5-1-2020

Prioritizing quality dimensions for a Polymer industry using Best-Worst Method.

Lalith Kumar Thugudam

Prioritizing quality dimensions for a Polymer industry using Best-Worst Method

By

Lalith Kumar Thugudam

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Industrial and Systems Engineering
in the Department of Industrial and Systems Engineering

Mississippi State, Mississippi

May 2020

Copyright by

Lalith Kumar Thugudam

2020

Prioritizing quality dimensions for a Polymer industry using Best-Worst Method

By

Lalith Kumar Thugudam

Approved:

_____
Raed Jaradat
(Major Professor)

_____
Junfeng Ma
(Committee Member)

_____
Michael Hamilton
(Committee Member)

_____
Linkan Bian
(Graduate Coordinator)

_____
Jason M. Keith
Dean
Bagley College of Engineering

Name: Lalith Kumar Thugudam

Date of Degree: May 1, 2020

Institution: Mississippi State University

Major Field: Industrial and Systems Engineering

Major Professor: Raed Jaradat

Title of Study: Prioritizing quality dimensions for a Polymer industry using Best-Worst Method

Pages in Study 40

Candidate for Degree of Master of Science

This research answers the complex decision-making question about identifying the quality dimensions in a polymer industry and to prioritize these quality dimensions to obtain the best quality product with minimum expenditure. This research takes use of expert opinion and right decision-making model to yield an optimal solution which will help the manufacturing plants to reduce wastage and to get a better consistent quality product throughout the production process.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Quality is always a primary criterion when it comes to manufacturing. Industries compete to enhance their quality standards by keeping the cost at a lower margin. There are various factors companies must concentrate on in-order to achieve optimal quality products at minimal production cost (Manufacturing Studies Board, 1986). Quality was first defined as "Fitness for Use" later the definition kept changing with time and case and the lately quality is defined as "Freedom from Variation" (Juran, 2017). Due to the rise of Total Quality Management (TQM) people started approaching quality in different perspectives Customer-based, Value-based, Manufacturing and Service based, after a conceptual analysis of pervious works done by the great scholars (smith et al, 1993) disclosed quality as "Goodness or excellence of something. It is assessed against accepted standards of merit for such things and against the interests/needs of users and other stakeholders". To reach those standards (Juren, 1986) have established quality trilogy with Quality Planning, Quality Control and Quality Improvement when implemented efficiently will ensures a steady quality product production. The quality factors to work on were first identified by (Garvin, 1984) and defined them as Performance, Reliability, Durability, Serviceability, Aesthetics, Features, Perceived Quality, and Conformance to standards. These eight dimensions, when balanced accordingly, will yield optimum product quality, the primary concern arrives in obtaining the balance between these dimensions to achieve better production at optimal sales prize.

1

Figure 1.1   Quality Dimensions

The eight quality dimensions identified by (Garvin 1984)

In most cases, companies rely on their experienced employees to decide which dimension they must work-on in order to achieve better results to satisfy their customers and exhibit the finished products intended operation effectively. The aim of this research is focused on the polymer industry our aim is to identify the quality dimensions for the polymer products and priorities them using a proper decision-making method

By identifying these dimensions, we will in a position to reduce the variation in the quality and achieve a uniform output each time. The quality dimensions were identified by the help of the industrial experts and each dimension has its own test to pass as specified in Table 1.

Table 1.2   Identified tests for quality dimensions.

Quality Dimensions	Quality Test	Purpose
Performance	Drape Test	To test for elasticity
Reliability	Tensile Test	To test for breaking strength
Durability	Abrasion Test	To test surface toughness
Aesthetics	Spectrometer Test and Smoothness Test	To test for color standards and feel of the product
Conformance to Standards	Thickness Test and GSM test	To test for thickness and weight
Features	Questionnaire	To look for more options
Perceived Quality	Questionnaire	To find the product value
Serviceability	Expert Opinion	To find its usability

Tests used to identify the quality dimension for polymers

Ranking these quality dimensions based on expert's opinions as well as a mathematical model will yield an optimal result. Thus, there is a requirement to employ a systemic approach in handling complex system problem (Nagahi 2019, 2020; Hossain et al., 2016; Alfaqiri et al., 2019; Kerr et al., 2020; Hossain et al., 2019;2020, Lawrence 2019, 2020). To address such crucial multi-

criteria decision making (MCDM) problems, Jafar Rezaei (2015) proposed the "Best-Worst Method" (BWM), which helps in making appropriate decision by a mathematical approach. This method makes a pair-wise comparison of the best criterion with the rest (best-to others) and all the criteria with the worst one (other-to-worst) on a scale 1-9. Jafar Rezaei (2015) proposed this method in two different approaches, one is by non-linear approach, and the other is a linear approach. In this research, we used a linear approach due to its homogeneity. This linear model is based on the fundamental matrix property $X_{ik} \times X_{kj} = X_{ij}$, which is most appropriate for pairwise comparisons for decision-making criteria.

In this research we gathered expert opinion combined with the Best-Worst Method to come up with the priority order for the polymer industry. We tried to find the critical dimension, a polymer manufacturing company should majorly focus on and the least essential dimension which requires less attention. This will help the management to concentrate on the right factors saving them resources, time, labor, money, and finally able to achieve optimal product quality. BWM was applied by various scholars in determining the sustainability of the supply chain, the sustainability of the manufacturing industry, linking the best supplier method, supplier selection, and in many more fields. In this research, we are trying to improve the production process by stressing on the terms which need utmost attention to achieve the intended product with desired operations. The significant advantage of the BWM is that it does not require massive data sets like other decision-making methods to conclude. We have surveyed around 50 experts and collected their opinion in the form of a questionnaire. Their opinions were then periodized by using BWM, and the conclusion is made, which is suitable for the manufacturers to concentrate on. This research has opened further possibilities in the field of manufacturing, cost, human reasoning, and decision-making. The work presented in this research is essential from academic and industrial perspectives.

4

The research addresses two critical gaps in the existing academic literature. The first gap refers to the assessment of interdependency between the quality dimensions and its surrounding manufacturing process comprehensive interdependency types. Secondly, we have used the BWM as a framework to outline the interdependency and highlight different factors affecting the quality dimensions. Thus, the proposed model could serve as a baseline to develop any kind of measure to test the mutuality. Drawn from the proposed framework and model can be further tailored and applied across a wide range of academic discipline as well. We believe that addressing these gaps will enhance the body of knowledge by providing a model that study interdependency. From the industrialist or practitioners' perspective, they can use the research for resilience exploration and decision-making purposes to develop a robust quality management. Using this method, practitioners could scale the priority levels during manufacturing process, and subsequently can develop strategic countermeasures to withstand any anticipated disruption. In summary, this research has significance on both academic and industrial perspective in a sense that the insights derived from this work can be applied in the real-life situation for any interdependent infrastructures and be a valuable resource for the academic and practical literature.

CHAPTER II

LITERATURE REVIEW

Manufacturing has entered a new age where quality is the prime priority for both manufacturers and consumers (Manufacturing Studies Board, 1986). This priority swift has occurred due to global growth in the competition (Young et al, 1985). The thrive to achieve better products kept growing, which triggered post-industrial evolution, which abetted industries to concentrate on various aspects of manufacturing systems (Doll et al, 1991). Deming (1986), in his book "Out of Crisis," has stated that apart from sophisticated business strategies, the positive way to see the growth in an industry is by endowing quality. Quality plays a significant role in satisfying consumers and, in return earning their loyalty. This idea of quality by Deming was well appreciated which can be applicable in all fields of studies, has become a major judgmental factor in assessing a product.

