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Improvement to Quality Function Deployment Methodology

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Abstract

Quality Function Deployment (QFD) is a quality improvement methodology which translates true customer requirements into technical solutions. The major purposes in implementing QFD are enhancing quality, decreasing production cycle time, and lowering costs. QFD methodology utilises a system of matrix like structures known as the House of Quality (HOQ) which work collectively to determine final weightings of the technical characteristics. The derivation of final weights of the technical characteristics and their prioritisation is the final key in QFD process. One of the main theoretical difficulties in employing QFD is that it deals with multidimensional categorical (ordinal) data variables. The rating data of these categorical variables varies from person to person and case study to case study. In prioritising the technical characteristics, QFD practitioners often fail to fully integrate the diverse information extractable from ordinal data and ignore some sections of QFD, House of Quality (HOQ). It is also observed that in each matrix of QFD-HOQ, numerous heuristics have been introduced to suppress the variation, uncertainty and vagueness. During the QFD process, any mistakes such as selection and interpretation of rating scales, application of methods, or integration of various matrices can fail the whole process.

In this project with the rationale to improve QFD methodology, a systematic emphasis is placed on the following issues i) Application of methods, procedures, techniques for the appropriate selection of likert scales within each matrix of QFD-HOQ. ii) Application to each matrix, data and their integration towards statistically valid conclusions. iii) Close observation and interpretation of the final prioritisation of technical characteristics (TCs), and its enhancement.

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I am extremely thankful to my parents without their prayers my dream “PhD in New Zealand” would never had fulfilled. Thank you Mom for your countless prayers.

List of Abbreviations

AHP	Analytical Hierarchy Process
ANP	Analytic Network Process
CA	Competitive Analysis
CI	Confidence Interval
CPR(s)	Competitor Performance Rating(s)
CR(s)	Customer Requirement(s)
FMEA	Failure Mode and Effects Analysis
FW(s)	Final Weight(s)
HOQ	House of Quality
I	Importance Ratings
IEEE	Institute of Electrical and Electronics Engineers
IR(s)	Improvement Ratio(s)
LS(s)	Likert Scale(s)
MCDM	Multiple Criteria Decision Making
MDM	Manhattan Distance Measure
MS Excel	Micro Soft Excel
RM	Relationship Matrix
QC	Quality Control
QE	Quality Engineering
QFD	Quality Function Deployment
QQ Plots	Quantiles Quantiles Plots

RMC(s)	Roof Matrix Correlation(s)
RPN	Risk Prioritization Number
SMM(s)	State Multipole Moment(s)
SQC	Statistical Quality Control
TA(s)	Technical Attribute(s)
TR(s)	Technical Requirement(s)
VOC(s)	Voice of Customer(s)

Chapter 1

Introduction and Literature Review

1. Introduction

Statistics is the science of variation and uncertainty (Fisher, 1925; MacGillivray, 2004). In manufacturing and service industries, there are certain qualitative and quantitative measures which help to determine the quality of products, services and the processes that provide them. Examples include defect count; capability; reliability; efficiency; and variation. Among these characteristics, variation is a major concern worthy of particular attention. Such variation is variously referred to as random, chance, unwanted, special cause or common cause variation. In manufacturing industries such variation might be due to temperature, material, weather conditions, wear and tear of machines etc. It can also occur due to physiological/psychological circumstances of individuals (Shewhart, 1925). Poor control of the variation sources in any development process commonly leads to poor results (Bjerke, 2002), so to improve quality, practitioners, researchers and engineers continually strive to seek methods to reduce or eliminate the effect of these variations.

Statistical methods/approaches play an important role in identifying types of variation or trends that might impact upon the quality of product. Shewhart (1931) proposed the following three central postulates in relation to statistical variation:

1: *All chance systems of causes are not alike in the sense that they enable us to predict the future in terms of the past.*

2: *Systems of chance causes do exist in nature such that we can predict the future in terms of the past even though the causes be unknown. Such a system of chance is termed as constant.*

3: *It is physically possible to find and eliminate chance causes of variation not belonging to a constant system.*

Shewhart therefore reasoned that controlled systems do exhibit random variation, but nonetheless behave predictably over time. Against the background of random, predictable variation (common cause), abnormal variations (special causes) can be identified and ultimately eliminated, thus bringing about control and a basis for improvement. Appreciation of variation is extremely important for all quality improvement methodologies.

This thesis is focused on Quality Function Deployment (QFD) which is a methodology heavily based on Likert score data. QFD uses various interrelated, single and two dimensional likert-scale data. QFD integrates these diverse likert scale variables together with various heuristics and suggests technical solutions to be employed in a definite order. Because of the diverse likert scale variables and the variation to which they are subject, the ranking or prioritisation of these technical solutions has potential flaws and needs continuous improvement. Fortunately, the notion of common and special causes of variation (found in Shewhart's postulates) is not only valid for continuous data but also for the ordinal scale data used in the QFD methodology. A literature review of published QFD studies revealed that many heuristics or procedures have been introduced to reduce variation in QFD and control reliability, uncertainty and vagueness (Olewnik and Lewis, 2008; Andronikidis et al., 2009; Enriquez et al. 2004; Garver, 2012). The following section: introduces QFD; presents its evolution, structure and applications; and summarises research conducted so far, discussing its limitations and shortfalls. The section examines what further methodological improvement might be needed, and how it can be achieved through the present research.

1.1 Quality Function Deployment

QFD is a methodology which ensures that customer needs and demands are deployed through technical solutions (Akao et al. 1983). Technical Solutions (TSs) are the outcome of the problem, obtained by systematic multi- disciplinary team analysis in order to achieve maximum customer satisfaction. QFD is a widely used methodology due to its simplicity and broad application: it not only helps to improve goods and services but also helps to improve strategic planning, procedures and processes (Schaal and Slabey, 1991; Griffin and Hauser, 1993; An et al. 2008). QFD begins with the ‘Voice of the Customer’ (VOCs) (referring to customers’ requirement, needs, demands, expectations, desires, quality attributes etc.) and translates these into a detailed plan to produce Technical Solutions (TSs). In literature, these are referred to using different terms, for example Technical Characteristics (TCs), Technical Attributes (TAs) and Engineering Characteristics (ECs). It is a multi-disciplinary team work approach which involves planners, managers, surveyors, engineers, data analyst etc., in determining the TSs (Özgener, 2003). These TSs have vital importance in

QFD. Any deviation from the correct deployment of these TSs can fail the whole process.

