A Heuristic Approach Solving for the Complex Design Process in the Quality Function Deployment

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Abstract

Viewed as a more systematic approach of creating high quality products and bringing them into market at a lower cost and in significantly less time, it attracts the attention of quality designers to quality function deployment (QFD) approach. In attempt to reduce the design cycle, the industry has responded with concurrent design effort. In a sense, concurrent engineering refers to the integration of various activities within the broad scope of the product life cycle [17]. Over the last ten years, much has been written about QFD but little has been available in terms of the underlying guide methodology. The methodology of QFD is quite simple and many will say that they have done it in the past but just have not formalized it into the form that this discipline requires. QFD ties the product, user, value, and manufacturing viewpoints together in a continuous process of defining the product design and manufacturing requirements. The value viewpoint recognizes the cost to obtain certain functionality, and the manufacturing viewpoint addresses conformance to requirements, but in a broader sense, the variability in production. In this paper, the QFD system acquisitions are described, and two heuristic approaches solving for the complex design process, especially the size reduction of design process and precedence-constrained relationship in QFD are proposed, and the empirical example is illustrated.

1. Introduction

The design, development, and manufacturing of a product is one of the greatest challenges today. The focus on quality of design a product must be balanced. One such a strategy certain to address the managerial and manufacturing is to invoke the concept of decomposition methods.

Design should be ultimately evaluated with respect to customer's perception of product quality. Products must be designed to assure that the highest possible quality and to facilitate manufacturing and assembly with the minimum lead time and cost for prompt delivery to the market.

In response to the customer requirements, designers must interpret the customer requirements for a range of products that match the design requirements. Decoupling the design task into subsystems can reduce the size of the working design group, and this may improve performance of the design process [2]. In attempt to reduce the design cycle, the industry has responded with concurrent design efforts.

Among those methods for concurrent engineering, formal methods are difficult to categorize. They include techniques that date to the 1930s and more recent approaches [19]. Statistical process control, design of experiments, design for assembly, value engineering and especially quality function deployment (QFD) are just a few of the formal methods in concurrent engineering.

2. Quality Function Deployment

Quality, considered as an elitist objective some time ago, has become the most important factor for survival in the competitive market. The entrepreneurial world has realized that quality is an attribute which may be pursued along four main directions as follows [15].

1. Multidimensionality. It involves more dimensions in the evaluation of the product such as performance, features, reliability, consistency, durability, serviceability, security, aesthetics, perceived quality.
2. Relativity. Its value is not compared with an absolute value, but what the customer has perceived.
3. Dynamics. Its value varies with time.
4. Globality. It involves every internal and external function of the company, although varying degrees.

QFD approach typically enables organizations to translate customer requirements into appropriate design parameters throughout the design process. Product designers need to know how to make tradeoffs in the selection of design parameters that result in the highest level of customer satisfaction.

Each of phases in Figure 1 can be in turn decomposed into set of interrelated design parameters, purposing to gain control over the total duration of the design process.

Owing to the complexity of the decision process, the design team will often rely on ad-hoc decision procedures to assist in this product development. Such procedures are often completely arbitrary, however, and subject to the whims of the design team rather then to the needs of the customer [18].

Today, we are in the midst of a customer revolution. Customers are becoming increasingly militant about the quality of the products and services they purchase. For a number of years, customers have been demanding better-made products [5].

If most of manufacturing companies are going to be able to compete, a customer's perspective must be ingrained into the systematic structure of the organization. With marketing techniques so much more sophisticated than ever before, companies can measure, track, and compare customers' perceptions of products with remarkable accuracy.

Product costs certainly justify an emphasis on quality design. By looking first at customer requirements, then designing across corporate functions, manufacturers can reduce pre-launch time and after launch tinkering.

QFD is a tool which is used to ensure that the voice of the customer is effective throughout the product planning and design stages [6]. QFD has been widely applied in support of product projects in Japanese industry.

Many applications have been reported regarding its contribution to product quality assurance, to time-to-market reduction, and to market share expansion. Its usefulness is particularly manifested when preliminary ideas both of the teamwork and of the customer are not just well defined. At present QFD is utilized in the following ways:

1. By customers and design teamwork to gather product information in a structural way
2. To analyze customer expectations and the characteristics of competitive products
3. To define the prioritization of technical / engineering design requirements for a new product.