Quality is defined in many ways, the one which relates to this research is given by Juran (2017) as "*Quality means freedom from deficiencies—freedom from errors that require rework.*" (Rust et al, 1995) have identified quality as the most important and complex element for business growth and to entice customers. The change of view on quality has led to the implementation of various strategic practices such as Total Quality Management, Material Resource Planning, Six Sigma, Lean Manufacturing, Waste Reduction, Time Study, and many others, which gives a competitive advantage over other rival firms (Powell at al. 1995). Academic research was carried out to demonstrate the direct proportion relationship of quality with customer expectation and

6

satisfaction (Boulding et al. 1999; Brady and Cronin, 2001). In spite of such advancements, there are different perspectives on quality, which led to further literature exploration to establish universal standards (Holbrook and Corfman 1985). In the research done by (Hillman et al. 1995) where they used the "Cost of Quality" formula drafted by (Lindsay et al. 1989) in the construction field to prove how quality can be directly proportional to the revenue.

(Cost of Quality = Cost of prevention and appraisal + Cost of failure and deviation correction)

This explanation shows how quality affects a company's growth, and it is hard to ignore the fact that quality accounts for profitability. People started analyzing "quality" analytically, and Deming (1982) laid the stepping-stones for the industries to follow the path towards optimal quality achievement and stressed on "continual never-ending improvement." Whereas Sheward (1986) came up with the Statistical Control Chart, which specifies the limits for the product to meet/reach the expectations.

Similar kind of study was done to show how customers' uncertainty and evaluation towards quality may disrupt the equilibrium and regulation levels of a fixed standard (Akerlof 1970, Spence 1975)

To avoid confusion regarding the quality of the products, quality standards must be updated time to time (Rahman et al., 2014; Hossain et al., 2014; Hossain and Jaradat, 2018). This research tried to address this issue by prioritizing the quality standards as per the scenario and by expert opinion.

From the popular cult novel by Pirsig (1974, pp 260) which says, "Even though quality cannot be defined, you know what Quality is!" to the modern definition by Montgomery (2013) "Quality is inversely proportional to variance." There has been much research done in

understanding what quality exactly means, and we have come a long way since then. This research is intended to disregard the statement made by Reeves and Bednar (1994) "different definitions of quality are appropriate under different circumstances", we intend to set up a universal norm which will be applicable to all kind of manufacturing firms. Quality improvement is a never-ending process they are always a slight scope for development, even if a company attains six-sigma standards that would be a 0.002% chance for improvement (Pyzdek, T., & Keller, P. A. 2018). Even after decades of research, a large proportion of manufacturing industries do not implement quality improvement techniques, as the complexity of the methods being the reason (Maani et al 1994). Keeping this in mind, Montgomery (2013), in his book "Statistical Quality Control," has sub-categorized quality into eight stages, which he termed as "The Eight Dimensions of Quality" (Garvin, 1984; Montgomery, 2013).

1. Performance

2. Reliability

3. Durability

4. Serviceability

5. Aesthetics

6. Features

7. Perceived Quality

8. Conformance to Standards

These dimensions were established on the basis of consumer decision factors and to simplify the improvement process by helping the management to concentrate on a single aspect at a time. All these aspects, when optimized homogeneously, will lead to achieving a better product with minimum deviation from the desired outcome. Each quality

dimension has been studied by Sebastianelli et al. (2002) to redefine quality in five different accessions: transcendent, Product-based, user-base, manufacturing-base, and value-based. In their research, they have collected questionnaire responses from a total of 188 quality professionals and carried out descriptive statistical approaches to determine the performance level and importance of quality dimensions to determine the quality in various aspects of manufacturing. They work as the foundation for this research. Since it is proven by Sebastianelli et al. (2002) that quality dimensions are the sub-factors of quality itself, this research intends to answer on "On which factors we need to be more focused to attain highest quality level."

Performance: A statistical study carried out by Montoya-Weiss, M. (1994) on new product performance, has identified 14 deterministic factors that have to be considered to enhance success rate or to avoid failure of a product newly launched in the market. This research indicates performance to be *"The ability of a product to give similar outcomes on every operation carried out by it."*

Reliability: Reliability Engineering is one field where there is a considerable amount of research is being carried out. In one of such research carried out by Meeker and Escoba (2004) titled "Reliability: The Other Dimension of Quality" which ideally provides for this paper have defined reliability as "the probability that a unit will perform its intended function until a specified point in time under encountered use Conditions." This says that reliability is influenced by time and environment where the product is operated. The more appropriate way would be "A product is said to be reliable, When the rate of probability of failure is close to zero."

Reliability Rate = (Failed outcomes/ Total outcomes)

Durability: If a product fails to provide service for an emphasized period, it leads to customer dissatisfaction. This is the significant factor consumers stress on. If a product lasts long, it comforts the consumer for the amount; they spent on it (Day et al.,1978). A study carried out by Avinger, R. L. (1981) on electric lamps to understand the durability of product by measuring the amount of light emitted in lumens for a significantly long period of time helped this study to define durability as "The ability of a product to remain functional and consistent with outcomes for a maximum possible period of time."

Serviceability: Robson (2013), in his book "Service-ability," stressed on the term *service* as a brand-building criterion which upraises the customer preferences towards the product. If the product is accessible to be replaced or to be fixed by the customer or the manufacturer provides satisfactory service to fix the problem at a bare period and cost the customer preference towards the product escalades. In short, serviceability can be termed as "The easy of repair the product at minimal cost and time."

Aesthetics: It determines the product sustainability, the way it looks, feels, and designed. Zafarmand et al. (2003) says a product even with high-quality standards sometimes fails to sustain in the market due to the fact it fails to attract the customers, the reason being missing aesthetic elements. Zafarmand points these aesthetic elements to be shape, shine, contrast, color, surface feel, and appearance.

Features: The capability of a product to operate multiple operations is considered as a feature. A feature can be something that can be an addition to product functionality. A feature addition has to a conscious decision; not all features lead to a hike of a product. In relevant research done on the product with multiple features conclude that a product has a saturation stage after the product starts to regress (Paulson et al. 2002).

10

Perceived Quality: In this context, perceived quality means product reputation. "The perception about the product value and usefulness to the customer" based on the reputation of the companies and products a customer can make decisions regarding the purchase (Allen, F. 1984). Conformance to Standards: Every manufacturing plant must meet some standards established by audit companies to certify a product fit for sale. Before manufacturing any product, a level of standards must be established, and the organization needs to take measures to meet and retain those levels. Any improvement in raising those levels is encouraged by the higher authorities internally. The main agenda of the companies will be to manufacture the product of the product as per the intended design within the planned budget.

Table 2.1   Quality dimensions description

Quality Dimension	Definition	In-short
Performance	The ability of a product to give similar outcomes on every operation carried out by it.	Intended Operation
Reliability	A product is said to be reliable. When the rate of probability of failure is close to zero.	Dependence on operation
Durability	The ability of a product to remain functional and consistent with outcomes for a maximum possible period.	Capability to sustain
Serviceability	The easy to repair the product at minimal cost and time.	Ease to fix a problem
Aesthetics	Matter of how the product feels, looks, designed, which appeals to the customer based on their personal preference.	Looks and feels like
Features	The accessory characteristics of a product which supplement the primary functionality.	Added operations
Perceived Quality	Opinion based on image, brand, advertisement, rather than attribute and operation.	Reputation
Conformance to Standards	The degree to which a product meets its designed specifications.	Intended Design

CHAPTER III

BEST-WORST METHOD

Rezaei developed new non-linear decision-making (2015), and linear decision-making method (2016) called the best-worst method to answer discrete multi-attribute decision making (MADM) problems by making a pairwise comparison. In this research, we have adopted the linear approach which was developed from multi-criteria decision-making (MCDM) method. The reason to adopted BWM in this research is due to the fact that the results exhibit low standard deviation compared to other decision making methods like AHP (Analytic Hierarchy Process), Intuitive, SIR (Superiority and Inferiority Ranking Method), SWARA (Step-wise Weight Assessment Ratio Analysis) In this method, the best (most desirable or most important) and the worst (least desirable or least essential) criteria are identified and compared on a scale of 1 to 9 (1 being the least desirable and 9 being most desirable). The consistency ratio can test the reliability of the comparison. The advantage of BWM is that:

1) It requires fewer data to come up with a solution.

