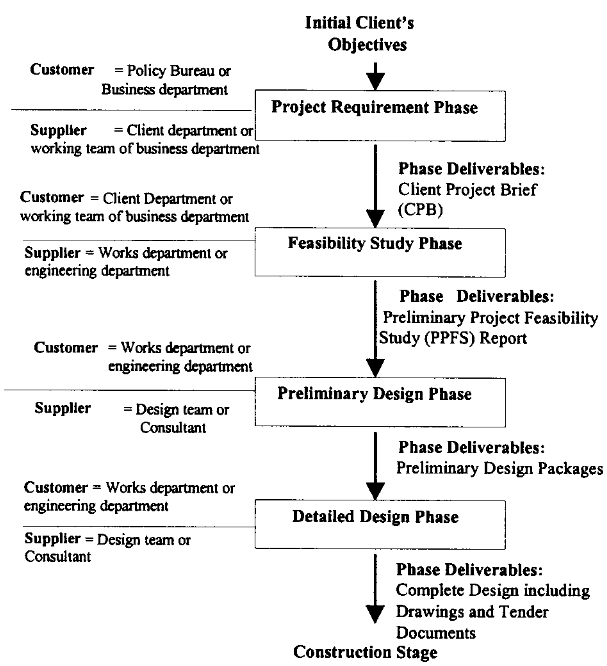


Fig. 4. Model of project planning process

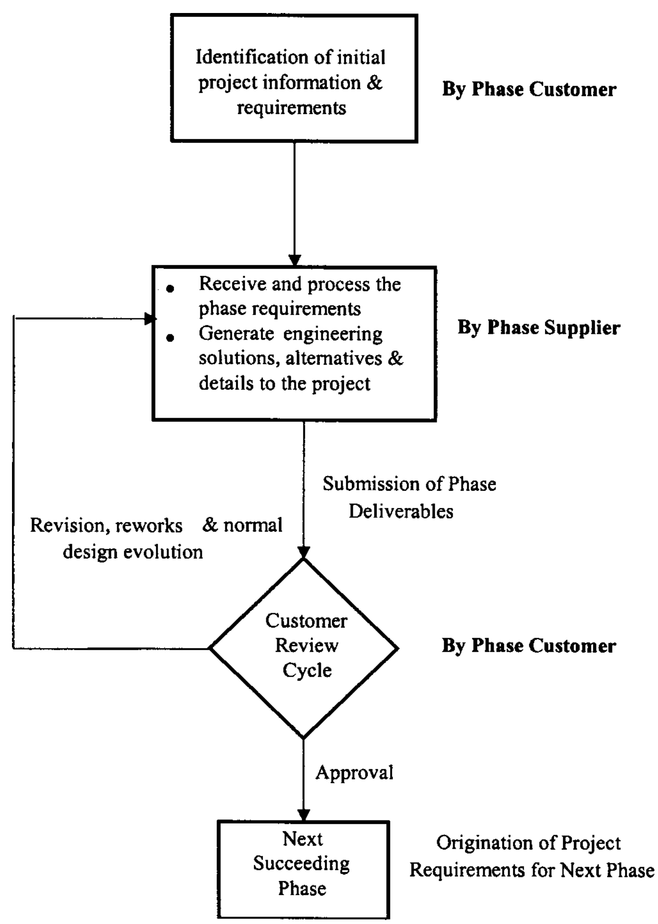


Fig. 5. Typical process flow in project planning phase

J. Constr. Eng. Manage., 2003, 129(4): 358-368

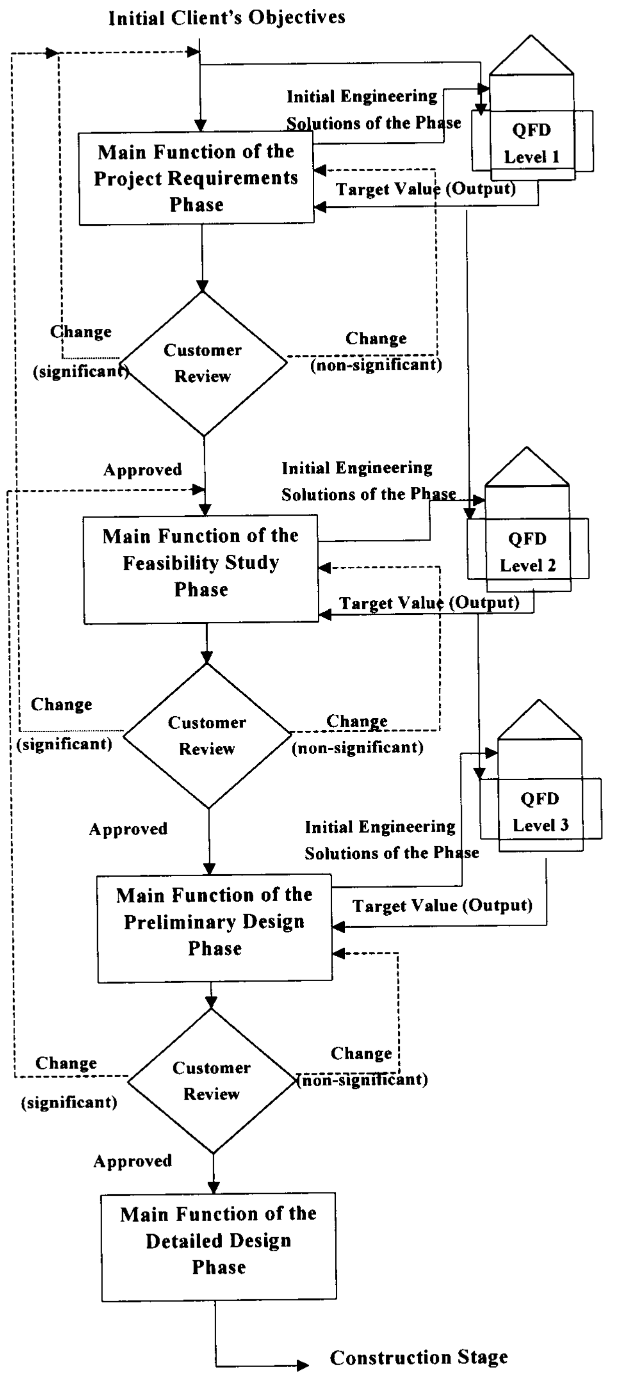


Fig. 6. QFD model of project planning process

Quality Function Deployment Model in Civil Engineering Capital Project Planning Process

A model that merges the QFD process with the project planning process is shown in Fig. 6. The left-hand side of the model is part of the project planning process (Fig. 4), while the right-hand side is the QFD process (Fig. 2). The underlying premise of this model is that QFD can be used in parallel with the respective phases of the project planning process to enhance the quality of the output of each phase.

The model starts with the initial client's objectives. The splitting arrows from the initial client's objectives enter into the project requirement phase and the "what" section of the QFD level 1; the same information is fed into the two parallel processes. It must be noted that QFD is a planning tool and is not meant to replace the main purpose of the phase, which is engineering in nature. The civil engineering project planning process is still heavily reliant on the talent and professional capabilities and skills of the designers. Instead, QFD is used here in parallel with the respective phases to enhance the quality of the output of each phase.

A set of initial engineering solutions on alternatives is developed through the works of the phase and is then fitted into the "how" section. What follows is the effectiveness of the QFD in helping prioritize the client's requirements as well as optimizing the engineering solutions to yield a set of target values. The output arrow of the QFD then goes back to the main work of the phase for formalizing the phase deliverables. This indicates that the decisions, prioritization, and other information generated by the QFD process become an integral part of the output of the phase.

Since the output of the QFD forms an integral part of the output of the respective phase, the project criteria or requirements in the two outputs should not be different; there should be no deviations between the requirements of the output going into the succeeding phase and those entering the corresponding QFD matrix. The process repeats in the second level onward, and the two parallel processes will still work in harmony, resulting in quality enhancement.

The output of the preceding QFD also enters the "what" section of the succeeding QFD; this is to ensure that the requirements are maintained throughout the deployment process. Any item at any level of QFD can be traced back to the original initial client's objectives. Dotted arrows represent the looping process should any change occur in the project planning process. Minor, nonsignificant changes may directly reenter the main function of the phase and undergo a design evolution. If a change is significant, however, the change shall go one phase backward; that is, the change must go through the work of the previous phase to determine the impact on the project. Whether a change is considered significant or nonsignificant depends on how severe an impact the change brings to the project in terms of cost, time, quality and risk.

It can be seen that the use of QFD for the detailed design phase is left out in this model. In the detailed design phase, the decision-oriented functions of the project should already have been finalized. The remaining work is the production of construction drawings, engineering details, and specifications, which transform the design intent into a full set of contract documents. Therefore, the opportunities for QFD are limited only to discrete applications.

