A clustering based matrix for selecting optimal tools and techniques in quality management

Hassan A. Alsultan

University of Northern Iowa

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A CLUSTERING BASED MATRIX FOR SELECTING OPTIMAL TOOLS AND TECHNIQUES IN QUALITY MANAGEMENT

An Abstract of a Dissertation

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Doctor of Industrial Technology

Approved:

_______________________________________
Dr. Ali E. Kashef, Committee Chair

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August 2014
ABSTRACT

The purpose of this research was to explore a systematic pattern for selecting quality tools and techniques in the manufacturing and service industries. This study asked, “What are the best DMAIC tools and techniques concerning circumstances of quality dimensions of products and services?” To answer this question, this research developed innovative, diagnostic matrices by mimicking the contradiction matrix of the Theory of Inventive Problem Solving (TRIZ). These innovative matrices are intended to help non-expert users to select the best sets of quality tools and techniques for solving different quality problems.

By conducting a cluster analysis, the researcher uncovered homogeneous patterns of enough quality case studies, which ultimately provided the basis for selecting optimal groups of quality tools and techniques in different circumstances. Thus, the researcher examined the association and prevalence of different quality tools and techniques (independent variables) and the quality dimensions (dependent variables).

The study developed the contradiction matrix for manufacturing, which includes the optimal 17 DMAIC lists of tools and techniques. Also, the study developed the contradiction matrix for service, which ultimately includes the optimal 15 DMAIC lists of tools and techniques. After developing and verifying the developed contradiction matrices, the researcher discussed their strengths and limitations as well as their roles for selecting the appropriate quality tools and techniques in the manufacturing and service industries. The results of this research can be used as a basis for many future investigations in the field of quality management and innovation.
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Hassan A. Alsultan
University of Northern Iowa
August 2014
DEDICATION

I humbly dedicate this dissertation to my dearest parents, Ali and Fatema, who have always stressed the importance of a good education. They successfully infused a love of learning in me; therefore, I am voracious for knowledge, and not surprisingly, I am relentless in my pursuit of my academic goals.

I also dedicate this dissertation to my beloved, small family, my wife Maryam and my son Loai, for their support, encouragement, love, and patience throughout my doctoral studies.
ACKNOWLEDGEMENTS

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# TABLE OF CONTENTS

| LIST OF TABLES | viii |
| LIST OF FIGURES | xi |
| **CHAPTER 1. INTRODUCTION** | 1 |
| Statement of the Problem | 2 |
| Statement of Purpose | 3 |
| Statement of Need | 4 |
| Research Questions | 6 |
| Assumptions of the Study | 6 |
| Limitations | 6 |
| Delimitations | 7 |
| Definition of Terms | 7 |
| **CHAPTER 2. REVIEW OF LITERATURE** | 10 |
| Quality Management | 10 |
| Quality Definition | 10 |
| Product Quality | 11 |
| Service Quality | 11 |
| The DMAIC Process | 12 |
| Define | 12 |
| Measure | 14 |
| Analyze | 16 |
Service Industry .......................................................................................................... 113
Data Collection .......................................................................................................... 113
Data Analysis ............................................................................................................. 117
Matrix Development ............................................................................................... 126
Matrix Validation .................................................................................................... 137
Summary ..................................................................................................................... 140

CHAPTER 5.  CONCLUSION, DISCUSSION, AND RECOMMENDATION .......... 142
Conclusion .................................................................................................................. 142
Research Question 1 ............................................................................................... 143
Research Question 2 ............................................................................................... 143
Research Question 3 ............................................................................................... 144
Discussion ................................................................................................................... 144
Recommendations ....................................................................................................... 147

REFERENCES ............................................................................................................... 149

APPENDIX A: DMAIC TOOLS AND TECHNIQUES IN MANUFACTURING ..... 175
APPENDIX B: DMAIC TOOLS AND TECHNIQUES IN SERVICE ....................... 191
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 List of Common Tools and Techniques Used in the Define Phase</td>
<td>14</td>
</tr>
<tr>
<td>2 List of Common Tools and Techniques Used in the Measure Phase</td>
<td>15</td>
</tr>
<tr>
<td>3 List of Common Tools and Techniques Used in the Analyze Phase</td>
<td>17</td>
</tr>
<tr>
<td>4 List of Common Tools and Techniques Used in the Improve Phase</td>
<td>19</td>
</tr>
<tr>
<td>5 List of Common Tools and Techniques Used in the Control Phase</td>
<td>20</td>
</tr>
<tr>
<td>6 Classification of QC7 into Quantitative and Non-Quantitative</td>
<td>25</td>
</tr>
<tr>
<td>7 Classification of QC7 Based on Role</td>
<td>25</td>
</tr>
<tr>
<td>8 Classification of QC7 Based on Presentation of Data</td>
<td>26</td>
</tr>
<tr>
<td>9 Sample Check Sheet</td>
<td>27</td>
</tr>
<tr>
<td>10 Safety Report</td>
<td>28</td>
</tr>
<tr>
<td>11 Pareto Chart Product Count</td>
<td>31</td>
</tr>
<tr>
<td>12 A Matrix Data Analysis Diagram of Customer Requirements for MicroTech</td>
<td>42</td>
</tr>
<tr>
<td>13 Short List of Quality Techniques</td>
<td>46</td>
</tr>
<tr>
<td>14 Rankings of Basic Quality Tools</td>
<td>51</td>
</tr>
<tr>
<td>15 Rankings of Advanced Techniques</td>
<td>52</td>
</tr>
<tr>
<td>16 Overall Rankings of Quality Tools and Techniques</td>
<td>53</td>
</tr>
<tr>
<td>17 The Forty Inventive Principles</td>
<td>61</td>
</tr>
<tr>
<td>18 The 39 Technical Parameters for the Contradiction Matrix</td>
<td>63</td>
</tr>
<tr>
<td>19 Portion of the TRIZ Contradiction Matrix</td>
<td>64</td>
</tr>
<tr>
<td>20 List of Quality Dimensions</td>
<td>73</td>
</tr>
</tbody>
</table>
21 Table of Data Collection for Manufacturing .........................................................74
22 Table of Data Collection for Service .................................................................75
23 DMAIC Quality Tools and Techniques in Each Case .........................................76
24 Cumulated Tools and Techniques for Clusters ...............................................79
25 Contradiction Matrix for Manufacturing Industry ...........................................82
26 Contradiction Matrix for Service Industry .......................................................83
27 Summary of Collected Data for the Manufacturing Industry .........................86
28 Number of Cases in each Dimension of Manufacturing .....................................89
29 Cluster Membership for the Manufacturing Industry ......................................92
30 Cases Number and Dimensions Used in Each Cluster of Manufacturing .........93
31 Cumulated Tools and Techniques for Clusters in Manufacturing ..................94
32 Performance and Reliability Dimensions .......................................................100
33 Contradiction Matrix for Manufacturing .......................................................101
34 Seventeen DMAIC Lists for the Contradiction Matrix for Manufacturing ..........102
35 Number of Cases Used in each DMAIC List of Manufacturing .......................109
36 Validated DMAIC Lists in the Contradiction Matrix for Manufacturing ...........111
37 Validation Cases for Manufacturing ...............................................................112
38 Validated DMAIC Lists Based on the Number of Cases in Manufacturing .......113
39 Summary of Collected Data for the Service Industry .......................................114
40 Number of Cases in each Dimension of Service .............................................117
41 Cluster Membership for the Service Industry ................................................120
42 Cases Number and Dimensions Used in Each Cluster of Service ...................121
43 Cumulated Tools and Techniques for Clusters in Service.................................122
44 Responsiveness and Reliability Dimensions ......................................................127
45 Contradiction Matrix for Service .......................................................................128
46 Fifteen DMAIC Lists for the Contradiction Matrix of Service .........................129
47 Number of Cases Used in each DMAIC List of Service .................................137
48 Validated DMAIC Lists in the Contradiction Matrix for Service .....................138
49 Validation Cases for Service ............................................................................139
50 Validated DMAIC Lists Based on The Number of Cases in Service .............140
A1 DMAIC Tools and Techniques for the 72 Cases in Manufacturing ...............175
B1 DMAIC Tools and Techniques for the 68 Cases in Service ..........................191
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scatter Diagram for Safety Report</td>
</tr>
<tr>
<td>2</td>
<td>Pareto Chart of Executive Escalation Complaints by Product</td>
</tr>
<tr>
<td>3</td>
<td>Control Chart Limits</td>
</tr>
<tr>
<td>4</td>
<td>A Cause-and-Effect Diagram for Poor Gas Mileage</td>
</tr>
<tr>
<td>5</td>
<td>Flowchart for the Filing Process</td>
</tr>
<tr>
<td>6</td>
<td>Example of an Affinity Diagram</td>
</tr>
<tr>
<td>7</td>
<td>Example “Why Why” Tree Diagram</td>
</tr>
<tr>
<td>8</td>
<td>Example Relations Diagram for Causes of Lost Files</td>
</tr>
<tr>
<td>9</td>
<td>An L-shaped Matrix Diagram</td>
</tr>
<tr>
<td>10</td>
<td>Example Process Decision Program Chart</td>
</tr>
<tr>
<td>11</td>
<td>Example Arrow Diagram</td>
</tr>
<tr>
<td>12</td>
<td>Flow Diagram for the New Seven Management Tools</td>
</tr>
<tr>
<td>13</td>
<td>Basic TRIZ Problem-Solving Process</td>
</tr>
<tr>
<td>14</td>
<td>The Overall Research Process</td>
</tr>
<tr>
<td>15</td>
<td>The Problem-Solving Process for the Research</td>
</tr>
<tr>
<td>16</td>
<td>Eight Garvin Dimensions of Product Quality and their Case Numbers</td>
</tr>
<tr>
<td>17</td>
<td>Dendrogram Diagram for the 72 Case Studies</td>
</tr>
<tr>
<td>18</td>
<td>Number of Cases Used in Each Cluster</td>
</tr>
<tr>
<td>19</td>
<td>Five SERVQUAL Dimensions of Service Quality and their Case Numbers</td>
</tr>
<tr>
<td>20</td>
<td>Dendrogram Diagram for the 68 Case Studies</td>
</tr>
</tbody>
</table>
21 Number of Cases Used in Each Cluster ...............................................................121
CHAPTER 1