The decade of the 1980s saw many changes in virtually all aspects of the quality area. Many manufacturing companies are facing rapid changes in industrial structure brought about by technological innovation and changing customer trends. These companies are finding that the effort to develop new products of high quality is crucial [4].

Some changes were precipitated by events of the 1970s, such as Japan's emergence as a producer of high quality manufactured goods. Quality is an abstract term viewed in the perspective of customers'satisfaction. It is the extent to which the customers believe that the product meets their requirements and expectations.

As set of planning and communication between customer requirements and company's management routines, QFD focuses and coordinates skills within an organization, first to design then to manufacture and market goods that customer wants to purchase and will continue to purchase. Hence, QFD is a kind of conceptual map that provides the means for inter-functional planning and communications [8].

QFD system has been used by Toyota

since 1977 following four years of training and preparation. Between 1977 and 1984, Toyota Autobody introduced four new van-type vehicles. Using 1977 as a base, Toyota reported a 20% reduction in a start-up cost on the launch of the new van in 1979, a 38% reduction in 1982, and a cumulative 61% reduction in 1984 [4].

During this period, the product development cycle was reduced by one third with a corresponding improvement in quality because of the reduced number of engineering changes [13].

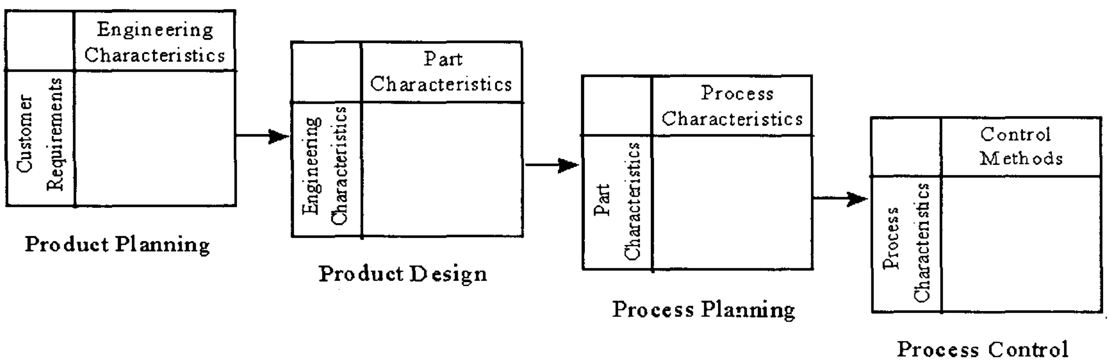
The concept of the QFD is consistent with the use of customer requirements to define quality. The basic idea of QFD is defined as an operating mechanism to transform customer requirements into specific design requirements, in that a discipline for product planning and development in which key customer wants and needs are deployed throughout an organization.

The foundation of QFD is the belief that products should be designed to reflect customers'desires and tastes, so marketing people, design engineers, and manufacturers must work closely together from the time a product is first conceived [7].

It provides a structure for ensuring that customer wants and needs are carefully heard, then directly translated into a company's internal technical requirements from component design through final assembly. The information in the various

QFD matrices requires that different group of individuals reach consensus on the product, process, and design requirements necessary to effectively meet customer requirements.

The thing that makes QFD unique is that the primary focus is on the customer requirements. The process is driven by what the customer wants, not by innovations in technology. Consequently, more effort is involved getting the information necessary for determining



<Figure 1> Quality Function Deployment cascade

what the customer truly wants.

This trends to increase the initial planning time in the project definition phase of the development cycle, but it reduces the overall cycle time in bringing a product to market. The four cascades shown in Figure 1 are documented using matrices with continuity between design process and matrices.

The product planning is viewed as information filtering process such as gathering customer requirements. This continuity is accomplished as key items are transferred from one matrix to the next. The basic four-stepprocess takes place throughout a design program. There are six key terms associated with QFD [15].

