Reinforcing QFD with group support systems: computer-supported collaboration for quality in design

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Abstract:

Over the last decade quality function deployment or QFD, thanks to the efforts of Akao and others, has gained widespread popularity in its applicability to business and industry. Many organizations have adopted it as a tool of continuous improvement in their quest for quality through total quality management (TQM). QFD in simple terms, has been looked on as a mechanism of translating the customers' expectations of a particular product or service into product planning, parts development, process planning, and production planning. Explores the robustness of QFD for translating the available knowledge within a product design group into appropriate design choices, ones that consider the customer's view of quality throughout the product's entire life cycle. Conventional QFD analysis allows equity of participation through "consensus", but often trades outcomes influenced by expertise for those attained with "fairness". This process may lead to less than optimal results. Discusses the role of group support systems (GSS) to improve the qualitative discussion of the whats and the hows in the QFD process. Also introduces influence allocation processes, methods that allow differential weighting of participants and an incremental usage of knowledge within groups. Discusses their potential impact for QFD analysis.

Keywords: New product development | Quality function deployment

Article:

Introduction

A critical factor for the success of organizations, especially in a global marketplace, is their ability to design high-performance, high-quality products and services that can be created reliably and profitably. Organizations must establish processes and operations with the total involvement of all concerned, and with a focus on customer satisfaction and quality. In this light, many processes and methodologies have been developed to formalize and improve the product life cycle.

In this article we contemplate the development of strategic and innovative software programs and the establishment of new business methodologies that reinforce the quality focus of manufacturing and service industries. We propose the development of an integrative technology that meshes quality function deployment (QFD) and group support systems (GSS) initiatives. QFD, a tool that contributes to the philosophies and practices of total quality management (TQM), is a system of matrices that explores interrelationships between customer demands, product characteristics, and service and manufacturing processes.

Group support systems are computer technologies designed to facilitate group work by addressing group needs and overcome constraints of time and geography. The application of technology to support task-oriented groups, to improve communication among members, to stimulate their creativity and help them structure and explore problems is an important and emerging field in the information sciences. We argue that the potential of QFD is curtailed because it is implemented as a personal productivity tool instead of a group productivity tool. With the QFD-GSS marriage, it is expected that major organizational benefits can be achieved.

A possible application

Consider the following situation. A group of employees and health professionals of a large hospital meets to make a recommendation to improve service in the emergency ward and trauma centre. The group includes surgeons, nurses, administrators, paramedics, ambulance crews, custodians, and other support personnel. Decisions must be specific. For example, the group may want to design an operating room schedule that best supports regularly scheduled operations and emergency procedures. The schedule must also incorporate the constraints of other hospital procedures and schedules (e.g., cleaning and sterilization plan, nurse timetable, availability of specialists). The group's desire is to make a precise and quantitative decision – or at least a ranking of acceptable alternatives on an interval or ratio scale. To define the group generally, these professionals are all interested in improving service, but they are, at best, experts in only a subset of each problem space to be considered. As a last constraint, assume that the issue should be settled in one sitting of perhaps one to four hours.

Is this situation realistic? The current trend in business environments is becoming increasingly team oriented[1]. In fact, multi-functional groups with names such as TQM teams, quality circles, internal customer meetings, feedback loops, interdepartmental meetings, and others are used to describe groups of people that share their insights and ideas for continuous improvement[2]. With genuine problems like that described above, there has been rapidly growing interest in the use of information technology to support group activities[3]. Our research proposes the fusion of three emerging technologies. These are:

1 QFD;
2 GSS; and
3 influence allocation processes

to create an innovative formal methodology that operationalizes the goals of TQM. Specifics of each component and their integration are explained in the following sections.

Background on quality function deployment

Quality function deployment started in Japan in the late 1960s and is now used by half of Japan's major companies. Since then, the technique has been implemented by many large US corporations[4,5,6,7]. In most implementations, QFD uses many matrix-like tables that explore interrelationships between customer demands, product characteristics, and manufacturing processes. Akao[8] and King[9] suggest many potential uses of QFD and Figure 1 depicts one such implementation, the product design matrix cascade. The top QFD table relates customer demands to quality characteristics in a product. Alternatively, in service organizations, these "product" characteristics are attributes of a business operation. The following stage investigates the relationships between these quality characteristics and product (business operation) characteristics. The next stage expresses relationships between the product (business operation) characteristics and the characteristics of the manufacturing (service) process. Lastly, the manufacturing (service) characteristics are related to the quality controls to be monitored during manufacturing (performing the business operation).