2) It provides a more significant comparison of decision criteria.

To illustrate the working of BWM Rezaei (2015) carried out the decision-making experiment on 50 university students to determine the best mobile phone out of 4 (Nokia Lumia 920, iPhone 5, Samsung Galaxy S III, Motorola Milestone 3). He compared his results with other decision-making methods such as the AHP method and the Intuitive method. All the three methods gave the same rankings to the mobile phones when considered the average values, but the

13

outstanding feature of the BWM is the consistency ratio, we can observe in his mathematics model the BWM produced more positive values with minimum deviation from the mean compared to the other methods. By looking at the nature of this method, many researchers have come forward to implement this method to solve complex decision-making problems. In one such research done by Badri et al.,(2017) to determine the social sustainability of supply chain, they have identified total of 15 criteria which they have ranked from high to low with the help of 38 experts to improve sustainability of supply chain in Iran where they were in position to develop sustainable supply chain management framework. The results show that the experts have weighed "contractual stakeholder influence" as the most crucial criterion, were as "occupational health and safety system" as the least important one. This framework will help the manufacturers in Iran to implement more efficient manufacturing systems. This research has even helped them to identify the limitation such as exploratory nature, non-homogeneity in the Iranian manufacturing sector, etc. which makes it hard to generalize the problem. However, it was clear that social sustainability in emerging economic countries needs further integrated studies if they want to see further development. A similar kind of study done by Munny et al (2019) has identified 10 enablers in the footwear industry to determine social sustainability in the supply chain. They have collected data from a team of 12 experts to develop an efficient supply chain plan. They constructed the framework in two steps; step one was to identify the enablers, and step two was to scale the enabler from 1-9 based on priority. After this, they carried out thorough research on the enablers by doing a sensitivity analysis to check for bias in results. They were able to determine workplace safety, wages and befits, and customer requirement as the top three enablers for the footwear industry. The author also ambits that this research cannot be limited to just the footwear but can be applied to various fields such as garments, leather, food processing, pharmaceuticals, and much more.

14

Table 3.1   Previous research on BWM

Author	Application
Rezaei (2015)	Mobile Phone selection
Badri et al (2017)	Social sustainability of supply chain
Munny et al (2019)	Social sustainability of footwear industry

CHAPTER IV

METHODOLOGY

The methodology for the proposed framework was conducted based on a systematic review of comprehensive literature. The search for relevant literature was guided using the Scopus and Web of Science databases through relevant keywords (i.e., Decision-making, multi-criteria, expert opinion, priority order) pertaining to the quality dimensions related to the polymer manufacturing plant performance. The database search included peer-reviewed papers, proceeding, and book chapters to comprehend all aspects related to the manufacturing and product quality. Initial search results produced 100+ publications. The initial screening of the publications was accomplished by reviewing the selected keywords and then filtering the publications based on the abstract to check the suitability and pertinence of the work. To further narrow the search results to obtain the most relevant list of publications related to only expert opinion on quality, we excluded papers that are not directly related to the research. A total of 6 relevant works was selected for extensive literature review for the right method. The proposed framework is developed based on the mentioned systematic review process. Figure 4.1 summarizes the steps used to develop the research methodology.
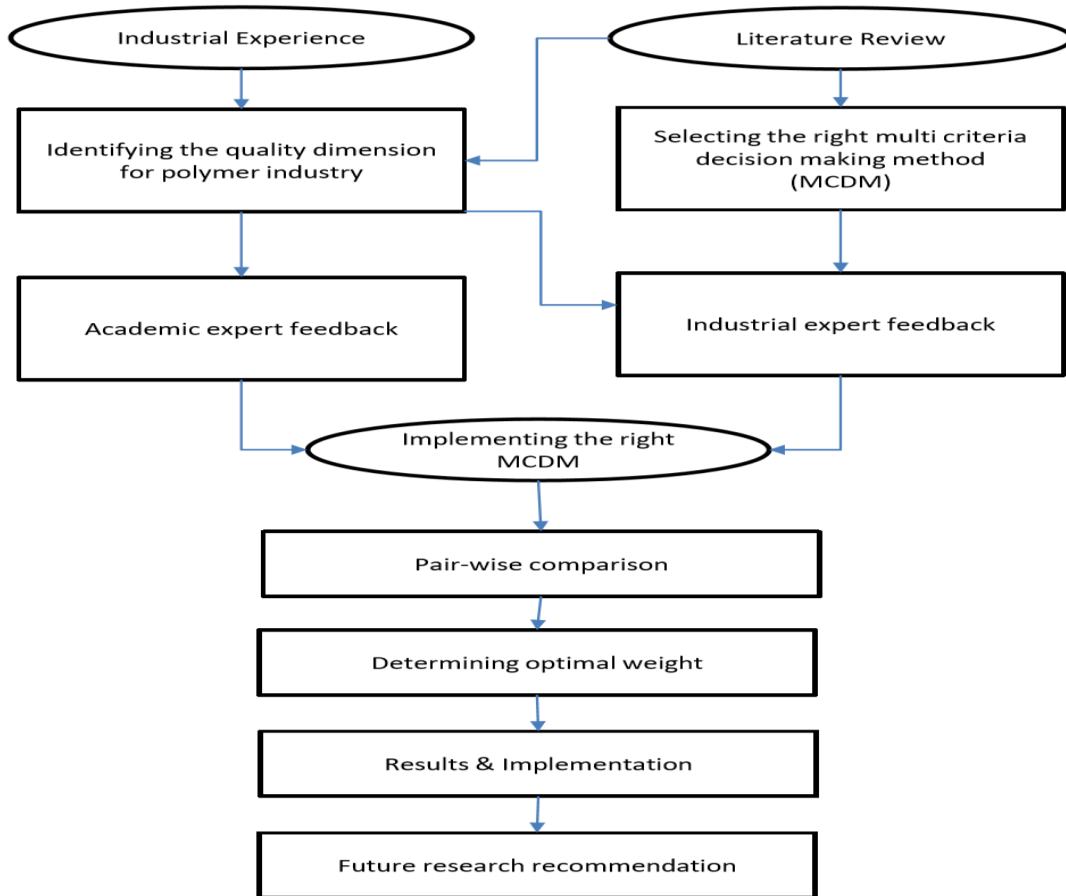
Figure 4.1　　Study flowchart

After identifying all the criteria, the other important step is to determine the priority of the quality dimensions based on pairwise comparison using BWM. This method is carried in a step by step manner to avoid any miscalculation. The procedure is as follows:

Step 1: Identify the criteria.

The decision-maker have the set of criterions $\{c_1, c_2, c_3, \ldots \ldots c_n\}$.

Step 2: To identify the best and worst criterion.

Out of these set of criteria, the best and the worst criterion must be identified by the decision-maker.

Step 3: To rank the best criterion over the others (Best-to-Others).

Determine the rank of the best criterion over other criteria based on the score ranging from 1-9, where 1 means the criteria have an equal preference with the best criteria, whereas 9 means the criteria have extreme preference over the best criteria. This results in the Best-to-Other (B.O.) vector, which is written as $X_b = (X_{B1}, X_{B2}, X_{B3}, \ldots \ldots X_{Bn})$ where X_{Bj} shows the rank of best criterion over the other criterion j, and it is clear that $X_{BB} = 1$.