1. Quality function deployment : an overall concept that provides means of transforming customer requirements into the appropriate technical requirements for each phase of product development and production.
2. The voice of customer : the customers' need expressed in their own terms.
3. Counterpart characteristics : an expression of the voice of the customer in technical language that specifies customer-required quality; counterpart characteristics are critical final product control characteristics.
4. Product quality deployment : activities needed to translate the voice of the customer into counterpart characteristics.
5. Quality tables : a series of matrices used to translate the voice of the customer into final product control characteristics.
6. Deployment of the quality function : activities needed to assure that customer-required quality is achieved; the assignment of specific quality responsibilities to specific departments.

QFD also brings several benefits to companies willing to undertake the study and training required to implement the system [15].

1. Product objectives based on customer requirements are not misinterpreted at subsequent stages
2. Particular marketing strategies or sales point does become lost or blurred during the translation process from marketing through planning to execution.
3. Important production control point are not overlooked - everything necessary to achieve the desired outcome is understood and in place.
4. Tremendous efficiency is achieved because the misinterpretation - of design objectives, marketing strategy, and critical control points - and the needs for changes is minimized.

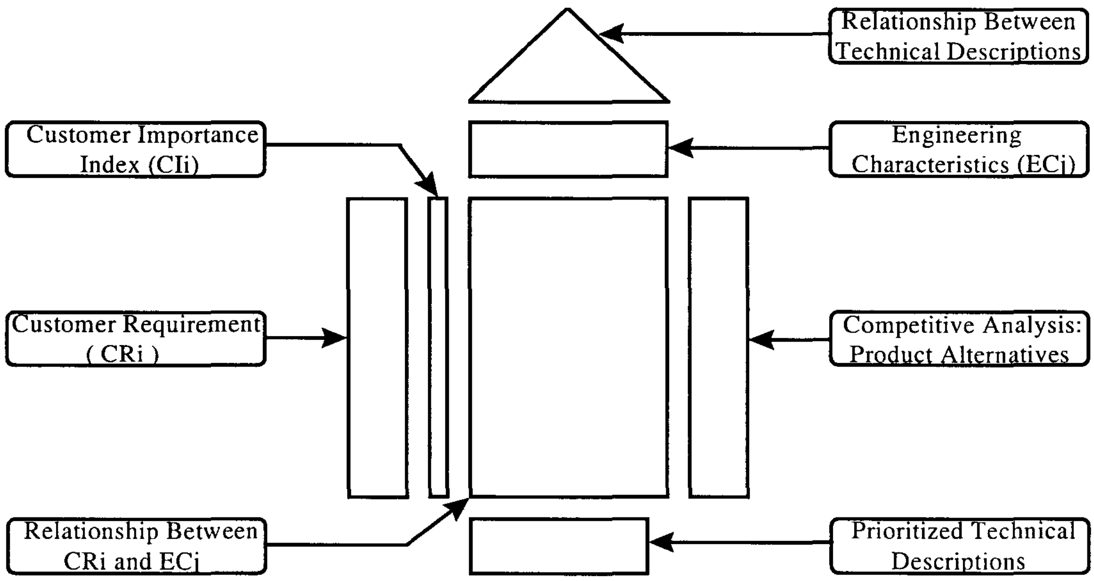
3. Relationship between Components in HOQ

The basic aim of QFD is totranslate product requirements stated in the customer's own words into a viable product stated in parameters that can be designed and manufactured [8]. A definition is given by the American Supplier Institute as a system for translating customer requirements into appropriate company's technical requirements at every stage from research through production design and development to manufacture, distribution, installation and marketing sales and services [3].

QFD uses four houses to integrate the information needs of marketing, engineering, R&D, manufacturing and management. Customer requirements (CR_i) are translated into engineering characteristics or design requirements in the company's internal technical language. Product planning phase focuses the customers'voice. Every chart begins with the voice of the customer by collecting accurate information directly from customers' wants and needs.

Figure 2 shows the foundation of house of quality (HOQ) practice. On the left side of HOQ are the customer requirements which may extended into a detailed list. This information usually comes from a variety of sources such as marketing groups, dealers, sales departments, customer opinion surveys, and so on.

