Failure Avoidance and Robust Design: Quality Tools in Market Research.

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Total quality management has influenced both the manufacturing and service industries. Within the service sector, application of quality principles to market research has been largely limited to the administration of the survey process, data processing and analysis. In this paper we attempt to redress this situation by focusing on the application of two quality methods, Failure Avoidance and Robust Design, to a crucial area of market research, namely problem definition. Both these methods have been successfully employed to improve quality in manufacturing industries throughout the world. The relevance of these methods to market research is illustrated in the context of a survey of attitudes towards cheese and cheese suppliers in the food service market.

Keywords: market research, failure avoidance, robust design, orthogonal arrays, fault tree

Introduction

Many market research organisations are involved in the introduction of TQM systems such as BS5750 and ISO9000. But there is concern that such systems will do little to improve the quality of the critical aspects of the market research process. Smith & Dexter (1994) argue that it is only the tangible (hygiene) factors, such as sampling and fieldwork, which can be improved as a result of these systems. The quality drivers which distinguish exceptional research, namely problem definition, research design and interpretation are not covered by these systems. In this paper it is suggested that the improvement of problem definition can be assisted by employing the principles of Failure Avoidance (CEO Sciences Lc) and Robust Design (Taguchi 1986).

Failure Avoidance and Robust Design

Failure Avoidance (FA) is a methodology which has grown out of a technique called Fault Tree Analysis, which was conceived in 1961 by H AWatson of the Bell Laboratories to evaluate the safety of an ICBM launch control system. Fault Tree Analysis has been defined by Witkin (1977) as an operations research technique used to analyse the most probable modes of failure in a system, in order to redesign or monitor the system more closely in order to increase its likelihood of success. The other major influences in the development of the FA technology have come from areas such as needs assessment, reliability engineering, system safety and fail-safe technology. Failure Avoidance (FA) can be defined as a decision support technology based on the concept that success in human endeavours can be increased by identifying, analysing and prioritising the most likely conditions for failure. This procedure aims to identify actual and potential failure events (problems), their causes in logically related cause and effect sequences, and their priorities in terms of solution urgency.

Failure Avoidance (FA) involves the following steps. Problems are identified and recorded in the form of a tree diagram. The highest twigs of the tree are regarded as the root or basic problems. The branches from which the highest twigs emanate represent the problems caused by the root problems. The thicker branches lower down represent problems caused by the problems further up the tree. The severity of each problem is assessed, allowing the identification of critical problem paths all the way up the tree and the assignation of problem priorities for each problem.

Robust Design (RD) also focuses on failure, but failure as it relates to poor quality. This procedure aims to design products which are less likely to fail. In other words, RD can be used to eliminate the problems identified by FA. However, in this paper we take a slightly different tack in that we consider RD as a tool for improving the quality of the information produced by FA, in particular, the quality of the problem priorities provided by FA.

Three key RD concepts are examined in this paper; orthogonal arrays, inner and outer arrays, and signal-to-noise ratios. These concepts have been discussed in depth in the RD literature (see Taguchi 1986; Phadke 1989; Nair 1992). Orthogonal arrays are an efficient method for evaluating several factors simultaneously, and in industry they are used to design cost-effective experiments. In such experiments optimum levels for several factors are determined in a single economical design. For example, an orthogonal array can be used to design a single experiment which allows the comparison of three different operating temperatures, two different pressure settings and two different mixtures for some industrial process. Each point of the orthogonal array matrix has a level specified for temperature, pressure and mixture. The best levels for temperature, pressure and mixture can be established by comparing the result (performance) of the industrial process at each of these points. These designs are economical in that statistical validity can be maintained without testing of all the factor level combinations. Thus, in the above example, it would not be necessary to test all 12 different factor combinations. An orthogonal array which considers only 6 of the possible 12 factor combinations would be sufficient. When many factors are to be evaluated, this is a very useful consideration.