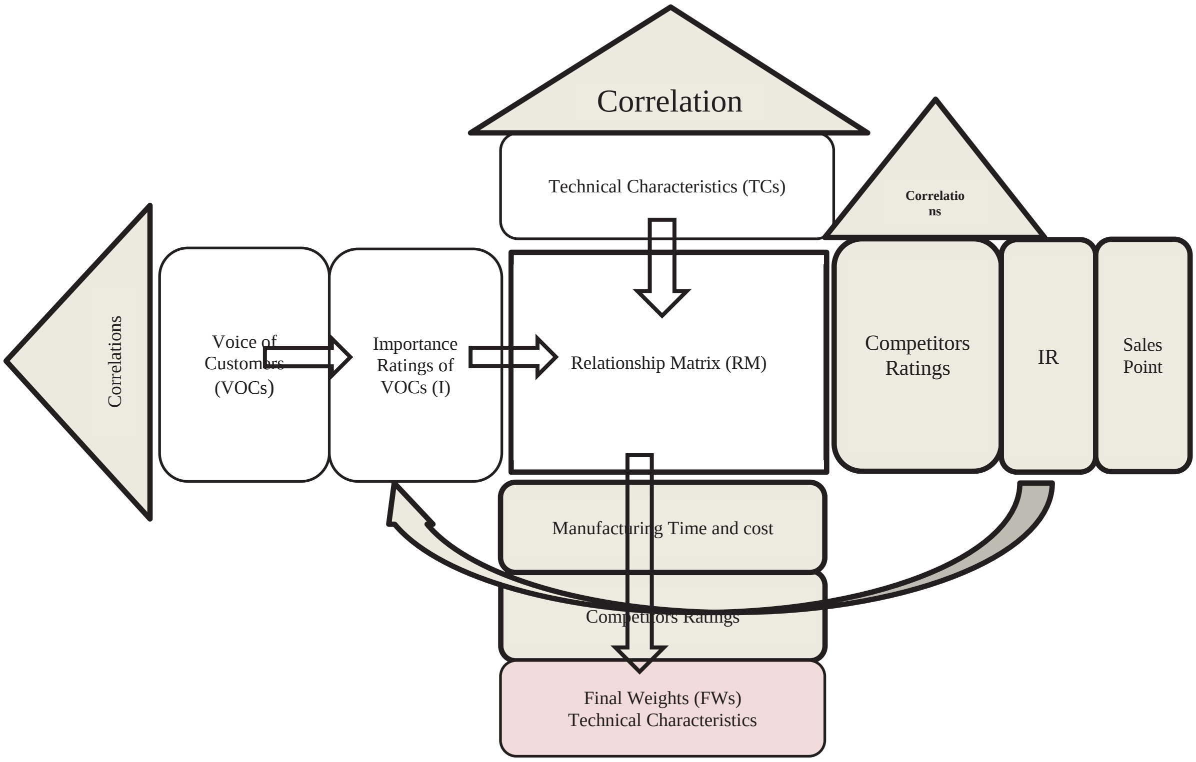
1.2 Evolution of Quality Function Deployment

QFD was introduced by Professor Yoji Akao in the late 1960s in Japan (Akao, 1997; Chan and Wu, 2002). Originally it was a literal translation of the Japanese words Hinshitsu Kino Tenkai which translates as quality function evolution. Before World War II, Japanese industry - especially product development - was in full swing, but after the War Japanese industries were crippled. QFD evolved in Japan due to two main ambitions: improvement in quality of design; and manufacturing (Chan and Wu, 2002). The Japanese started giving attention towards developing manufacturing industry. This was the era when Prof Akao first presented the concept and methodology of QFD. Initially QFD was presented as a new product development method under the umbrella of Total Quality Control (TQC) (Akao, 1972; Akao, 1997). Later, the further ideas for example quality deployment, quality chart, assurance items table, customer needs etc. by Shigeru Mizuno, Yasushi Furukawa, Kiyotaka Oshiumi and Akira Takayanagi were integrated and eventually shaped into QFD (Akao, 1972; Maritan, 2015; Akao and Mazur, 2003).

1.3 Structure of Quality Function Deployment

QFD is a well-structured methodology. The structure in which QFD organises and analyses the information consists of various matrices (also referred to as sections, rooms, components, parts, quality tables, charts) resembles a house and is therefore called the ‘House of Quality’ (HOQ) (Hauser and Clausing, 1988 ; Akao, 1990). The essential fundamental matrices of the QFD-HOQ are Voice of the Customer (VOC), Technical Characteristics (TCs) and Relationship Matrix (RM). There are some other matrices, which sometimes are part of QFD-HOQ and are sometimes ignored by practitioners, these are Correlations Matrix (CM); Competitors section (CS) etc. Figure 1, QFD-HOQ, shows the most commonly used sections. It is a multi-disciplinary team work approach which involves planners, managers, surveyors, engineers, data analyst etc., and needs systematically collective effort(s) to come up with a technical solution (Özgener, 2003).

Figure 1. Modified form of Quality Function Deployment, House of Quality



In figure 1, the white shaded sections are compulsory sections of QFD process, while. The light grey sections are optional sections, some practitioners utilise these and some do not. The lowest coloured section express the FWs of TCs which are the final results or outcomes of the whole process. The arrows show the transition of results from one section to other.

1.4 Application of Quality Function Deployment

Initially the Kobe Dockyard of Mitsubishi Heavy Industries employed the ideas of QFD in 1971, (Chan and Wu, 2002). A proper initial application of QFD was to develop a quality coolant sensor (Prasad, 1998). Later the major pioneer companies in Japan who employed QFD were Toyota group and Hino motors. QFD introduced to Europe and America in 1983 (Akao, 1997; Akao et al.; 1983). Other prominent companies who started employing QFD were Mitsubishi Heavy Industry, General Motors, Chrysler, Procter and Gamble, Baxter Healthcare, Hewlett-Packard, American Telephone and Telegraph Company and the Ford Motor Company (Hauser and Clausing, 1988; Prasad, 1998). Nowadays, the major areas where companies have started applying QFD are marketing, manufacturing, logistics, sports, engineering, agriculture, transport, education, defence, environment, software, e-business, medicine, hospitality etc. (Chin et al., 2001; Ghiya et al., 1999; Hanumaiah et al., 2006; Jeong and Oh, 1998). The main benefits of applying QFD in the above areas are to benchmark, design quality, planned quality, continuous improvement, reducing development cycle time, reducing design changes, decreasing initial quality problems and lowering development costs etc.

1.5 Final Weights and Prioritisation of Technical Characteristics

In the above section various important distinctive aspects of QFD are described. The important final step of QFD process starts when surveyors, planners, managers, engineers etc. finish determining information for all possible section of QFD, and then they apply simple mathematical expression to determine Final Weights (FW) of TCs.

$$FW_j = \sum_{i}^{n} (RM)_{i,j} \times I_i \times \{X \times Y \times Z\} \;, i = 1 \ldots n \;, \; j = 1 \ldots m \qquad (1)$$

Where,

FW represents final weights for m TCs, I is the customers' importance for n VOCs, RM is the relationship matrix's strength (Franceschini and Rossetto, 2002; Thakkar et al., 2006; Tan et al., 1998). Here X, Y, Z are some of the optional sections of HOQ. X, Y, Z may contain data in form of a vector or matrix. Derivation of FWs of TCs and their prioritisation order is the final key step in QFD. All the efforts in various sections (methods, procedure, likert scales selections, analysis etc.) of QFD-HOQ are to achieve better prioritisation of TCs. In this research project, it is claimed that TCs prioritisation by the current practice is not the final step, it can be enhanced further.