Step 4: To rank all the criteria over the worst (Others-to-Worst).

The ranking of all the criteria over the worst criterion is expressed using the same scale 1-9. This results in the Other-to-Worst (O.W.) vector, which is written as $X_w = (X_{1w}, X_{2w}, X_{3w}, \ldots .. X_{nw})$ where X_{jw} shows the preference of the criterion j over the worst criterion, and it is clear to deduct that $X_{ww} = 1$.

Step 5: To determine the optimal weights.

The optimal weights $(w_1^*, w_2^*, w_3^*, \ldots \ldots w_n^*)^T$ were calculated and has to satisfy the following requirements: for each pair of w_B/w_j and w_j/w_W, the ideal situation was where $|w_B/w_j - X_{Bj}|$ and $|w_j/w_W - X_{jw}|$. Therefore, to get as close as possible to the ideal situation, we minimize the maximum among the set of $\{|w_B - X_{Bj}w_j|, |w_j - X_{jw}w_w|\}$, and the problem was formulated as follows:

$$\min \max_j \{|w_B/w_j - X_{Bj}|, |w_j/w_W - X_{jw}|\}$$

subject to

$$\begin{aligned} \Sigma_j \, w_j &= 1 \\ W_j &\geq 0, \, \forall \, j \end{aligned} \tag{4.1}$$

18

Problem Equation (4.1) can be transferred to the following linear programming problem:

min ξ^*

subject to

$$|w_B/w_j - X_{Bj}| \leq \xi^*, \forall j$$
$$|w_j/w_W - X_{jW}| \leq \xi^*, \forall j \qquad (4.2)$$

$$\sum_j w_j = 1$$
$$W_j \geq 0, \forall j \qquad (4.3)$$

After solving the problem, Eq. (2), the optimal weights $(w_1{}^*, w_2{}^*, w_3{}^*, \ldots, w_n{}^*)$ and ξ^{L*} were obtained. ξ^{L*} indicates the comparison system's consistency. The closer the value of ξ^{L*} is to zero, the higher the consistency, and consequently, the more reliable the comparisons become.

$$A = \begin{pmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \ddots & X_{2n} \\ \vdots & & & \vdots \\ X_{11} & X_{2n} & \cdots & X_{nn} \end{pmatrix} \qquad (4.4)$$

Here, X_{ij} shows the pairwise preference of criterion i to j, and $X_{ij} = 1$ tells that they are equally preferred. If $X_{ij} > 1$, then it says that i is preferred over j. The preference of j to i is shown by X_{ji}. For the matrix A to be reciprocal, it is required that $X_{ij} = 1/X_{ji}$ and $X_{ij} = 1 \; \forall \; i,j$. Taking into account the reciprocal property of a matrix, to obtain a complete matrix, it is necessary to have n(n-1)/2 pairwise comparisons.

A matrix is said to be perfectly consistent if:

$$X_{ik} \times X_{kj} = X_{ij} \quad \forall \; i, j \qquad (4.5)$$

19

A better understanding of pairwise comparison can be derived from equation (4.5), which serves as the foundation for BWM. In most cases, experts have no difficulty expressing the *direction*, but the real issue comes in expressing the *strength* of the preference, and it leads to inconsistency. To avoid such disorientation Rezaei (2015) recommended the following steps to implement the BWM more effectively.

Assumption 1: X_{ij} is considered as a reference element where i is the best criterion, and j is the worst.

Assumption 2: X_{ij} is considered as a secondary element if i nor j are the best or the worst criterion and $X_{ij} \geq 1$.

If we look at the matrix (4.4), we can see for n elements there are n^2 possible comparisons from which we can conclude for all similar n criteria i=j the value remains 1, i.e., ($X_{ii} = 1$). Whereas for rest $n(n-1)$, half of them, which are $X_{ij} > 1$ and the other half is reciprocal of the first half, and there are 2n-3 reference elements, and the remaining are the secondary elements. The secondary comparison is executed based on the knowledge of reference comparisons. The efficient way of approach would be to execute the reference comparison first, followed by the secondary comparison. This can be illustrated by considering three criterions A, B, and C. If we assign a value 7 to A over B and a value 5 to A over C then we can calculate the preference level of c over B as 7/5 ($X_{AC} \times X_{CB} = X_{AB}$; $5 \times X_{CB} = 7 \Rightarrow X_{CB} = 7/5$) each such secondary comparison can be represented in two ways:

$$X_{best,i} \times X_{ij} = X_{best,j} \tag{4.6}$$

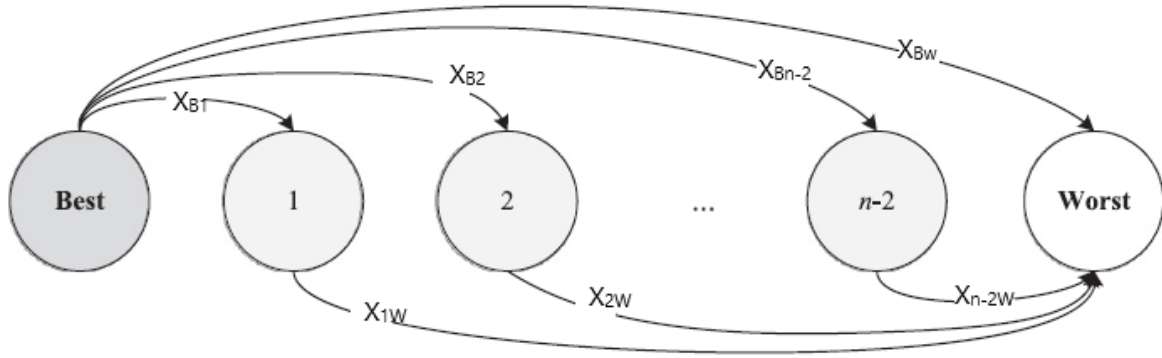$$X_{ij} \times X_{j,worst} = X_{i,worst} \tag{4.7}$$

20

Figure 4.2   Reference Comparisons

Nonetheless, there is another possibility that the relation $X_{AC} \times X_{CB} = X_{AB}$ has two more elements of this equality, and it is easy to determine the value of the other elements and prove that X_{AC} and X_{AB} are reference comparisons for X_{CB}. It implies that the decision-maker uses all the comparisons used for X_{AC} and X_{AB}. Besides, we need more elements that make comparison difficult. The fundamental purpose of this method is to keep the computation simple and provide an optimal solution.

Consistency Ratio: To assess the consistency of the data collection, we can use the fundamental matrix property $X_{Bj} \times X_{jW} = X_{BW}$, for all j, where X_{Bj} is the best criterion over j, X_{jW} is the ranking of j over the worst criterion. It is possible W_j for j=1,….n to be inconsistent in such cases we use consistency ratio to demonstrate the consistency of the data such that the sum of all the weights is equal to 1 and the maximum contravention of weights from their corresponding pairwise comparison be ξ. The consistency ratio ranges from 0 to 1, where the value 0 indicates the minimum variation of the results and fully consistent, and the value 1 indicates more variation in the data and hence inconsistent. First, we calculate the minimum consistency as, $X_{ij} \in \{1,…..,$ $X_{BW}\}$ where the value of X_{BW} ranges from 1 to 9, If $X_{Bj} \times X_{jW} \neq X_{BW}$ its consistency is lower. The

21

inequality which is denoted by ξ which occurs when X_{Bj} and X_{jW} have maximum value (equal to X_{BW}), we know that $(W.B./\ W_j) \times (W_j/w.w.) = W_B / W_W$. By removing the inequality (ξ) from the X_{Bj} and X_{jW} and adding to X_{BW} we get the equation.