A customer important index (CI_i)



<Figure 2> The House of Quality

indicates which customer requirements are most important to customers. This step is the most critical part of the process and it is usually the most difficult because it requires obtaining and expressing what the customer truly wants. The top of the matrix shows what the manufacturer does to ensure the quality of the product. The right side of the matrix contains the planning information, competitive analysis, target value, amount of scaling up necessary, and the sales point. The comparison of competitive products may be on the basis of rating indicating how well the design requirements are met.

The product features are then related to themselves in the roof of the diagram, typically using correlation symbols. As a result of this process, features with the conflicting design requirements can be identified. This implies that some trade-off may be necessary, and QFD has identified it early in the design process.

Enhancements to the QFD process include adding importance measures to the customer requirements, including target values for product design features and relating product design features to part and mechanism characteristics. The top of the matrix includes the technical description while the bottom is the prioritized technical description.

The relationships between customer requirements and engineering characteristics are categorized in the body of the matrix. The engineering characteristics relate directly to the customer requirements and must be selectively deployed throughout the manufacturing, assembly, and service process to manifest themselves in the final product performance and customer acceptance.

At its various phases, the proposed approach employs concepts from cluster analysis. The components of row that can be converted to the column are selected by using proposed network decomposition method.

1. Product planning
   - The suitable engineering characteristics for satisfying the customer requirements should be selected. The proposed system has the capabilities of working with a designer interactively, decomposing design activities, allowing for incremental analysis of the design as it involves, and dealing with incompleteness of information at design stages.
2. Product design
   - Engineering characteristics are translated into part characteristics. This step includes the highest priority items from the house of quality since the design requirements are translated into tangible part characteristics. Part characteristics required to meet the engineering characteristics are assigned and relationship values giving the same procedures as before.
3. Process planning
   -Part characteristics are translated into

process characteristics. This step not only defines how critical part characteristics are achieved but also identifies critical process characteristics and target values.

4. Process control
   -Process characteristics are assigned specific control methods. This step assigns suitable method for process characteristics in the overall QFD process.

4. Optimizing the Quality of Design Process

4.1 Reduction of Design Process in House of Quality

A designer may deal with a large volume of information and subassemblies that have been previously designed. It is difficult to process this information without decomposing the overall system into smaller, manageable subsystems.

QFD tables are filled in by design teamwork and product customer in such a way as to establish what interactions exist between customer requirements and given characteristics. The relationship matrix links customer requirements with technical design requirements utilizing an ordinal scale.

Although much has been referred about QFD, the universal QFD method for decomposition is needed. In that sense, a heuristic approach considering weight of the relationship between rows and columns is proposed, which finally deletes weak weighted components, and groups with strong components depending on threshold value α, where $0 \le \alpha \le n$ for an integer n.

The value of is defined as integer and should guarantee the minimum number of controllable components for the next phase. It also assumes at most half of column components are to be covered by design. One of advantages of decomposition approach is that one can determine potential group of activities that might be scheduled simultaneously. The degree to which the activities can be scheduled simultaneously depends on the quality of clusters and the nature of constraints. The following notations are defined for the proposed algorithm solving for the product design problem by the QFD approach in a concurrent manner.

- CR_i customer requirements i
- EC_j engineering characteristic j
- CI_i customer importance index i
- P_j part characteristic j
- PC_j process characteristic j
- CM_j control method j
- a_{ij} degree of relationship between row i and column j, $i=1$ to m, $j=1$ to n, where ($a_{ij}=1,3,9$) to represent a weak, medium, and strong relationship respectively.

w_{ij} weight of column j,

$$w_{ij} = \sum_{i=1}^{m} a_{ij} CI_i$$

r_j ranking of column j based on w_j

α threshold value = $\lfloor n/2 - 1 \rfloor$, where $\lfloor f \rfloor$ is the largest integer not greater than f.

Step 0. Begin with the weighted matrix $[a_{ij}]$

Step 1. Calculate the weight w_j and rank r_j of each column j

Step 2. Calculate the threshold value α

Step 3. Delete column(s) with r_j not greater than α

Step 4. Use the remaining columns as rows i for the next phase

Step 5. Go to Step 1 until the final phase has been reached.

The proposed algorithm operates with the objective of identifying columns that yield a minimum interaction in terms of weight. The interaction is measured by the degree of relationship between given two components at each phase.

