Why we need matrices in QFD

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ABSTRACT

In this paper, we describe the need of using special matrices in QFD to achieve sustainability. These matrices inside of the House of Quality (HoQ) were always criticized regarding the time consuming effort and the minimum of benefit in regard of the results. But in the last decade, there is a revival of the QFD matrices. This paper will present the specific reasons for this future trend and the prerequisites to handle the matrices inside QFD and discuss the results of several, selected projects.

KEYWORDS

QFD, House of Quality, Special Matrices, Optimization Direction, Conflicts and Contradictions, QFD and TRIZ, Mahalanobis-Distance

1. INTRODUCTION

When QFD was born, the House of Quality (HoQ), as a tool was an important integral part of using QFD. The HoQ was derived from the "fish-bone" diagram, which was one of the most important "new 7 tools" to identify all potential factors causing one effect. [1]

Sometimes, the meaning of QFD was identical to the HoQ and reverse.

The negative impacts in using the House of Quality were discussed ever since it was published in the QFD Literature (Mazur et.al). [2]

Main items refer to:

- The enormous time needed to handle large matrices
- Wrong input in regard to Customer Requirements gives wrong output:
- Garbage in = expensive garbage out
- The results as outcome of the calculations with the relationship-figures were nontransparent, sometimes obscure.
- The results did not get any acceptance in the R&D Departments. Engineering was more interested in getting valid Customer Requirements (if there was already a customer orientation) and no technical solutions "produced by QFD".

But talking to practiced customers, who are using QFD since more than a decade and our own experience, there is now a revival in using Matrices and in the calculation of the results. New needs and requirements in a global development world are reasons for this approach.

2. The Impact of using matrices.

2.1 Time consuming?

Using QFD for a product with 5 Customer Requirements (CR) and 5 Technical Requirements (CTQ) gives a feasible Matrix 5 x 5 = 25. But there is no need to use QFD for this simple product.

E.g. in areas of high-end home appliances or medical healthcare equipments, these products have several hundred of requirements and technical features. It is, of course, impossible to handle these large matrices. It was the impact of the Kano-Chart, which allows an effective filter, to reduce the number of requirements, and in connection the number of CTQ's. The filter is very simple and easy to use:

Only these Requirements are listed for QFD:

They are:	They are not:
1. **New** and	1. Already implemented
2. **Important** for Customers and	2. Basic requirements
3. **Difficult** for R&D	3. R&D says: "Easy…"

In most cases, it reduces the number of items between 30 to 80.

This gives still large matrices and would likely kill the QFD session. The solution is in separating the global group into "sub-groups" of 3 people, each of the subgroup is handling a part of the matrix. Only the outcome will be discussed at the end within the total group. ("Reading the Matrix, Sanity check"). E.g. given 50 CR and 25 CTQ's and the total group of 15 People, gives 250 relationship numbers for one subgroup.

The main reasons for extensive discussions in this timeframe are caused by the unanswered meanings and understandings regarding customer requirements, which was skipped at the beginning of the QFD. And remember: It takes us 3 to 5 years to develop these products, we should be able to find 2 – 4 days in this period….

2.2 The "positive" and "negative" relationships

In the past, we asked only, if there is any relationship between a specific customer Requirement and a Technical Feature. If yes, we tried to rate, how much, with values 9, 3, 1.

The value of this information for the R&D was too simply, because it was not a new expert knowledge.

Adding the figures or calculating the product of a matrix by a scalar was an misleading result.

The new approach (which was not a total new one) was the appearance of TQM (Total Quality Management) with the request, to add the Improvement Direction (or: Optimization direction)