$$(X_{Bj} - ξ) \times (X_{jW} - ξ) = (X_{BW} + ξ) \tag{4.8}$$

To minimize the inconsistency, consider $X_{Bj} = X_{jW} = X_{BW}$

Then we get,

$$(X_{BW} - ξ) \times (X_{BW} - ξ) = (X_{BW} + ξ) \tag{4.9}$$

$$\Rightarrow ξ2 - (1 + 2XBW)ξ + (X_{Bw}^2 - XBW) = 0 \tag{4.10}$$

We can find the maximum possible ξ by solving with different values of X_{BW} ranging from 1 to 9. The consistency ratio can be calculated by using $ξ^*$ and the corresponding Consistency Index (C.I.) as proposed by the author Rezaei (2015) is as follows:

$$\text{Consistency Ratio} = \frac{ξ^*}{Consistency\ Index} \tag{4.11}$$

Here we can notice that for a fully consistent problem where $ξ^* = 0$, each constrain can be converted to one other constrain for example $|\ w.b. - X_{Bj}W_j| \le ξ^*W_j$ is equated to W.B. $- X_{Bj}W_j = 0$ while for an inconsistent problem where $ξ^* > 0$ each constrain can be converted to two other

22

constraints, for example, $| W.B. - X_{Bj}W_j| \leq \xi^*W_j$ is converted into $W.B. - X_{Bj}W_j \leq \xi^*W_j$ and $X_{Bj}W_j - W.B. \leq \xi^*W_j$. Hence, we can see that there are 2n-3 equality constraints for fully consistent problems and 2(2n-3) equality constraints for an inconsistent problem. The weights of the criterion are calculated and represented as a consistency index table in the following manner.

Table 4.2   Consistency Index Table

X_{BW}	1	2	3	4	5	6	7	8	9
C.I	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9

The consistency index of a matrix of comparisons is given by Saaty TL (p-8,9; 2012) as an eigenvalue formulation $Aw = nw$, A is the pairwise comparison matrix and assuming the priorities $w = (w_1,w_2,\ldots\ldots w_n)$ with respect to the single criterion

$$\begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} = n \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} \qquad (4.12)$$

$$C.I = (\lambda max - n)/(n - 1)$$

If we do not have a consistent scale then it is hard to provide precise value for w_i/w_j then the eigenvalue becomes $A'w' = \lambda_{max}w'$; Where, λ_{max} is the largest eigenvalue ($A = a_{ij}$ with reciprocal $a_{ij} = 1/a_{ji}$) and $(w_i / w_j)\xi_{ij} = X_{ij}, \xi_{ij} > 0$, "n" is the number of rows in the matrix. For a fully consistent problem, we get a nonhomogeneous linear systems having "n" weighted variables and "n" constraints which results in a unique optimal solution and for a not-fully consistent

23

problem with "n" criteria always have a unique optimal solution, but if the criteria are more than three, it might have multiple optimal solutions, and the ranking of these criteria in multiple optimality is done by first calculating the lower and upper bounds of the weights of criterion "j." This method is carried out after solving equation 4.3 and having the value of ξ^*.

$$min\ wj \tag{4.13}$$

s.t.

$$|wB/wj - XBj| \leq \xi*, \forall j$$

$$|wj/wW - XjW| \leq \xi*, \forall j$$

$$\sum j wj = 1$$

$$Wj \geq 0, \forall j$$

$$max\ wj \tag{4.14}$$

$$s.t.$$

$$|wB/wj - XBj| \leq \xi*, \forall j$$

$$|wj/wW - XjW| \leq \xi*, \forall j$$

$$\sum j wj = 1$$

$$Wj \geq 0, \forall j$$

All the criteria can be determined by solving these two models. The ranking of criteria is done by using the center of intervals. The other way to rank the criteria is based on internal weights using a matrix of degree of preference and matrix of preference. We can carry out the interval

analysis to compare and rank the criteria by introducing basic operations of interval arithmetic and comparing interval numbers (Alefeld G, 1983).

Interpretation 1: An ordered pair is in a closed interval, shown in a bracket as:

$$U = [uL, uR] = \{x : uL\ v \leq x \leq uR, x\backslash \setminus in\ R\},$$

Where u_L and u_R are the left limits and right limit of U, respectively, the closed interval can also be defined by its center (u_C) and width (u_W).

$$U = [uC, uW] = \{x : uC - uW \leq x \leq uC + uW, x \setminus in\ R\},$$

Interpretation 2: Let $* \in \{ +, -, \times, / \}$ be a binary operation on two closed intervals U and V, then

$$U * V = \{x * y : x \in U, y \in V\}$$

Defined as binary operation on the set of closed intervals. It is assumed that, in the case of division, $0 \notin$ V.

The operation on closed intervals used in this paper is as shown.

$$U + V = [uL + vL, uR + vR]$$

$$U \times V = [min(uL \times vL, uL \times vR, uR \times vL, uR \times vR), max(uL \times vL, uL \times vR, uR \times vL, uR \times vR)]$$

$$U / V = [min(uL/vL, uL/vR, uR/vL, uR/vR), max(uL/vL, uL/vR, uR/vL, uR/vR)], if\ 0 \notin [vL, vR]$$

$$kU = \begin{cases} (ku_L, ku_L) & \text{for } k \geq 0 \\ (ku_L, ku_L) & \text{for } k < 0 \end{cases}$$

Where k is a real number

25

Here we describe some definition for comparing interval number

Let $U = [u_L, u_R]$ and $V = [v_L, v_R]$ be two interval numbers.

Interpretation 3: The degree of preference of U over V (U>V) is defined as:

$$P(U > V) = \frac{[\max(0, u_R - v_L) - \max(0, u_L - v_R)]}{[(u_R - u_L) + (v_R - v_L)]} \tag{4.15}$$

The degree of preference of V over U (V>U) is similarly calculated as:

$$P(V > U) = \frac{[\max(0, v_R - u_L) - \max(0, v_L - u_R)]}{[(u_R - u_L) + (v_R - v_L)]} \tag{4.16}$$

We can notice that P(U>V)+P(V>U) = 1 and P(U>V) = P(V>U) = ½ when U=V which implies $u_R=v_R$ and $u_L=v_L$.

Interpretation 4: If P(U>V) > P(V>U) or equivalently P(U>V) > ½, then U is said to be superior to V to the degree of P(U>V), denoted by U ∧ V; if P(U>V) = P(V>U) = 0.5, then U is said to be indifferent to V; denoted by U∼V; if P(V>U) > P(U>V) or equivalent P(V>U) > 0.5, then U is said to be inferior to the degree of P(V>U) denoted by U ∨ V.

As per the inferences, a not-fully consistent system with criteria over criterion "n" will have interval weights and the upper and lower limits of these intervals can be found by solving equation 4.13 and 4.14 respectively, The interval weights can be compared by using the 'matrix of

degree of preference' DP_{ij} and 'matrix of preference' P_{ij} respectively as discussed before and this

matrix is represented as following:

$$DP_{ij} = \begin{pmatrix} P(x_1 > x_1) & P(x_1 > x_2) & \cdots & P(x_1 > x_n) \\ P(x_2 > x_1) & P(x_2 > x_2) & \ddots & P(x_n > x_n) \\ \vdots & \vdots & & \vdots \\ P(x_n > x_1) & P(x_n > x_2) & & P(x_n > x_n) \end{pmatrix}_{n*n} \quad (4.17)$$

Where:

$$P_{ij} = \begin{pmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P_{n1} & P_{n2} & \cdots & P_{nn} \end{pmatrix} \quad (4.18)$$

$$P_{ij} = \begin{cases} 1, & \text{if } P(i > j) > 0.5 \\ 0, & \text{if } P(i > j) \leq 0.5, \ i, j = 1,2 \ldots n \end{cases}$$

Then we sum up the elements in the matrix P_{ij} and rank the criteria based on their sum value. We

can find the weights of the criterion j in the form of an interval as $w_j = [w_{jC} , w_{jW}] = \{x: w_{jC} - w_{jW}$

$\leq x \leq w_{jC} + w_{jW} , x \in R\}$ when done determining the weights as intervals equation $4.15 - 4.18$ can

be used as an input for debating and making an agreement on a set of weights within the range. In

such a case, we represent the center value as w_{jC} as an alternative.