INTRODUCTION

The equation of business success today counts on two major factors: competition and innovation (Speegle, 2009). Companies should consider quality as an inevitable and competitive tool for improving products and services in the market. Quality supports companies become more innovative, take advantage of workforce skills, cut waste, and improve efficiency and profit. According to Field and Swift (2012), companies cannot be competitive without making balance among quality, cost, and delivery. A successful company should strive to provide the highest quality at the lowest possible cost so that customers gain the best value (Imler, 2006).

Focusing on quality improvement is more about the process than the final result. After all, the way organizations manage their daily activities, the way quality is controlled (Swanson, 1995). In the quality field, many useful tools and techniques are used; Pyzdek and Keller (2003) estimated the list to be more than 400 tools and techniques. However, the importance/relevance of these tools and techniques relies on their appropriate selection and implementation in the right circumstances (Longenecker, Moore, Petty, & Palich, 2008). Swanson (1995) indicated that some teams make the mistake of inappropriately using the same quality tools and techniques consistently. Using various quality tools and techniques should not be fixed to every condition; rather, they should be flexible to specific problems and situations. Individuals involved in quality tasks need to know which quality tools to use, and when and how to implement those tools (Brady & Allen, 2006; Kwok & Tummala, 1998). Some tools might be more
applicable and useful for specific sectors, whereas others are not (Dale, 2003). Why do some organizations benefit and succeed enormously in implementing various tools and techniques, while others see limited benefits? What specific circumstances are best for implementing certain quality tools and techniques? Many questions must be addressed in this arena.

In addition to competition and improvement, business success also relies on innovation. While quality experts like W. Edwards Deming, Joseph M. Juran, and Philip B. Crosby have already established quality improvement principles within solid structures for more than five decades; innovation is not yet fully followed systemically, and is still ambiguous, as there is no structure or common path to fulfill innovation (Silverstein, DeCarlo, & Slocum, 2008). In today's world, improvement and innovation are not mutually exclusive; to gain a sustainable, competitive advantage in the current market, continuous innovation and improvement are needed at the same time. In order to set and balance the two parts of the business success equation, a method of applying innovation and improvement in a systematic and structured manner is needed. Thus, this study applied the Theory of Inventive Problem-Solving, or the Russian acronym TRIZ, which stands for Teoriya Resheniya Izobreatatelskikh Zadatch to establish a framework so as to solve problems concerning quality control and management systemically, effectively, efficiently, and innovatively.

Statement of the Problem

Although all quality tools and techniques are helpful, many companies do not utilize certain quality tools and techniques because they had bad experiences in applying
them (Novak, 2005). Among many reasons, the failure of utilizing these tools and techniques stem from the inappropriate selection of the right ones. Thus, the problem addressed in this study was to develop and validate a matrix model that helps manufacturing and service industries determine appropriate sets of quality tools and techniques in certain quality circumstances.

**Statement of Purpose**

The purpose of this proposed cross-sectional study, which using quantitative and qualitative secondary data analysis, was to find optimal sets of tools and techniques in the field of quality management related to the manufacturing and service industries. This study intended to develop innovative and diagnostic matrices by imitating the contradiction matrix of the Theory of Inventive Problem Solving (TRIZ). The innovative matrices help individuals and teams in the field of quality management to maximize the benefits of various quality tools and techniques within the quality dimensions of products and services. Antony, Antony, Kumar, and Cho (2007) indicated that building a roadmap to facilitate the decisions of selecting different tools and techniques is the key element for effective application. Also, according to Clegg, Rees, and Titchen (2010), the name of the overall methodology (such as Six Sigma, Lean, or TQM) is not a big concern for organizations, as long as the methodology used works and that clear benefits can be seen. Thus, the researcher attempted to develop a general Define, Measure, Analyze, Improve and Control (DMAIC) approach for optimal sets of tools and techniques, which allows quality tools and techniques to be implemented effectively and practically, especially for non-expert users.
Statement of Need

There is increased recognition of the need to identify appropriate tools and techniques to be used in the improvement process, as there are over 400 tools and techniques in the quality management area (Basu, 2004; Charantimath, 2011). Identifying such tools and techniques could use several criteria, including: their successful implementation in different circumstances; whether or not the tools and techniques selected are required or alternate in different conditions; and whether or not they apply to the manufacturing or service industries (Dale, 2003). Dale indicated that there is an urgent need for educating employees on the various benefits of quality tools and techniques. Designing a training program on how to use quality tools and techniques is essential. Although quality tools and techniques provide significant benefits, inappropriately applying them could create more problems in the quality system. Brady and Allen (2006) and Kwok and Tummala (1998) also indicated that tools and techniques sometimes fail to be effectively applied because of a lack of their roles and knowing when, where, and how to apply them.

