Investigations Into More Exact Weightings of Customer Demands in QFD

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Abstract

Apart from the customer demands themselves, the weightings of the customer demands are one of the main input data of a QFD (Quality Function Deployment) and furthermore of the actual construction process of products.

Up to now, most interviews with stakeholders have been carried out with questionnaires and then absolute weightings have been used. Now it has been analysed if the use of other interview and evaluation techniques, e.g. relative weightings and Analytic Hierarchy Process (AHP), can improve the precision of the demands and wishes of the stakeholders. Now the task was to analyse if the use of relative weightings as input of a QFD is possible at all, how they have to be adapted and if an increase in precision compared to the use of absolute weightings is reached. When using AHP during the product development it has become clear that only up to seven demands can be rated at the same time by customers. That means that a kind of hierarchy has to be developed to correctly transfer the demands and their weightings into the QFD.

Key Words: QFD, AHP, Customer Requirements, Relative Weighting

1. Introduction

The preferred application of the QM method Quality Function Deployment [QFD] is to achieve high-quality products by means of systematic processes already in the early stages of the product creation process; whereby quality in this context is understood to mean a high rate of customer satisfaction which in turn is a decisive factor for the long-term success of an enterprise. For this purpose, customer requirements must be acquired as completely as possible and accurately weighed. Only then, the finally defined product characteristics which have been derived from customer requirements can be optimized to provide the best possible benefits.

A conventionally applied QFD, the method used in most cases, does not gather customer

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wishes with great accuracy. That means that the results will likewise be inaccurate as their significance depends decisively on the quality of the input quantity. Therefore, new considerations are looking at how to achieve increased accuracy of input quantity by employing the Analytic Hierarchy Process [AHP]. The outcome is that the weighted customer requirements are included in the calculations not as an absolute value of a defined interval scale e.g. from 1 to 5 or 1 to 10 as before but in the form of relative figures between 0 and 1. The relative weightings result from making comparisons of the requirements in pairs in order to achieve increased quality of outcomes. As the employment of relative evaluation methods based on the AHP method - in particular that of making comparisons in pairs - involves considerably increased time and effort, it is essential to observe that wherever possible no or only minimal loss of accuracy is involved when integrating the relative values. Otherwise, the considerable increase in time and effort spent becomes unjustifiable.

2. The Analytic Hierarchy Process

A pairwise comparison for customers is a simple and, at the same time, exact method to gain requirements by a questionnaire. Including the required hierarchization, the Analytic Hierarchy Process provides decisive advantages regarding the precision of requirements' weightings. The AHP is a method developed at the beginning of the 1970s by Dr. Thomas Saaty to support multi-criteria problems in decision-making. It can be illustrated by means of a hierarchal structure. The AHP is mainly used in the Anglo-American sector in political committees and industrial projects in decision-finding processes. Although the methodology can be ideally integrated into a QFD project, it is currently seldomly used for prioritizing customer requirements, engineering characteristics and product alternatives.

The AHP can be broken down into two phases. First, all of the relevant, determining factors of a defined problem must be collected and then given a hierarchal structure. When the named procedural steps in the hierarchal design are completed, all of the determining factors at one level are compared with one another pairwise using a ratio scale of nine elements which allows differentiated valuation. Both qualitative and quantitative determining factors can be employed to describe the problem. In addition, the logics of single and overall decisions may also be determined as the AHP is based on mathematics (Saaty, 1990).

The determining factors of a problem are split up into specification characteristics (criteria) and possible solutions (alternatives). Criteria can be described using further characteristics (sub-criteria) which are hierarchically subordinated under criteria. The alternatives are always shown on the last level. According to definition, customer requirements expressed in the language of the AHP are therefore criteria or sub-criteria. Alternatives are not considered but they can be easily integrated into a QFD project in the requirements hierarchy to evaluate product alternatives.

2.1 Example:

In an initial step, possible product requirements must be defined. Numerous methods are available for this, e.g. brainstorming. As the AHP demands that requirements must be compared pairwise with one another on one level with a view to their importance, the following restrictions regarding the type of criteria arise: all criteria on one level must be independently and meaningfully comparable with one another (Saaty, 1990). The latter assumes that only "can" requirements can be observed. It is advantageous to implement them as the functionality of a product and thus the benefit of it from the customer's point of view is enhanced. In contrast, "must" requirements are absolutely essential, i.e. of such fundamental significance that should they not be met, an acquisition of the product can be excluded from the very beginning. They therefore cannot be meaningfully related to other criteria. Requirements, whose implementation is of no significance for the customer, are not included into the evaluation progress from the outset.