27

4.1   A LINEAR APPROACH OF BWM

This model can product an outcome in multiple optimal solutions. If, instead of minimizing the maximum value among the set of $\{|w_B / w_j - X_{Bj}|, |w_j / w_W - X_{jW}|\}$, we minimize the maximum between the set of $\{w_B - X_{Bj}w_j|, |w_j - X_{jW}w_W|\}$, the problem can be demonstrated as follows.

$$min\ max_j\ \{|\ wB - XBjwj|, |wj - XjWwW|\}$$

$$s.t.$$

$$\sum j\ wj = 1$$

$$aWj \geq 0\ \forall\ j$$

This can be transformed into a following linear programming model as shown below

$$min\ \xi^*$$

$$s.t.$$

$$|wB - XBjwj| \leq \xi^*, \forall\ j$$

$$|wj - XjWww| \leq \xi^*, \forall\ j$$

$$\sum j\ wj = 1$$

$$Wj \geq 0, \forall\ j$$

The optimal weights $(w_1^*, w_2^*, w_3^*, \ldots\ldots, w_n^*)$, ξ^*_L, and a unique solution can be obtained by solving this linear model. Moreover, ξ^*_L can be directly considered as an indicator to assess the consistency of comparisons. The value of ξ^*_L close to zero shows the higher level of consistency.

28

CHAPTER V

DATA COLLECTION

We collected data on prioritizing quality dimensions from plastic film experts who have at least 2 years of experience in plastic film manufacturing. First, the experts were briefed and defined the 8 types of quality dimensions. Later a questionnaire was provided to them to fill out, and the data was collected for analysis using the Best-Worst method. A total of 40 experts were surveyed; based on the initial evaluation, eight sheets had to be excluded due to dubious responses. By analyzing the data, we found the following responses.

29

Table 5.1   Best Dimension for the plastic film as per the expert's opinion

Dimensions	Best Dimention by Experts	Percentage
Performance	6	18.75
Reliability	1	3.125
Durability	10	31.25
Serviceability	3	9.375
Aesthetics		0
Features		0
Preceived Quality	4	12.5
Conformance to Standards	8	25
Sum	32	

By looking at the raw data, we can notice that "Durability" was the most preferred dimension picked by 31% of experts.

Table 5.2   Worst Dimension for the plastic film as per expert's opinion

Dimensions	Worst Dimension by Experts	Percentage
Performance	1	3.125
Reliability	1	3.125
Durability		0
Serviceability	10	31.25
Aesthetics	8	25
Features	9	28.125
Preceived Quality	2	6.25
Conformance to Standards	1	3.125
Sum	32	

Here we can notice that the worst dimension picked by the experts with respect to the plastic film manufacturing is "Serviceability." When we compare both the tables 5.1 and 5.2, we can infer that if a product is durable enough, then it requires minimal repairs. When it comes to the plastic film production one, the plastic sheet roles out, it's impossible for any changes to the product. The purpose of the plastic is to last long without getting degraded, and experts believe in this concept while manufacturing. When we look at the worst dimension table, there is no expert who picked "Durability" to be the worst criteria. The below table 7 shows the results from the best worst method.

Table 5.3　　　Weights obtained from the BWM.

Experts	Quality Dimentions								Ksi (Consistency index)
	Performance	Reliability	Durability	Serviceability	Aesthetics	Features	Perceived	Comformance to standards	
1	0.135223555	0.1832061	0.183206107	0.017448201	0.091603053	0.022900763	0.183206107	0.183206107	0.047982552
2	0.165876777	0.3317536	0.099526066	0.071090047	0.02764613	0.055292259	0.165876777	0.082938389	0.165876777
3	0.257343384	0.1793605	0.071744216	0.071744216	0.031193138	0.08968027	0.119573694	0.179360541	0.101377697
4	0.149635036	0.2080292	0.069343066	0.018248175	0.069343066	0.069343066	0.208029197	0.208029197	0.058394161
5	0.389007852	0.1199143	0.085653105	0.035688794	0.074946467	0.074946467	0.099928622	0.119914347	0.210563883
6	0.315851157	0.0779373	0.066803399	0.077937299	0.116905948	0.233811896	0.032815705	0.077937299	0.151772634
7	0.268456376	0.0805369	0.134228188	0.033557047	0.201342282	0.134228188	0.067114094	0.080536913	0.134228188
8	0.294840295	0.1105651	0.088452088	0.147420147	0.049140049	0.088452088	0.073710074	0.147420147	0.147420147
9	0.105220558	0.1578308	0.078915419	0.052610279	0.032375556	0.063132335	0.206394172	0.303520842	0.109267503
10	0.135080645	0.1633065	0.163306452	0.014112903	0.163306452	0.034274194	0.163306452	0.163306452	0.036290323
11	0.102915952	0.1234991	0.077186964	0.030874786	0.068610635	0.102915952	0.416809605	0.077186964	0.200686106
12	0.098214286	0.1607143	0.160714286	0.080357143	0.160714286	0.017857143	0.160714286	0.160714286	0.0625
13	0.101265823	0.0759494	0.101265823	0.208860759	0.151898734	0.056962025	0.151898734	0.151898734	0.094936709
14	0.098684211	0.1315789	0.197368421	0.230263158	0.078947368	0.098684211	0.131578947	0.032894737	0.164473684
15	0.0625	0.0875	0.145833333	0.275	0.109375	0.145833333	0.028125	0.145833333	0.1625
16	0.185728643	0.1238191	0.185728643	0.050653266	0.053065327	0.046432161	0.092864322	0.261708543	0.109748744
17	0.199556541	0.1330377	0.133037694	0.066518847	0.049889135	0.027716186	0.079822616	0.310421286	0.088691796
18	0.112798265	0.1691974	0.084598698	0.039045553	0.112798265	0.169197397	0.084598698	0.227765727	0.110629067
19	0.139534884	0.1395349	0.139534884	0.139534884	0.069767442	0.093023256	0.139534884	0.139534884	0.139534884
20	0.112967157	0.0753114	0.075311438	0.225934315	0.030577576	0.064552661	0.112967157	0.302378256	0.149490374
21	0.153564899	0.0319927	0.115173675	0.065813528	0.0511883	0.057586837	0.230347349	0.294332724	0.166361974
22	0.196870268	0.0984351	0.078748107	0.065623423	0.131246845	0.040383645	0.131246845	0.257445734	0.136294801
23	0.081836781	0.0954762	0.071607183	0.114571494	0.06365083	0.031825415	0.190952489	0.350079564	0.222777904
24	0.090909091	0.1363636	0.136363636	0.136363636	0.136363636	0.136363636	0.136363636	0.090909091	0.136363636
25	0.122775801	0.0818505	0.202846975	0.122775801	0.185053381	0.017793594	0.185053381	0.081850534	0.042704626
26	0.142144638	0.0947631	0.179551122	0.142144638	0.024937656	0.142144638	0.094763092	0.179551122	0.104738155
27	0.146703925	0.0880224	0.332084339	0.220055887	0.062873111	0.028007113	0.073351962	0.048901308	0.108027436
28	0.109289617	0.1092896	0.237704918	0.163934426	0.024590164	0.081967213	0.109289617	0.163934426	0.090163934
29	0.199795082	0.2643443	0.133196721	0.043032787	0.133196721	0.079918033	0.079918033	0.066598361	0.135245902
30	0.11627907	0.0930233	0.290697674	0.11627907	0.058139535	0.093023256	0.07751938	0.15503876	0.174418605
31	0.136219898	0.1021649	0.242641693	0.081731939	0.058379956	0.038311846	0.136219898	0.204329847	0.166018
32	0.087682672	0.131524	0.183716075	0.087682672	0.121085595	0.020876827	0.121085595	0.246346555	0.079331942