There is a need for a thorough investigation as to the reasons or preferences of using certain tools over others, and what difficulties are encountered when implementing quality tools and techniques (Bamford & Greatbanks, 2005; Fotopoulos & Psomas, 2009). A critical mistake occurs when organizations try to implement tools and techniques separately, as the major benefits of these techniques depend on their sequential implementation (Dale, 2003). In order to effectively implement quality tools
and techniques in a sequence manner, they must be embedded within a systematic problem-solving approach.

There are many problem-solving approaches, such as PDCA cycle, the seven-step process, 8D, and Lean; however, the DMAIC approach is considered the best method to integrate as a part of other continuous improvement activities. Applying the DAMIC process as a general approach for improvement provides an effective and structured methodology that is adaptable to various quality tools and techniques—whether they originate from Six Sigma, Lean, Baldrige criteria, ISO 9000, or others (Snee, 2007). In addition to a problem-solving approach for effectively implementing different quality tools and techniques, there is an increased need to create a roadmap that guides individuals to select the right quality tools and techniques (Clegg et al., 2010; Hagemeyer, Gershenson, & Johnson, 2006).

Although there are abundant of studies about the degree of importance in applying various quality tools and techniques (Clegg et al., 2010; Drew & Healy, 2006; Fotopoulos & Psomas, 2009; Lagrosen & Lagrosen, 2005; Lam, 1996; Miguel, Satolo, Andrietta, & Calarge, 2012; Rowland-Jones, Thomas, & Page-Thomas, 2008; Sahran, Zeinalnezhad, & Mukhtar, 2010; Sousa, Aspinwall, Sampaio, & Rodrigues, 2005; Tari, 2005; Tari & Sabater, 2004), there are very few studies that propose a limited diagnostic methodology or a framework for implementing them (Hagemeyer et al., 2006; Miguel et al., 2012; Shahin, Arabzad, & Ghorbani, 2010; Timans, Ahaus, & Van Solingen, 2009). There are no comprehensive studies on quality tools and techniques, as many cover only a small portion of tools or one industry. Thus, developing innovative, diagnostic matrices that
consists of an optimal and a broad list of quality tools and techniques in both manufacturing and service industries is necessary for investigation.

**Research Questions**

The study addressed the following research questions:

1. What are the optimal tools and techniques for quality management in the manufacturing and service industries?

2. How does one diagnose which quality tools and techniques are more applicable in specific circumstances related to quality dimensions?

3. How does one maximize the benefits of all quality dimensions of products and services while tradeoffs have to be made between them?

**Assumptions of the Study**

The following assumptions were made in pursuit of this study:

1. Secondary data collected related to various quality tools and techniques are assumed to be accurate.

2. It is assumed that the variables of quality dimensions contradict each other, as indicated from the literature review.

3. It is also assumed that the Garvin dimensions of product quality, and that the SERVQUAL dimensions of service quality, are the best representative quality dimensions for manufacturing and service industries.

**Limitations**

The following limitations were identified for this study:

1. The study is limited to secondary data analysis.
2. Using non-random sampling method is one of the limitations of the study because the sample case studies have to be selected based on specific criteria.

3. Research resources and time are major limitations for this study; thus, the number of selected case studies that match the criteria of this research limit the study.

**Delimitations**

The following delimitations were identified for this study:

1. The study is delimited to data collected from case studies that include (a) DMAIC process, (b) quality dimensions, (c) tools and techniques successfully implemented, and (d) books and peer-reviewed articles that published between 2000 and 2014.

2. The developed matrices are delimited to the applicability of tools and techniques in the manufacturing and service industries.

3. The developed matrices are delimited to the applicability of tools and techniques in the area of quality (i.e., the Garvin dimensions of product quality and the SERVQUAL dimensions of service quality).

**Definition of Terms**

The following terms were defined to clarify their use in the context of the study:

**Quality tools and techniques.** Tools and techniques are a set of applications that have been adapted from various disciplines to provide a strong, data-driven methodology for solving issues and improving processes (Evans, 2011).
Tools. A tool is a narrow application that has a clear-cut role, and is mostly used separately, such as Cause-and-Effect Diagram, Control Chart, and Histogram (Dale & McQuater, 1998).

Techniques. A technique is a broader application that might depend on a collection of tools, and requires more knowledge, skills, and training, such as Statistical Process Control, Quality Function Deployment, and Design of Experiments (Dale & McQuater, 1998).

Continuous improvement. “Sometimes called continual improvement. The ongoing improvement of products, services, or processes through incremental and breakthrough improvements” (Russell, 2013, p. 197).

DMAIC process. Recognized as the Six Sigma methodology, which stands for Define, Measure, Analyze, Improve, and Control, is an effective methodology that aims to eliminate the root cause of a problem and improve the process by employing various sets of tools and techniques in a sequential and rational manner (Shankar, 2009).

PDCA cycle. A closed-loop cycle for a continuous improvement process, which comprises of four steps: Plan, Do, Check, and Act. This four-step cycle continues to rotate in an endless process for improvement to meet the customer’s changing needs and provides the best quality at the lowest possible cost (Bose, 2010).

Total Quality Management (TQM). TQM is a continual and total approach that seeks to involve everyone in the organization for the purpose of achieving customer satisfaction at the lowest cost (Roberts, 1993).
Theory of Inventing Problem Solving (TRIZ). “Empirical, constructive, qualitative, universal methodology for generating ideas and solving problems, primarily when projecting engineering systems, on the basis of contradiction models and methods to solve them were extracted from known inventions” (Orloff, 2012, p. 64).

Critical to quality characteristics (CTQ). It is a measurable way to turn customers’ needs for a product or service into a list of critical requirements that must be achieved (Voehl, Harrington, Mignosa, & Charron, 2013).

Quality function deployment (QFD). It is a systemic and planning tool that used to present the voice of the customer so that customers’ needs are turned into appropriate technical requirements (Stamatis, 2002).

Optimal: It means, in general, the most constructive way in determined circumstances (Bejan & Moran, 1996), “one that is most suited to its environment, one that will have the best mix of various tradeoffs” (Pongracic, 2009; p. 12).

Contradiction: “A contradiction is a conflict in the system” (Rantanen & Domb, 2008, p. 12). Contradiction is the best single world to describe the idea of TRIZ, which operates under the principal that if we try to improve or increase one part of a system, the other is forced to deteriorate or reduce.