2. Literature Review

This project aims to address gaps/limitations in three main aspects of the QFD process. 1) Analysis of matrices data (especially correlation and competitors' matrices) and their integration for determination of final results (i.e. FWs). 2) Analysis of likert scales current practices 3) Close observation of FWs priorities and tackling of TCs.

2.1 Correlations and Competitors Matrices in QFD

Although all the matrices in the QFD-HOQ are of significant importance, published literature review of case studies revealed that correlations and competitors' matrices are normally the most important and most neglected matrices, being seldom incorporated in QFD process (Stehn and Bergström, 2002; Ibusuki and Kaminski, 2007). Using databases such as Google Scholar, Scopus and Web of Science, we collected statistics of explicated QFD published case studies. It is observed that only 22% of the case studies used competitors' data, while only 45% of the case studies displayed the correlation section. In case of correlation, it is further found that in case studies where correlation matrix is included in HOQ, half of them are not integrated with QFD process to determine FWs. The reasons for not applying these methodologies might include cost and time of measuring and unavailability of methods to incorporate with FWs (Temponi, et al., 1999). For example, Chaudhuri & Bhattacharyya (2009) felt that measuring the strength of relationship between all pairs of TCs is difficult task so assumed that the presence of one TC has no effect on the other TCs.

QFD literature shows that various attempts have been made by researchers to factor-in the correlations with FWs of TCs. Each researcher addressed the correlation issue in his own way and developed different expressions (Pramod et al. 2006; Sharma and Rawani, 2008). By application of these methods using different examples, it has been explored whether each of them has shortcomings and generates invalid results in some cases. Correlations analysis can help in many ways, for example, to trade-off TCs, reduce duplicate of efforts, replacement of one TC with other, reduce the TCs, resources allocation, understand conflict between TCs, etc. Correlation matrix needs attention to be analysed comprehensively and simple method to re-quantify FWs.

Competitive pressures and customers' needs and demands compel companies to make continuous improvement and introduce new plans to improve the quality of products. In QFD-HOQ, the competitors' matrix helps practitioners to analyse their product with respect to opponents in the market and to set the bench mark for improvement. In QFD process this section is one of most important but most overlooked section as it is part of QFD in only 22% of case studies. So far only one method i.e., 'Improvement Ratios (IRs)' has been observed in practice to set the bench mark of current VOCs. IRs only based on Goal, (target to achieve) and not on the actual ratings. It is also found that these IRs have potential flaws and may change the VOC rating from lowest to highest and vice versa. A wrong selection target value may ended with invalid decision and deprive the result to achieve maximum customer satisfaction. There is a need to introduce new method other than IR for better benchmarking and better decision making.

2.2 Qualitative-Quantitative Measures in QFD

Likert scales are used to measure qualitative characteristics such as strength, importance, perception, attitudes, opinions and so on. To facilitate data analysis each qualitative characteristic is assigned by an integer (Likert et al., 1934). It is found that all the sections of HOQ use ordinal type of a likert scale to express qualitative measure for example importance, strength, or perception. Some of the sections are composed of linguistic-numeric categories while some have symbolic-linguistic-numeric categories. It is also revealed that length, strength and interval of this data not only vary from section to section, but also from case to case. For example: Crowe and Cheng (1996), Ibusuki and Kaminski (2007), Hochman and O'Connell (1993) adopted a 5-point scale (1-5); Prasad (1998) applied a 6-point scale (1-6); Stehn and Bergström (2002) employed 9-point scale (1-9); while Andronikidis et al. (2009) and Haron et al. (2014) employed normalised percent-based likert scale. Similarly diverse use of likert scales is found in other matrices of QFD-HOQ.

Qualitative or subjective measurements are difficult to analyse. In order to overcome this problem assigning a numerical score to qualitative data is introduced (Likert et al., 1934; Snell, 1965). In many cases while applying statistical methods, the statistician makes some assumptions to be followed. For example while doing ANOVA, it is assumed that population is normal and variances are constant, however such assumptions are not considered while analysing likert scale data (Wu, 2007). Likert scales always subject to varied criticism relating to characteristics including their labelling, division, interval, inconsistencies, ambiguity analysis, and interpretation. As all matrices of QFD-HOQ rely on likert a scale which has substantial variation so there is a need to analyse and extract information before their integration to determine the FWs. This extracted information can be helpful for quality enhancement and better decision making.

Secondly, these likert scales may be prone to bias, inconsistencies, or ambiguity. The focus of this study is not on these issues, but rather what happens if a QFD user employs 1-3-9, instead of 1-3-5 or 1-3-7. Are these scales analogous to each other? Definitely changes in scale will change the FWs of TCs, but is there any mathematical/statistical method to prove that their priority order is still same or has been changed significantly. Only one article found in literature has tested the robustness of these scales (Ghiya et al., 1999) and indicated small change in results but does not demonstrate whether the final TCs ranking remains the same, or change.

2.3 Enhancing Prioritisation of Technical Characteristics

The literature review revealed that FWs computation and prioritisation of TCs is the final key step in QFD process (Tan, et al., 1998; Lam and Zhao, 1998; Tan, 2003; Gunasekaran et al., 2006; Maritan and Panizzolo, 2009; Stehn and Bergström, 2002; Liu, X. et al., 2004; Crowe and Cheng, 1996; Ibusuki and Kaminski, 2007; Hochman and O'Connell, 1993; Andronikidis et al., 2009; Pai & Yeh, 2012; Yu et al., 2012; Haron et al., 2014; Cho et al., 2015). Practitioners advise technical teams to tackle the TCs in the set order to improve the product or service. Under the assumption that the TCs are the true translation of customer demands, the concluding prioritisation order of TCs is not enough and can be enhanced further. It has already been a custom that various likert scales are involved to determine the FWs, so it might be possible that two FWs are different (one TC has priority to be tackled over other TC) just because of common cause. In other words this difference in FWs could be due to common/random cause or special/systematic cause variation as illustrated in Shewhart

(1931) postulates. It can also be investigated that higher statistical significance of few TCs can do a better job than all the rest TCs which may follow an application of Pareto's 80/20 principle (Sanders, 1987)

2.4 Limitation and Gaps

Literature review exposed that the reason for ignoring the some of the matrices are diverse ratings scales and unavailability of simple methodology to integrate these with FWs of TCs. The likert scales vary from matrix to matrix and case study to case study. In some case practitioners have no choice and are limited to employ only one method. There is not much work done to extract information from these matrices and also the likert scales employed in these matrices. Literature review revealed that there is a need to observe the likert scales critically and develop statistical heuristics, which are easy to apply and extract more information for better decision making.