House of Quality (HOQ) Template

The core of QFD is a series of matrices called the house of quality (HOQ). In the following section, an HOQ template is presented for use in the capital project planning process. The "what" section is developed by collecting, grouping, sorting, eliminating duplicates, and combining all the basic elements required in the phase deliverables. The basic requirements of a typical civil engineering capital works project can be categorized under the following areas: scope (objectives), budget (costing), scheduling (program), land requirements, technical and safety requirements, and statutory (regulatory) and environmental requirements. These are considered standard categories of "what" in most capital works projects. Progressively further detailed derivatives would flow from these categories across the project planning phases. The

J. Constr. Eng. Manage., 2003, 129(4): 358-368

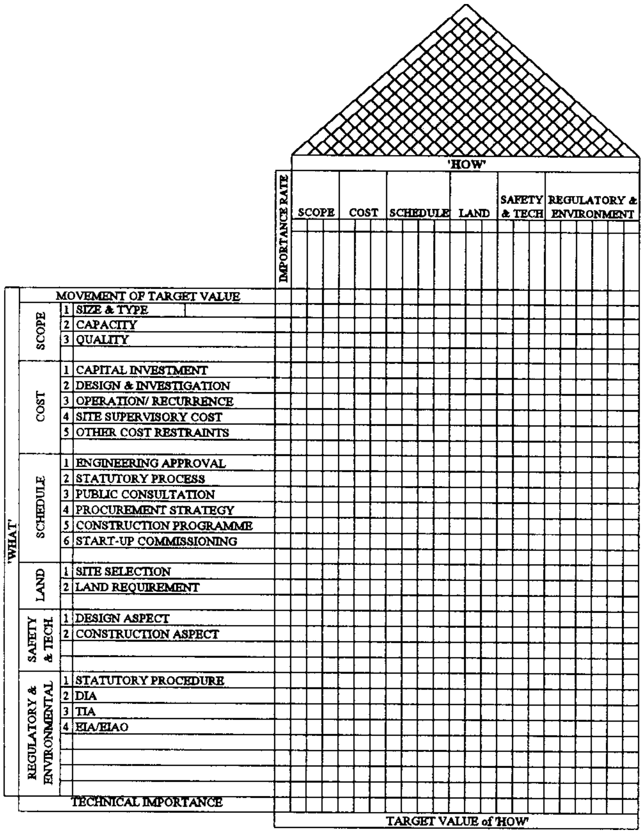


Fig. 7. Generic house of quality (HOQ) template

typical "what" section with main category and subitems of the HOQ template is shown in Fig. 7.

Development of the "how" section is the professional work of the phase supplier, while the basic purpose of QFD remains to assist the phase supplier to better meet the phase customer's needs. There are no standard technical solutions to each item in the "what" section. Since the "how" responses (technical solutions) must be fully in line with the client's basic business objectives of scope, cost, schedule, technical and safety, and regulatory compliance, it is possible to use the same categories in the "what" section as in the "how" section. Therefore the supplier could follow the main categories in the "what" section and generate technical solutions corresponding to each subitem in it.

The next step is to combine and evaluate a set of supplier-generated responses (how) to a structured set of customer-generated requirements (what) through the HOQ matrix. Fig. 7 represents a generic HOQ template constructed for use in the project planning process of a typical civil engineering capital project. The generic HOQ template presented here is not all-inclusive; each and every civil engineering project has its own uniqueness. The HOQ template must be adjusted to suit the needs of an individual project and may or may not reflect all project planning processes of individual organizations or companies.

Testing of Model

Two case studies of real-life projects were conducted to test the proposed QFD model and to investigate the benefits resulting from the use of QFD in civil engineering capital project planning. Project A was upgrading an existing sewage treatment works in a

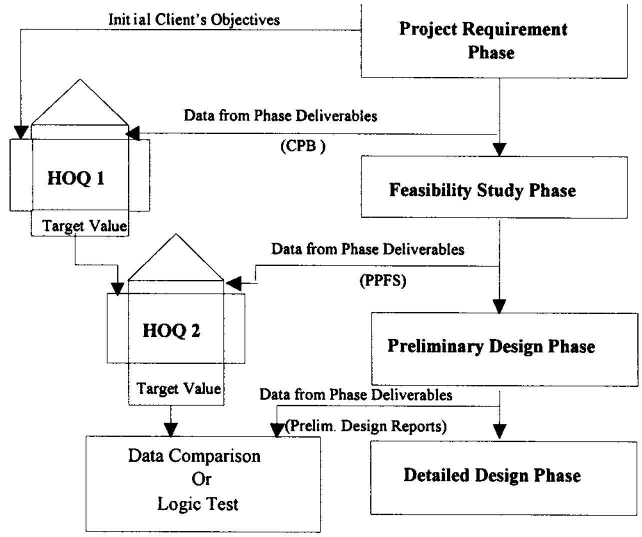


Fig. 8. Process flow of QFD modeling of case study

new town, and project B was a redevelopment project consisting of reclamation and infrastructure to expand the business area in Hong Kong. Due to space limitations, our discussion about specifics will be limited only to project A; for interested readers, the details of the use of QFD on project B are available upon request.