Tradeoffs: Tradeoffs is a term used interchangeably with “technical contradictions” in TRIZ literature (Rantanen & Domb, 2008).
CHAPTER 2

REVIEW OF LITERATURE

Quality Management

Quality Definition

To understand the concept of quality management, it is imperative to highlight what the term \textit{quality} means. Notably, the term \textit{quality} has no single definition, because various quality gurus and organizations have different interpretations of it. For instance, Crosby (1984) defined \textit{quality} as “conforming to requirements” (p. 59); whereas Juran (1989) defined it as “fitness for use” (p. 58). The International Organization for Standardization (ISO) interpreted \textit{quality} as “the degree to which a set of inherent characteristics fulfills requirements” (as cited in Besterfield, 2009, p. 2). However, according to Summers (2010), Armand Feigenbaum’s definition of \textit{quality} is the most comprehensive:

\begin{quote}
Quality is a customer determination which is based on the customer’s actual experience with the product or service, measured against his or her requirements-stated or unstated, conscious or merely sensed, technically operational or entirely subjective-and always representing a moving target in a competitive market. (p. 4)
\end{quote}

Feigenbaum’s definition demonstrates that it is difficult to define \textit{quality} simply because customers’ expectations are consistently changing and can vary dramatically from one person to another. Thus, it is well-recognized that quality of products and/or services has different dimensions, all of which have been identified by various scholars (Sower, 2010).
Product Quality

Garvin (1988) developed one of the most respected definitions of quality dimensions for products (as cited in Charantimath, 2011):

1. Performance: The primary characteristics of the product.
2. Features: The additional characteristics that supplement the basic performance of the product.
3. Reliability: The ability of the product to perform or function over a period of time.
4. Conformance: The degree to which product performance can meet pre-selected specifications.
5. Durability: The strength of product life to perform without failure.
6. Serviceability: The degree to which a product is easy to repair.
7. Aesthetic: This deals with sensory aspects of a product, like appearance, sound, smell, and taste.
8. Perceived Quality: This refers to the customer’s perception and opinion about the product.

Service Quality

In the service arena, there are several lists of quality dimensions developed by various researchers for different industries. However, as a general service set, the SERVQUAL dimensions of service quality are considered to be the most widely accepted of lists (Carmona & Sieh, 2004; Morris, Pitt, & Honeycutt; 2001). The SERVQUAL dimensions are:
1. Reliability: The ability of the service to perform perfectly, as promised.
2. Responsiveness: The ability to provide support and help for customers.
3. Assurance: The ability of organization’s employees to install trust and credibility to customers through knowledge and courtesy.
4. Empathy: The ability to provide full attention and caring for individuals.
5. Tangibles: The physical appearance of organization’s facilities, equipment and employees.

The DMAIC Process

The DMAIC process is an updated and structured methodology for improvement, similar to the PDCA cycle (Plan, Do, Check, and Act; Burton, 2011). The DMAIC process is a powerful, problem-solving approach that forces individuals to think about the right questions through five sequential phases. Although the DMAIC process is associated with the Six Sigma methodology, it can also be implemented as an overall process for improvement (Snee, 2007). It is essential to realize that considering Total Quality Management (TQM) as an old approach that needs to be replaced with a new technique (such as the DMAIC process of Six Sigma) is not quite accurate, as the DMAIC process is not an entirely new technique; rather, it has a deep roots in the concept of TQM (Mohanty, 2009). Discussed below are the five phases of the DMAIC process.

Define

This phase defines the problem or goals of the improvement process. These goals must be outlined—whether they are intended for the top and strategic level, the
operational level, or the project level. Additionally, quality attributes, which are recognized as Critical to Quality characteristics (CTQ), must be clearly prioritized and identified. These attributes are determined by customers; thus, they must be updated periodically because customer expectations change over time (Charantimath, 2011). The following questions are addressed in the Define phase:

- What is the problem to be addressed?
- What is the goal? And by when?
- Who is the customer impacted?
- What are the CTQs in concern?
- What is the process under investigation? (Tang, Goh, Yam, & Yoap, 2006, p. 5)

Table 1 shows a list of the most common tools and techniques used in the Define phase of the DMAIC process.
Table 1

List of Common Tools and Techniques Used in the Define Phase

<table>
<thead>
<tr>
<th>Common Tools Used in the Define Phase</th>
<th>Common Tools Used in the Define Phase</th>
<th>Common Tools Used in the Define Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 whys</td>
<td>Data collection plan</td>
<td>Prioritization matrix</td>
</tr>
<tr>
<td>Activity network diagrams</td>
<td>Failure mode and effects analysis (FMEA)</td>
<td>Process decision program chart</td>
</tr>
<tr>
<td>Advanced quality planning</td>
<td>Flowchart/process mapping (as is)</td>
<td>Project charter</td>
</tr>
<tr>
<td>Affinity diagrams</td>
<td>Focus groups</td>
<td>Project management</td>
</tr>
<tr>
<td>Auditing</td>
<td>Force field analysis</td>
<td>Project scope</td>
</tr>
<tr>
<td>Benchmarking</td>
<td>Gantt chart</td>
<td>Project tracking</td>
</tr>
<tr>
<td>Brainstorming</td>
<td>Interrelationship digraphs</td>
<td>Quality function deployment (QFD)</td>
</tr>
<tr>
<td>Cause-and-effect diagrams</td>
<td>Kano model</td>
<td>Run charts</td>
</tr>
<tr>
<td>Check sheets</td>
<td>Matrix diagrams</td>
<td>Sampling</td>
</tr>
<tr>
<td>Communication plan</td>
<td>Meeting minutes</td>
<td>Stakeholder analysis</td>
</tr>
<tr>
<td>Control charts</td>
<td>Multi-voting</td>
<td>Supplier-input-process-output-customer (SIPOC)</td>
</tr>
<tr>
<td>Critical-to-quality (CTQ) tree</td>
<td>Normal group technique</td>
<td>Tollgate review</td>
</tr>
<tr>
<td>Customer identification</td>
<td>Pareto charts</td>
<td>Tree diagrams</td>
</tr>
<tr>
<td>Customer interviews</td>
<td>Project evaluation and review technique (PERT)</td>
<td>Y=f(x)</td>
</tr>
<tr>
<td>Data collection</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Kubiak (2012, p. 57)

Measure

After knowing what the problem is and identifying all of its elements, full documentation of the existing process needs to be measured. This stage requires collecting as much data as possible about the current process, which can be done by mapping the process in great detail. It is important that the details depict the period, cost,
and defects of each activity or task in the process. The reliability and validity of tools used to measure the process should be considered in this phase (Vanzant-Stern, 2012).

The following questions are addressed in the Measure phase:

- What are the performance variables and their impact?
- What is the gap between benchmark and existing status?
- What is the performance capability of the process/processes? (Charantimath, 2011, p. 207)

Table 2 shows a list of the most common tools and techniques used in the Measure phase.

Table 2

*List of Common Tools and Techniques Used in the Measure Phase*

<table>
<thead>
<tr>
<th>Common Tools Used in the Measure Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic statistics</td>
</tr>
<tr>
<td>Brainstorming</td>
</tr>
<tr>
<td>Cause-and-effect diagrams</td>
</tr>
<tr>
<td>Check sheets</td>
</tr>
<tr>
<td>Circle diagrams</td>
</tr>
<tr>
<td>Correlation</td>
</tr>
<tr>
<td>Data collection</td>
</tr>
<tr>
<td>Data collection plan</td>
</tr>
<tr>
<td>Failure mode and effects analysis (FMEA)</td>
</tr>
<tr>
<td>Flowcharts</td>
</tr>
<tr>
<td>Gage R&amp;R</td>
</tr>
<tr>
<td>Graphical methods</td>
</tr>
</tbody>
</table>

Source: Kubiak (2012, p. 57)
Analyze

Rushing directly to a solution without a rigid analysis is a critical issue in a problem-solving approach. In the Analyze phase, finding the root cause of the problem by analyzing defects already identified, or extreme variations from the previous phase, is performed (Evans, 2011). Reaching this step means working to reduce the gap between future performance (i.e., the Define phase) and current performance (i.e., the Measure phase), which cannot be done by merely listing all possible solutions or sources of the problem. Thus, identifying the “vital few” root causes is essential in this phase, and requires further statistical analysis, such as “what-if” calculations (Vanzant-Stern, 2012). Table 3 shows a list of the most common tools and techniques used in the Analyze phase.
Table 3