Literature review further exposed that there is no doubt that the TCs are the true translation of customer needs and demands, but the current prioritisation order of TCs is not enough and can be enhanced further. One TC may has priority over the other TC just because of common cause. In other words this difference in FWs could be due to common/random cause or special/systematic cause variation as illustrated in Shewhart (1931) postulates. It can also be investigated that higher statistical significance of few TCs can do a better job than all the rest TCs which may follow an application of Pareto's 80/20 principle (Sanders, 1987).

So based on the limitation and gaps in the current practice of QFD process, some aims and objective have been set which are describe in the following section.

2.5 Aims and Objectives

In order to achieve the aim of ‘Improvement to QFD methodology”, the following research objectives will be followed.

1. Analysing correlation matrix, deriving information for better decision making and developing method to reduce the TCs and integrating correlations with final prioritisation order of TCs.
2. Analysing linguistic-numeric scales using State Multipole Moments method to extract information and developing a method to compare them
3. Developing methodologies to test the priority importance of one TC over the other TCs, in the perspective of common and special cause variations i.e. One TC might has priority over other TC due to common cause variation.
4. Investigating the robustness of different linguistic-numeric scales used in QFD process to determine the final prioritisation of TCs.
5. Developing method to enhance the VOCs rating by integrating competitors’ ratings

Chapter 2

A distance-based methodology for increased extraction of information from the roof matrices in QFD studies

Zafar Iqbal, Nigel P. Grigg, K. Govindaraju and Nicola Campbell-Allen

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Chapter 3

Performing competitive analysis in QFD studies using state multipole moments and boostrap sampling

Zafar Iqbal, Nigel P. Grigg, K. Govindaraju and Nicola Campbell-Allen

Quality Engineering, 1-11

Publication: pages 34-45

Erratum

In the following article there are two errors.

1) In the article it is stated that second SMM is quadrupole moment, m_2, measures "centeredness" in the data distribution. When m_2 is +ve, there are more responses on each end of the LS (than in the center), and we can infer that the responses are highly polarized (i.e., not centered; Figure A3a). On the other hand, when m_2 is -ve, there are more responses in the center and fewer responses at the extremes, and we can infer that the responses are centered.

   In the **Statistical comparison of SMMs** section, while comparing $m_2 = -0.42$, m_2 is converted to abs(-0.42) and compared with theoretical population of all $abs(m_2)$, which is incorrect because $-ve\ m_2$ and $+ve\ m_2$ have specific meaning. So $m_2 = -0.42$ must be compared with the theoretical population of m_2 without converting it to +ve. In some cases where a sign has no significance, then negative values can be converted to positive.

2) In the **Interpretation** section it is stated that "The second SMM (quadrupole moment m2 = −0.42) shows that the case company ratings are quite polarized (with more density towards the center)" Here 'polarized' is a typographical error, rather, it should be described as 'centered'.

Chapter 4

Statistical comparison of final weight scores in Quality Function Deployment (QFD) studies

Zafar Iqbal, Nigel P. Grigg, K. Govindaraju and Nicola Campbell-Allen

International Journal of Quality & Reliability Management, 31(2), 184-204

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Chapter 5

Enhancing prioritisation of technical attributes in quality function deployment

Zafar Iqbal, Nigel P. Grigg and K. Govindaraju and Nicola Campbell-Allen

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Publication: pages 69-86

Chapter 6

Enhancing Voice of Customers rating by integrating competitors' ratings using AHP and GM

Zafar Iqbal, Nigel P. Grigg and K. Govindaraju

Publication: pages 88-102

Enhancing Voice of Customers rating by integrating competitors' ratings using AHP and GM

Zafar Iqbal, Nigel P. Grigg, K. Govindaraju

Abstract

Quality Function Deployment (QFD) is a quality improvement methodology. QFD uses a system of interrelated matrices, where effect of one matrix, meaningfully may change the result of other matrix. In these interconnected matrices, Voice of Customers (VOCs) matrix and Competitor Matrix has a strong relation. Competitors' ratings help to determine improvement ratios (IRs) for each of the VOCs. The method of finding IRs does not incorporate competitors' rating in a way that fully utilises competitor rating information. The current practice of computing IRs may divert QFD practitioners' attention from a potentially important VOC to less important VOC. In order to enhance given VOC ratings, we present an efficient method by utilising the application of Analytic Hierarchy Process (AHP) together with Geometric Mean (GM). In the first step using the current competitors' ratings, we generating a matrix of multiple comparisons of all competitors, and then determine GM for each VOC. In this way, our develop method can overcome the possible deficiencies in the current practice of finding IRs. We then use a QFD case study from published literature and illustrate the use of the new AHP-based IRs. We demonstrate that in this way re-ranking of existing VOCs better achieve the goal of customer satisfaction in relation VOC ratings and competitors' rankings.

Keywords: Quality Function Deployment; Geometric Mean, Improvement Ratio, AHP, Competitors Ratings

1. Introduction

Quality Function Deployment (QFD) is multi-disciplinary team tool, which systematically analyses a sequence of matrices collectively referred to as the House of Quality (HOQ). QFD aims to produce products or services that efficiently meet customers' needs and demands which are generally referred to as the Voice of Customer (VOC) (Kalluri & Kodali, 2013). Professor Akao is the founder of QFD, introducing QFD in Japan in the late 1960s. Ginn & Zairi (2005) demonstrate that QFD acts as a bridge between the customer and the product/service development process. From the sequence of QFD matrices, one of the key matrices is the competitors' matrix. The competitors' matrix helps practitioners to analyse their product with respect to opponents in the market. Kalluri & Kodali (2013) report that the success of a new product depends on the appropriate identification of customer requirements, their translation into technical requirements and benchmarking of competitors' best practices. Competitors' analyses of the best industry standards will lead to exceptional performance through the implementation of these best practices.

In the QFD competitors' matrix, customers express their satisfaction level by assigning qualitative-quantitative ratings. For example, by employing a 5-point rating where 1 = very low, 2 = low, 3 = moderate, 4 = high and 5 = very high. This charts the performance level of the existing company and its competitors about the various VOCs. Shen, Tan, & Xie (2000) state that customer satisfaction benchmarking can help practitioners and decision makers to identify the areas of improvement and to make strategic solutions.

This paper is based on a research project that aims to develop new mathematical and statistical heuristics to improve the QFD process, systematically examining each room of the HOQ in turn (e.g. Iqbal, Grigg, Govindaraju and Campbell-Allen, 2014 & 2015). In this paper, our focus is on competitors' data and its analysis (rooms 3-4), not only to improve existing VOCs' importance ratings but also to extract additional information. We identify where VOCs are lacking and require improvement as compared to competitors. In this article, we propose a new method which integrates Analytical Hierarchy Process (AHP) with one of the existing approaches – Improvement Ratio (IR). The new proposed method is based on AHP and involves all competitors instead of only relying on one future goal. The identification of the weaker VOCs and their estimated rate of improvement will be used to set new importance ratings for VOCs. In the next section, we present a review of the relevant literature relating to QFD qualitative-quantitative ratings scales and methods or techniques that have already been developed. This is followed by our proposed methodology and its application by way of a case study.