Planning the two projects was done in the traditional way without using QFD. To demonstrate how the QFD model works and to test the validity of the model, project data are extracted from various phase deliverables of the project and fed into the HOQ template for back-analysis. Since QFD was not actually carried out in the project planning process but instead was used in the back-analysis, the process flow must be modified to address that situation. The modified process flow is illustrated in Fig. 8.

The necessary modifications to the process flow and the explanations are

- The only source of the initial client's objectives is the data in the project requirement phase;
- Instead of using the output from an HOQ as an input for the corresponding phase to produce the phase deliverables, data from the phase deliverables are input into the "how" section of the corresponding HOQ; and
- There is no looping of the process due to changes.

Two levels of HOQ are conducted for this back-analysis. The relationship matrix, technical matrix, and technical correlation of the HOQs are built up following the methodology outlined in this paper. Allocation of the degree of relationship in the relationship matrix is based entirely on professional judgment. The planning matrix, except for the degree of importance, and the technical matrix, except for the importance weight and relative weight, have no relevance to the capital project planning process and are excluded from discussion.

The output (target values) of HOQ level 1 is deployed as the "what" section of HOQ level 2. At the same time, the data will be extracted from the phase deliverables of the feasibility study and fed into the "how" section of HOQ level 2. In a real QFD process, the engineering solutions in the "how" section will be iterated several times according to the direction of improvement until an optimal set of "how" is found. This set would be the target value of the HOQ, but as this HOQ is using the output of the phase deliverables for demonstration and verification purpose, the iteration is omitted and the "how" section is assumed to be at optimal value.

J. Constr. Eng. Manage., 2003, 129(4): 358-368

Table 1. ''What'' Section Level 1

''What'' section	Importance rate	Remarks
Scope		
Provide sewage treatment facilities for the additional flows	5	Basic objective of utmost importance
Provide sewage treatment facilities for the new effluent standard	5	
Budget		
Order of capital cost <$650 million	4	Rough estimate only, subject to refinement
Annual operating and maintenance costs <$25 million	3	Old data of operation cost may be exceeded due to stringent requirements
Delivery Schedule		
Project completes before end of 2004	3	Tolerable if project is partially operative by end of 2004
Land		
Best to locate within premise of existing STW-A	3	Subject to technical viability
Minimize or no additional land required	3	
Safety and Technical		
Design for population forecast in 2011 plus 30% reserve capacity	4	Reserve capacity of slightly less than 30% is still tolerable
Regulatory and Environmental		
Control and minimize environmental nuisances	2	Less important because project involves less nuisance in nature, especially if sited within the existing sewage treatment facility

It may be argued that the validity of the QFD model can be verified only by carrying out a full-scale QFD process, completely independent of the original project design, and by comparing the design output from a traditional project design process with the output (target value) of the HOQ. Such a full-scale comparison, however, cannot be conducted for the following reasons:

- Use of QFD in civil engineering project planning is to enhance the quality of the output by prioritizing the client's objectives and to ensure that the client's requirements are properly transformed into the final attributes of design of the project without sidetracking. QFD is in no way meant to replace the professional work of the designer, but must be carried out in parallel with the traditional project planning and design process.
- The effort required to produce independent QFD planning would be almost the same as another full-scale project design, requiring a team of consultants working full time for several months. Also, there is no solid proof that investing such a tremendous effort would lead to anything of significant academic value.

Consequently, the full-scale data comparison between the output of the two methods was not carried out. Instead, a logic test of the HOQ output is carried out to verify whether the following objectives are accomplished:

- The client's initial requirements are fully addressed;
- All output is traceable from its origin and can be checked for any distortion throughout the project planning process; and
- Each target value is logical by itself.

This self-contained logic test is considered sufficient to demonstrate the validity of the QFD model.

Case Study

The objective of this case study is to demonstrate how QFD can be used in capital project planning and to test the validity of the proposed model. Two levels of HOQ will be developed using the project data extracted from the various phase deliverables of the project for back-analysis. A project herein referred to as project A is an upgrade of an existing sewage treatment facility (STF), currently in the preliminary design phase. The project undergoes the traditional method of project development, and the project requirements, feasibility study, and preliminary design are all conducted internally by an engineering team in the relevant works department of the client (Hong Kong government).