Inner and outer arrays are used to monitor the effect of environmental variability on performance. The inner array refers to the matrix of factor levels for those factors which can be controlled, such as the temperature, pressure and mixture variables considered above. The outer array controls the environmental factors, artificially allowing the monitoring of their effect in an experimental situation. Taguchi's (1986) philosophy is to choose the levels of the controllable factors in such a way as to minimise the uncertainty caused by environmental factors. For example, ambient temperature and humidity may cause variation in the results produced by the industrial process described above. The inner array consists of a matrix (orthogonal array) of the temperature, pressure and mixture levels, while the outer array consists of a matrix of ambient temperature and humidity levels. At each point in the inner array matrix, the outer array matrix is repeated. This means that the levels of the controllable variables can be compared in terms of consistency in the face of environmental variation as well as mean performance.

Signal-to-noise ratios are used to perform this comparison. They permit the points of the inner array to be compared while penalising those points associated with high environmental (outer array) uncertainty. The penalty for high uncertainty (variability) makes such points less likely to be regarded as optimum. Instead of considering only the mean result (e.g., efficiency) for each point of the inner array matrix, a signal-to-noise ratio also takes outer array variability into consideration. The optimum setting for the control (inner array) variables is that with the best mean and the lowest uncertainty. The signal-to-noise ratio combines the means and their associated uncertainty, providing a compromise measure for these two goals.

Both Failure Avoidance (FA) and Robust Design (RD) share a common perspective. They acknowledge that to achieve successful results control must be exercised over those factors which degrade the prospect of success. The focus is on weakening failure factors rather than strengthening success factors. Some subjective but persuasive explanations for the apparent success of this approach in practice are presented below (Stephens 1974).

- In determining methods for combating failure, formulae for success are often inadvertently developed.
- Success factors are usually already in place because they are integral and essential to operations. They customarily receive ongoing managerial attention.
- The potential of failure factors to totally debilitate a mission statement is often left unrecognised.
- Strengthening success factors is often a more expensive operation than weakening failure factors.
- Success prescriptions encourage conformity whereas trying to solve problems stimulates initiative and creativity.

Each failure factor is specific and can be considered in isolation. Such factors are easier to research than the often more general success factors and it is easier to obtain consensus on how to handle such specific factors.

Both the FA and RD methodologies also share a common environmental emphasis. One branch of every fault tree should be reserved for problems which emanate in the (external) environment. In RD, decisions are evaluated in terms of product reliability and robustness in an uncertain environment. These uncertainties can cause products to fail in the real world.

In the context of the popular strategic management tool SWOT (strengths - weaknesses - opportunities - threats), FA can be seen as a diagnostic tool for detecting weaknesses and threats, whereas RD can be seen as a vehicle for transforming weaknesses into strengths and threats into opportunities. As suggested by Figure 1, FA and RD bring rigour to an area of desired creative brainstorming, permitting lateral consideration of influential factors. The arrow pointing from Robust Design to Failure Avoidance illustrates the use of RD as an efficient supplier of reliable problem priority information to FA. This is the RD use which is emphasised in this paper.

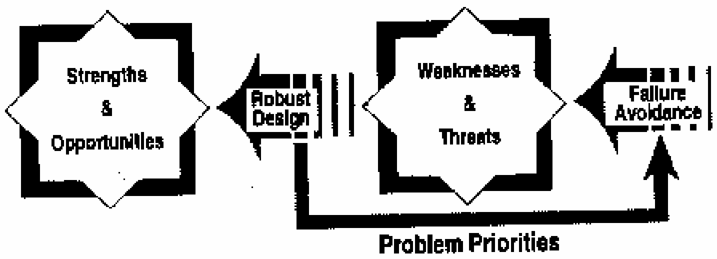

Figure 1. Failure Avoidance and Robust Design in the context of a SWOT analysis

Failure Avoidance and Robust Design in Market Research

Market Research is a platform for determining who one's customers are and what they want. In other words, market research is a method for hearing the voice of the consumer (Hauser & Griffin 1993). Quality control systems in the areas of sampling and fieldwork are well - established in the market research industry, but quality control in the more vital areas, such as problem definition, research design and interpretation is more difficult. It is in the area of problem definition that FA and RD can make a constructive contribution to quality control.