2. Literature Review

We first examine the qualitative-quantitative rating scales used by practitioners/researchers to operationalise customer perception of both the existing company, and its competitors. The literature review reveals that various qualitative-quantitative rating scales have been adopted by practitioners to express customer needs and wants (VOCs). The literature review shows that 3-point (1-3), 4-point (1-4), 5-point (1-5), 6-point (1-6), 7-point (1-7), etc. linguistic-numeric scales have been adopted by practitioners. Smaller numeric numbers express low performance levels while higher numbers express high performance levels. For example: Duffuaa, Al-Turki, & Hawsawi (2003) adopted a 3-point scale; Utne (2009) applied a 4-point scale; while Tanik (2010), Hochman and O'Connell (1993), Dikmen, Talat Birgonul, & Kiziltas (2005), Chin et al. (2001), Bouchereau and Rowlands (2000), Hoyle and Chen (2007), Deros, Rahman, Rahman, Ismail, & Said (2009), Pakdil, Işın, & Genç (2012), Reich (2000), Stuart & Tax (1996) all employed 5-point scales; and Abu-Assab & Baier (2010) examined customers' perception via a 6-point rating scale. The published literature also indicates some continuous, fuzzy, percentage-based and Kano-model-based rating scales. For example Liu (2009) used a fuzzy scale, Bai and Kwong (2003) used a continuous scale and Garibay, Gutiérrez, & Figueroa (2010) employed a Kano-model-based scale. We observe that the 5-point rating scale is the most frequently used rating scale and can be seen in various published case studies to express customers' perceptions.

The literature reveals, however, that relatively few heuristics have been developed that have integrated competitors' ratings to improve the QFD analytical process and final weight (FW) scoring. For example, Chan, Kao, & Wu (1999) and Wu & Lin (2012) employed entropy method to extract information from competitors' data to improve VOC: the rationale of entropy is that the variation in the data is directly proportional to information in the data. Another methodology - conjoint analysis (CA) - has been employed by Abu-Assab & Baier (2010) in contrast with QFD, to set priorities when different levels are available for selection. The literature review also revealed that Improvement Ratio (IR) is the most commonly used method for analysing QFD competitors' data. It defines the rate that is required for each VOC criterion to further improve. Practitioners set goals and measure the rate to improve i.e. IR, for each VOC (González, Quesada, Picado, & Eckelman, 2004). IR is quantified by dividing the target (goal) performance level by the current performance level of the existing company's VOC (equation 1). Researchers integrate IR with the current importance rating of VOCs to set new importance ratings. The objective of this computation is to adjust the importance weighting of the VOC by incorporating competitors (Dikmen, Talat Birgonul, & Kiziltas, 2005; Hochman & O'Connell, 1993; Jeong & Oh, 1998).

$$\text{IR} = \frac{\text{Goal rating to achieve}}{\text{Existing rating of Company}} \qquad (1)$$

Some other approaches have also been found in the published literature to analyse competitors' data, such as Tan & Shen (2000) who re-rank VOCs' importance by integrating IR with Kano's model; while Kumar, Antony, & Dhakar (2006) incorporate sales points importance with the IR to re-quantify the importance of VOCs. In order to analyse competitors and determine the impact of competitors on existing VOCs' importance ratings, IR was found to be the most frequently used and most effective method so far. The current practice of quantifying IR is basically dependent on the goals' rating (future target) which does not really involve all of the given competitor ratings. IRs based on changes in VOCs importance may divert focus from those VOC which require significant attention. For example, a case study by Hochman & O'Connell (1993) describes that one VOC '*recycled*' had a customer importance rating of '3', and due to a higher IR its importance increased to 9. However, for this particular VOC, the existing company and its competitor show the same level of performance. So if customers assign the same performance level to our company and to competitors, then do we need to increase the importance of VOC at such a relatively high rate? Our new approach, based on AHP to quantify IR (AHP-IR), includes all competitors' ratings. In the next section we describe the proposed methodology.

3. Research Methodology

The new developed methodology is based on Analytical Hierarchy Process (AHP). AHP was developed by Saaty in the early 1970s. It is a popular methodology for problems related to complex decisions involving multiple criteria. AHP has been extensively used by researchers and practitioners because of its wide application (Ho, 2008). AHP generates a reciprocal matrix of multiple comparisons (RMMC) by making all possible paired comparisons of various criterions and derives ratio scales for each comparison. These ratio scales of RMMC are then used to create an Eigenvector, which expresses the ranking or priorities for each criterion. Our proposed methodology used two dimensions of RMMC to: i) estimate the rate to improve (AHP-IR, formally called IR) for each VOC, and adjust the importance rating of VOCs accordingly; and ii) quantify the ranking of competitors for each VOC. The traditional method of employing AHP generates pairwise qualitative-quantitative comparisons, which may create inconsistencies. To avoid these inconsistencies, we will use the QFD case study based performance ratings given directly to each competitor on a rating scale of 1-5.

In order to demonstrate the steps of our methodology, for each VOC we suppose there are n competitors including our company. We denote competitors by $C_i, i = 1, \dots n$, here C_1 denotes our company and from C_2 to C_n denote competitors. Similarly we denote their respective rating given by customers by $R_i, i = 1, \dots n$, here R_1 denotes rating of our company and from R_2 to R_n denotes competitors' ratings.

As a first step, in order to generate the RMMC of ratios for these ratings, we use the following equation:

$$RMMC = [R_{i,j}]_{(n,n)} = \frac{R_j}{R_i}, where\ i = 1, \dots, n, j = 1, \dots, n \quad (2)$$

Now using the AHP-based matrix (i.e. RMMC, equation 2), we quantify the geometric mean of each row of ratios (as equation 3) and each column of ratios (as equation 4).

$$GM1_i = \left(\prod_{j=1}^{n} \frac{R_j}{R_i}\right)^{1/n}, i = 1, \dots, n \quad (3)$$

$$GM2_j = \left(\prod_{i=1}^{n} \frac{R_j}{R_i}\right)^{1/n}, j = 1, \dots, n \quad (4)$$

Equation 2's expression helps to develop RMMC using all competitors. Equation 3 and equation 4, compute geometric means (GM) of the ratios from RMMC, as a measure of central tendency. Fleming & Wallace (1986) describe that in the case of ratios, GM is the best estimator to express a central measure. Computations of simple average, for example arithmetic mean of ratios, may lead to incorrect conclusions. The traditional way of employing AHP only quantifies the Eigenvector using one of the GMs i.e. $GM2$, which explores the ranking of competitors. The rationale of quantifying $GM2$, is to know where we rank and where our others competitors stand. On the other hand the basis for quantifying $GM1$ is to determine the estimated rate to improve (AHP-IR). AHP-IR derived from equation 3, estimate the rate to improve for our company i.e. C_1 and all of the competitors i.e. C_2 to C_n. AHP-IR for our company will be integrated with the initial importance rating of VOCs to find the actual importance. In the next section, we see the application of our methodology in a published case study example.