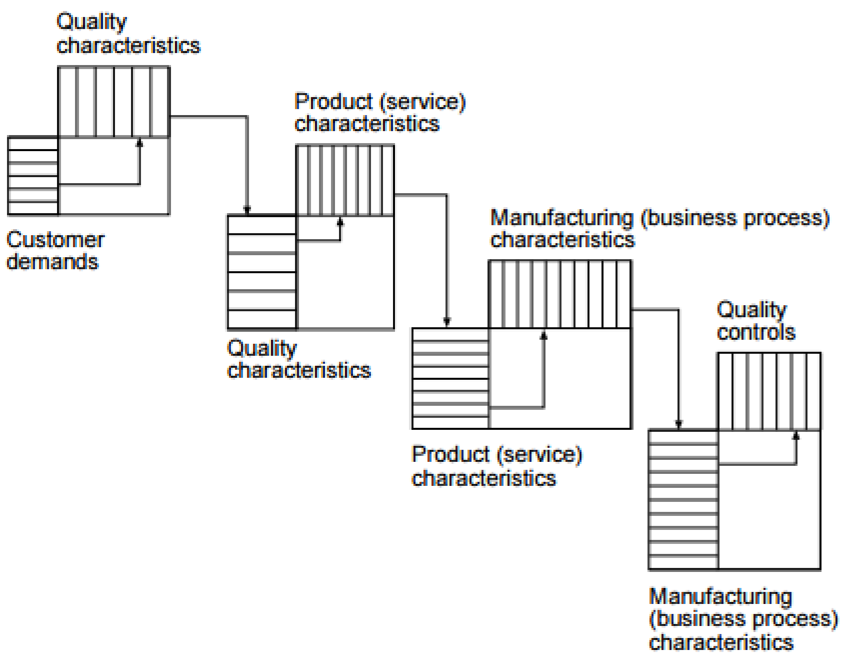


Figure 1. The product (service) matrix cascade

The systematic mathematical evaluation of each cell in the table will lead to the building of the "house of quality", a graph that rationalizes all possible relationships encountered in product development and implementation[10]. As described above, similar cascades can be employed to study other business processes and service activities. Riffelmacher provides one such example of the application of the QFD tool in the banking industry[11]. Norman *et al.* report that the three key ingredients of accurate and timely information, well-defined and disciplined process, and knowledgeable team workers are needed for the effective implementation of QFD[12].

A constant feature of planning and analysis tools is the matrix, or *X*-*Y* grid. The *X*-*Y* grid is not a novel idea – it had been proposed by Descartes, a French philosopher and mathematician, in the sixteenth century. From multi-column process flowcharts, to decision tables, to grid charting, to time automated grids (TAGs), to QFD analysis, the *X*-*Y* grid has always been a powerful yet intuitive approach to discuss problems. Almost any horizontal criterion can be paired against a vertical criterion. So what are the weaknesses of such a time-tested approach, and how can technology address these?

Enhancing QFD analysis

The imprecise nature of QFD is its foremost principle. It must be simple to use and should not be overpowered by standards. Akao postulates "copy the spirit, not the form"[8]. However, this philosophy begets three main weaknesses in current QFD usage:

1. the unsophisticated scoring system used by QFD for evaluating relationships;
2. the lack of attention to calibration between evaluators; and
3. the lack of formal aggregation of opinions between people collaborating on a group endeavour.

Researchers have begun investigations of the problems. For example, Wasserman[13] describes the QFD analysis equivalent of the "tree effect" of decision trees[14], which demonstrates that when factors are evaluated each using a different number of criteria or measures, the factors should be normalized in order not to skew the result towards those with more measures. Chapman and Bahill analysed the effect of small variations in weights supplied by the customer and found that when the weights were altered by plus or minus one point on a ten-point scale, the effect on a QFD chart could be as large as 10 per cent of its original value[15].

The latter two weaknesses of QFD described earlier assume that QFD supports a group process. However, the true main flaw of QFD may be that it is truly an individualistic tool, void of any valid group interaction, and its framework disregards the lessons of group support systems research altogether.

Improving QFD evaluations

Evaluating relationships within QFD matrices is a very imprecise process – especially if attempted as a group process. It involves assigning a symbol with a preset value to each relationship. Usually a numerical value of "9" is assigned to strong relationships, a value of "3" to common relationships, and "1" to weak relationships. This function is replicated for each evaluator and group point totals would then be calculated from a summation over evaluators of points for each relationship. Three major problems are inherent to the use of the traditional QFD scoring system. First, these systems do not give the voter a means to indicate truly an intensity of preference between the relationships. Second, the algorithm does not differentiate between the

“0” allocation from an evaluator indicating no relation and the “0” from an evaluator having no opinion. In QFD, these two situations would be aggregated in a similar fashion to attain a group score. Last, and arguably most important, the QFD scoring system does not make allowance for the possibility of variations in the relative expertise of the group members on the issue at hand.

McGrath suggests that it is especially important to consider the pattern of relations among group members prior to any group interaction process[16]. He notes that groups consist of patterned relations among group members that are influenced by among other factors, the relative expertise of individual group members. Because the QFD scoring system does not map relationship information to group member expertise, information is lost to the group and as a consequence, both the group interaction process and the quality of the group task outcome may be adversely affected.