List of Common Tools and Techniques Used in the Analyze Phase

<table>
<thead>
<tr>
<th>Common Tools Used in the Analysis Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affinity diagrams</td>
</tr>
<tr>
<td>Hypothesis testing</td>
</tr>
<tr>
<td>Qualitative analysis</td>
</tr>
<tr>
<td>ANOVA</td>
</tr>
<tr>
<td>Interrelationship digraphs</td>
</tr>
<tr>
<td>Regression</td>
</tr>
<tr>
<td>Basic statistics</td>
</tr>
<tr>
<td>Linear programming</td>
</tr>
<tr>
<td>Reliability modeling</td>
</tr>
<tr>
<td>Brainstorming</td>
</tr>
<tr>
<td>Linear regression</td>
</tr>
<tr>
<td>Root cause analysis</td>
</tr>
<tr>
<td>Cause-and-effective diagrams</td>
</tr>
<tr>
<td>Logistic regression</td>
</tr>
<tr>
<td>Run charts</td>
</tr>
<tr>
<td>Components of variation</td>
</tr>
<tr>
<td>Meeting minutes</td>
</tr>
<tr>
<td>Scatter diagrams</td>
</tr>
<tr>
<td>Design of experiments (DOE)</td>
</tr>
<tr>
<td>Multi-vari studies</td>
</tr>
<tr>
<td>Shop audits</td>
</tr>
<tr>
<td>Exponential weighted moving average charts</td>
</tr>
<tr>
<td>Multiple regression</td>
</tr>
<tr>
<td>Simulation</td>
</tr>
<tr>
<td>Failure mode and effects analysis (FMEA)</td>
</tr>
<tr>
<td>Multivariate tools</td>
</tr>
<tr>
<td>Supplier-input-process-output-customer (SIPOC)</td>
</tr>
<tr>
<td>Force field analysis</td>
</tr>
<tr>
<td>Nonparametric tests</td>
</tr>
<tr>
<td>Tollgate review</td>
</tr>
<tr>
<td>Gap analysis</td>
</tr>
<tr>
<td>Preventive maintenance</td>
</tr>
<tr>
<td>Tree diagrams</td>
</tr>
<tr>
<td>General linear models (GLMs)</td>
</tr>
<tr>
<td>Process capability analysis</td>
</tr>
<tr>
<td>Waste analysis</td>
</tr>
<tr>
<td>Geometric dimension and tolerancing (GD&amp;T)</td>
</tr>
<tr>
<td>Project management</td>
</tr>
<tr>
<td>Y=f(x)</td>
</tr>
<tr>
<td>Histograms</td>
</tr>
<tr>
<td>Project tracking</td>
</tr>
</tbody>
</table>

Source: Kubiak (2012, p. 58)

Improve

After the root cause of the problem has been recognized, the Improve phase begins by proposing various ideas and solutions, and by testing them to find the best possible solution that leads to improvements in the process and in CTQs (Evans, 2011). In this step, it is critical to involve those who work regularly on the process. Their
experience may help uncover the best overall solution (Cano, Moguerza, & Redchuk, 2012). According to Persse (2008), the Improve phase generally takes the following steps:

- **Assess:** Study the outcomes of the Analyze phase in order to find potential opportunities for improvement.
- **Develop:** Develop and record different solutions and how those solutions may improve performance.
- **Select:** Evaluate different solutions and select the best one.
- **Modify:** Modify the structure of the current process to accommodate the new solution.
- **Pilot:** Pilot the new process after implementing the solution, and evaluate its performance.
- **Verify:** Verify the outcomes of the pilot for the new process to see if the process runs as planned. If so, implement it as a whole; if not, re-design the process.

Table 4 lists the most common tools and techniques used in the Improve phase.
Table 4

List of Common Tools and Techniques Used in the Improve Phase

<table>
<thead>
<tr>
<th>Common Tools Used in the Improve Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity network diagrams</td>
</tr>
<tr>
<td>Analysis of variance (ANOVA)</td>
</tr>
<tr>
<td>Brainstorming</td>
</tr>
<tr>
<td>Control chats</td>
</tr>
<tr>
<td>D-optimal designs</td>
</tr>
<tr>
<td>Design of experiments (DOE)</td>
</tr>
<tr>
<td>Evolutionary operations (EVOP)</td>
</tr>
<tr>
<td>Failure mode and effects analysis (FMEA)</td>
</tr>
<tr>
<td>Fault tree analysis (FTA)</td>
</tr>
<tr>
<td>Flowchart/process mapping (to be)</td>
</tr>
<tr>
<td>Gantt charts</td>
</tr>
<tr>
<td>Histograms</td>
</tr>
<tr>
<td>Hypothesis testing</td>
</tr>
</tbody>
</table>

Source: Kubiak (2012, p. 58)

Control

The main objective of the control phase is to maintain improvements in the process over time. One main issue with any continuous improvement process is the likelihood of things returning to the old way, as people tend to resist change (Gardner, 2004). One way to sustain control over the process is to take a mistake proofing
approach, which is a way to immediately correct errors as they occur, before being passed on to the next level. This method eliminates many errors from becoming defects later in the process. Another way to sustain control over the process is by using appropriate and applicable charts to graphically monitor the process over time. A detailed reaction plan—one that covers any out-of-control activities—has to be followed in the process to ensure that issues are addressed immediately (Stamatis, 2004). Table 5 lists the most common tools and techniques used in the Control phase.

Table 5

*List of Common Tools and Techniques Used in the Control Phase*

<table>
<thead>
<tr>
<th>Common Tools Used in the Control Phase</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5S Lessons learned</td>
<td>Standard operating procedures (SOPs)</td>
</tr>
<tr>
<td>Basic statistics Measurement systems analysis (MSA)</td>
<td>Standard work</td>
</tr>
<tr>
<td>Communication plan Meeting minutes</td>
<td>Statistical process control (SPC)</td>
</tr>
<tr>
<td>Continuing process measurements Mistake-proofing/poka-yoke</td>
<td>Tollgate review</td>
</tr>
<tr>
<td>Control charts Pre-control</td>
<td>Total productive maintenance</td>
</tr>
<tr>
<td>Control plan Project management</td>
<td>Training plan deployment</td>
</tr>
<tr>
<td>Data collection plan Project tracking</td>
<td>Visual factory</td>
</tr>
<tr>
<td>Kaizen Run chart</td>
<td>Work instructions</td>
</tr>
<tr>
<td>kanban Six Sigma storyboard</td>
<td></td>
</tr>
</tbody>
</table>

Source: Kubiak (2012, p. 57)
Quality Tools and Techniques

The successful implementation of quality management requires an effective and suitable use of different tools and techniques (Ahmed & Hassan, 2003; Barnes, 2008; Evans, 2011; Jafari & Setak, 2010; Longenecker et al., 2008; Mahadevan, 2010). Before discussing further the application of tools and techniques, it is paramount to distinguish between tools and techniques. Dale and McQuater (1998) identified clear definitions for tools and for techniques. They suggested that a tool is a narrow application that has a clear-cut role, and is mostly used separately, such as cause-and-effect diagrams, control charts, and histograms. A technique is a broader application that depends on a collection of tools, and requires more knowledge, skill, and training, such as statistical process control, quality function deployment, and design of experiments. Tools and techniques have been adapted from various disciplines to provide a strong, data-driven methodology for solving issues and improving processes (Evans, 2011). They range from simple tools to more complex techniques, and provide indispensable benefits and roles, such as identifying relationships, summarizing and organization data, discovering and eliminating the root cause of a problem, planning, and performance measurement (Dale, 2003).