All of the determined "can" requirements are now structured according to hierarchy in a second step. As an example, ten requirements will be observed. The higher the number of the criteria to be compared directly with one another, the more difficult it becomes to reach a consistent decision. An investigation carried out by Miller has shown that a person can on average only consider seven items of information at the same time. (Miller, 1956) Thus, if possible, comparing ten requirements in order to achieve qualitatively premium results should be avoided. If it is assumed that the requirements can be meaningfully placed together in three clusters, this will result in the following example hierarchy:

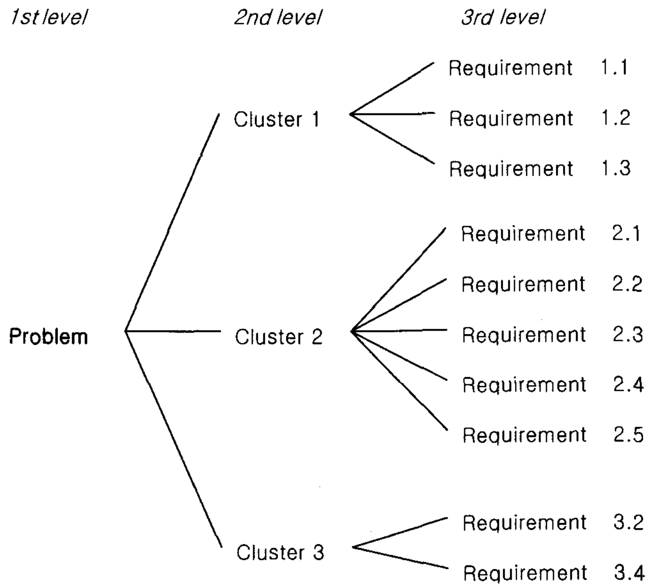

Figure 1. Hierarchy of customer requirements

With reference to the cluster in question, the clusters are then compared pairwise with one another regarding the problem and the requirements. This is shown as an example using the requirements of the first cluster. The priorities are entered into a so-called pair comparison matrix.

Table 1. Matrix of priorities for the customer requirements of cluster 1

Cluster 1	Requirement 1.1	Requirement 1.2	Requirement 1.3
Requirement 1.1	1	3	6
Requirement 1.2	1/3	1	4
Requirement 1.3	1/6	1/4	1

The pair comparison scale according to Saaty comprises all of the numbers from 1 to 9, plus their associated reciprocals. If two criteria are given the same weighting, they are valued at 1. On the other hand, if one of the criteria absolutely dominates another one, it is rated with 9. The other elements on the scale represent interim values.

Requirement priorities can be determined from the pair comparison matrix. Saaty was able to mathematically prove that because of the special properties of the matrix, the elements of the associated eigenvector agreed with the priorities of the evaluated determining factors (Saaty, 1990). Thus, EV = [65.48, 24.99, 9.53] applies. The associated inconsistency factor with whose help a statement can be made concerning the logics of individual weightings is 5%; i.e. the evaluation shows minor inconsistencies, which however are less than 10% and can therefore be tolerated; the weightings would otherwise need to be re-determined.

When all of the pairwise comparisons have been conducted according to the described schema, individual weightings may be consolidated using an algorithm described by Saaty to a final outcome (Saaty, 1990). All requirements are attributed a relative value as a result. The sum of requirement priorities (level 3) comes to 100%.

2.2 Advantages of AHP Compared with an Absolute Evaluation:

In contrast to an absolute evaluation which is often used for weighing customer requirements, AHP features decisive advantages. One significant difference is that AHP not only demands the prioritization but also the structuring of the requirements. In that way, observing requirements of differing dimensionality at one level is avoided. Moreover, a hierarchal breakdown of requirements supports the ability of the assessor to judge as a person because his/her cognitive capabilities generally strive to analyse complex problems by splitting them up into partial decisions, in order to find a sensible solution (Meixner, 2002)

Furthermore, the pairwise comparison is a method of evaluation which is easily understood as in each case only two requirements need to be compared with one another. However, a consistent evaluation requires in a further sense that the assessor takes previous weightings into consideration when making judgement. In the case of absolute evaluations these restrictions do not exist. Each requirement can be evaluated individually although then the customer tends hardly to rate the value at all and to generally rate all requirements as important. However, as not all correlating product characteristics can be optimized with the requirements, the QFD team then lacks important information for the product design if absolute evaluation is employed. In contrast, AHP demands that the customer differentiates between values in order to be able to derive a preferred focus.