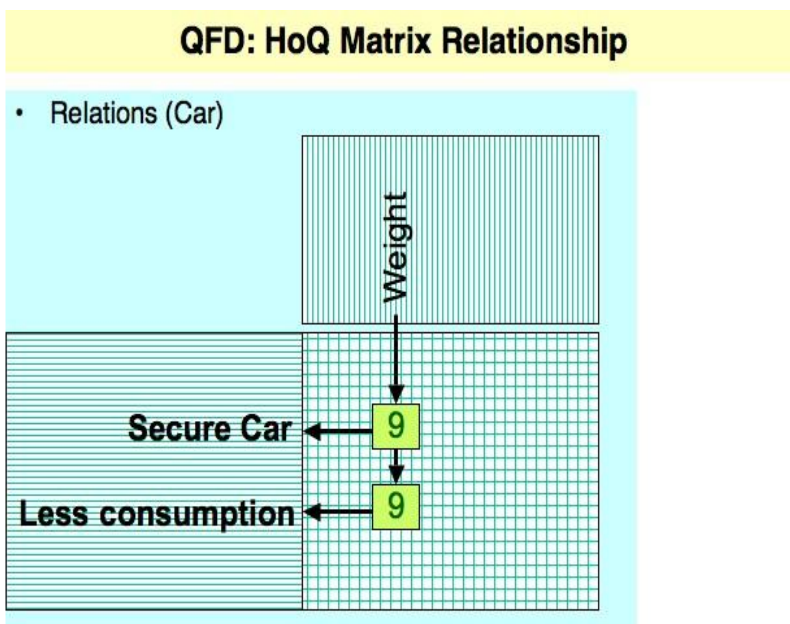


Figure 1: Simplified relations

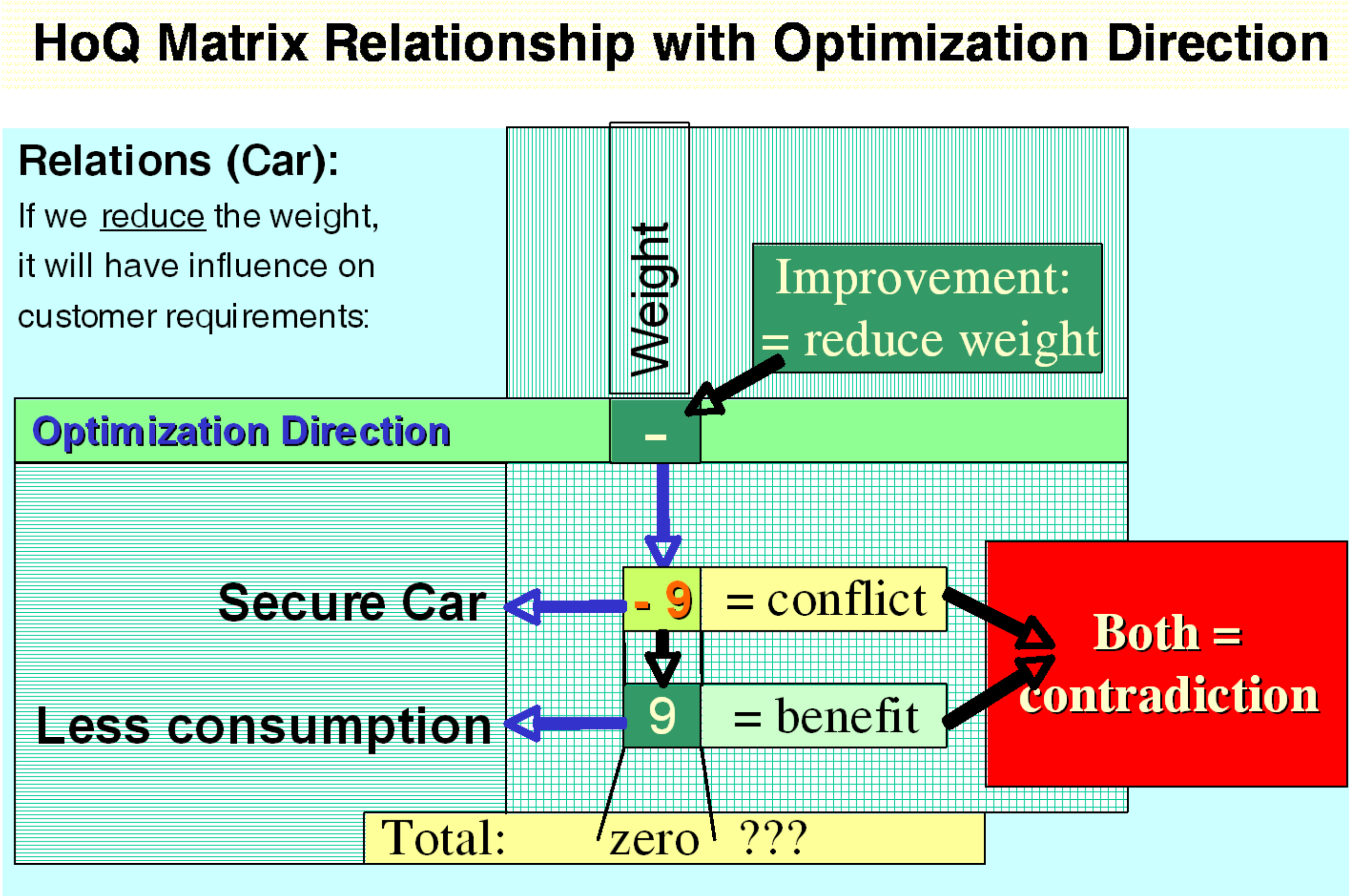


Figure 2: Relations with optimization direction

There are now three questions to evaluate the relationship values:

1. Are there any relationship between a specific customer Requirement and a Technical Feature?
2. If yes, how much (1,3,9)?
3. If we improve the technical requirement because of customer request:
    a. Will it be a benefit for the customer (positive)?
    b. Or will it be a conflict in the view of the customer (negative)?

Remark: The summary of the technical Feature (e.g. scalar product, Tensor) must be separated in a positive and negative result. To combine both together (e.g. positive = 50, negative = -50, Result = 0) is useless and misleading.

2.3 The correlation-Matrix ("Roof of the House of Quality")

Technical features are always more or less strong correlated among one another. The analysis gives two interesting results:

1. This one Technical feature has influence to all other Technical Features; measured by the correlation matrix.
2. All technical Features together have influence to this one Technical Feature; measured by the multiple correlation coefficients

It is obvious, the optimization direction has an important influence within the correlation matrix.

Considering the optimization direction together in the relation-matrix and the correlation-matrix, it gives a total new picture and is difficult to evaluate. But it answers the question: what happens, if we improve a product in the view of the customers' requests.

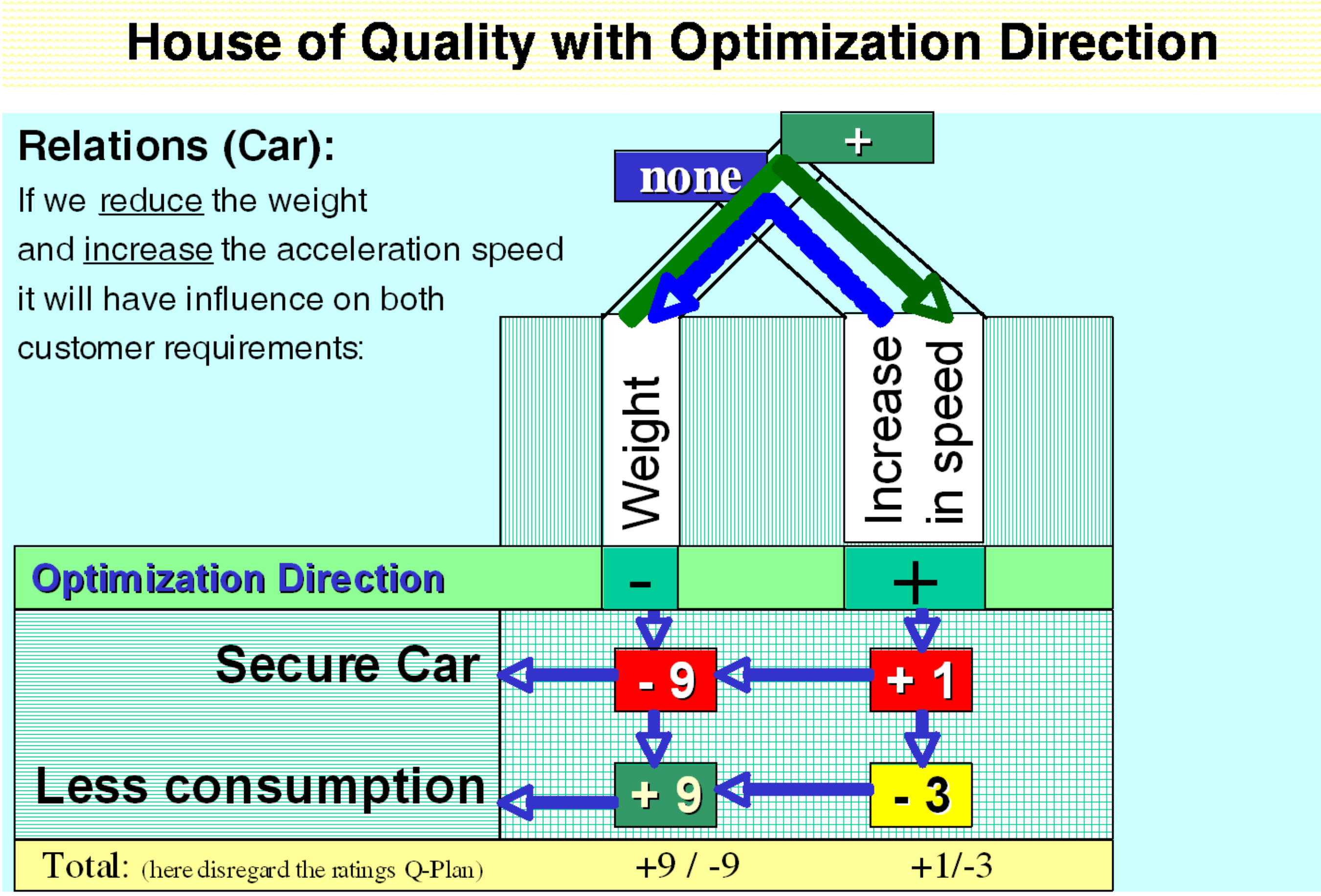


Figure 3: House of Quality with optimization direction

2.4 The House of Quality with optimization direction

To solve the negative influences is not an easy task:

- To leave just one strong negative relation, this could become a "killing item", which prevents the customer to buy or to recommend the whole product.
- To change the optimization direction only moves the conflict from one relation to the other(s)
- To compromise is always a way out to prevent new solutions.
- To skip the Customer Requirement, which "causes" the conflict, means, we just "skip" the customer. Nevertheless, it is one of the most misappropriated solutions. (Motto: The customer is always the central point in our business, that the reason, why he always stands in our way….)