Furthermore, the QFD scoring system is a hybrid ordinal scale. In the strictest propriety (and contrary to practice) the ordinary statistics involving means and standard deviations ought not to be used with ordinal scales, for these statistics imply a knowledge of something more than the relative score of relationships. We should then proceed cautiously with our statistics, and especially with the conclusions we draw from them[17]. In addition, since group members generally have opinions that extend beyond just the relative score given to relationships, a method that allows fuller expression of opinion is desirable.

Exploiting group support systems for QFD

Continuous improvement requires a participative process. All people concerned must put their heads together to identify problems, define goals, and plot strategies to reach those goals. QFD analysis is one manifestation of a group decision-making process, and computers have been employed for many years to assist groups in these. For example, several studies have been performed on the capability of the computer to explore multi-dimensional decision space[18, 19,20,21 ,22], or to aid in the aggregation of member opinions[23,24, 25,26,27 ,28,29]. However, early attempts at linking the computer technology with the group process, such as MacKinnon’s[23] use of an off-line Fortran-based batch process to compile votes, might perhaps be best labelled as premature. Their failure was not on the part of the technology itself but rather with the man-machine boundary. Even to this day, the central problem remains enhancing the group process so that members’ outputs, in real-time, become inputs for the computer process and vice versa[30].

Of all studies, perhaps the most interesting results were obtained using the electronic voting and discussion technique (EVDT) at MIT, a computer polling method where individuals in the group would enter their opinions as votes in a system[31, 32]. The ability to present and discuss results in real-time permitted the groups to explore previously unquestioned avenues of thought. As a result, the polling technique was found to be highly effective in structuring an agenda and in focusing on important issues[30]. Such results indicate a great potential for computer-based analytical tools that assist groups in arriving at a better understanding of a problem and to generate new and synergistic options for action. These studies, and many others, have led to the development of group support systems which combine computer, communications, and decision technologies and methodologies to support problem finding, formulation, and solution in group meetings[33]. These systems have concentrated on communications among group members and qualitative methods for group problem solving.

Finley describes three levels of GSS tools that support QFD analyses:

1 low-end GSS tools are single, off-the-shelf PC programs run by a technical facilitator while other people provide input;

2 mid-level GSS tools provide all participants with voting keypads linked to a single PC, and a screen on which questions and answers are projected; and

3 high-end GSS tools are multimedia meeting environments with networked computers for collaborative groupwork[3].

Finley then rejects the low-end tools because they offer inadequate support for groups of over three members and disqualifies high-end tools because of their expense and lack of portability[3]. While we agree with the evaluation of low-end GSS tools, we feel that the decreasing cost of systems such as the University of Arizona's GroupSystems V and the power and flexibility of notebook computers and wireless local area networks should change the latter recommendation.

Regardless of its level, GSS researchers (e.g. [34,35,36]) are convinced that computer-supported meetings improve group processes and outcomes. They argue that the benefits are derived because of:

- parallel communication, which promotes broader input into the meeting process and reduces the likelihood of a few individuals dominating the meeting;
- anonymity, which mitigates conformance pressure and evaluation apprehension so that issues can be discussed truthfully and spontaneously;
- process structure, which focuses the group on key issues and discourages dysfunctional group behaviours;
- task structure, which provides approaches to analyse information; and
- group memory, which serves as a permanent record of the proceedings.

In sum, the major task domain of GSS has been earlier phases of the overall decision-making processes such as problem exploration and idea generation under the assumption that these tasks are much more effectively performed by groups[35]. GSS research has not, however, explored the later phases of group processes, such as aggregation of different opinions or collective endorsement of a final agreement. It is these later processes which could potentially provide QFD analyses with precision, validity, and outcomes correlated with expertise. However, algorithms for quantitative decisions have been an unexplored variable in GSS research; an area we propose investigating.

Combining qualitative and quantitative judgements

By implementing an integrative technology that promotes collaboration, process improvement will benefit. A synergy will be created by combining qualitative and quantitative evaluations of the relationships defined in Figure 1. Though using current GSS technologies to support a QFD endeavour will improve the process qualitatively, the pivotal issue for the translation of current QFD usage into a true group process lies with the mathematical aggregation of opinions and the allocation of weights among group members. The simplest possible assignment, an equal weight to all, leads to average group positions which are often unacceptable to all – Ferrell states “two opposed zealots do not combine to a bland indifference” [37, p. 112]. QFD assigns an equal weight to each participant. Alternatively, unequal weighting schemes attempt to trade simplicity and “fairness” for accuracy. They reflect the understanding that not all contributors are equal, and they attempt to correlate influence with expertise. These techniques appear in the literature under the rubric linear opinion pools (e.g. [37,38, 39,40,41]).