The validity of this objective is bolstered by the fact that the concept of group technology aims at segregating the plant operations into independent cells. Hence, the unimportant or unnecessary components in HOQ are eliminated, and the overall weight of design process can be finally reduced.

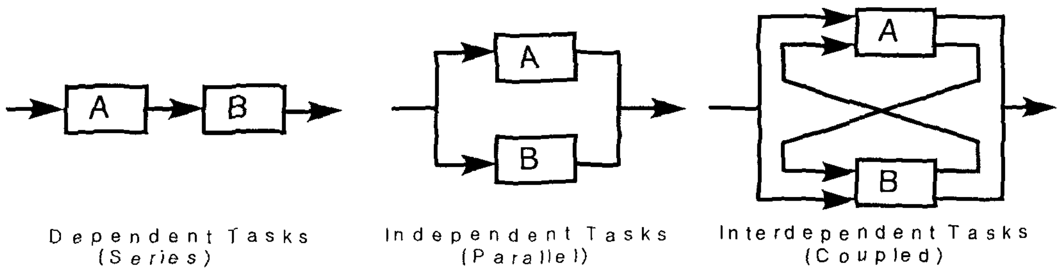
4.2 Precedence-Constrained Design Process Network in House of Quality

Engineering design involves the specification of many variables that define a product, how it is made, and how it behaves. Before some variables can be determined, other variables must first be known or assumed. This fact implies a precedence order of the variables. Moreover, design of complex systems may involve a large number of design activities. In general, the precedence-constrained networks have been used for representing the design process.

In response to the customer needs, the design process should deliver better quality products and systems in a shorter time. The sequential design process is likely to lead to a long design cycle time. One way of reducing the design cycle is to use decomposition methods, which break the overall design tasks into smaller groups of activities that might be executed concurrently [12].

In most industrial applications, what is it that must be modeled and how is it to be represented sub-problems can be regarded as orthogonal, and their solutions can be based upon different techniques, quite independent of each other.

Consider two design tasks, labeled A and B. Figure 3 shows digraphs of three possible ways in which the two can be related. If task B simply requires the output of task A, then the two tasks are



<Figure 3> Three possible sequences for two design tasks

dependent and are typically done in series. On the other hand, the two would be entirely independent if tasks A and B could be performed simultaneously with no interaction between the designers. Finally, if task A needs information from task B, and also task B requires knowledge of task A's results, then the two tasks are interdependent [14].

A proposed heuristic algorithm had been proposed solving for the complex design process, especially in the precedence-constrained network [11]. For the convenience of computation, the precedence relationship between design activities is represented with an activity-activity incidence matrix m_{ij}, where each element m_{ij} is defined as $m_{ij}=*$ if activity j precedes activity i, otherwise zero.

For example, Table 1 shows the precedence relationship between design activities. If we apply element m_{ij} for Table 1, an activity-activity incidence matrix can be represented in Figure 4.

Design activities can be also represented with a digraph $G(N,A)$, where N is the set of nodes corresponding to the activities

<Table 1> Precedence relationship between design activities

Design Activity	Predecessor(s)	Design Activity	Predecessor(s)
1		9	1, 2, 4, 12
2	1, 3, 7, 11, 12	10	
3	2, 4, 6, 7, 11	11	8, 9, 10
4	1, 2, 3, 7, 11, 12	12	1, 2, 3, 4, 7, 11
5	3, 6, 8, 9, 10, 13	13	
6		14	2, 3, 4, 6, 7, 12
7	5, 6	15	1, 2, 8, 10, 12, 13
8		16	14, 15

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	*															
2	*	*	*				*				*	*				
3		*	*	*		*	*				*					
4	*	*	*	*			*				*	*				
5			*		*	*		*	*	*			*			
6						*										
7					*	*	*									
8								*								
9	*	*		*					*			*				
10										*						
11								*	*	*	*					
12	*	*	*	*			*				*	*				
13													*			
14		*	*	*		*	*					*		*		
15	*	*						*		*		*	*		*	
16														*	*	*