The existing STF is the only one in the area and provides sewage treatment for the vicinity. Ever since its first completion in the late 1980s, the facility has undergone various stages of upgrading and expansion; the last upgrade was completed in 1997. In 1992, the Hong Kong government concluded, after conducting a number of studies, that further expansion would be required as a result of the forecast population increases. It is anticipated that the present flow capacity will be reached by 2004. Two new effluent quality requirements regarding bacteria and ammonia removal were recently imposed by the Environmental Protection Department. A complete review of the existing treatment processes will be carried out as part of the project so as to determine the most practical and economical way to provide disinfection and ammonia removal facilities.

House of Quality (HOQ) Level 1

The QFD model and process flows are depicted in Fig. 8. The project requirements are abstracted from the client project brief (CPB), which is the phase deliverable of the project requirement phase. The process begins by collecting the initial client's objectives for the project to build up the ''what'' section of the HOQ. The importance rates are assigned to each objective using a scale ranging from 1 (least important) to 5 (of utmost importance). Table 1 summarizes the ''what'' section of HOQ level 1.

Several engineering solutions or alternatives have been explored in the CPB to tackle the project requirements. These engineering solutions will become elements of the ''how'' section. Table 2 summarizes the engineering solutions that will form the ''how'' section of the HOQ.

For the relationship matrix buildup, the following numerical system was used: 9 (very strong), 6 (moderate), 3 (weak), and blank (no relationship). Calculation of the importance weights (technical importance) and the relative weights (rounded off to

J. Constr. Eng. Manage., 2003, 129(4): 358-368

Table 2. "How" Section and Direction of Improvement Level 1

"How" section (engineering solution)	Movement of target value
Scope	
1. Provide new units for additional flows	No improvement in performance
2. Modify existing facilities for additional flows	
3. Modify existing facilities for new effluent standard	
Budget and Cost	
1. New facilities would cost about \$130 million	Less cost the better
2. Upgrade existing facilities would cost about \$210 million	
3. Modification for new effluent standard cost about \$120 million	
4. Environmental mitigation cost about \$5 million	
5. Allow \$45 million (10% of total cost) as project contingencies	
6. Recurrent and operating cost estimate as \$18 million	
Schedule	
1. Complete study (PPFS) by late 1998	Earlier the better
2. Complete project by mid-2004	
Land	
1. To site project within existing STW	No improvement in performance
2. Use adjacent landfill site if additional land required	
Safety and Technical	
1. Design for population = 282,800	More the better
2. Add 30% reserved capacity	
3. New bacteria removal requirement	Less the better
4. New ammonia removal requirement	
Regulatory and environmental	
1. Environmental mitigation measures	More stringent the better

whole numbers) of "how" was done by using the following equations:

$$\text{technical importance}(i) = \sum_{1}^{n} \text{importance rate}(i) \times \text{correlation}(i) \quad (1)$$

$$\text{relative weight}(i) = \frac{\text{technical importance}(i) \times 5}{\text{Max}[\text{technical importance}(i)]} \quad (2)$$

Fig. 9 shows the result of the first round of the HOQ.

The "roof" section represents any interactions or conflicts among the elements in the "how" section. If two elements of "how" are in conflict with each other, then improvement of one element will mean worsening the other. The roof section helps the QFD team recognize the conflicting situation early to avoid waste of resources. Deciding which element should be improved more and which could be traded off a little depends on the degree of importance of the element. Some of the major items in the technical correlation section (roof) are discussed below.

1. Scopes (1) and (2) are mutually exclusive. The total capacity required for the additional flow is the sum of two. If the capacity provided by upgrading existing facilities increases, then the capacity required from new units will decrease and vice versa;
2. Costs (1), (2), and (3) correspond to scopes (1), (2), and (3), respectively, and will follow the same correlations;
3. All scope items tie positively with the corresponding cost items and adversely with schedule items (time for completion);
4. Costs will go up if the design treatment capacity increases (technical items);
5. Scope (1) will adversely affect the choice of siting because the existing sewage facility may not have sufficient space to locate all new units;
6. Project contingencies are a percentage of the cost items; and
7. Environment (1) is a positive function of cost (4).

House of Quality (HOQ) Level 2

For building up the second level of the HOQ, the target values and relative weights of engineering solutions in HOQ-1 are transferred to the "what" section in HOQ-2. Following that, the engineering proposals explored in the preliminary project feasibility study are reproduced as the "how" section in HOQ level 2. Other sections of HOQ-2 will repeat the same processes and analysis as in HOQ-1. The completed HOQ-2 is shown in Fig. 10.

Observation from Quality Deployment

After going through two levels of the HOQ, the project profile gradually takes shape. More than 30 detailed project requirements are generated from the 9 basic project requirements. These 30+ project details are the refinement of the initial project objectives. The interrelationship between the requirements ("what") and the engineering solution ("how") can be easily traced back. Each "what" has more than one corresponding "how," indicating that each requirement is fully addressed.