Smith & Dexter (1994) have developed two frameworks which can be used to structure quality improvement work as it relates to market research. In reference to problem definition. Smith and Dexter stress "creativity and lateral thought". By focusing on weaknesses rather than strengths, threats rather than opportunities, FA and RD stimulate creativity and lateral thought processes. There is also mention of "working within an analytical framework", which will help an understanding of the problem. The fault trees of FA and the orthogonal, inner and outer arrays of RD offer such a framework. In addition, Smith and Dexter refer to a "prioritising" stage in which a priority order for addressing research objectives is defined. FA's problem priorities, which we will define using RD’s signal-to-noise ratios, address this requirement. This suggests that FA and RD are appropriate tools for improving the quality of the problem definition stage of market research. The actual application of these methods in this context is best illustrated using a case study. Figure 2 summarises the various steps in this procedure.

Case Study

Cheese in the Food Service Market

A survey is to be conducted in order to assess attitudes to cheese and to cheese suppliers in the Food Service Market. This market includes restaurants and fast food outlets. The objective is to determine the problems which are inhibiting the consumption of cheese in the food service market. FA and RD are to be used to improve the quality of the problem definition stage of this research.

Focus Groups

RD Objective: Harness a broad environmental focus
FA Objective: Construct a problem tree

Two focus groups are set up, one for each of the two types of organisation, restaurants and fast food outlets. Participants are chosen carefully so as to ensure a wide coverage of experience and background. The groups are required to identify the negative factors which they encounter in their dealings with cheese. The facilitator produces a list of complaints and their causes which can be recorded in tree form. A second meeting of the focus groups is called to check and discuss the complaint or problem trees. The relationships between the problems are understood from the branching of the tree diagram. A simplified version of such a tree appears in Figure 3.

Figure 3 illustrates the form of a hypothetical tree for the problems being experienced with cheese in the food service market. For simplicity, only two levels of branching are considered. The problems associated with the quality of the cheese are related to packaging and to shelf life, while the problems associated with supply are related to availability and range and delivery.

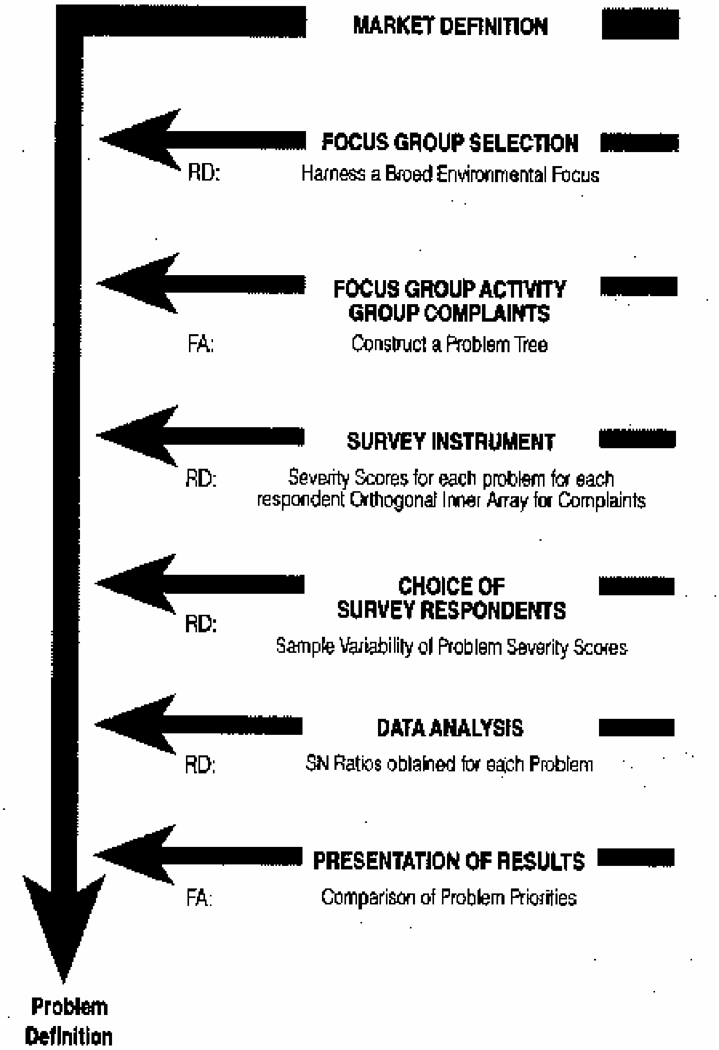

Figure 2. Failure Avoidance and Robust Design for problem definition in market research