In all the QFD Sessions, we run in the last years, there was none one without negative relations in the matrix. Changing Parameters have always a positive and negative impact. This is also valid for changing parameters in the direction of improvement.

In the meantime, R&D (not the Marketing or Sales teams) is looking more than ever to find these conflicts from the very first as to look after the positive numbers. But these dependencies could only be detected, analyzed and justified by using a matrix. A single, linear deployment of just one Customer Requirement will not ensure the faultfinding's.

2.5 Detecting "Killing Items"

We all know the exemplary cases, where single faults cause extreme cost and reputation. E.g. the product recalls in the automotive industry. In practice, there are few negative relations, especially if only enhancements of a product are requested. But it needs the QFD-House of Quality to detect these single "killing items", showcased in the picture below.

Case 1: It is apparently a negative relationship; the increase of speed of the shutter will cause an increasing noise. In practice, very often these basic contradictions are overseen. But to know these contradictions at the beginning of the product development is essential, because in most cases technical solutions could be found at this stage.

Case 2: More difficult are hidden contradictions. The Customer requires the turn down of the shutter, not only if a bright sunshine is detected, also if a high temperature is measured. But in this case, also a fire inside of a house will close the shutter and prevent the fire fighters to enter the rooms. This single feature - "killing item" -would definitely produce a recall or stop the sales.

Also in products, which are well known in all aspects of development, simple changes causes contradictions, even though the quantity is in general not high. Also Teams, adept very well in QFD, need the QFD Matrices to detect them. It is the human behavior, that you will get after the detection of killing items comments like: "….if anybody has asked me before…"

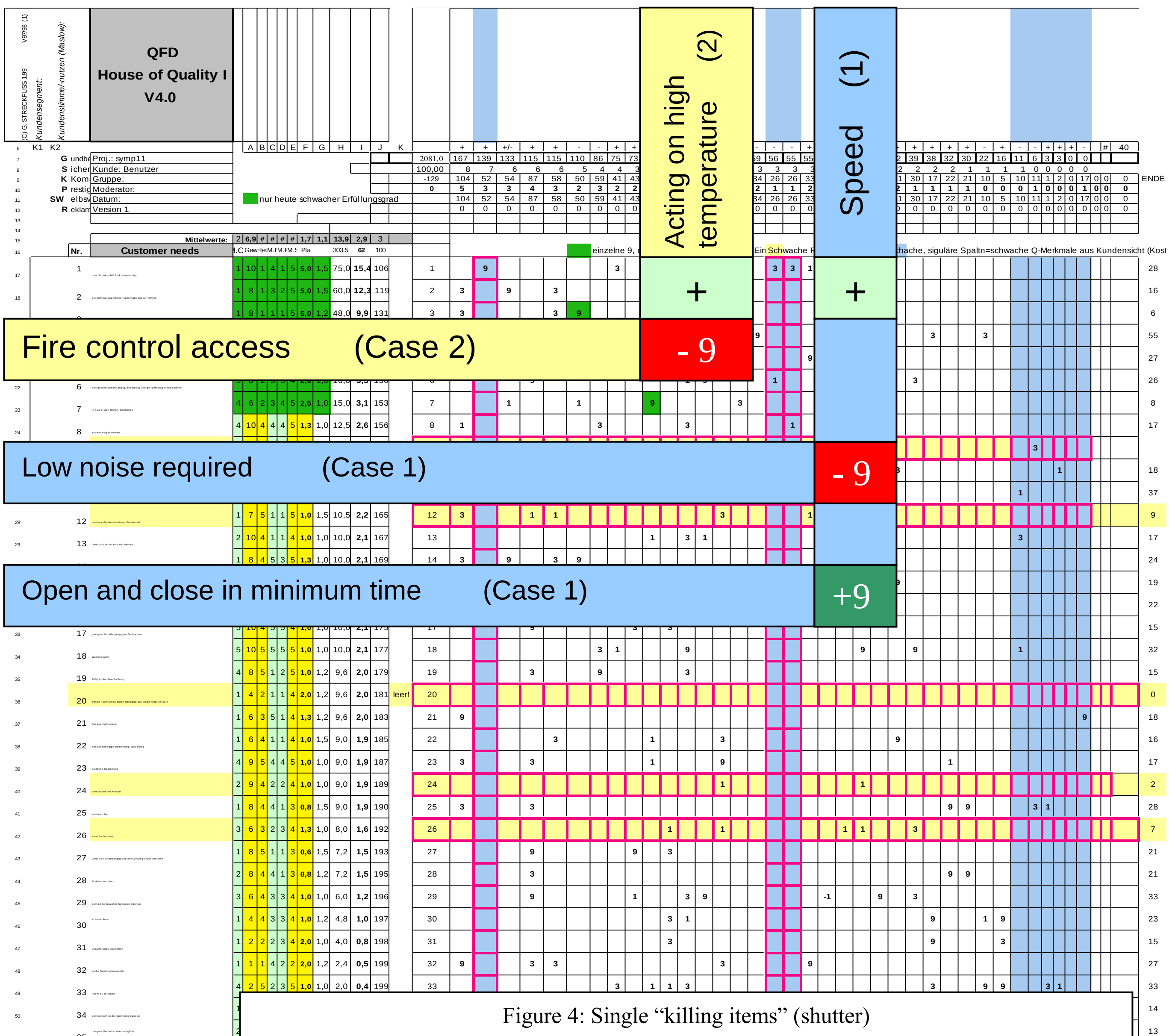


Figure 4: Single "killing items" (shutter)