4. Literature Case Study Application

The selected case study comes from an article written by (Kumar et al., 2006). In the case there are seven VOCs. Customers' perception ratings at the scale 1 to 5 are given for each of the seven VOCs for the existing company and its three competitors (table 5). Table 5 also shows IRs which are quantified by using equation 1.

Table 5: VOCs importance, competitors' ratings, goals and IRs (Kumar, et al., 2006)

Voice of Customers VOCs)	Importance	**Our Company (C_1)**	**Competitor 1 (C_2)**	**Competitor 2 (C_3)**	**Competitor 3 (C_4)**	**Goals**	**IRs**
Speed of Adjustment (VOC_1)	4	2	2	2	3	5	2.50
Adjustment Range (VOC_2)	5	3	4	2	3	5	1.67
Easy Adjustment (VOC_3)	4	3	2	2	4	5	1.67
Customisable (VOC_4)	4	3	2	2	3	5	1.67
Safe (VOC_5)	5	4	4	4	3	4	1.00
Comfortable (VOC_6)	4	3	4	4	4	4	1.33
Interchangeable (VOC_7)	3	3	3	3	4	4	1.33

In table 5, our company and three competitor's ratings for each VOC are the main source for generating RMMC. We will apply our methodology on each VOC, one by one, to quantify the ranking of competitors and also to estimate the rate to improve, i.e. AHP-IR. In other words, we will generate RMMC for each VOC followed by GMs. Now in order to apply our methodology, we select $VOC_{1.}$ Using equation 2, first we generate ratios and develop RMMC for VOC_1 (table 6).

Table 6: RMMC, Ranking and AHP-IR for VOC_1

	Competitors	C_1	C_2	C_3	C_4	AHP-IR
Competitors	Ratings	$R_1 = 2$	$R_2 = 2$	$R_3 = 2$	$R_4 = 3$	
C_1	$R_1 = 2$	1.00	1.00	1.00	1.50	1.11
C_2	$R_2 = 2$	1.00	1.00	1.00	1.50	1.11
C_3	$R_3 = 2$	1.00	1.00	1.00	1.50	1.11
C_4	$R_4 = 3$	0.67	0.67	0.76	1.00	0.74
	Ranking	0.90	0.90	0.90	1.36	

Using table 6 ratios, we quantify GM for each row (i.e. GM_1, using equation 3), which actually estimates the rate to improve, not only for our company (i.e. C_1, but also for competitors (i.e. $C_2, C_{3,} C_4$). In the next step, from table 6 we quantify GM for each column (GM_2, using equation 4) to set the ranking.

Now in table 6, we have two dimensions of results. The first dimension of results (the last column on table 6), derived AHP-IR as the GM of each row, which is the estimated rate of improvement for our company and its competitors. Now the second dimension of results (the last row), displays the ranking (importance weight) as the GM of each column for our company and competitors. Both dimensions of results help to make a better analysis not only for the existing company but also for its competitors.

In the case of VOC_1, both GMs provide a clear idea of how much we need to improve and where we stand with respect to our competitors. Following the same procedure, we proceed with the same steps for the rest of the VOCs, i.e. VOC_2 to VOC_7. As our final focus in this article is to estimate the rate to improve (AHP-IR) for each VOC, so in table 7, the AHP-IR column expresses the rate to improve for all VOCs, and the column Adj-AHP-IR shows the adjusted AHP-IR, because it can be seen that for some VOC, AHP-IR it is less than 1, which means that in that particular VOC, the existing company overall performance is better. So in that situation AHP-IR will be adjusted by replacing it with 1.

Table 7: AHP-IR and Adj-AHP_IR for all VOCs of Our company

	Importance	Our	$C1$	$C2$	$C3$	**AHP-IR**	**Adj-AHP-IR**
Speed of Adjustment (VOC_1)	4	2	2	2	3	1.11	1.11
Adjustment Range (VOC_2)	5	3	4	2	3	0.97	1.00
Easy Adjustment (VOC_3)	4	3	2	2	4	0.88	1.00
Customisable (VOC_4)	4	3	2	2	3	0.82	1.00
Safe (VOC_5)	5	4	4	4	3	0.93	1.00
Comfortable ($VOC6_2$)	4	4	4	4	4	1.00	1.00
Interchangeable (VOC_7)	3	2	3	3	4	1.46	1.46

Replacement of AHP-IRs with 1 will keep the new importance of VOCs same as the original. Now finally, we integrate the Adj-AHP-IR with the existing importance of VOCs to quantify the new-importance(table 8).

Table 8. Existing VOCs Importance and VOCs New-Importance

	Importance	AHP-IR	Adj-AHP-IR	New-Importance
Speed of Adjustment (VOC_1)	4	1.11	1.11	4.44
Adjustment Range (VOC_2)	5	0.97	1.00	5.00
Easy Adjustment (VOC_3)	4	0.88	1.00	4.00
Customisable (VOC_4)	4	0.82	1.00	4.00
Safe (VOC_5)	5	0.93	1.00	5.00
Comfortable (VOC_6)	4	1.00	1.00	4.00
Interchangeable (VOC_7)	3	1.46	1.46	4.38

New Importance = Importance x Adj-AHP-IR

In table 8, the proposed methodology suggests that two VOCs i.e. VOC_1 and VOC_7 need to improve, while other VOCs' customer ratings show that they are already leading the competitive market. The last column shows the adjustment of the existing importance of VOCs based on the rate to improve.

5. Results and Discussion

First we describe how the existing results of the case study (Kumar, et al., 2006) may divert to include erroneous decisions. The IR derived for VOC_1 is 2.50. This IR when integrated with the existing importance of VOC_1, increases from 4 to 10. So $VOC_{1,}$ which was equal or of lesser importance among the five other VOCs, becomes the most important. The point to be noted here is that theVOC_1 for two competitors have similar ratings, while one competitor's is only one point higher. So it provides a clear indication that VOC_1 should not be one of the most important VOCs as competitors have almost the same rating. This increase in importance for VOC_1 (from 4 to 10) may also affect the priority rating of the technical attributes which can change the practitioners way of tackling the technical attributes. On the other hand, our proposed methodology generates AHP-IRs by integrating all of the given competitors' rating. It generates AHP-IRs not only for each VOC but also for competitors. RMMC (table 6) derived the GM results in both directions of the matrix. The AHP-IR (GM_1) estimate for VOC_1 recommends that our company and two of its competitors need to improve at the same rate i.e. 1.11, while a third competitor is already performing well because its AHP-IR is less than 1. On the other hand GM_2, defines that only competitor 4 has a high ranking; all the others including our company have the same ranking. Table 7 shows AHP-IR for all VOCs and suggests that VOC_1 and VOC_7 need to improve at the rate of 1.11 and 1.46 respectively while other VOCs are already performing well. Finally, table 8 shows the new-importance of VOCs.