Moreover, both evaluation methods can be differentiated regarding the measurement level on which they are based. The results of absolute evaluation merely provide information concerning the ranking of the requirements. The gap between the preferences cannot be meaningfully interpreted-similar to the marking systems used in schools. Saaty's pairwise comparison, on the other hand, is based on a ratio scale and the evaluation results provide relative weightings. Consequently, not only the ranking of the results can be evaluated but also the respective difference in benefits between the individual requirements. For example, it is possible to determine that the implementation of requirement 1 is considerably more important for a customer than the implementation of requirement 2. However, no statements can be made on the absolute importance of both requirements.

Furthermore, it is possible to state the logics of an evaluation which has been carried out using the AHP. If the inconsistency of a completed pairwise comparison is not tolerable, the customer is directly requested to re-consider the weightings. This feedback is only permitted by the mathematical structure of the AHP and is unique within the methodical requirement prioritization.

The remarks made in this section have shown that the AHP is excellently suited to prioritize customer requirements from both the customer's perspective as from the perspective of the QFD team. However, as the usual QFD strategies e.g. Akao and American Supplier Institute [ASI] are based on absolute weightings, it is necessary to discuss how relative weightings can be integrated here.

3. Problems in Using Relative Weightings as Input Quantity in QFD

Converting the absolute value into a relative one causes in some cases serious changes which highly influence the QFD. One of the most conspicuous changes is the dependency of the numerical values of the weightings on the number of incoming customer requirements.

In a conventional QFD, the numerical value of a single customer requirement is, on the one hand, dependent on the scale used and, on the other hand, on the judgement of the persons conducting the QFD. If relative weightings of customer requirements are used, the numerical value remains significantly dependent on the judgement of the persons carrying out the QFD. In contrast, the second input parameter behaves differently. An evaluation scale no longer exists for relative weightings; instead, a new input parameter appears. As the number of customer wishes increases, the single numerical values of the weightings tend to become smaller. The reason for this is that in relative weightings, 100% is always distributed over all of the customer requirements. Of course, of this 100%, more will fall on a single requirement if there are e.g. a total of eight than if there are 30 or more.

This inter-relationship must always be taken into consideration when using relative weightings. However, there is another far-reaching problem in integrating relatively weighted customer requirements in a QFD. When calculating the results, the weight of customer wishes and the values for correlation of requirements with product characteristics are multiplied with one another. By using these values from a prescribed framework such as a scale from 1 to 5, these two input quantity stand in a defined relationship to one another. Using relative weightings can lead to completely different results. In most cases, input qualities stand in no definite relationship as here those evaluations are possible which are excluded from a scale evaluation. Therefore, a customer cannot be evaluated as just "five" or "ten times as high" but can be rated purely in figures e.g. 40 times higher than another.

Consequently, the input parameter of the weighting of customer requirements always has varying degrees of strong impact on the calculated results of the total evaluation in every QFD and causes an imbalance which is difficult to survey.

Converting the integration of weightings from the AHP into a QFD must take this problem into consideration. Equal attention must also be given to the fact that the highest possible increase in quality is incurred for the output quantity of a QFD. If this is not ensured, the implementation is of no value as increasing the accuracy of the output quantity is the motivation behind and the objectives of integrating weightings from the AHP.

Beginning with these requirements, it would appear that it is possible to determine relative values for all numerical input quantities made possible by integrating relatively weighted customer requirements Such a process has the advantage that there will be no miscalculations of precise weightings with values from rough scales as, in these cases, an increase in the accuracy of the results can only be very unsatisfactorily met. In addition, it would appear to be advantageous that all of the values which are to be later calculated together come from a similar development process so that the dimension of all input quantities is identical.

A process such as this however has a distinct disadvantage in that it is intensely time-consuming. The relative evaluation of all the numerical input quantity e.g. using an

AHP takes considerably longer than conventional rating. In particular, the time needed to observe many customer requirements and product characteristics through a large number of pairwise comparisons increases rapidly. The amount of time can be reduced by reverting to processes which are not based on complete pairwise comparisons although it must be noted that this solution is hardly feasible for a comprehensive QFD and will therefore be little used in practice.