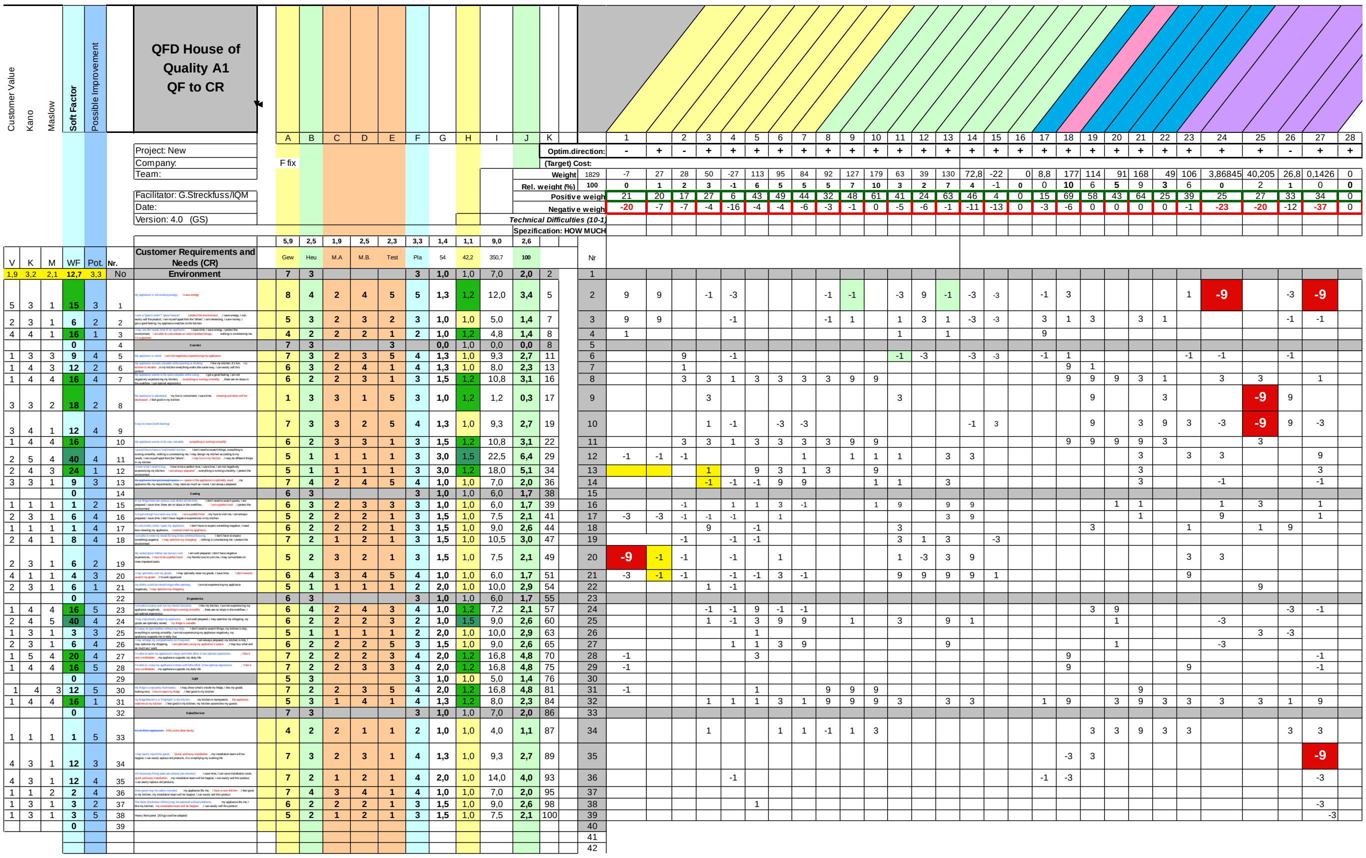
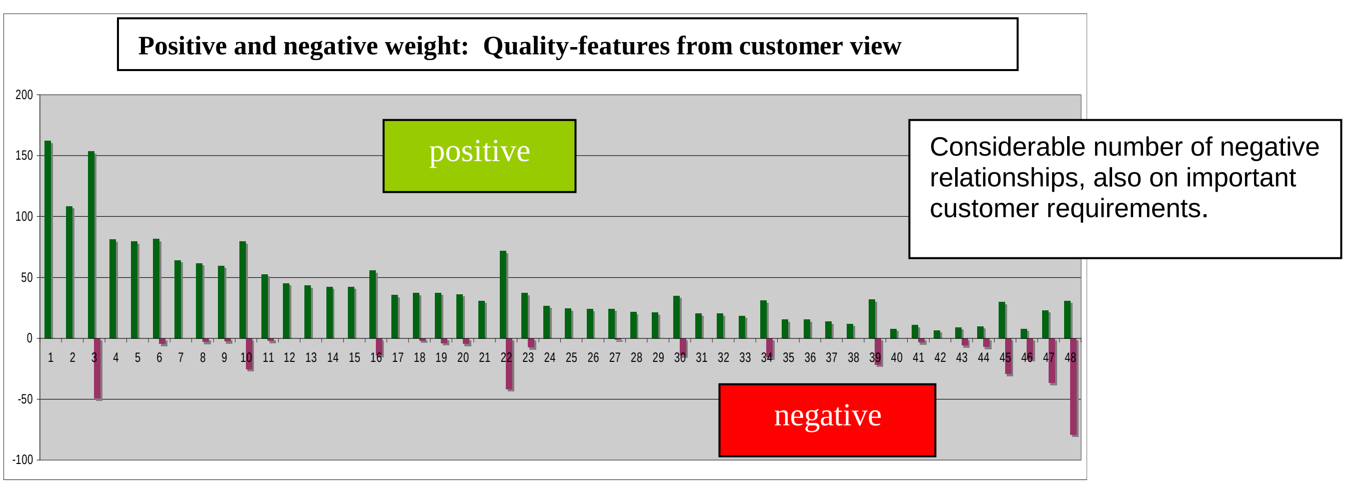
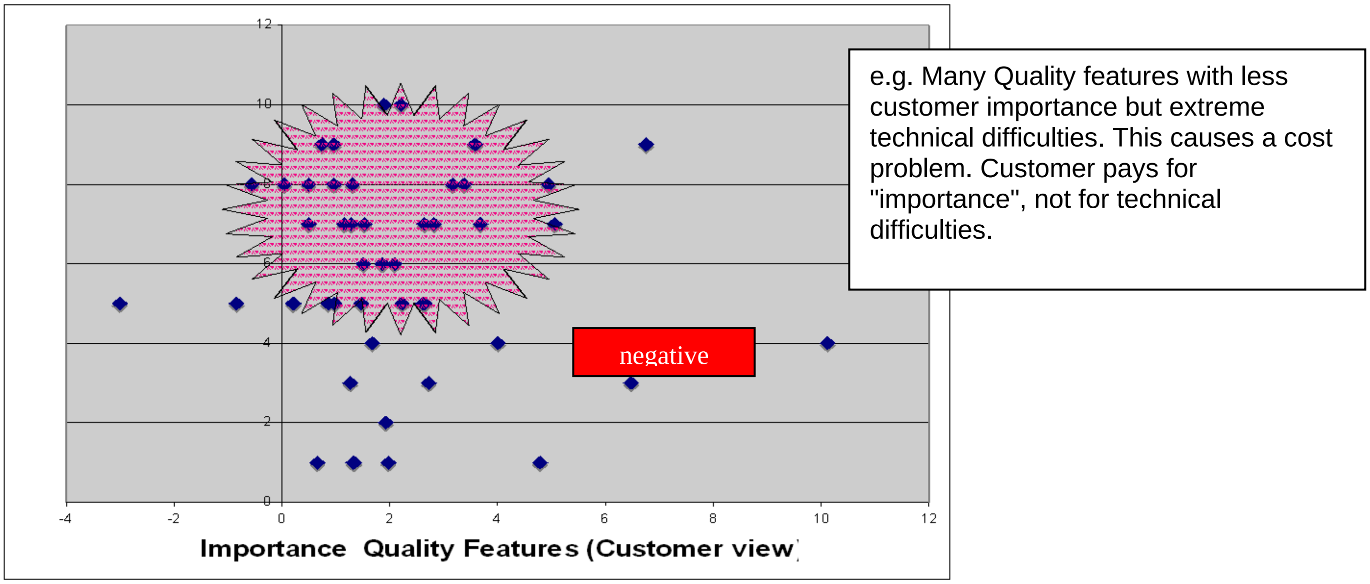


Figure 5: "Only" six contradictions in a product improvement, but likely killing the product.