There are three major elements that must be considered when selecting tools and techniques for quality issues. They are:

1. Tools and techniques must follow the purpose of their selection;
2. All workers intending to use tools and techniques must be trained on how to apply them effectively; and
3. The success of tools and techniques is measurable by the outcomes of the implementation. Does the implementation of the selected tools and techniques really help in solving the problem or not? (Basu, 2009)

**Application of Tools and Techniques**

Dale (2003) states that excessive dependence on one technique or tool is a major mistake, because no single tool or technique is more important than another; they may play a different role in different situations. Unfortunately, some managers use certain tools or techniques for a quick solution to a problem that may arise without considering their specific purpose or application. Real benefits of process improvement will not appear from a single tool or technique; rather, from a cumulative application of different tools and techniques in the long term.

Good advice for selecting tools and techniques is to start with simpler ones, such as the seven basic quality control tools, because they are often as useful as complex techniques. Astonishingly, many Japanese companies create great benefits in quality because they utilize the seven basic quality control tools effectively together. In the West, companies tend to overlook the seven basic quality control tools by underestimating their importance or by using them inefficiently—by employing them separately (Dale, 2003).

One key issue for the ineffective application of tools and techniques is poor implementation, which is usually caused by the following reasons:

1. Tools and techniques are used routinely for work activities without full consideration to their specific roles.

2. Using computer software exclusively for data collection and interpretation.
3. Tools and techniques hinder change instead of causing improvement.

4. Tools and techniques are limited only to be used by specialists. (Basu, 2009)

**Role of Management**

Even though many tools and techniques are simple, they are still not fully utilized, especially in small- or medium-sized organizations. Workers consider tools to be an overload to their regular responsibilities (Bamford & Greatbanks, 2005). In a study of quality management, Hennessy (2005) found that the support of management was the largest concern for quality professionals. Therefore, one factor influencing the successful application of tools and techniques is top management’s commitment. The use and application of tools and techniques must be embedded in the organization’s culture. Without an endorsement from the senior management team, and without recognizing the potential benefits of the tools and techniques, the tools and techniques cannot be effectively utilized. Management must also make sure that the resources available for applying tools and techniques are readily available to all employees. In this case, having a small group of employees trained effectively to pass knowledge of the various tools and techniques to other employees is a good strategy. This helps design training programs based on the culture of the organization, while also reducing cost by eliminating the need to hire consultants or outside trainers (Basu, 2009).

**Types of Quality Tools and Techniques**

In the process of identifying and eliminating quality problems, it is crucial to understand that there are two types of variation that may lead to a quality problem: special causes or common causes. Special causes occur because something wrong, but
controllable, has happened. On the other hand, workers cannot solve problems that occur because of common causes, because the problem is part of the system and not controlled by individuals; therefore, only management take action to solve the problem. Deming and Juran considered that around 85% of quality problems are common causes, and that these problems can be solved by basic quality tools (Mitra, 2012; Walker, Elshennawy, Gupta, & McShane-Vaughn, 2012). Dr. Ishikawa (as cited in Morrow, 2012) goes further and suggested that basic quality tools can solve 95% of quality issues.

Seven Basic Quality Control Tools (QC7)

Dr. Ishikawa originally presented the seven basic quality tools in 1968. These tools primarily provide a structure and a means for identifying, prioritizing, and analyzing data (Omachonu & Ross, 2004). They are also considered scientific tools that are illustrated graphically to improve the process (Christensen, Coombes-betz, & Stein, 2007). It is important to note that the seven quality tools are not in a fixed list, since some authors exclude one or more of the tools, and replace them with others. They are classified into quantitative and non-quantitative tools, as shown in Table 6.
Table 6

Classification of QC7 into Quantitative and Non-Quantitative

<table>
<thead>
<tr>
<th>Quantitative</th>
<th>Non-Quantitative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pareto chart</td>
<td>Cause-and-effect diagram</td>
</tr>
<tr>
<td>Control charts</td>
<td>Flowchart</td>
</tr>
<tr>
<td>Check sheet</td>
<td></td>
</tr>
<tr>
<td>Scatter diagram</td>
<td></td>
</tr>
<tr>
<td>Histogram</td>
<td></td>
</tr>
</tbody>
</table>

Source: Christensen et al. (2007, p. 54)

These tools could also be classified into three categories, as shown in Table 7.

Table 7

Classification of QC7 Based on Role

<table>
<thead>
<tr>
<th>Identifying Tools</th>
<th>Prioritizing &amp; Communicating Tools</th>
<th>Analyzing Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check sheet</td>
<td>Histogram</td>
<td>Cause-and-effect diagram</td>
</tr>
<tr>
<td>Flowchart</td>
<td>Pareto chart</td>
<td>Scatter diagram</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control charts</td>
</tr>
</tbody>
</table>

Adapted from Omachonu and Ross (2004).

Basic quality tools—except the check sheet—from the point of presentation of data on a process, can be categorized as shown in Table 8.
Table 8

Classification of QC7 Based on Presentation of Data

<table>
<thead>
<tr>
<th>Graphical Tools</th>
<th>Flow Diagrams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histograms</td>
<td>Cause-and-effect diagram</td>
</tr>
<tr>
<td>Pareto charts</td>
<td>Scatter diagram</td>
</tr>
<tr>
<td>Control charts</td>
<td>Flowchart</td>
</tr>
</tbody>
</table>

Adapted from Ahmed and Hassan (2003).

Check sheet. A check sheet is a systemic and structured form used at the start of data analysis. A check sheet can be used later as an entry for other techniques, such as a histogram, a Pareto chart, or a control chart (Omachonu & Ross, 2004). In addition to data collection, this technique could be used to monitor items that need to be accomplished (Vanzant-Stern, 2012). Although this type of data collection technique is simple and easy to understand, it is very critical that the data collected be accurate and related to the problem being investigated. Vanzant-Stern labeled five types of check sheets, which are:

- Classification;
- Location;
- Frequency;
- Measure; and
- Check list.

According to Omachonu and Ross (2004), the three major forms used in check sheets are defect-location check sheet, tally check sheet, and defect-cause check sheet. In
conclusion, a check sheet is a form used to differentiate between fact and opinion by recording data frequencies as well as different types of problems. Table 9 shows a sample check sheet.