Another way of integrating relatively weighted customer requirements is to convert the relative value to an absolute one; a process which requires very little time and allows relative values to be transferred to any scale whatever. However, it must be observed that there are many different types of scales, as has already been pointed out.

Into which of the different scales the relative values will be eventually transferred depends mainly on the preferences of the user.

In order to convert the relative values, intervals with certain threshold values are determined. Then the interval in which existing relative values fit in each case is checked. As each interval is allocated to an exact number, each relative value can now be allocated to an absolute one.

3.1 Example:

The following demonstrates how a conversion of this type is carried out. To begin with, the relative values shown in Figure 2 are required for the ten customer requirements A to J. These could have been determined by means of an AHP.

Using these relative values and knowing into which scale the values are to be converted, the size of the intervals can now also be determined. To do this, the highest realtive value is divided by the maximum scale value. With a scale from 1 to 10 in this case that would mean:

$$24/10 = 2.4$$

Customer requirement	Relative value
A	24.48
B	20.63
C	14.91
D	10.08
E	8.25
F	6.14
G	5.81
H	4.19
I	3.96
J	1.55

Figure 2. Relative values for customer requirements

This value is the starting basis for determining all the interval limits. As a scale of 1 to 10 was selected for this example, ten intervals are required. These lie between a total of eleven threshold values which are determined by multiplying each of the numbers 0 to 10 by 2.4. Figure 3 shows how these interval limits have been reached.

Calculation	Interval limits
10 • 2.448	24.48
9 • 2.448	22.03
8 • 2.448	19.58
7 • 2.448	17.14
6 • 2.448	14.69
5 • 2.448	12.24
4 • 2.448	9.79
3 • 2.448	7.34
2 • 2.448	4.90
1 • 2.448	2.45
0 • 2.448	0

Absolute value	Intervals
10	22.03-24.48
9	19.58-22.03
8	17.14-19.58
7	14.69-17.14
6	12.24-14.69
5	9.79-12.24
4	7.34-9.79
3	4.90-7.34
2	2.45-4.90
1	0 2-.45

Figure 3. Calculation of interval limits

When the interval limits have been determined, the respective intervals can be simply read off, as the right column in Figure 3 shows. Finally, for each relative value, the interval in which it lies and the absolute value it thus has must be determined. Figure 4 shows the results of such allocation using values from Figure 2 for this example.

Relative value	Corresponding interval	Absolute value
24.48	22.03-24.48	10
20.63	19.58-22.03	9
14.91	14.69-17.14	7
10.08	9.79-12.24	5
8.25	7.34-9.79	4
6.14	4.90-7.34	3
5.81	4.90-7.34	3
4.19	2.45-4.90	2
3.96	2.45-4.90	2
1.55	0-2.45	1

Figure 4. Allocation of absolute values

Of course, a conversion of this nature always results in the maximum scale value for the highest relative value. The reason for this is that the highest relative value is co-responsible for determining the interval limits. Thereby, the upper limit value of the maximum scale value is always identical with the highest value of the relative numbers in a process like this. These absolute values are used exclusively in further QFD calculations and observations.

4. Conclusion

The motivation for using an AHP and the thus resulting relative weightings is justified by the accuracy of results in a QFD. This level of increased accuracy compared with conventional processes results mainly from prioritizing requirements using pairwise comparisons and in most cases this is conducted with increased awareness and consideration. The quality of decisions taken can also be measured using the inconsistency factor whereby the quality of the QFD is increased in each case and the combined use of a QFD and an AHP can be justified.

One problem which must be observed when integrating relatively weighted customer requirements is that the input quantities for calculating an overall evaluation no longer stand in the same or at least firmly defined relationship with one another. The determination of results is strongly impacted to varying degrees by the input quantity, depending on the structure of the relative numbers. Consequently, in each QFD with relative values, the weighting of customer requirements has a different impact on the result.

One solution which adequately considers the named problem is to convert relative weightings into absolute weightings. In this way, the accurate AHP results can be utilized; and at the same time, the QFD can be carried out in the conventional form without any considerable alienation. Furthermore, there is no considerable increase in the amount of time required, a fact which positively affects acceptance of this process.

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