To find out the various relationships between Customer Requirements and Features respectively Functions and the correlations between the Features (Quality Features, CTQ's) are important on new, innovated products. In an extreme situation, the result of a QFD could lead to a stop of these developments. The following charts are demonstrating the various QFD results of an new inventive product development, which was after the QFD sessions reappraised as too difficult to continue without making major changes.

2.5.1 Results of a relationship matrix





Figures 6: Results of the relationship matrix (new innovative product)

2.5.2 Results of the correlation matrix ("roof")

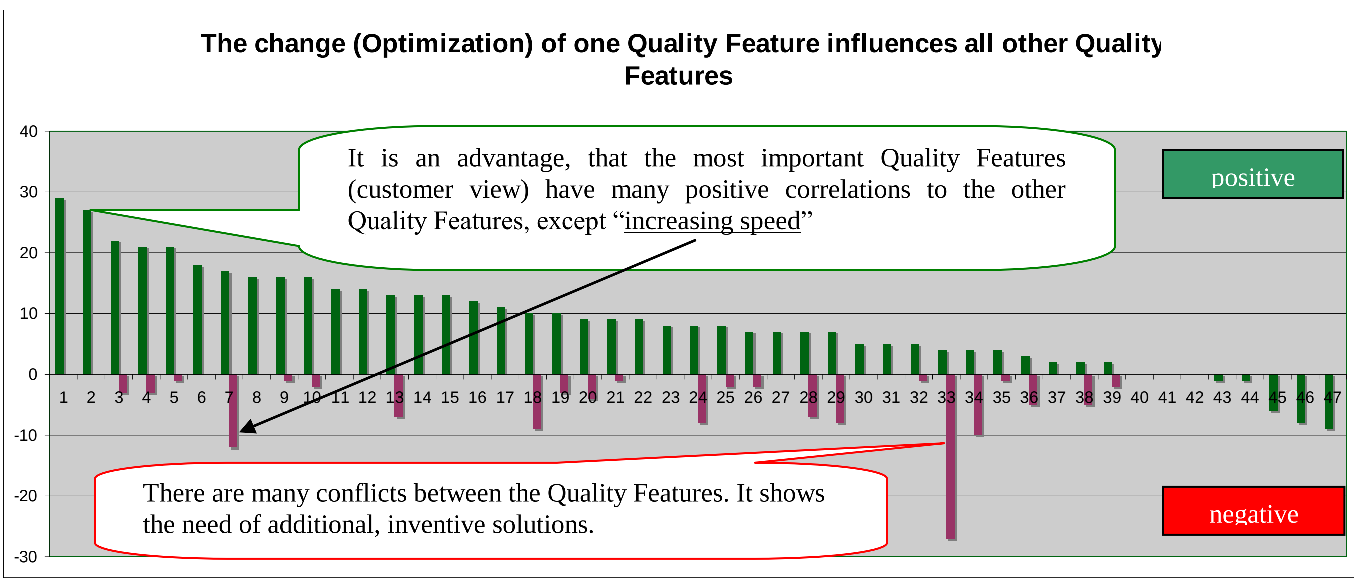
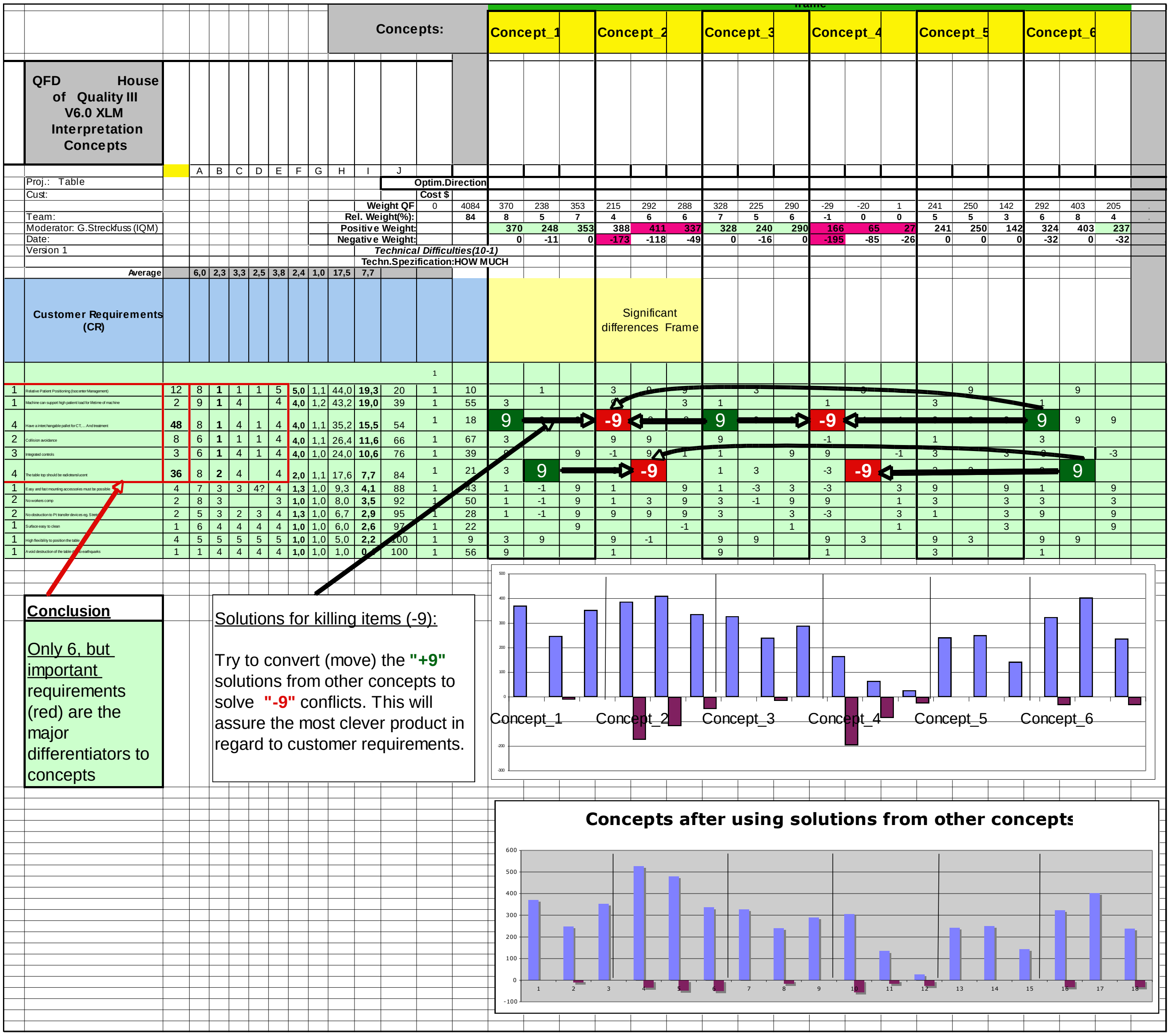


Figure 7: Results of the "roof" of the House of Quality (new innovative product):

2.6 QFD Matrices in concept selections



2.7 QFD and TRIZ

QFD was originally not qualified to generate inventive solutions; the focus was on the deployment of customer requirements. TRIZ on the other hand concentrates on finding new ideas to solve contradictions.