The weights obtained by applying BWM on the data by the expert evaluation of quality dimensions.
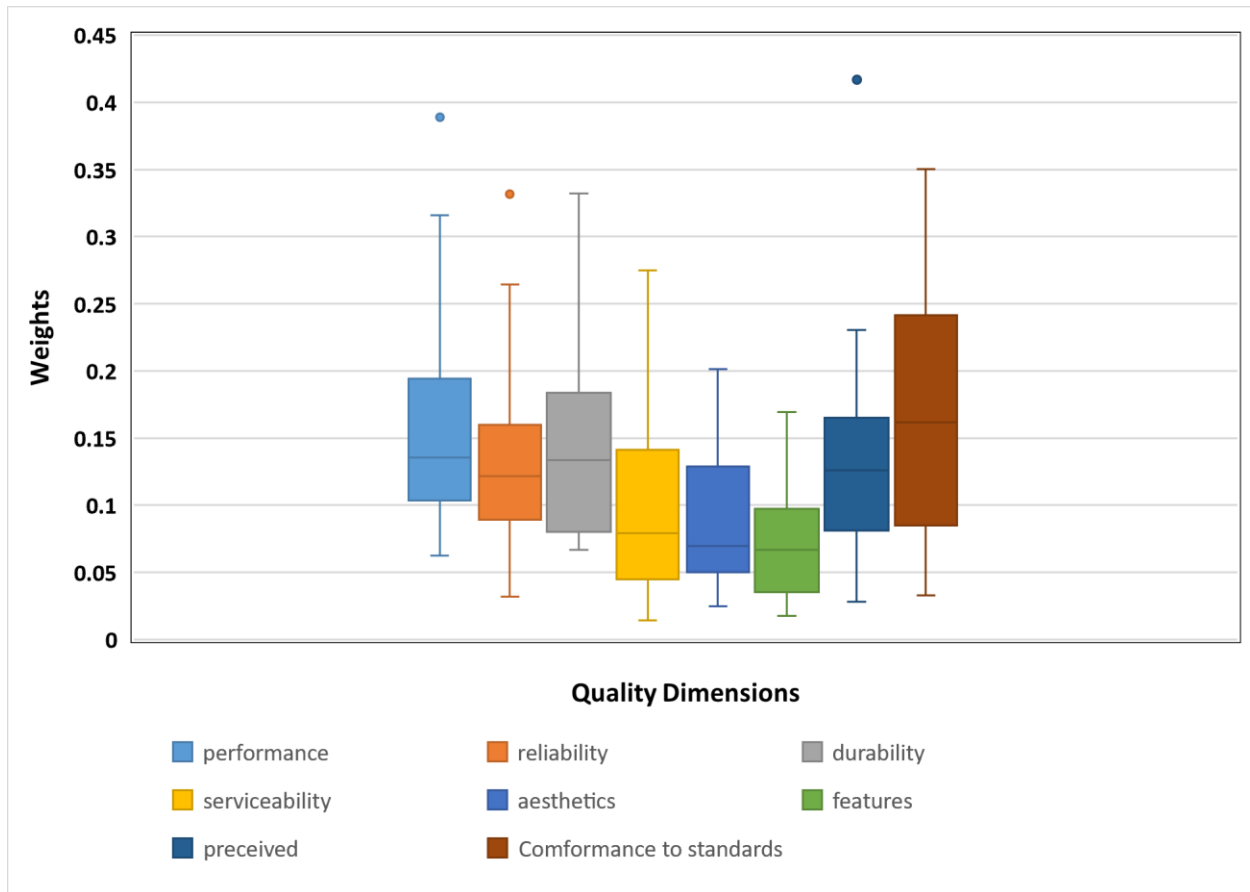
Figure 5.1   Box and Whisker plot of the optimal weights of BWM data.

The box and whisker plot for the data shows the reliability of the weights we obtained from the BWM. There are few outliers which shows the consistency of the results we obtained.

CHAPTER VI

RESULTS AND CONCLUSION

Based on each individual quality dimension weight from the Table 8 we get the average optimal weights, which is used to decide the priority order of the quality dimensions for the polymer industry.

Table 6.1   Average optimal weights.

Order	Quality Dimensions	Average Weights
1	Conformance to Standards	0.17174
2	Performance	0.15671
3	Durability	0.14207
4	Perceived Quality	0.13391
5	Reliability	0.12999
6	Serviceability	0.10147
7	Aesthetics	0.08732
8	Features	0.07679

By considering the average weights, we can rank the quality dimensions in the following order.

Consistency Ratio	0.125275

The priority of the quality dimensions is obtained in the following order for polymer industry.

Here, we can notice that "Conformance to Standards" is the highest priority dimension as determined by the BWM and "Featured" is the least important dimension respectively for the quality testing in the polymer industry.

REFERENCES

Akerlof, George A. (1970), "*The Market for 'Lemons': Quality Uncertainty and the Market Mechanism*," Quarterly Journal of Economics.

Alefeld G, Herzberger J (1983). "Introduction to interval computation." Academic Press, New York, USA.

Alfaqiri, A., Hossain, N. U. I., Jaradat, R., Abutabenjeh, S., Keating, C. B., Khasawneh, M. T., & Pinto, C. A. (2019). A systemic approach for disruption risk assessment in oil and gas supply chains. International Journal of Critical Infrastructures, 15(3), 230-259.

Allen, F. (1984). Reputation and Product Quality. The RAND Journal of Economics.

Avinger, R. L. (1981). *"Product Durability and Market Structure: Some Evidence*." The Journal of Industrial Economics.

Badri Ahmadi, H., Kusi-Sarpong, S., & Rezaei, J. (2017). Assessing the social sustainability of supply chains using Best Worst Method. Resources, Conservation and Recycling

Boulding, W., Kalra, A., & Staelin, R. (1999). *The Quality Double Whammy. Marketing Science.*

Brady, M. K., & Cronin, J. J. (2001). *Some New Thoughts on Conceptualizing Perceived Service Quality: A Hierarchical Approach. Journal of Marketing.*

Day, R. L., & Bodur, M. (1978). "*Consumer Response to Dissatisfaction with Services and Intangibles*." Advances in Consumer Research. 1978, Vol. 5, Issue 1, p263-272. 10p.

Deming, W. Edwards (1982), *Quality, Productivity, and Competitive Position*. Cambridge, MA: MIT Press.

Deming, W. Edwards (1986), *Out of Crisis: Quality, Productivity, and Competitive Position*. Cambridge, MA: MIT Press.

Doll, W., & Vonderembse, M. (1991). *The evolution of manufacturing systems: Towards the post-industrial enterprise. Omega*

Evans, J.R., and Lindsay, W.M., *The Management and Control of Quality, West, St. Paul, MN, 1989.*

Garvin, D. A. (1984). "*Product quality: An important strategic weapon*." Business Horizons,

Hillman Willis, T., and Willis, W. (1996), *"A quality performance management system for industrial construction engineering projects," International Journal of Quality & Reliability Management, Vol. 13 No. 9, pp. 38-48.*

Holbrook, M. B., & Corfman, K. P. (1985). *Quality and value in the consumption experience: Phaedrus rides again. Perceived Quality.*

Hossain N.U.I., & Jaradat, R. (2018). A synthesis of definitions for systems engineering. *Proceedings of the 2018 International Annual Conference of American Society for Engineering Management*, Coeur d'Alene, ID, October 17-20.