Weighting QFD participants

Allocating weight to group members is a task that must be completed with care – it is often based on some combination of a subjective evaluation and each contributor’s past track record[42]. Opinions and weights then become inputs to aggregation functions such as linear opinion pools[37,38,39 ,40,41], logarithmic opinion pools[41], Bordley scores[39,40], and others to form a group consensus.

Fisher said that from a practical standpoint it makes little or no difference how one aggregates the conflicting opinions of experts. “Any reasonable approach is likely to be as good as any other”[43, p. 97]. However, research in mathematical aggregation has led Ferrell to dispute this statement[30]. Ferrell states that “specific knowledge about the judgement situation is needed, and it must be combined at its own level before rather than after it has been summarized into a final estimate by each individual”[30, p. 142]. An aggregation method that promotes an evaluation by each individual of each individual is needed. This section discusses how and why it might be meaningful to assign different weights to different people in a QFD group.
Four approaches have been mentioned in the literature for obtaining the weights for a weighted aggregation of group member opinions: weighting by a central figure, self-weighting, performance weighting, and weighting by the entire group.

Weighting by a central figure

Many approaches for weighting individual opinions suggest the use of an oracular decision maker who represents, according to Hogarth, the “synthetic personality” of a decision group[44]. It is the task of this entity to evaluate the group members, their prior information space, the interdependence of this information, and member’s calibration. Once this decision maker has determined its prior probability the opinions can then be put in and, using Bayesian mathematics, the oracle can update its prior probabilities. The weighting of the individuals is implicit in the use of their input by the oracle. The decision maker’s posterior probabilities become the group consensus decision.

However, this fictitious bearer of prior probabilities does not exist. In practice, the Bayesian combination model must be agreed on by the group itself or be imposed by a leader. But it is actually a modelling task requiring judgement, and there is no algorithm for doing it. In real groups, the leader of the group often takes the place of the oracle. In this case, all discussion, opinions, judgements and the like are filtered through a group leader who may have objective measures of past performance for each group member and subjective opinions about the group members' current contributions. The leader distils the prior knowledge and opinions with the current inputs and returns with a verdict, which is then considered the group consensus decision. The problem with this approach is the subjectivity of the central figure which may discount the important inputs from certain participants, or emphasize lesser inputs from others, perhaps for inappropriate reasons.

Self-weighting

In self-weighting, each member gives an assessment of personal expertise with respect to the judgement in question. This is done using a standard scale for all participants. Each assessment is then divided by the total of all the assessments to produce a normalized percentage weight for each participant.

Performance weighting

All methods discussed to this point are based on subjective judgements. This assumes that the evaluators, i.e., group leaders, oracles, or each participant, have the ability to make these judgements. An alternate approach, based on objective data, is performance weighting. The weights associated to each member's contributions are based on objective measures of past performance. The main drawback of this method is that the data required to compute the weights might be very difficult to collect or not exist, or the assumptions about the properties of the judgements might be wrong[37].

Weighting by an entire group

A more participative approach than the previous methods is one that distributes the weight assessment task to all group members. Each member judges each other member and him or herself. Ferrell mentions two techniques:

1 the summing of each individual's rating and then normalizing; and

2 normalizing first to give weights assigned by each individual and then averaging these.

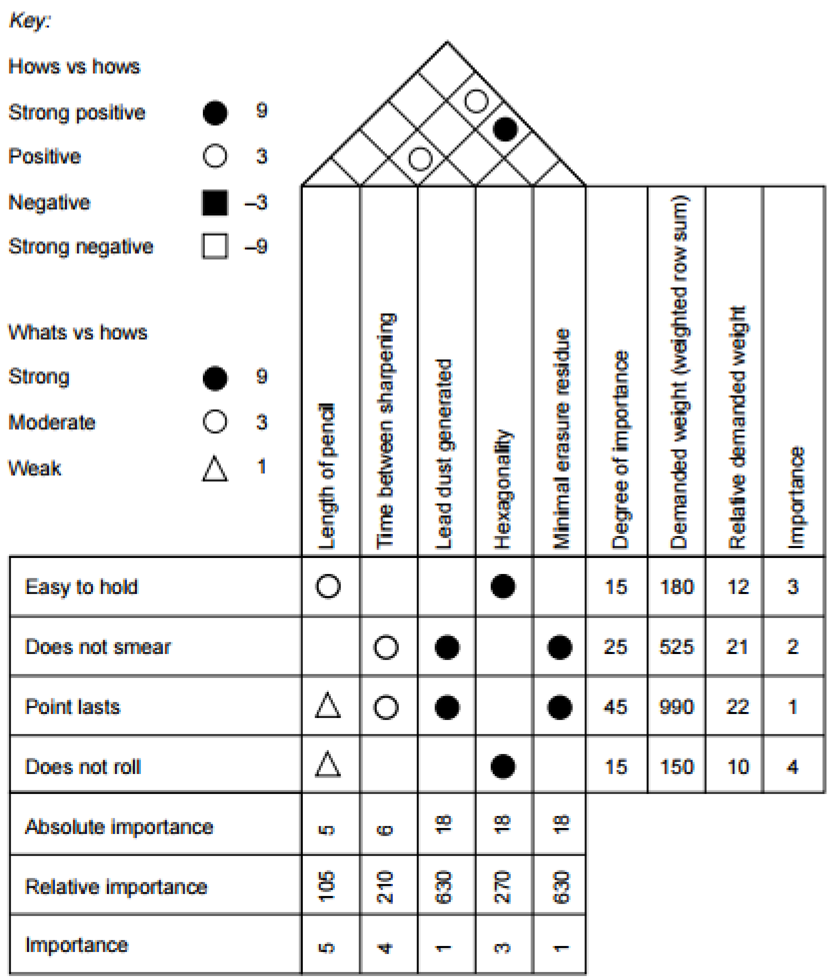
The next section further expands on the contribution of weighting by the entire groups by considering methods called influence allocation processes[37].