Only new, innovative solutions can solve these contradictions. This was one of the reasons, why TRIZ was successful adapted in the QFD community. TRIZ asks for an “input” of conflicts and contradictions and promises to support the findings of inventive solutions by using a systematic workflow. QFD Matrices deliver this input.

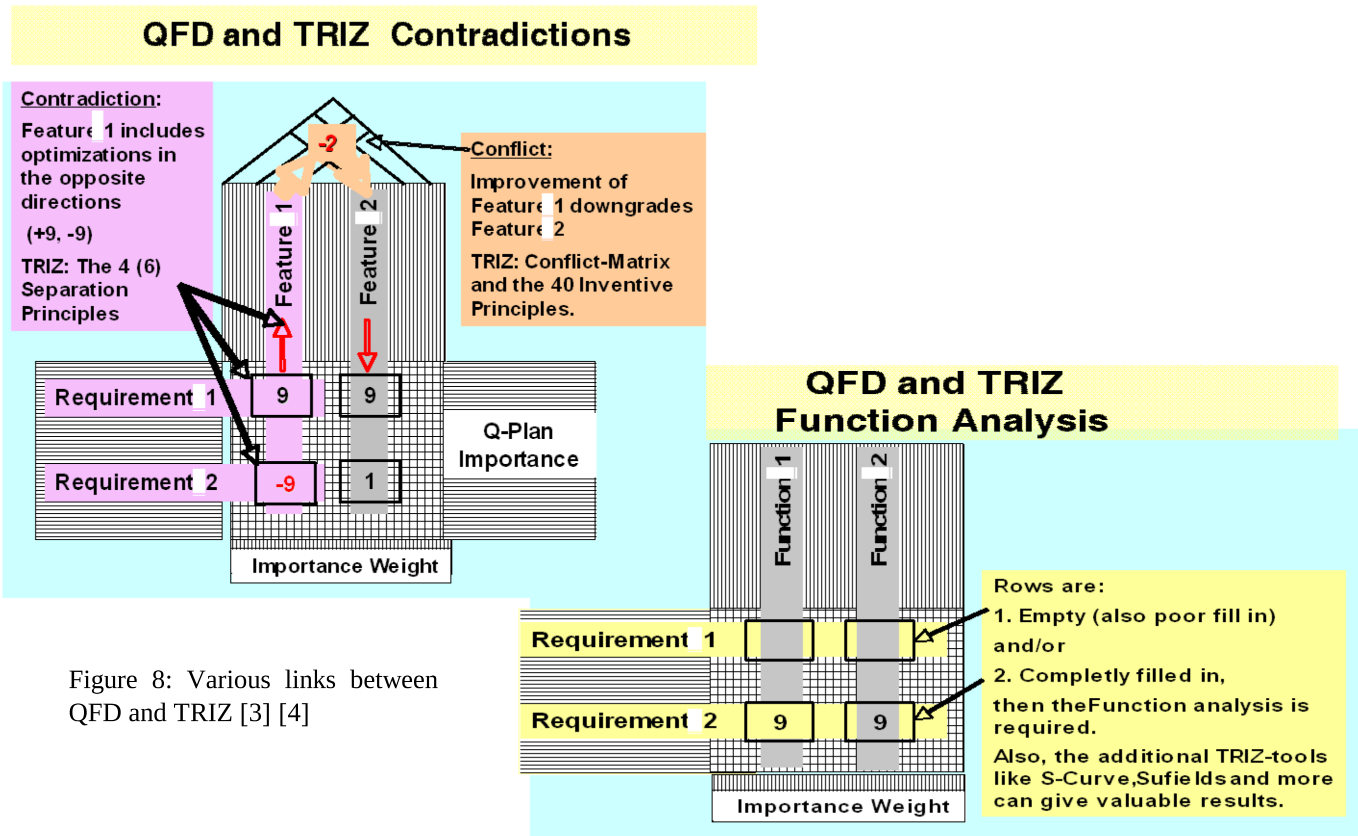


Figure 8: Various links between QFD and TRIZ [3] [4]

2.7.1 Analyzing TRIZ results

TRIZ has 3 Levels of contradictions (Altshuller) . [4]:

Level 1: Administrative, e.g. between needs and solutions

Level 2: Conflicts (“technical contradiction”), inverse correlation between technical features.

Level 3: Contradictions (“physical contradiction”), contradictory optimization direction of one requirement.

Altshuller has proven the fact, that Conflicts (Level 2) are derived from Contradictions (Level 3). This implies, that the inventive solution is embedded in contradictions.

Considering these arguments, it demonstrates the contrary way of the common way of engineering: We try to solve the conflicts between technical features first (Level 2), and than, we discuss the impact on customer needs.

But it is the customer(!), who gives us the level 3 contradictions! It is the customer, who requires inventive ideas.

2.7.2 TRIZ tools in the QFD process

The method TRIZ includes numerous tools, which are very different in regard of effort, knowledge and cases of application. If conflicts between technical features are relevant to customer requirements, than the first step is using the conflict Matrix with the attached inventive principles (Altshuller, Matrix 2003). Also, this matrix is debatable among the TRIZ-Guru's, it is our experience that the matrix is able to deliver on the spot the first signs of new ideas, which are worth to follow up.

To solve the contradiction of one technical feature (Customer request low weight because of… and high weight because of…) is not an easy task. TRIZ recommends using the 4 (or 6) principles in separation (in time, in space, in parts/whole, in conditions). Practical experience realized in these cases also the need for additional TRIZ tools to address inventive solutions. Common tools are here the Function Analysis, the Su-Field Analysis and the Anticipating Fault Determination)

3. The QFD-Q-Plan and the Mahalanobis-Distance

To manage customer requirements (CR) in the QFD Process is still a never-ending story. Also QFD is in charge to deploy CR in the various R&D and Engineering processes, it still requires, to ensure the quality of CR. Wrong input in QFD guarantees well structured and expensive, but still wrong output.

Based on the Q-Plan structure, published in Akaos QFD book (1988/1992), QFD teams used these templates to analyze CR. The row "importance" was availed oneself of an opportunity to discuss the meaning and understanding of CR than for rating issues. The row "Current Status " is one of the aching tasks, because it is often the result of: "We already fulfill these requirements".