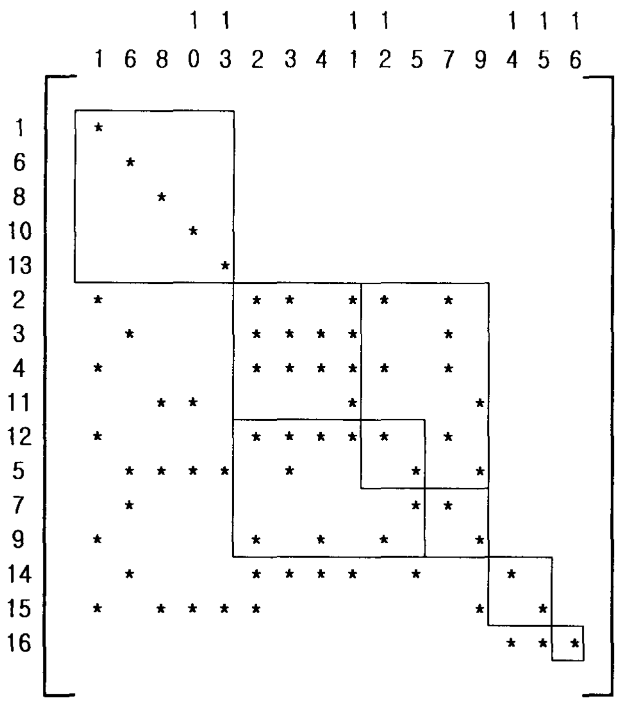
<Figure 4> The initial activity-activity incidence matrix

to be performed, and A is the set of arcs representing precedence relations. For each node $i=1$ to N, define P_i is the set of arcs preceding node i, and Q_j is the set of arcs following node j. The digraph $G(N,A)$ is then defined as strongly connected if for any two vertices $i,j \in N$, a path from i to j exists [9].

A subset $X \subseteq N$ of vertices is called a strongly connected vertex subset if for

<Table 2> Project duration time for each design activity

Group	Activity	Duration	Group	Activity	Duration
1	1	10	4	11	10
1	6	15	4	2	15
1	8	10	4	3	10
1	10	15	4	4	15
1	13	10	4	12	15
2	16	15	4	5	10
3	14	10	4	7	10
3	15	15	4	9	15



<Figure 5> The final activity-activity incid

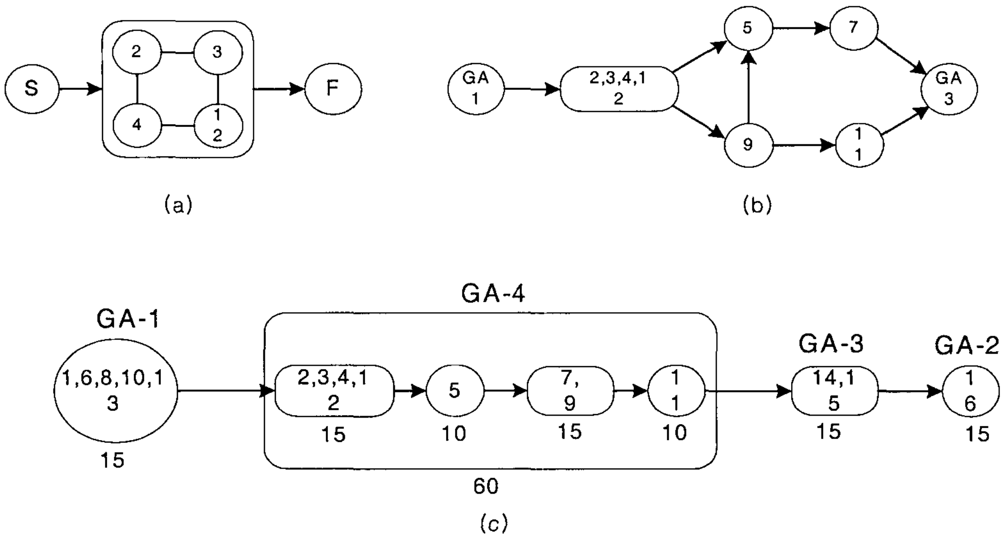
any two vertices $i, j \in X$, there is a path from i to j in the graph, and X is contained in no other set with the same property. The subgraph generated by a strongly connected vertex subset is called a strongly connected component of the original graph [10, 16].