Summary on weighting QFD participants

Weighting methods have been tested in a variety of contexts but mostly in connection with assessment of subjective probabilities and with methods for aiding group opinion aggregation. In the empirical work that has been done, differential weighting of opinion has seldom been found to perform much better than equal weighting as a means of improving group performance[37, 45,46,47]. This conclusion achieved salience with Wainer's Equal Weights Theorem in his article entitled "Estimating coefficients in linear models: it don't make no never mind"[48]. However, in problems with a single optimal solution, Barron demonstrates that weights do matter[49]. It may be that weighting methods have not been tested in those situations where they can be especially effective[37].

An example of participant weighting in QFD

To show how differential weighting of participants can affect the outcome of a QFD analysis, we borrow Wasserman's product planning matrix for a hypothetical writing instrument[13]. The chart appears in Figure 2.



Source: Adapted from [13]

Figure 2.
The product planning matrix for a hypothetical writing instrument

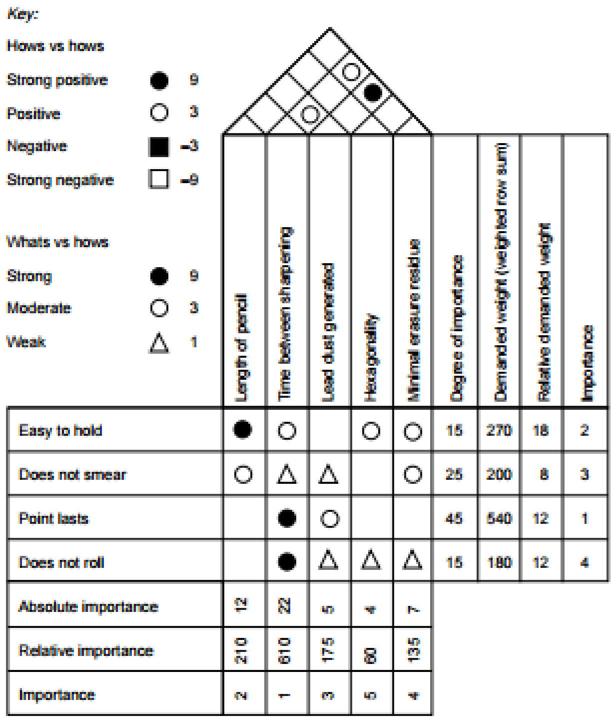
Based upon results from a market survey, the important customer requirements, or wants – easy to hold, does not smear, point lasts, and does not roll – are listed on the left hand side of the matrix. For each customer requirement, such as point lasts, for example, the design team must respond to this need by identifying the important engineering design requirements such as time between sharpening, lead dust generated, and minimal erasure residue, which if the requirements are fulfilled, would fulfil this need[13, p. 59].

Wasserman's matrix most probably represents the evaluation of a single expert or, at best, an agreed on "consensus" evaluation. Our research premiss suggests that a formal aggregate evaluation from a team of experts will produce a different and potentially better QFD analysis. Different experts will ground their evaluations on their particular knowledge, their distinct perspectives of the problem, and the different agendas each brings to the design task. In our example, we complement the initial evaluation with two other expert opinions. Figure 3 shows the independent evaluations of the two additional hypothetical participants. As would be expected in a real group, the evaluations are not grossly dissimilar from one expert to the next. However, each has scored the intensity of the various relationships differently. Figure 4 shows the "traditional" aggregation matrix, an arithmetic mean of the three evaluations. Figure 5shows the aggregation matrix produced from an algorithm that arbitrarily assigns twice the weight to the third evaluator. These matrices clearly demonstrate that different weighting of evaluators in QFD exercises can and will lead to very different process outcomes – and (potentially) very different actions by the organization.