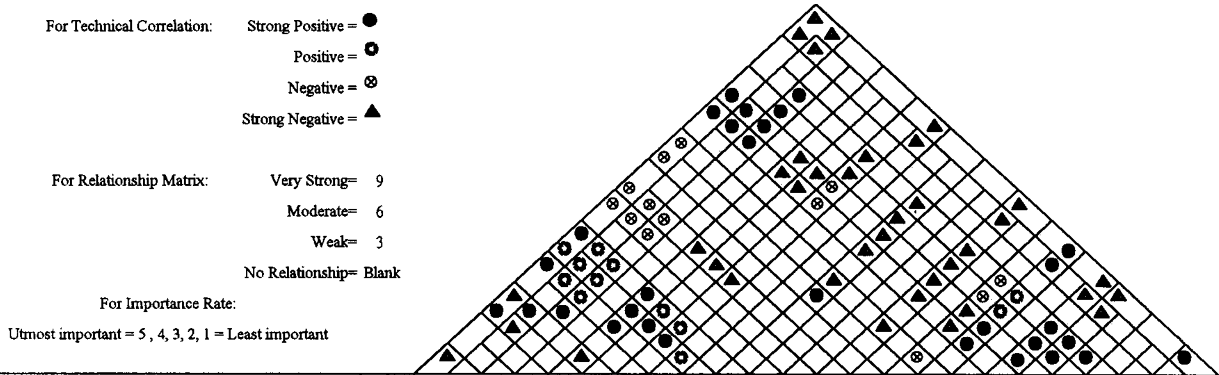
Throughout the QFD process, the utmost customer requirements are always maintained. For instance, the design flow is 130,000 cm/day because the new sewage treatment facilities must be able to handle the flow generated from the population in year 2001 plus a 30% reserved capacity. Interconnection facilities (scope 5) are required to connect the new units with the existing facilities so that together they can accommodate the future flow and the new effluent standard. A quick look at the "schedule" section in Fig. 10 can demonstrate how the decisions and tradeoffs can be made using the QFD structure. The relative weights for "upgraded to category A by December 2002" (schedule 4) and "contracts award by June 2003" (schedule 5) are 0 and 1, respectively, indicating low importance. As a result, the project delivery program delays beyond the end of 2004 to July 2006 (schedules 6 and 7).

A quick sensitivity test can be easily conducted if any one of the requirements changes in any phase. For instance, if the space in the existing sewage treatment facility is not sufficient to site the new sewage treatment facilities, then the project needs to site at the adjacent landfill. The impact on the scope, cost, schedule, and technical aspects as well as the environment could quickly be visualized from the HOQ. By demonstrating that each of the initial objectives is fully addressed, all outputs are traceable back to their origin, and each target value is logical, one can conclude that the QFD model has passed the logic test criteria.

Comments from Output Target Value

As can be seen from the previous exercise, the target values of cost and schedule do not comply with the initial client's objec-

J. Constr. Eng. Manage., 2003, 129(4): 358-368



CUSTOMER NEEDS 'WHAT' / TECHNICAL RESPONSE 'HOW'	Importance Rate	SCOPE 1 New units for additional flows	SCOPE 2 Modify existing facilities for additional flows	SCOPE 3 Modify existing facilities for new standards	COST 1 New sewage treatment facility=$130M	COST 2 Upgrade existing facility=$210M	COST 3 Additional cost for new Standard=$120M	COST 4 Environmental mitigation measures=$5M	COST 5 Project Contingencies=$45M	COST 6 Recurrent Cost=$18M	SCHEDULE 1 Study (PPFS) complete in late 98	SCHEDULE 2 Project complete in mid-2004	LAND 1 Site location within existing STW	LAND 2 Adjacent landfill site if additional land required	SAFETY and TECHNICAL 1 Design for population=282,800 (year 2011)	SAFETY and TECHNICAL 2 Design for 30% reserved capacity	SAFETY and TECHNICAL 3 New bacteria removal requirement	SAFETY and TECHNICAL 4 New ammonia removal requirement	REG. & ENVIR. 1 Mitigation measures to control nuisance	REG. & ENVIR. 2 Minimize environmental impact
Movement of Target Values					↓	↓	↓	↓	↓	↓	↓	↓			↑	↑	↓	↓	↑	↑
SCOPE 1 Provide treatment facilities for additional flows	5	9	9		9	9		3		6	3	6	6	6	9	6			6	6
SCOPE 2 Provide treatment facilities for the new effluent standard	5			9			9		3	3	3	9	6				9	9		
COST 1 Order of Cost<$650M	4	6	6	6	6	6	6	3	3			6		6	6	6	6	6	3	3
COST 2 Annual operating & maintenance costs<$25M	3	6	6	6						9				9	6	6	6	6		
SCHEDULE 1 Project complete by end 2004	3	6	6	9							9	9			6	6	6	6		
LAND 1 Locate within the premise of the existing STW	3	9	6	3						9			9		9	6	6	6	6	6
LAND 2 Minimize or no additional land required	3	6			6								9	6	9	6	6	6	9	9
SAFETY &TECH. 1 Design for population increase to year 2011+30%	4	9	9	6	9	9		6		6			9	6	9	9	6	6	6	6
REG. & ENVIR. 1 Control & minimize environmental nuisances	2	6						9						9					9	9
Technical Importance		198	159	147	123	105	69	69	27	123	57	126	150	141	195	162	165	165	129	129
Relative Weight of 'HOW'		5	4	4	3	3	2	2	1	3	1	3	4	4	5	4	4	4	3	3