Today, nearly all companies using regularly QFD modified and improved the Q-Plan to address their specific needs. They added additional rows, common are "Value for the customer", "Kano" and "Needs based on Maslow's Theory". These different rows allow us, to discuss and rate the CR under different perspectives.

	Value	Kano	Maslow	WF=V+K+M	Potential	"Sanity Check" of the QFD Q-Plan Matrix (extract)											
avr.	2,3	3,7	2,3			Remark: the text and the figures are slightly modified compared to original input	6,6	2,2	2,0	2,6	2,8	3,6	1,9	1,1	13,1	4,1	
	V	K	M	WF	P	Customer Requirements and Needs	Imp	Cur.	M.A	M.B.	Tes	Pla		13,3	157,5	50	
	2	5	4	11	4	I like to have a "multimedia" environment	4	1	1	1	1	3	3,0	1,5	18,0	5,7	6
	2	4	3	9	1	I know what I need to buy	5	1	4	5	5	3	3,0	1,2	18,0	5,7	11
	1,0	5	4	10	4	To open and closing the cover with little effort, it has optimal ergonomics	8	2	2	2	3	4	2,0	1,2	19,2	6,1	17
	1,0	4	3	8	5	The enviroment is enjoyably illuminated	9	2	2	3	5	4	2,0	1,0	18,0	5,7	23
	4	2	1	7	4	All necessary fixing parts are already set-up	7	2	1	2	1	4	2,0	1,0	14,0	4,4	28
	5	3	1	9	3	The environment is not wasting energy, I save energy	8	4	2	4	5	5	1,3	1,2	12,0	3,8	31
	1,0	4	4	9		The environment seems to be very valuable	7	2	3	3	1	3	1,5	1,2	12,6	4,0	35
	2	4	1	7	4	To store my food for long times whithout freezing	6	2	1	2	1	3	1,5	1,0	9,0	2,8	38
	2	3	1	6	1	The drinks could be stored longer after opening	5	1	1	1	1	2	2,0	1,0	10,0	3,2	41
	1,0	3	3	7	4	The enviroment is silent, the sound is pleasant	9	3	2	3	5	4	1,3	1,0	12,0	3,8	45
	3	4	1	8	4	I want to see a selfcleaning enviroment	7	3	3	2	5	4	1,3	1,0	9,3	2,9	48
	4	3	1	8	3	I may easily mount the cover	4	3	2	3	1	4	1,3	1,0	5,3	1,7	50

5 = high, 1= low

(red) no customer value, means: Customer will not spend any money for it.

(green) High value, but no excitement, no prestige issue?

(red) Question: why is this importance high rated, if Value is low?

(green) Question: why is importance low rated, if WF is high? and there is challenge for improvement

(yellow) Question: why is this importance low rated, if competition is high rated?

(blue) Question: hight rated, also current status OK'

Figure 9: Extended QFD Q-Plan Matrix

This gives us a picture of a matrix (pattern), which could be analyzed. The focus is more on identifying the discrepancy between the different values and not to calculate detailed numbers. Our first Goal is to understand and accept the customer requirements.

3.1 The Mahalanobis Distance

But the research of various examples demonstrated very clear, that the pattern in the QFD-Q-Plan are NOT independent, there are correlations between these values. We used the Mahalanobis Metric to verify the differences.

In statistics, **Mahalanobis distance** is a distance measure introduced by P. C. Mahalanobis in 1936. It is based on correlations between variables by which different patterns can be identified and analyzed. It is a useful way of determining similarity of an unknown sample set to a known one. It differs from Euclidean distance in that it takes into account the correlations of the data set and is scale-invariant. In other words, it is a multivariate effect size….

Mahalanobis distance is widely used in cluster analysis and classification techniques. It is closely related to Hotelling's T-square distribution used for multivariate statistical testing and Fisher's Linear Discriminant Analysis that is used for supervised classification.

Definition [edit]

Formally, the Mahalanobis distance of a multivariate vector $x = (x_1, x_2, x_3, \dots, x_N)^T$ from a group of values with mean $\mu = (\mu_1, \mu_2, \mu_3, \dots, \mu_N)^T$ and covariance matrix S is defined as:

$$D_M(x) = \sqrt{(x-\mu)^T S^{-1} (x-\mu)}.^{[2]}$$

Mahalanobis distance (or "generalized squared interpoint distance" for its squared value[3]) can also be defined as a dissimilarity measure between two random vectors $\vec{x}$ and $\vec{y}$ of the same distribution with the covariance matrix S :

$$d(\vec{x}, \vec{y}) = \sqrt{(\vec{x}-\vec{y})^T S^{-1} (\vec{x}-\vec{y})}.$$

If the covariance matrix is the identity matrix, the Mahalanobis distance reduces to the Euclidean distance. If the covariance matrix is diagonal, then the resulting distance measure is called the *normalized Euclidean distance*:

$$d(\vec{x}, \vec{y}) = \sqrt{\sum_{i=1}^{N} \frac{(x_i - y_i)^2}{\sigma_i^2}},$$

where σ_i is the standard deviation of the x_i over the sample set..