Hossain N.U.I., & Jaradat, R. (2018). Leveraging six sigma approach to reduce patient waiting time. *Proceedings of the 2018 International Annual Conference of American Society for Engineering Management*, Coeur d'Alene, ID, October 17-20.

Hossain N.U.I., El Amrani, S., Jaradat, R., Marufuzzaman. M., & Buchanan,R (2020). Modelling and assessing interdependencies between critical infrastructures using Bayesian network: A case study of inland waterway port and surrounding supply chain network. *Reliability Engineering and System Safety*.

Hossain N.U.I., Jaradat, R. M., Marufuzzaman, M., Buchanan, R.K., & Rinaudo C. (2019). Assessing oil and gas supply chain resilience: Bayesian Network approach. *Proceedings of the 2019 Industrial and Systems Engineering Conference*, Orlando, FL, May 19-23.

Hossain N.U.I., Nagahi. M., Jaradat, R., Shah, C., Hamilton, A., & Buchanan, R. (2019). Modeling and assessing cyber resilience of smart grid using Bayesian network-based approach: A System of Systems (SoS) problem. *Journal of Computational Design and Engineering. (Article in press)*

Hossain, N.U.I, Nagahi, M., Jaradat, R.M., & Keating, C. (2019). Development of an new instrument to assess the performance of systems engineers. *Fourth North American International Conference on Industrial Engineering and Operation Management,* Toronto, Canada, October 23-25.

Hossain, N.U.I., Jaradat, R., Hamilton, A, Keating, C., & Goerger, R. (2019). A historical perspective of Systems Engineering: A review and analysis. *Journal of Systems Science and Systems Engineering.*

Hossain, N.U.I., Jaradat, R., Hosseini, S., & Marufuzzaman, M. (2019). A framework for modeling and assessing system resilience using a Bayesian network: a case study of an interdependent electrical infrastructure system. *International Journal of Critical Infrastructure Protection*, 25, 62-83.

Hossain, N.U.I., Nur, F., & Habib, M. A. (2014). Achieving competitive advantage through practicing TQM tools in Pharmaceuticals Company. *Journal of Mechanical Engineering*, 43(2), 103-109.

Hossain, N.U.I., Nur, F., Jaradat, R., Hosseini, M., Marufuzzaman, M., & Puryear, S. (2019). M. A Bayesian network-based approach for modelling and assessing resilience: a case study of a full service deep water port. *Reliability engineering and System Safety*, 189, 378-396.
Hossain, N.U.I., Nur, F., Jaradat, R., Hosseini. M., Marufuzzaman. M., Puryear, S.M., & Buchanan R.K. (2019). Metrics for assessing overall performance of inland waterway port: a Bayesian network-based approach. *Complexity*.

Juran, J. M., & A., D. F. J. (2017). Juran's quality handbook: the complete guide to performance excellence. New York: McGraw Hill Education.

Maani, K. E., Putterill, M. S., & Sluti, D. G. (1994). *"Empirical Analysis of Quality Improvement in Manufacturing." International Journal of Quality & Reliability Management.*

Manufacturing Studies Board (1986). "*Towards New Era in U.S. Manufacturing: The Need for a National Vision*". National Academy Press, Washington, DC.

Meeker, W. Q., & Escoba, L. A. (2004). "*Reliability: The Other Dimension of Quality.*" Quality Technology & Quantitative Management

Montgomery, D. C. (2013). *"Introduction to statistical quality control*." Hoboken, NJ: Wiley.

Montoya-Weiss, M. (1994)*. "Determinants of new product performance: A review and meta-analysis*." Journal of Product Innovation Management.

Munny, A. A., Ali, S. M., Kabir, G., Moktadir, M. A., Rahman, T., & Mahtab, Z. (2019). Enablers of social sustainability in the supply chain: An example of footwear industry from an emerging economy. Sustainable Production and Consumption.

Nagahi, M., Hossain, N.U.I, Jaradat, R.M., Georger, S., & Abutabenjeh, S. (2020). Do the practitioners' level of systems-thinking skills differ across sector types? Proceedings of 14th Annual IEEE International Systems conference, Montreal, Canada, April 20-23. (Accepted)

Nagahi, M., Hossain, N.U.I, & Jaradat, R.M.(2019). Gender differences in practitioners preferences for systems thinking skills. Proceedings of the 2019 American Society for Engineering Management Annual Conference, Philadelphia, PA.
Nagahi, M., Hossain, N.U.I, Jaradat, R. M., & Grogan, S. (2019). Moderation effect of managerial experience on the level of systems thinking skills. Proceedings of 13th Annual IEEE International Systems conference, Orlando, FL, April 8-11.

Nur, F., Marufuzzaman, M., Puryear, S. M., Wall, E. S., & Burch, R. (2020). Inland waterway ports selection and evaluation using stochastic analytical hierarchy process. International Journal of Systems Science: Operations & Logistics, 1-21.

Nur, F., Alrahahleh, A., Burch, R., Reeves, K.B., & Marufuzzaman, M. (2020). Last mile delivery Drone selection and evaluation using the Interval Valued Inferential Fuzzy TOPSIS. Journal of Computational Design and Engineering.

Nur, F., Marufuzzaman, M., & Puryear, S. M. (2020). Optimizing inland waterway port management decisions considering water level fluctuations. Computers & Industrial Engineering, 140, 106210.

Paulson Gjerde, K. A., Slotnick, S. A., & Sobel, M. J. (2002). *"New Product Innovation with Multiple Features and Technology Constraints*." Management Science.

Pirsig, Robert M. (1974), *"Zen and the Art of Motorcycle Maintenance: An Inquiry into Values*." New York: HarperTorch.

Powell, T. C. (1995). *Total quality management as a competitive advantage: A review and empirical study*. Strategic Management Journal.

Pyzdek, T., & Keller, P. A. (2018). *"The six-sigma handbook*." New York: McGraw-Hill Education.

Reeves, Carol A. and David A. Bednar (1994), "*Defining Quality: Alternatives and Implications,"* Academy of Management Review

Rezaei, J. (2015). "Best-worst multi-criteria decision-making method". Omega (United Kingdom).

Rezaei, J. (2016). "Best-worst multi-criteria decision-making method": Some properties and a linear model. Omega,

Robson, K. (2013). *"Service-ability: create a customer-centric culture and gain a competitive advantage*." Chichester, West Sussex: Wiley.

Rust, R. T., Zahorik, A. J., & Keiningham, T. L. (1995). *Return on Quality (ROQ): Making Service Quality Financially Accountable. Journal of Marketing.*

Saaty TL, VargasLG (2012). How to make a decision. Models, methods, concepts & applications of the analytic hierarchy process. Springer.

Sebastianelli, R., & Tamimi, N. (2002). "*How product quality dimensions relate to defining quality."* International Journal of Quality & Reliability Management.

Shewhart, Walter A. (1986*), Statistical Methods from the Viewpoint of Quality Control*. New York: Dover.

Smith, G. F. (1993). The meaning of quality. Total Quality Management, 4(3), 235–244.

Spence, A. Michael (1975), "*Monopoly, Quality, and Regulation*," Bell Journal of Economics.

Young JA (1985). "*Global competition: The new reality". Calif.* Management Rev.

Zafarmand, S. J., Sugiyama, K., & Watanabe, M. (2003). *"Aesthetic and Sustainability: The Aesthetic Attributes Promoting Product Sustainability*." The Journal of Sustainable Product Design.