Table 9

Sample Check Sheet

<table>
<thead>
<tr>
<th>Defect Type</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Assembly</td>
<td>II</td>
</tr>
<tr>
<td>2. Print quality</td>
<td>I I I I I I I I I I</td>
</tr>
<tr>
<td>3. Print detail</td>
<td>III</td>
</tr>
<tr>
<td>4. Edge flaw</td>
<td>I I I I I I I I I I I I I</td>
</tr>
<tr>
<td>5. Cosmetic</td>
<td>I I I I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer Complaints</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Missing ring</td>
<td>II</td>
</tr>
<tr>
<td>2. Print quality</td>
<td>I I I I I I I I I I I I I I I I I I I I</td>
</tr>
<tr>
<td>3. Misplace print</td>
<td>III</td>
</tr>
<tr>
<td>4. Rough edge</td>
<td>III</td>
</tr>
<tr>
<td>5. Type error</td>
<td>I I I I</td>
</tr>
<tr>
<td>6. Excess flash</td>
<td>I I I I I I I</td>
</tr>
<tr>
<td>7. Late shipment</td>
<td>I I I I</td>
</tr>
<tr>
<td>8. Bad count</td>
<td>I I I</td>
</tr>
</tbody>
</table>

Source: Charantimath (2003, p. 68)

Scatter diagram. A scatter diagram is a technique used to study two variables (Stamatis, 2012). It seeks to find if there is a relationship between the two variables that are depicted by plotting points on two axes ($x$ and $y$). The plotted points generate a visual pattern that determines the direction of the relationship, either positive or negative correlations, or no relationship at all. For instance, a positive correlation occurs when the increase in one variable leads an increase in the second variable, while a negative correlation occurs when the increase in one variable leads a decrease in the second.
However, the degree of the relationship between the two variables—whether a positive or a negative relationship—depends upon how closed or dispersed is the plotted points are. One important point to be identified is that the scatter diagram portrays only a visual relationship; it does not necessarily lead to a causal relationship. Table 10 and Figure 1 illustrate a scatter diagram for a large industrial plant that has seven divisions of the same type of work (Brase & Brase, 2011, p. 134). A safety inspector visited each division and recorded the number of work hours designated to safety training ($x$) and the number of work hours lost due to accidents ($y$). The results of the scatter diagram show, in general, that there is a negative correlation: as the number of hours in safety training increase, the number of hours lost because of accidents decreases.

Table 10

*Safety Report*

<table>
<thead>
<tr>
<th>Division</th>
<th>$x$</th>
<th>$y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>19</td>
<td>65</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>68</td>
</tr>
<tr>
<td>4</td>
<td>45</td>
<td>55</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>65</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>80</td>
<td>12</td>
</tr>
</tbody>
</table>

Source: Brase and Brase (2011, p. 134)
Figure 1. Scatter diagram for safety report. Source: Brase and Brase (2011, p. 134).

Histogram. A histogram is a simple bar graph used to portray the frequency distribution of multiple variables (Mahadevan, 2010). Each bar in the histogram is constructed based on the frequency number of each variable or attribute. Visual distribution of the attributes provides a significant benefit to organizations by highlighting the area needing to be traced to eliminate the root cause of the problem (Duffy, 2013). Duffy underlined three questions for interpreting histograms:

1. Is the process performing within specification limits?
2. Does the process seem to exhibit wide variation?
3. If action needs to be taken on the process, what action is appropriate? (p. 80)

To answer these three questions, the center and width of the histogram, based on its distribution, must be analyzed. Also, the shape of the histogram must be examined to determine if the process is normal. Typically, a bell-shaped curve indicates normality in
the process, while a significant deviation from a normal distribution may indicate problems in the process, which then must be considered.

**Pareto chart.** A Pareto chart is a graphical tool used to portray a large issue into small parts in order to distinguish the most important issues (Mears, 2009). A bar graph is constructed based on the Pareto principle, which is 80% of variance stemming from 20% of the causes. This means that only a few factors contribute the most to a process and that such factors should be prioritized in order to concentrate on those “vital few” first to solve the most pressing issue to improve the process. This technique is used for quality improvement of both products and services, where problems are addressed individually (Vasconcellos, 2003). By identifying which factors to improve first, quality improvement can be implemented specifically and accurately. While data on the Pareto chart are organized to illustrate the “vital few” and the “trivial many,” the data are limited to a specific point in time for a process (Gopalakrishnan, 2012). To overcome this limitation, the Pareto chart may be repeated as necessary so that more than one chart is presented for a single process (Harry, Mann, De Hodgins, Hulbert, & Lacke, 2010).

Overall, the significance of the Pareto chart in area of quality management is recognized as tackling the following questions: “What are the largest issues facing a team or business? What 20% of sources are causing 80% of the problems (80/20 rule)? What efforts should be focused on to achieve the greatest improvement?” (Vasconcellos, 2003, p. 27). A Pareto chart example is illustrated in Figure 2, where a manufacturing company wanted to know which products were the sources of the escalation of customer complaints. Table 11 provides the raw data used in the chart.
Figure 2. Pareto chart of executive escalation complaints by product. Source: Harry et al. (2010, p. 221).

Table 11

<table>
<thead>
<tr>
<th>Pareto Chart Product Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
</tr>
<tr>
<td>Percent</td>
</tr>
<tr>
<td>Cum %</td>
</tr>
</tbody>
</table>

Source: Harry et al. (2010, p. 221)

Control chart. A control chart is a graphical tool used to portray the variation of the process over time (Tague, 2005). There are several types of control charts used in different processes or for specific data, including averages charts, range charts, moving range charts, target charts, cumulative sum charts, proportion charts, and count charts. All of these types of charts are depicted in three lines: (1) a centerline (CL); (2) an upper line
for the upper control limit (UCL); and (3) a lower line for the lower control limit (LCL).

While the centerline represents the process average, the upper and lower control limits represent the spread of the process within -3\(\sigma\) and +3\(\sigma\) (Summers, 2010). Figure 3 illustrates the control chart limits. According to Summers (2010), there are two primary functions for a control chart. The first is as a decision-making tool that investigates an action regarding the current process. The information generated from the control chart provides the base for decision-makers to decide whether the process is in control or out-of-control conditions and determine the current capability of the process. Second, it is also a problem-solving tool that directs what or when improvements or adjustment need to be made based on an analysis of the scattered data in the graph.

Since control charts deal with variation of a process, it is essential to distinguish between two sources of variation, which are chance and assignable causes (Besterfield, 2009). Chance causes of variation are random and cannot be avoided because they are typically inherent in the process and are trivial. In contrast, assignable causes of variation have a great importance; they are not naturally part of the process and need to be eliminated. The process is recognized to be in control only when chance causes are found in the process, but when a process is out-of-control, there are assignable cases presented; thus, action needs to be taken to improve the process.
Figure 3. Control chart limits. Source: Rastogi (2010, p. 66).

**Cause-and-effective diagram.** A cause-and-effect diagram, also called a fishbone diagram, is a graphical technique used to identify the root causes of a major problem (Rastogi, 2010). This technique could be used in the brainstorming process, where the causes of a key problem are categorized by possible factors. Typically, the possible factors in a cause-and-effect diagram are organized within four major groups in the manufacturing and service industries. They are: methods, machines, manpower, and material in the manufacturing industry; and equipment, policies, procedures, and people in the service industry (Charantimath, 2003). After constructing a cause-and-effect diagram, all of possible causes that branch from the major groups are reviewed to identify the most likely factors by asking, “Could be the root cause of the problem?” Figure 4 illustrates a cause-and-effect diagram regarding the issue of a poor gas mileage.
Flowchart. A flowchart is a detailed map of a step-by-step process for the manufacturing and service operations (Mitra, 2012). It is used to simplify graphically the overall process so that bottlenecks can be identified, while redundant steps and non-value-added activities can be eliminated. The greatest benefit of a flowchart is derived from its ability to depict a general picture of the process by documenting and communicating the sequence of all activities at the same level to every individual in the organization (Omachonu & Ross, 2004). Although a flowchart provides basic information for an entire process, a different type of flowchart, called a deployment flowchart, may contain more details on a process, such as times, tools, and responsibilities (Westcott, 2006). Figure 5 shows a flowchart example for the filing process.
In conclusion, these seven basic quality tools serve tremendous benefits to organizations by eliminating most of the problems that may arise in their processes. It is unfortunate that organizations in general and small-to medium-sized enterprises (SME) in particular, rarely exploit these tools to their full benefit (Bamford & Greatbanks, 2005; Sahran et al., 2010; Tari & Sabater, 2004).
Seven New Management Tools