Source and more information's in: Wikipedia.org

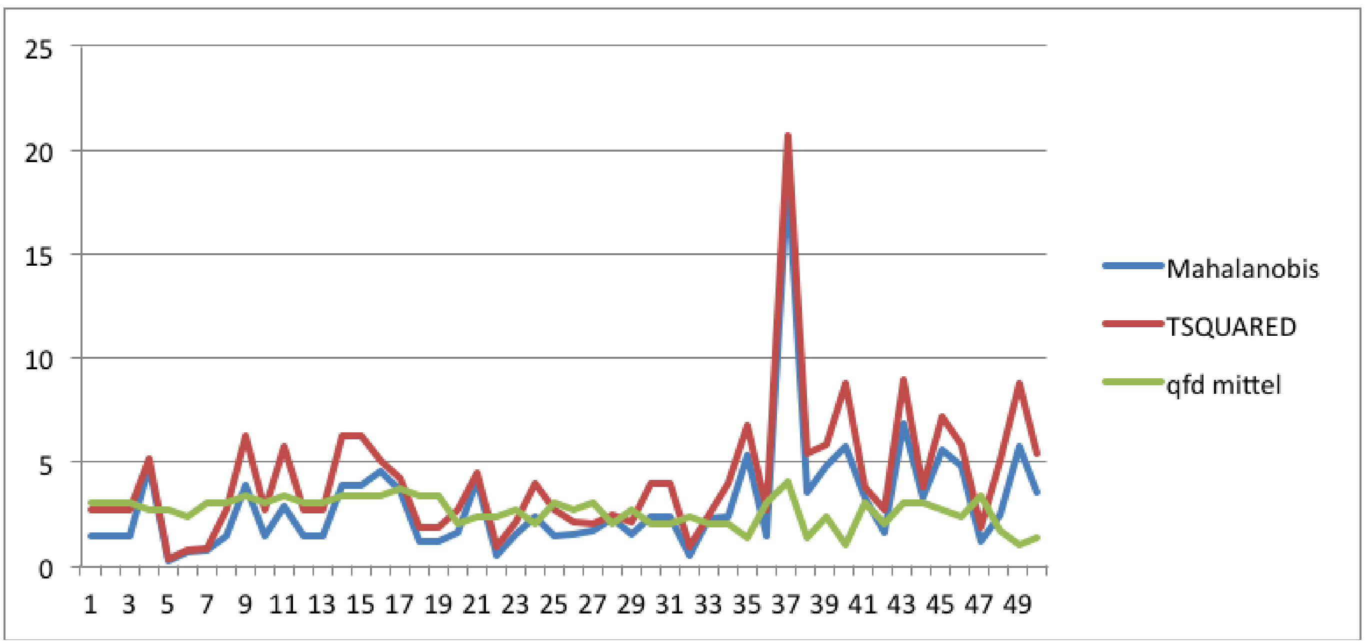


Figure 10: Different results using Linear Ratio, T-square and Mahalanobis

The chart above shows the different results, using QFD linear ratio, Statistic Hotellings (T-square) and the Mahalanobis Distance. Mahalanobis and Hotelling are very close in regard to the results, but the QFD linear average values are considerable different.

The different results are caused by the fact, that the figures: "Value (V)", "Kano(K)", "Maslow(M)" are NOT independent. The Correlation-Matrix shows, that between "Kano" and "Maslow", it exist a high rated positive correlation. But "Value" has no correlation to "Kano" and even a negative correlation to "Maslow".

Correlationmatrix

	V	K	M
V	1.000	0.052	-0.208
K	0.052	1.000	0.467
M	-0.208	0.467	1.000

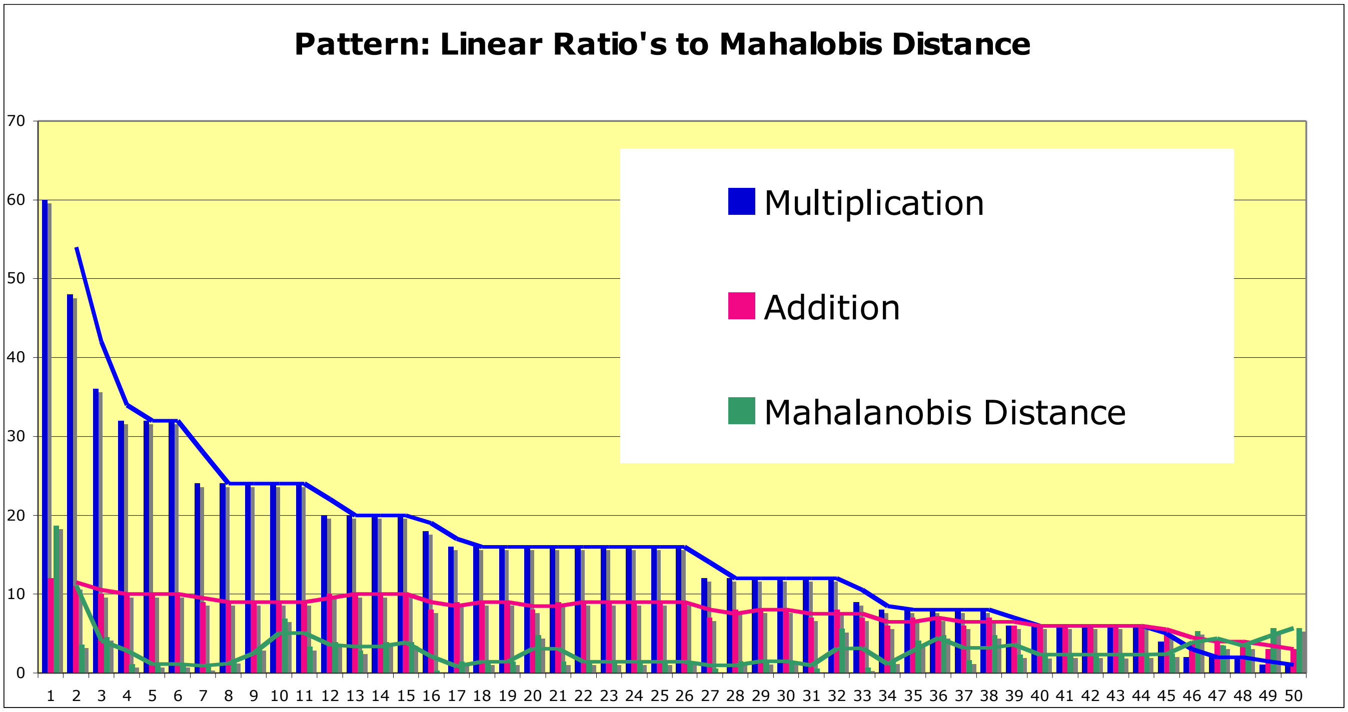


Figure 11: QFD-Q-Plan Pattern: Findings from the comparison

The addition of numbers is more close to the Mahalanobis distance compared to the multiplication.

The conclusion today is:

- The patterns in the QFD-Q-Plan are not independent.
- To multiply the numbers as a final result is critical.

But further research is required, to underline this predication and to understand the different results in practice.

4. Summary

1. Product development faces increasing demands on management and employees to fulfill different challenges:
   - Customers are today more critical in demanding fulfillment of their specific requirements.
   - Marketing must be positioned in a global world; product development is today a global task.
   - The number of CR's and CTQ's are growing because of the increasing complexity of products.
   - Very few faults and/or misunderstanding regarding customer needs could lead to unforeseeable major problems.
2. Product development is confronted with numerous multi-dependences.
   - It requires more multivariate methods, adapted to the needs of QFD.

3. QFD has to address these challenges to remain sustainable:
   - We accept, it is the Customer who gives us the input in QFD as a human being and not as linear equation.
   - Therefore, it is more important to understand and accept the customer needs as to use intransparent math methods.
4. The House of Quality with the different tables, pattern and matrices is the link between understanding customer needs and point out the various dependencies.
5. R&D is more looking to find conflicts and contradictions in the early stage of development. This saves time and money.
   - In QFD, only the relationships and correlations in matrices are capable to do this.
6. Because of the increasing complexity of the today products, it is necessary to find ways to handle large matrices.
   - Matrices are images, illustrating the "Quality" of a product in the view of a customer. Therefore, we should more read these images and as to calculate the figures.
7. Last, but not the least, Marketing and R&D are the customer of QFD. Therefore, QFD has to fulfill their requirements (and not reverse) to guarantee its sustainable future.

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Monika Thiess is Senior Project Manager, responsible for global R&D projects at Gaggenau Industrie in Lipsheim near Strasbourg/France. Since 1999, she is also responsible for the introduction of Quality methods in product development, process optimization, standardization, R&D processes, also qualified as DGQ- and internal auditor. Since 2007, Monika Thiess is certified as QFD Moderator and since 2009 Certified QFD Architect according to the QFD-Institute Germany e. V.

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Some of the books with applications are:
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