The emerging issue then for the use of QFD analysis in groups is the selection of an appropriate weighting scheme, one that emphasizes knowledge and accuracy over democratic fairness and means. The next section introduces influence allocation processes (IAP) which are sophisticated group weighting tools that allow each group member to evaluate his own and each other member's knowledge relevant to a specific issue and incorporate this incremental usage of knowledge within aggregation of opinion processes, such as in a group QFD exercise. The proposed methodology is a hybrid of linear opinion pools where weights are not decided a priori but are outcomes of a group process[36,50, 51]. With IAP, the "traditional" implicit weighting of participants is enhanced with an explicit group weighting methodology.

Influence allocation processes and QFD

Influence allocation processes are voting and opinion aggregation methods that allow members to distribute some or all of their decision-making influence to others in the group in order to exploit not only the group's knowledge of alternatives, but its knowledge of itself. The technique can be used for numerical estimation – as in the estimation of the importance of "whats versus hows" relationships in QFD analysis. Consider the exercise of "filling up" the house of quality. One group member might have a strong opinion that some minimum weight allocation is needed for certain cells and not care about, or not know enough about the facts involved within, other cells. In the latter situation, one might wish to defer to others in the group of "experts", defer to those whom one might believe to have better understanding of the issue at hand. This freedom of group members to allocate influence allows each individual to substitute knowledge about the other members of the group for uncertainty and limited knowledge concerning a specific problem.



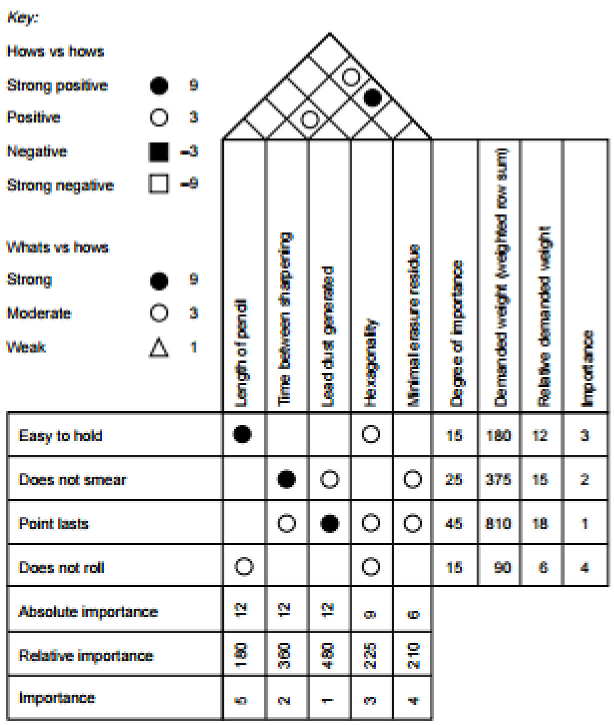
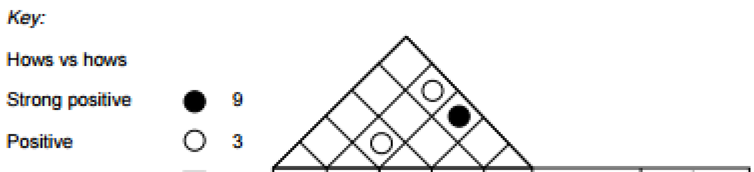


Figure 3.
A matrix for a mythical second and a third participant in the product plan for a hypothetical instrument

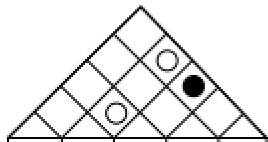


	Length of pencil	Time between sharpening	Lead dust generated	Hexagonality	Minimal erasure residue	Degree of importance	Demanded weight (weighted row sum)	Relative demanded weight	Importance
Easy to hold	7	1	0	5	1	15	210	14	3
Does not smear	1	$4\frac{1}{3}$	$4\frac{1}{3}$	0	5	25	367	$14\frac{2}{3}$	2
Point lasts	$\frac{1}{3}$	5	7	1	4	45	780.3	$17\frac{1}{3}$	1
Does not roll	$1\frac{1}{3}$	3	$\frac{1}{3}$	$4\frac{1}{3}$	$\frac{1}{3}$	15	140.4	$9\frac{1}{3}$	4
Absolute importance	$92\frac{2}{3}$	$131\frac{1}{3}$	$112\frac{2}{3}$	$101\frac{1}{3}$	$101\frac{1}{3}$				
Relative importance	165.4	393.5	428.6	185.1	325.1				
Importance	5	2	1	4	3				

Figure 4.
An aggregation matrix for the product plan of a hypothetical writing instrument. This aggregation uses the arithmetic mean of the three evaluations

Consider the group of employees and health professionals of a large hospital introduced earlier. Assume that the group is evaluating a "whats versus hows" cell focusing on the hypothetical relationship between efficient admission process (the "what") and availability of computerized patient database (the "how"). Recall that the group meets to recommend techniques to improve service in their trauma centre and that the group is made up of:

- surgeons;
- nurses;
- administrators;
- paramedics;
- ambulance crews;
- custodians; and
- other support personnel.