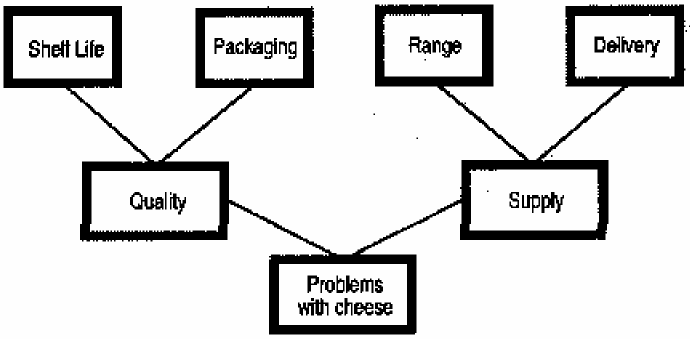

Figure 3. A hypothetical Complaint Tree for cheese in the food industry

Survey Instrument

RD Objective: Assess the severity of each problem.

Next, the survey instrument is designed. Each complaint which was listed by the focus groups is considered. A severity ranking is achieved for each complaint using conjoint analysis (Hair, Anderson, Ronald & Black 1995).

It is assumed that cheese consumption is inhibited by the existence of a combination of problems. An overall evaluation of the severity of problem combinations is therefore favoured. If the problem combinations are constituted using an orthogonal array (or a fractional factorial design (Box, Hunter & Hunter 1978), the importance of each individual problem can be determined. In the sense that we hope to control (eliminate) the worst of these problems, this orthogonal array represents RD's inner array.

In the cheese example we are considering four problems each at two levels. This means that there are 16 possible problem combinations. This is too large a number of situations for respondents to rank. However, by using an orthogonal array statistical validity can be maintained when only eight of the 16 combinations are considered. In general more than four problems can be expected, so the use of orthogonal designs will be obligatory for the definition of even a reasonably small number of problem combinations.

Phadke (1989) presents a wide range of orthogonal designs. An example of one of these orthogonal arrays which can be used to prioritise the four root problems shown in Figure 3 appears below.

First project the four root problems into four factors each at two levels.

Factors	**Level 1**	**Level 2**
Shelf-life	problem	no problem
Packaging	problem	no problem
Range	problem	no problem
Delivery	problem	no problem

Next construct an orthogonal array of eight problem combinations using one of Phadke's designs. Each respondent is asked to rank each of these eight problem combinations in terms of concern. The highest rank is assigned to the most unacceptable problem combination. Conjoint analysis can then be used to quantitatively assess the severity of each separate problem for each respondent

Problem Combination	Shelf-life	Packaging	Range	Delivery
1	problem	problem	problem	problem
2	problem	problem	no problem	problem
3	problem	no problem	problem	no problem
4	problem	no problem	no problem	no problem
5	no problem	problem	problem	no problem
6	no problem	problem	no problem	no problem
7	no problem	no problem	problem	problem
8	no problem	no problem	no problem	problem

Choice of respondents

RD Objective: Measurement of variability in problem severity scores across the entire sample (outer array).

The survey respondents are chosen in such a way that an orthogonal array which incorporates all the relevant environmental factors is achieved. This array represents the outer array of RD. These environmental factors must be chosen bearing in mind that our objective is to identify, in a global sense, the most important problems associated with cheese in the food service market. Variation induced by these environmental (noise) factors will detract from the importance of any problem. The following environmental factors might be considered:

- the type of organisation at two levels : restaurant and fast food outlet
- job experience at two levels: manager and chef.

This produces an outer array of the following form when five randomly chosen people are surveyed for each of the four combinations of factor levels:

	Type of Organisation	
Job Experience	**Restaurant**	**Fast-food outlet**
Manager	5 respondents	5 respondents
Chef	5 respondents	5 respondents

In total this produces a sample of 20 respondents. A sample of this size permits an accurate measure of variability for the severity rating for each problem.

Data Analysis

RD Objective: Obtain overall priority scores for each problem using signal-to-noise ratios.