6. Conclusion

In this article, in the first step, using a published case study we described how all competitors' ratings can be used to generate RMMC which is the first basic requirement of AHP. In the next step, we illustrated how two-dimensional results (AHP-IR and Ranking), can provide a better picture to practitioners in observing their company's position and required rate to improve. From the case study results, we reported the deficiency and described how our proposed methodology works better. We can see that there is no possibility of inconsistent results as the ratio of RMMC is derived directly from the performance ratings given by customers. Finally, by setting new importance ratings for all VOCs, we clarified that weaker customer satisfaction ratings, increase the importance of VOCs. However during the application of the whole QFD process, the proposed methodology may not be applicable to every case study; there may be other strategic matters to be considered as well. We hope the developed methodology will be useful to practitioners and researchers as well as academics.

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Chapter 7

Conclusions, Future plans and Shortcomings

7 Conclusions, Future plans and Shortcomings

7.1 Conclusion

In this research project, with the aim to improve the Quality Function Deployment Methodology, the first emphasis is on enhancement of the prioritisation of TCs. In order to go a step ahead of the current practice, a statistical testing procedure is developed (discussed in Chapters 2 and 3). It is demonstrated that TCs with different FWs may have equal importance. According to Shewhart's (1931) three postulates, presented earlier, differences between FWs may just be due to chance or common cause variation. By the application of developed methodology on a published case study, it is revealed that one TC with higher weight has the same priority over a TC with lower weight. The developed method provides more reliable logical basis for QFD practitioners to determine whether TCs are statistically different. This research would help practitioners to make more statistically valid and effective selections when determining which TCs to prioritise and which to treat as practically equal. Further focusing on likert scales in order to test their robustness, relationship matrix likert scales were tested as an example. It is concluded that the choice of QFD rating scale does not present serious problems. as it is illustrated that the use of various likert scales with different strength does not significantly change the FW prioritisation. This makes it possible for practitioners to continue utilising the rating scale which was found best to suit their normal QFD procedures and practices.

While exploring the correlation matrix between TCs (covered in Chapter 4), it is found that this is one of the most neglected sections of QFD process. Employing Manhattan Distance Measure (MDM), some new methods are proposed which not only help to integrate correlations into the FWs of TCs, but also measure the overall strength of correlations, level of conflict; and reduce the dimensionality of the TCs. The Methodology helps QFD practitioners to avoid duplicating efforts, and to address contradictions between TCs.

In the exploration of likert scales (which play a vital part in every matrix of QFD), a method is presented to extract information from likert scales by computing the first two state multipole moments (SMMs) i.e. Dipole moment and Quadrupole moment. (presented in chapter 5). By employing the most frequently used ratings scales (1–5), it is illustrated how SMM measurements can be applied to competitors' matrix of QFD-HOQ. SMM moments determination helps to better understand the true tendency or inclinations of the customers. It is further shown how statistical comparisons will be made on the resulting SMMs, to observe the significance differences between them.

Systematically exploring and improving QFD, lastly focusing on competitors matrix, it is demonstrated how the current practice of competitors' performance ratings could be used to generate reciprocal matrix of multiple comparisons (RMMC) without making multiple comparisons, see chapter 6. Further it is illustrated, how two dimension of RMMC provide a picture to practitioners to observe their company's position and estimated required rate to improve. Using results from a published case study, a deficiency of current method is reported, further describing how the proposed methodology works better.

7.2 Achievement of Aims and Objectives

In order to achieve the aims and objectives described in chapter 1, so far four articles have been published in well reputed international journals and fifth one is ready to send. List of articles is as follows.

Iqbal, Z., Grigg, N. P., Govindaraju, K., and Campbell-Allen, N. (2015). "A distance-based methodology for increased extraction of information from the roof matrices in QFD studies". International Journal of Production Research, 1-17.

Iqbal, Z., Grigg, N. P. and Govindaraju, K. (2016), "Performing competitive analysis in QFD studies using state multipole moments and bootstrap sampling", Quality Engineering, Vol. No. pp. 1-11.

Iqbal, Z., Grigg, N. P., Govindaraju, K., and Campbell-Allen, N. (2014). Statistical comparison of final weight scores in Quality Function Deployment (QFD) studies. International Journal of Quality & Reliability Management, 31(2), 184-204.

Note: Above article achieved, 2015 Highly Commended Paper Award, from the Emerald Group Publishing Limited.

Iqbal, Z., Grigg, N. P., Govindaraju, K., and Campbell-Allen, N. (2015). Enhancing prioritisation of technical attributes in Quality Function Deployment. International Journal of Productivity and Performance Management, 64(3), 398-415.

Iqbal, Z., Grigg, N. P. and Govindaraju, K. (2016), "Enhancing Voice of Customers rating by integrating competitors' ratings using AHP and GM"

Objective 1

Analysing correlation matrix, deriving information for better decision making and developing method to reduce the TCs and integrating correlations with final prioritisation order of TCs.

This objective is achieved and a peer reviewed journal articles was produced and published (article attached as chapter 2).

Objective 2

Analysing linguistic-numeric scales using State Multipole Moments method to extract information and developing a method to compare them.

This objective is achieved and a peer reviewed journal articles was produced and published (article attached as chapter 3).

Objective 3

Developing methodologies to test the priority importance of one TC over the other TCs, in the perspective of common and special cause variations i.e. One TC might has priority over other TC due to common cause variation.

This objective is achieved and peer reviewed journal articles were produced and published (Articles attached in chapter 4 and chapter 5).

Objective 4

Investigating the robustness of different linguistic-numeric scales used in QFD process to determine the final prioritisation of TCs.

This objective is achieved and a peer reviewed journal articles was produced and published (article attached in chapter 4).

Objective 5

Developing method to enhance the VOCs rating by integrating competitors' ratings.

This objective is achieved and article is ready to submit an international journal (article attached as chapter 6).

7.3 Contributions

In the first attempt, focusing on the FWs of TCs, a statistical testing procedure is introduced which provides direction to researchers and practitioners regarding statistical inference when there is no means of defining traditional testing procedure. Investigating the robustness of the rating scales, it is found that a linear change in likert scales in not precarious and provides practitioners reasonable freedom to employ any rating scale which best suit their QFD example. These findings have implications for practitioners, researchers, academics and others involved in QFD research or similar field of research.

Improving QFD by employing correlations between TCs, new methods are introduced using the application of Manhattan Distance Measure (MDM). These methods would help practitioners to determine the overall nature of correlation, the effect of correlations on TCs, avoiding duplication of effort, reducing TCs and to address contradictions between TCs in appropriate manner.

Application of State Multipole Moments (SMMs) on QFD likert scales is a unique contribution. This would be very helpful for researchers, practitioners and academics, not only to improve functionality of QFD process but also in other areas where likert scales are used.

Over all these exclusive contributions would be helpful to improve QFD methodology to achieve maximum customer satisfaction. These developed heuristics would be helpful for organisations, companies, firms, practitioners, researchers and academics to teach.