Key:

Hows vs hows		
Strong positive	●	9
Positive	○	3
Negative	■	–3
Strong negative	□	–9

Whats vs hows		
Strong	●	9
Moderate	○	3
Weak	△	1

	Length of pencil	Time between sharpening	Lead dust generated	Hexagonality	Minimal erasure residue	Degree of importance	Demanded weight (weighted row sum)	Relative demanded weight	Importance
Easy to hold	7.5	1.5	0	4.5	1.5	15	225	15	3
Does not smear	1.5	3.5	3.5	0	4.5	25	325	13	2
Point lasts	0.25	6	6	0.75	3	45	720	16	1
Does not roll	1	4.5	0.5	3.5	0.5	15	150	10	4
Absolute importance	10.25	15.5	10	8.75	9.5				
Relative importance	176.25	447.5	365	153.75	277.5				
Importance	4	1	2	5	3				

Figure 5. An aggregation matrix for the product plan of a hypothetical writing instrument. This aggregation uses an algorithm that gives twice the weight to the third evaluator. This is an arbitrary weight allocation

Though much of this group is constituted of highly educated and trained personnel, each individual is only a true expert in only a subset of all possible interrelationships being considered by the group. Examine the IAP ballot found in Table I. This ballot represents the allocations of the head surgeon. This ballot, with its two distinct columns, is that of SPAN, the social participatory allocation network algorithm. The left-hand column lists the participants constituting the quality improvement team (less the head surgeon who is represented by the right-hand column). The right-hand column contains the values "0" through "9" found in traditional what versus how matrices for the evaluation of the strength of the relationship contemplated in any given cell. The evaluator must distribute 100 points either over the participants or the values. A distribution over the members represents the head surgeon's evaluation of each participant's relative perceived knowledge in the specific area being considered in this cell. The points disbursed over the strength of relationship values indicate the head surgeon's opinion as to relatively what the strength of relationship value should be. The total weight allocated to values also indicates the relative importance of the head surgeon's allocation to the solution in comparison to the others in the group. In this case 15 points were allocated to values and 85 to other people in the group. This indicates that, for this cell, the surgeon considers the opinions of others in the group to be relatively more important than his own opinion. Thus, the head surgeon's predominant role for this cell is the evaluation of the other participants, a second level of knowledge disregarded in most non-IAP aggregation mechanisms. In this "respect" column, the head surgeon indicates that the admission nurse and the hospital administrator have the most relevant opinions. Although less than the importance given to his own evaluation, the allocation also indicates some "respect" to the head nurse, the head paramedic, and to the ambulance despatcher (five points each versus 15 points to himself). A score of "0" indicates a total lack of "respect" for a participant, for this particular cell. A "0" indicates that, in the opinion of the evaluator, the targeted participant's opinion is no better than that produced by a random number generator.

This method allows the evaluator to assess using a distribution instead of a single value. The added variance may better represent the allocative disposition of the evaluator. Further, the method allows to formally distinguish between a "no link" evaluation and the ubiquitous "no opinion" blank evaluations (also scored erroneously as "0" in traditional QFD). With this IAP, an evaluator with no or little knowledge would allocate heavily to others whereas a true expert would distribute most of the 100 points over the relationship strength values, possibly on the "0" "no link" value.

	SPAN ballot		
Participants	Weight	Relationship	Weight
Head nurse	5	No link – "0"	0
Surgeon	0	Very weak link – "1"	3
Admission nurse	30	Weak link – "2"	9
Hospital administration	30	Weak to moderate – "3"	3
Head paramedic	5	Low moderate – "4"	0
Ambulance despatcher	5	Medium moderate – "5"	0
Operation room nurse	0	High moderate – "6"	0
Head custodian	0	Moderate to strong – "7"	0
Head clerical staff	10	Strong link – "8"	0
		Very strong link – "9"	0

Notes: This is the head surgeon's ballot
Votes allocated: 100
Votes remaining: 0

Table I.
Example influence allocation process ballot

Two flavours of IAP have been proposed in the literature. SPAN was originally proposed by MacKinnon[23, 24,25] and implemented into group support systems by Balthazard[36, 50,51]. A method we call RCON (rational consensus) was originally proposed by DeGroot[52] and later analysed as a normative aggregation method by Lehrer and Wagner in a series of papers[53,54,55] and in their book *Rational Consensus in Science and Society*[28]. RCON has also been implemented in a group support system[36,50,51]. Both SPAN and RCON, though quite sophisticated in the way they do so, produce a weighting of the individual members' opinions – a linear opinion pool. What is significant is that they do so anonymously and make use of a wider range of members' perceptions, discoveries, and inferences. For example, they harvest the knowledge that members have about other members' knowledge. They allow members to rescue themselves proactively from an evaluation by assigning power to those they judge to be better evaluators than themselves.