If activities could be reordered so that the final matrix (Figure 5) is block diagonally lower triangular form which all marks * are either on or below the diagonal, then the elements could be determined one at a time by proceeding in this order by the proposed algorithm [11].

Priority rules for grouping and critical path method can be applied to the entire arrow diagram that gives a graphic representation of the interdependencies between the decomposed groups of design activity.

Grouping of activities can be viewed as breaking down of an original network into a number of subnetworks in terms of activity on nodes (AON) representation. Each subnetwork has associated nodes and arcs. Arcs connecting two different activities that belong to different sub-networks define relationships between the sub-networks.

Suppose Table 2 shows time required for each design activity. Then Figure 6 shows the formation of design activity



<Figure 6> Formation of design activity groups and its makespan
(a) priority rule application
(b) interrelationship of all elements in fourth formed design activity group
(c) makespan of the each design groups

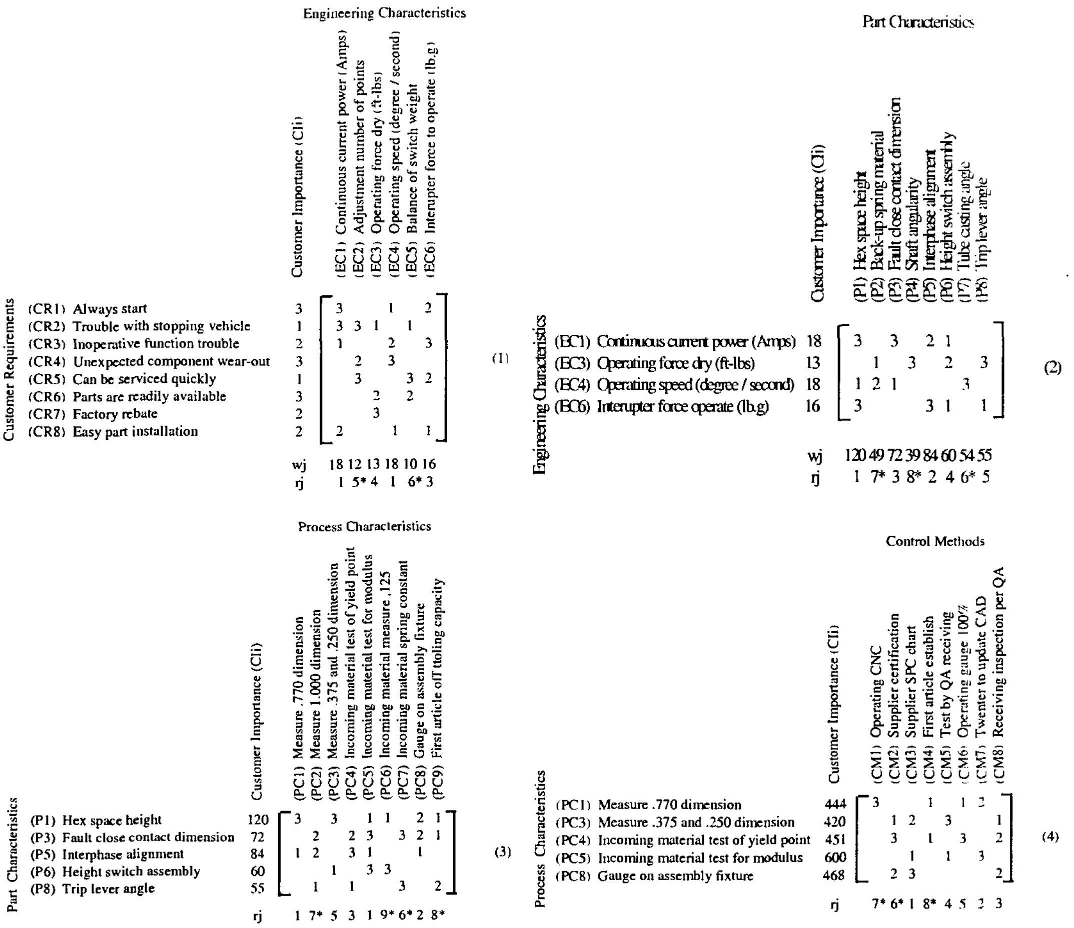
groups and its makespan [11].