7.4 Future Work

The research completed in this project can be extended further in different dimensions. For instance, application of SMMs in likert scales (Chapter 3) is demonstrated only for the first two moments. The future research can use higher order SMMs i.e. third moment (octopole) and the fourth moment (hexadecapole). In this research, application of SMMs is illustrated by using competitors' matrix of QFD-HOQ, but it can also be extended to other matrices of QFD-HOQ. In chapter 4 (Enhancing Voice of Customers rating by integrating competitors' ratings using AHP and GM) is used to improve current VOCs' ratings but this methodology can also be extended to set benchmarking for each VOC. In order to test the significance of between all TCs, (Chapter 4 and Chapter 5), the develop methods in this research make pairwise comparisons, which can increase the chances that some of the true hypothesis may be rejected. Researcher can develop a method which can do multiple comparisons instead of pairwise comparison. It will reduce error which is accumulating due to pairwise comparisons.

In this research different matrices' data from published case studies are used to develop methods and procedures. In the research study no source is found to get the actual data from where these matrices data are finalized. Researcher/practitioners who has access to actual primary data or if they doing a case study can use primary data and can derive better results from the methods developed in this research.

At the moment no comprehensive software is available to analyse QFD data with multiple options. There is a need to develop software, which provides the FWs and their ranking not only for basic matrices of QFD-HOQ but also to integrate other matrices of QFD-HOQ, for example, correlations and competitors and likewise.

7.5 Limitations

During the application of the whole QFD process, the proposed methodologies may not be applicable to every case study. There may be other strategic matters to be considered as well. There are many cases where practical considerations take preference over mathematical and theoretical precision and accuracy. These practical considerations vary from industry to industry and may include: the effort, cost, time, or inconvenience involved in tackling or addressing a selected TC. Besides these general limitation, the following shortcoming may be kept in mind while using developed heuristics in this project. In chapter 2, the methods are developed with the thought that positive correlation as good sign for work place. It might be possible that some working environment prefer independent relationship between TCs instead of positive association. In chapter 3, results and their conclusion based on only first two SMM. Inclusion of third and fourth moments, which is left as future work, may change the overall results and their conclusion. In chapter 4 and 5, in order to test the significance of all TCs, pairwise comparison has been made to generate p-values table. Pairwise comparisons may increase the probability to reject the true null hypothesis. In the same chapter, when robustness check has been made on different rating scales, The rating scales are consider within the domain of values which has been employed by various practitioners. It does not mean that any set of given ratings would be robust for any other set of ratings values. Any values outside the domain of values may largely affect the final results.

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Statements of Contribution

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Zafar Iqbal

Name/Title of Principal Supervisor: Prof. Nigel Grigg

Name of Published Research Output and full reference:

A distance-based methodology for increased extraction of information from the roof matrices in QFD studies

Iqbal, Z., Grigg, N. P., Govindaraju, K. and Campbell-Allen, N. M. (2016), "A distance-based methodology for increased extraction of information from the roof matrices in QFD studies", International Journal of Production Research, Vol. 54 No. 11, pp. 3277-3293.

In which Chapter is the Published Work: Chapter 2

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  Zafar Iqbal, as the PhD candidate, led this research inquiry, collected and analysed the data, and wrote the first draft of the paper. Prof Nigel Grigg edited the first draft to ensure readability in English, paper structure, and the flow of argument. He acted as corresponding author, dealing with the journal submission process and editorial queries. Dr Raj Govindaraju proposed the research methodology to be followed, and gave comments and suggestions to improve the various drafts of the paper. Nicky Campbell-Allen provided input on QFD in practice and helped to edit the various drafts of the paper.

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Name of Candidate: Zafar Iqbal

Name/Title of Principal Supervisor: Prof. Nigel P. Grigg

Name of Published Research Output and full reference:

Performing competitive analysis in QFD studies using state multipole moments and bootstrap sampling

Iqbal, Z., Grigg, N. P. and Govindaraju, K. (2016), "Performing competitive analysis in QFD studies using state multipole moments and bootstrap sampling", Quality Engineering, pp. 1-11.

In which Chapter is the Published Work: Chapter 3

Please indicate either:

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- Describe the contribution that the candidate has made to the Published Work:

  Zafar Iqbal, as the PhD candidate, led this research inquiry, collected and analysed the data, and wrote the first draft of the paper. Prof Nigel Grigg edited the first draft to ensure readability in English, paper structure, and the flow of argument. He acted as corresponding author, dealing with the journal submission process and editorial queries. Dr Raj Govindaraju proposed the research methodology to be followed, and gave comments and suggestions to improve the various drafts of the paper.

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Name of Candidate: Zafar Iqbal

Name/Title of Principal Supervisor: Prof. Nigel P. Grigg

Name of Published Research Output and full reference:

Statistical comparison of final weight scores in quality function deployment (QFD) studies

Iqbal, Z., Grigg, N. P., Govindaraju, K. and Campbell-Allen, N. (2014), "Statistical comparison of final weight scores in quality function deployment (QFD) studies", International Journal of Quality & Reliability Management, Vol. 31 No. 2, pp. 184-204.

In which Chapter is the Published Work: Chapter 4

Please indicate either:

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Name of Candidate: Zafar Iqbal

Name/Title of Principal Supervisor: Prof. Nigel Grigg

Name of Published Research Output and full reference:

Enhancing prioritisation of technical attributes in quality function deployment

Iqbal, Z., Grigg, N. P., Govindaraju, K. and Campbell-Allen, N. (2015), "Enhancing prioritisation of technical attributes in quality function deployment", International Journal of Productivity and Performance Management, Vol. 64 No. 3, pp.

In which Chapter is the Published Work: Chapter 5

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  Zafar Iqbal, as the PhD candidate, led this research inquiry, collected and analysed the data, and wrote the first draft of the paper. Prof Nigel Grigg edited the first draft to ensure readability in English, paper structure, and the flow of argument. He acted as corresponding author, dealing with the journal submission process and editorial queries. Dr Raj Govindaraju proposed the research methodology to be followed, and gave comments and suggestions to improve the various drafts of the paper. Nicky Campbell-Allen provided input on QFD in practice and helped to edit the various drafts of the paper.

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Name of Candidate: Zafar Iqbal

Name/Title of Principal Supervisor: Prof. Nigel P. Grigg

Name of Published Research Output and full reference:

Enhancing Voice of Customers rating by integrating competitors' ratings using AHP and GM.
Iqbal, Z., Grigg, N. P., and Govindaraju, K. "Enhancing Voice of Customers rating by integrating competitors' ratings using AHP and GM".

In which Chapter is the Published Work: Chapter 6

Please indicate either:

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  and / or

- Describe the contribution that the candidate has made to the Published Work:

  Zafar Iqbal, as the PhD candidate, led this research inquiry, collected and analysed the data, and wrote the first draft of the paper. Prof Nigel Grigg edited the first draft to ensure readability in English, paper structure, and the flow of argument. He acted as corresponding author, dealing with the journal submission process and editorial queries. Dr Raj Govindaraju proposed the research methodology to be followed, and gave comments and suggestions to improve the various drafts of the paper.

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