In the original realization of SPAN by MacKinnon[23], the allocation of a fixed number of votes was carried out as an iterative process by computer. Each member starts with a number of votes that may be allocated among one or more of the other members of the group and/or among one or more of a set of discrete alternatives. For QFD analysis, a set of ten alternative values (0 to 9 points) would be proposed for each cell and a group value can be selected by a weighted average of the judgement distributions. The influence a member receives from others is then passed on according to the same initial allocation. Under suitable conditions, this iterative process converges with everybody's votes assigned to the alternatives, thereby obtaining a score to be the group value. An easily met sufficient condition for convergence is that every member assigns some proportion of influence to at least one alternative value. The iterative allocation may be the easiest way to conceptualize SPAN but the structure of the process can be modelled, as Ferrell showed, as an absorbing Markov chain, a fact that is useful for tallying the vote and computing measures of performance[37]. The members of the group are represented by the transient states, the alternatives by the absorbing states, and the passing of votes is represented by the state transitions. The proportion of votes allocated by one member to another or to an alternative is the transition probability from the transient state representing the "sending" member to the transient state representing the "recipient" member or to the absorbing state representing the alternative.

The probability of ending in a particular absorbing state *k* given that the process started in a particular transient state *i* is the proportion of member *i*'s votes that eventually are allocated to alternative *k*. The sum of this measure over members is the total vote allocation to alternative *k*. This computation is performed as in the ensuing algorithm.

Let the matrix of the proportion of votes member *i* allocates to member *j* be [m7sub;ij] = Q. Members do not allocate to themselves. Let the matrix of the proportion of votes member *i* allocates to alternative *k* be $[a_{i}k]$ = R. Then, from the theory of absorbing Markov chains, the probability the process will end in absorbing state *k* if it starts in state *i* is $b_{i}k$ where $[b_{i}k]$ = B = $[I-Q]^{-1R}$. Thus $b_{i}k$ is the proportion of votes that goes to alternative *k* from member *i*, by whatever route, and the total votes for the alternatives are the column sums of *B*, assuming one vote per member.

MacKinnon and his students tested SPAN in a few experiments and generally found it somewhat more effective than methods that did not involve influence allocation[56]. It was found that individuals chose to allocate most of their voting power to other members and that these indirect allocations were more effective than their allocations directly to alternatives. In a separate experiment, SPAN was used first by a larger group, fraternity members, to allocate voting weight to each member of a committee, fraternity officers. The committee then used either SPAN or percentage voting to distribute this weight to the alternatives. This preliminary use of SPAN to allocate voting power within the committee did not produce better performance than when the committee members had equal weight when using the voting methods[23,24, 25,56,57].

However, in none of these tests did the group members have any special differential expertise at the task that other members might know about and that would afford a basis for allocating them more influence. Moreover, the dimensions of skill required for the task were not clear enough that one could reliably judge another person's skill. Hence the conditions under which influence allocation processes could be particularly effective were not met in these early studies.

In an empirical review of SPAN, RCON, and other IAP using *n* alternative, forced-choice tasks, Balthazard[36] and Balthazard *et al.*[50] report that when appropriate conditions exist, IAP are significantly better at finding a correct answer than are traditional GSS decision aids. However, the study of forced-choice tasks only initiates research on influence allocation. Though many appropriate tasks have been defined for IAP, there is still no solid guidance concerning which methods are best for which tasks, or for which types of groups – including QFD analysis. Considerably more empirical testing is needed to establish IAP legitimately as a method of choice for decision making and opinion aggregating in groups. Nevertheless, the solid findings of these seminal studies may indicate an exciting and untapped potential for improving the efficiency and effectiveness of group decision making, including its usage in QFD analysis.

Potential contribution

The increasingly widespread adoption of computer-supported collaboration techniques and emerging network technologies (such as the Internet) in business provides an interesting arena for the integration of QFD and GSS. In concurrent engineering, representatives of all parts of an industrial firm, finance, marketing, manufacturing, human resources, design and engineering, work together simultaneously on the creation of new products[58]. The essence of TQM, and especially the QFD process, requires sequences of decisions that invoke a diversity of skills, knowledge and viewpoints from each of the primary functions of marketing, engineering, and operations[59]. An explicit and incremental use of knowledge, at different levels and from different players, will lead to more representative QFD outcomes and a higher degree of satisfaction from those that must also implement the changes indicated by the QFD outcomes.

This research stream could also potentially add value to the broader areas of co-ordination theory[60, 61,62], small group research[16,63], total quality management[64], value engineering[65], and combination of judgements and forecasts (e.g.[66]). Medical decision making has also been shown to benefit from the combination of opinions[67,68]. In sum, many endeavours could benefit from formal group aggregation processes and the integration of QFD and GSS technologies.

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