The proposed algorithm [11] can be applied to organize design activities for effective planning of the design process. The term mark * has been referred to any nonblank entry in the precedence matrices. If the variables could be reordered so that the matrix is lower triangular form, all marks are either on or below the diagonal, then proceeding in this order, the variables could be determined one at a time.

5. Empirical Example

Suppose a simple example such that the customer requirements (CR_i) and customer importance (CI_i) of the automobile carburetor are surveyed, and the relationship between CR_i and EC_j is shown in matrix (1).

The weight of matrix $[a_{ij}]$ can also represent the precedence-constrained relationship between design process. The design process network also represents the duration of completion time. The motive of this algorithm is to find out not only appropriate control methods for satisfying the customer needs as an efficient way,



<Figure 7> Algorithm procedures in QFD cascade
Matrix (1) product planning : EC2, EC5 reduction
Matrix (2) product design : P2, P4, P7 reduction
Matrix (3) process planning : PC2, PC6, PC7, PC9 reduction
Matrix (4) process control : CM1, CM2, CM4 reduction

but also reduction of size of design process.

The whole process of the proposed algorithm goes through filtering the column components by the threshold value. Figure 7 shows the procedures of the proposed algorithm.

The first step of the optimizing the quality of design process is to reduce the problem size based upon the proposed algorithm shown in the section 4-1. The second step is to find the final matrix, and to allocate the design attributes, for example control method in the final matrix, and to find the optimal schedule, if there is time duration, in a minimum time.

Hence, if the design process is followed by precedence constrained network relationship, then the optimal sequence of design process can be solved by proposed algorithm shown in the section 4-2.

In matrix (1) in Figure 7 shows the threshold value is 2, which delete the engineering characteristics 2 and 5, representing the lowest ranking value 8 and the next lowest value 7. In a same procedures, all the remaining matrices are developed. Although the precedence constrained network between design attributes and time duration of each design attributes are not given in this simple example, the solving procedures will lead to optimal solution.

Although it is felt that all of the given components were equally important, weighting and ranking must have been necessary to decompose the matrices at each phases because all components are hardly considered and performed practically.

Finally, a variety of control methods such as supplier SPC chart, test by QA receiving, operator gage 100%, tweeter to update CAD, and receiving inspection per QA are included in the example without precedence constraints.

In all cases, the process capability on these parts will be checked and compared with similar parts used for the variation analysis. QFD is not an exercise to merely fill out matrices but the use of the data providing new insights. It is very flexible and can be tailored to many applications. The future study can be evaluation of QFD problems and formulation of solutions to other than design.

The fundamental of the proposed approaches is to consider the customer's requirements that reflect the priority order expressed by the customer, without in any way violating any intentions. The traditional method normally used to generate a meaningful customer degree of importance to the customer in the prioritization of technical design requirements makes use of the analytic hierarchy process.

6. Conclusion

The reduction of duration of the design process, and the better quality of the final design can be performed by considering design activities simultaneously. Design of products in concurrent environment viewed as a strategic task that has a major effect on subsequent manufacturing and service activities [1]. The concurrent design should possess procedural knowledge of a general framework for the entire product development. The process, based in part on QFD, encompasses all elements of product design after customer requirements have been identified.

Up to this point, QFD plays a typically organizational role in the design of a product. However, if information contained in the relationship matrix is utilized to steer the design's attention toward the relative importance of the product's various characteristics, then QFD may become a decisional supporting tool.

The proposed methods, although it does not give a definite reply on the effectiveness of QFD in the management of large projects, seem adequate, however for the purpose of utilizing approximate customer information without applying rigid and arbitrary conversion of quantified scales.

1. The number of components that can be considered in HOQ are reduced
2. The design process network that involves the precedence-constraints in HOQ is well-ordered.
3. If the design process in HOQ has the duration time, then the total makespan can be minimized.

The proposed approaches can give rise of developing more efficient approach for quality problem which is a customer driven system for evaluating relationship between product development procedures. The results of this study will improve product quality and shorten product development time, it also ensures that QFD is incorporated into the design before its completion and to be a worthwhile exercise.

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