Fig. 9. House of quality (HOQ) level 1

tives. The total project estimate and annual recurrent expense exceed the initial budgets ($681.78 million = cost 1 + cost 2 + cost 6 versus $650 million and $93.38 million = cost 7 + cost 8 versus $25 million) and also the project delivery program delays beyond the end of 2004 (schedules 6 and 7). This was due to the number of small changes made by the client during the process of project planning and design. In traditional project planning it is very difficult to identify the impact of one small change on the whole project due to the complexity of a civil engineering project and the interrelationship among various project elements.

QFD provides a road map for navigating the process as a whole. All project deficiencies encountered on project A could have been identified had QFD been used in the planning process. Not only can signs of deficiencies be identified early, but the project deficiencies can also be traced back to their origin. As a result, the client and the designer would have been in a position to act early to mitigate the potential loss to the project.

The quality matrix developed is usually of substantial size and complexity, which is a great burden to the designer and demands substantial initial staffing resources. However, the matrices produced most likely cannot be reused for other projects. It is also noted that some elements in the matrices are quite independent and do not involve much interrelationship with the other elements. If it were feasible to devise standard QFD matrices for such subsystems, the size of the HOQ as well as the necessary staff resources could be greatly reduced. Such reduction in matrix size would not only cut costs, but would also reduce the chances of overlooking some important issues. Further investigation and research in this direction are worthwhile and should be encouraged.

Conclusion

This paper explores the applicability of QFD in civil engineering capital project planning. A QFD model is proposed that concentrates on the six basic project management areas: project scope (functional requirements), budget costing, scheduling, land requirements, technical and safety requirements, and statutory (regulatory) and environmental requirements. Data from two