The data for each respondent are analysed using conjoint analysis, resulting in a severity score for each respondent on each problem. This represents the inner array analysis of RD.

Variation in the scores for any problem across the entire sample represents the outer array analysis of RD. In terms of giving an overall problem priority for each complaint, the following signal-to-noise ratio is recommended.

$$SN = 10\ Log_{10}(m/s)^2.$$

In this function m represents the mean score for each problem and s represents the standard deviation for each problem, taken over the entire sample of respondents.

This signal-to-noise ratio reduces the priority of those problems (complaints) for which more dissension occurs among respondents. The signal-to-noise ratio for each problem is regarded as its problem priority. A high score is indicative of a severe problem requiring urgent attention.

The table below shows a hypothetical calculation of the signal-to-noise ratio for each of the four root problems shown in Figure 3. For the sake of simplicity, only one respondent (instead of the proposed five respondents) has been considered for each point of the outer array.

This table suggests that the most critical root problem is delivery with a problem priority score of 19.55, closely followed by packaging with a problem priority score of 17.33. This ranking is achieved despite the higher mean score for packaging. The greater consistency of the priority scores for delivery achieved in this sample has served to raise the problem priority for delivery above that of packaging.

	Priority Scores for Root Problems			
Respondent	**Shelf-life**	**Packaging**	**Range**	**Delivery**
Restaurant Manager	3	6	5	5
Restaurant Chef	4	7	4	4
Fast-food Manager	2	5	5	5
Fast-food Chef	2	6	3	5
Mean Priority Score(m)	2.75	6.0	4.25	4.75
Standard Deviation(s)	0.96	0.82	0.96	0.50
SN Ratio[1]	9.17	17.33	12.95	19.55
Priority Ranking	4	2	3	1

Note: 1. Signal-to-Noise Ratio = $10\ Log_{10}(m/s)^2$.

Presentation of Results

FA Objective: Comparison of Problem Priorities

The final step is to go back to the complaint trees and insert the problem priority for each problem. A process review is essential at this stage. The focus group participants should be asked to review the trees to check if they make sense. The effect of environmental changes that have occurred since the original complaint trees were derived also need to be considered. Do these changes make nonsense of the tree structure or of the problem priorities that have been calculated?

Once a tree has passed this review stage it can be trusted to give a complete picture of how complaints are connected and which complaints need to be addressed first. In particular, critical problem sequences (paths) can be identified. In other words, the research problem can be defined.

Conclusion

The above case study shows how FA and RD can be used to assist with the problem definition stage of market research. The FA/RD approach is highly structured, involving its own research design and interpretation. In this approach a broad environmental focus is ensured. Carefully chosen focus groups suggest a list of possible problems and relate these problems to each other using a fault tree. The severity of each problem is quantitatively assessed for each respondent and priority scores are assigned to each problem, using signal-to-noise ratios to downgrade the priority of those problems for which there is much dissension amongst the respondents' assessments. These priority scores are entered on the fault tree, allowing the critical problem sequences to be identified.

References

Box GEP; Hunter WG & Hunter JS (1978). Statistics for experimenters: An introduction to design, data analysis and model building. New York: Wiley.

CEO Sciences Lc., Marketing brochure.

Hair JF; Anderson RE; Ronald LT & Black WC (1995). Multivariate data analysis with readings. Prentice Hall International Editions.

Hauser JR & Griffin A (1993). The voice of the consumer. Marketing Science, 12, 1 -25.

Nair VN (Ed.) (1992). Taguchi's parameter design: A panel discussion, Technometrics (2), 127 -161.

Phadke MS (1989). Quality engineering using robust design. Prentice Hall, Engelwood Cliffs, New Jersey.

Smith D & Dexter A (1994). Quality in market research: hard frameworks for soft problems. Journal of the Market Research Society, 36, 2, 115 -132.

Stephens KG (1974). A Fault Tree approach to analysis of behavioural systems: An overview. ERIC No. ED095588, pp 21.

Taguchi G (1986). Introduction to quality engineering. Productivity Organisation (distributor American Supplier Institute, Inc.)

Witkin BR (1977). Fault Tree analysis as a planning and management tool: A case study. Educational Planning, 3, 71 -85.

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