J. Constr. Eng. Manage., 2003, 129(4): 358-368

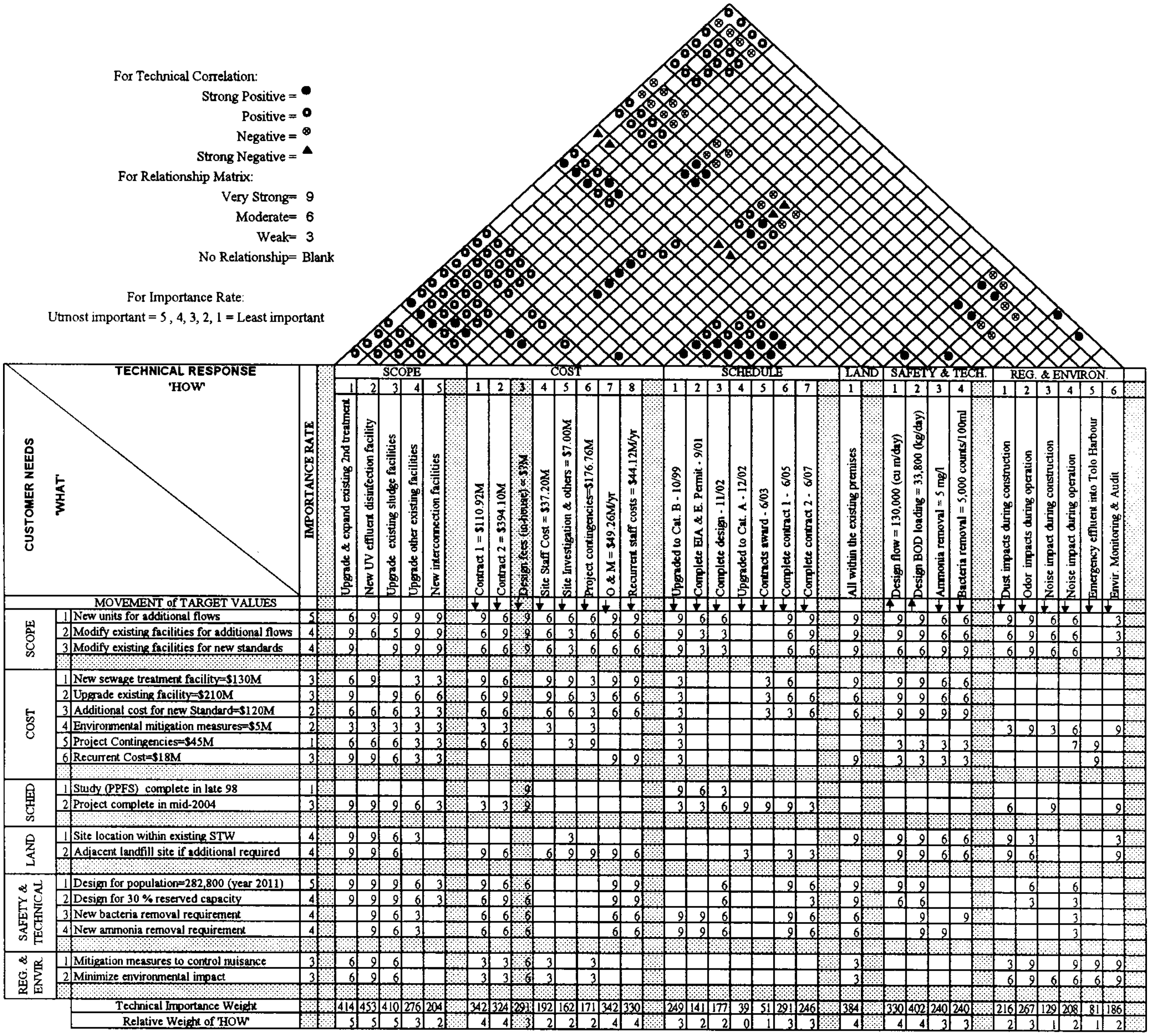


Fig. 10. House of quality (HOQ) level 2

projects of different type, scale, and nature are fed into the model for validity testing. Verification has given encouraging results, suggesting the validity of the QFD model. It is found that the use of QFD can enhance the project planning process in the following ways:

1. QFD serves as a road map for navigating the planning process and always keeping track of customer requirements and satisfaction. This actually helps eliminate human inefficiency;
2. The process of building a QFD matrix can be a good communication facilitator that helps break through the communication barriers between the client and the designer and among members of the design team;
3. QFD can be an excellent tool for evaluating project alternatives, balancing conflicting project requirements, and establishing measurable project performance targets; and
4. QFD can be used as a quick sensitivity test when project requirements change.

To ensure the best utilization of QFD in the project planning process, the following points need to be taken into consideration:

1. While there are many different ways to apply QFD, it must be applied as early as possible in the planning process, starting with the original customer's requirements. QFD has no magic to get a quick result, nor is it a remedial measure to save a project when its original customer's requirements are already sidetracked.
2. Empowerment from the client side is necessary. A client who is just there to provide the necessary funding and land for the project is not enough. To ensure success, a client must actively participate in the QFD process and work with the designers to provide policy directives, refine the project objectives, set project priorities, and make decisions when conflicts occur.
3. Total involvement of team members is necessary. All team members, who represent different fields, need to work to-

J. Constr. Eng. Manage., 2003, 129(4): 358-368

gether to share the common goal of the project and make their valuable contributions supplement each other.

There are many barriers to successful use of QFD in civil engineering capital project planning. The concept of QFD is still new to civil engineering professionals, who require extensive training to become familiar with QFD tools. Different enabling departments within the client organization will provide consultative input to the project in various project stages. Sometimes individual departments' objectives may be in conflict with those of others or with a project's common objectives. To overcome this barrier, the enabling departments should be part of the QFD team so that the project vision and project objectives are clearly understood and maintained throughout the client's organization. Also, the use of QFD will require an initial up-front investment.

The uniqueness of every civil engineering capital project makes it difficult to reuse a QFD matrix on more than one project. This raises a major question: what is the business driver for the project planning profession to use QFD? In theory, the answer lies in the opportunity costs involved; would the extra benefits of using QFD have outweighed the extra costs in implementing it?

Despite being preliminary and to some extent limited, the study findings are very encouraging, indicating that QFD as a project planning tool can bring benefits and enhancements to civil engineering capital project planning. Some research topics suggested for further study are streamlining the QFD process, computer-aided QFD application, evaluation of the costs and benefits of using QFD, use of QFD in detailed design, and how to integrate QFD with total project quality management systems.

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