In 1977, the Japanese Union of Socialists and Engineers (JUSTE) released new quality tools to cope with issues that accounted for 15% to 20% of quality problems and could not be solved by basic quality tools (Bose, 2010). Initially, the trend of quality management was concentrated only on work process improvements; thus, utilizing the seven basic quality tools by first-line workers was significantly impactful. Later, focus shifted from first-line workers to managers (Dahlgaard, Khanji, & Kristensen, 2007). Therefore, new management tools became very helpful because they transferred large amounts of mostly qualitative, raw data into useful information that ultimately assisted management in planning (Sower, 2010). The new seven management tools are as follows:

1. Affinity Diagram;
2. Relations Diagram;
3. Tree Diagram;
4. Matrix Diagram;
5. Matrix Data Analysis Diagram;
6. Process Decision Program Chart (PDPC); and
7. Arrow Diagram.

**Affinity diagram.** An affinity diagram is a tool used to categorize a large and complicated sets of dispersed, qualitative information—typically generated from a brainstorming session—into small, understandable, and relevant groups (Christensen et al., 2007). Thus, this technique is not very useful for small and easy problems, or problems requiring instant solutions (Oakland, 2004). According to Sage and Rouse
(2009), creativity—more so than logic—is involved in the process of constructing the affinity diagram. Creating an affinity diagram is usually a team effort, and creativity is required for analyzing and identifying large sets of ideas, common thoughts, and patterns (Frigon, 1997). A simple example of an affinity diagram is shown in Figure 6.

Figure 6. Example of an affinity diagram. Source: Naagarazan and Arivalagar (2005, p. 85).
Tree diagram. A tree diagram is a logical framework used to branch a general and a complex issue into several, specific subdivisions (Lighter & Fair, 2004). It is a hierarchical approach, just like an affinity diagram; however, a tree diagram is developed from the top down using logic and analysis, while an affinity diagram is developed from the bottom up using creativity to link ideas together (Ficalora & Cohen, 2009). Also, while an affinity diagram is developed from raw data, a tree diagram is developed from a structure that is already built, such as a structure completed from an affinity diagram.

There are different types of tree diagrams, according to Marsh (1998):

1. The “Why Why” tree diagram: A “why” question is asked at every breaking branch until root causes are identified.
2. The “How How” tree diagram: A “how” question is asked at every breaking branch until controllable tasks are recognized.
3. The “What What” tree diagram: A “what” question is asked at every breaking branch until acceptable details are recognized.

An example of a “Why Why” tree diagram is illustrated in Figure 7 by Leebov (2003). Also, according to Arthur (2001), the four steps for constructing a tree diagram are:

1. Develop a clear statement of the problem.
2. Brainstorm all of the sub-goals, tasks, or criteria.
3. Repeat this process.
4. Check the logic of the diagram. (p. 123)
Relations diagram. A relations diagram is a graphical representation of a complicated issue in which the cause-and-effect relationships are identified (Charantimath, 2003). Relations diagrams are often used after constructing an affinity diagram for further exploration of the relations among collected information, where multi-directional (rather than linear relationships) are prescribed. Although this technique can be used individually, it is more effective when implemented in a team composed of
different departments, where every one in the team takes part in identifying the major problem. In contrast to an affinity diagram, a relations diagram is more logical than creative (Allison, 1996). It is constructed by placing the major problem at the center, and surrounding it with repeated arrows. Relations diagrams depict a network of cause-and-effects relationships that lead ultimately to the major problem. Figure 8 shows an example of a relations diagram.

Figure 8. Example relations diagram for causes of lost files. Source: Allison (1996, p. 47).

Matrix diagram. A matrix diagram is a systemic analysis that identifies relationships between two or more factors presented in a number of columns and rows (Pyzdek & Keller, 2003). A good approach to build a matrix diagram is to use details from the last level of a tree diagram to fill in the columns and rows in the matrix diagram. This type of technique is very helpful when there is a need to simplify the strength of the
correlations between different factors (Bialek, Duffy, & Moran, 2009). Depending on the number of factors needed to be compared, the appropriate type of matrix diagram is selected. For instance, an L-shaped matrix depicts relationships between two factors; T-shaped, Y-shaped, and C-shaped matrices depict relationships between three factors; and, an X-shaped matrix depicts relationships between four factors. An example of a simple L-shaped matrix diagram is illustrated in Figure 9.

![An L-shaped matrix diagram](image)

**Figure 9.** An L-shaped matrix diagram. Source: Evans and Lindsay (2012, p 577).

Matrix data analysis diagram. Once the analysis from the matrix diagram does not propose enough information for the targeted issue or task, the matrix data analysis diagram is used for further details (Stamatis, 1996). The matrix data analysis diagram is a graphical and numerical analysis that prioritizes variables quantitatively to augment decision-making (Bose, 2010). This technique is exceptional among the new seven management tools because it is the only technique that uses a numerical analysis. In practice, prioritization matrices are used instead of the matrix data analysis diagram.
because it is less rigorous to be implemented daily (Hambleton, 2007). An example of a matrix data analysis diagram is illustrated in Table 12.

Table 12

_A Matrix Data Analysis Diagram of Customer Requirements for MicroTech_

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Importance Weight</th>
<th>Best Competitor Evaluation</th>
<th>MicroTech Evaluation</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>+2</td>
</tr>
<tr>
<td>Reliability</td>
<td>4</td>
<td>7</td>
<td>8</td>
<td>+1</td>
</tr>
<tr>
<td>Delivery</td>
<td>1</td>
<td>8</td>
<td>5</td>
<td>-3</td>
</tr>
<tr>
<td>Technical support</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>-2</td>
</tr>
</tbody>
</table>

Source: Evans and Lindsay (2012, p 577)

Process decision program chart (PDPC). A process decision program chart is a tree-like diagram with extra preventive tasks (Bialek et al., 2009). It is a systematic technique that maps out all activities involved in a task or project during the entire process, with a documented contingency plan for anything that might go wrong. Thus, it is useful for identifying problematic elements in advance and for projecting specific solutions for those elements as they occur. This technique is particularly useful for large and complicated tasks, for when a task has very limited time, or when the cost of failure is considerably high. An example PDPC program chart is illustrated in Figure 10.
Figure 10. Example process decision program chart. Source: Westcott (2006, p. 343).

**Arrow diagram.** An arrow diagram, also known as an activity network diagram, is used to map the sequence of all activities and their time requirements for completing a specific task (Soleimannejed, 2004). This technique simplifies the complexity involved in the critical path method (CPM), the program evaluation, and review technique (PERT) to include scheduled tasks and their timing. The graphical presentation of the arrow diagram is useful for eliminating unnecessary activities and re-evaluating time specifications for each task while also knowing if the activities should be completed sequentially or simultaneously. A sample of an arrow diagram is illustrated in Figure 11.
Although the new seven management tools have proven to be useful in many management applications, several studies indicated limited use of them on a daily basis. For instance, in a study conducted by Sahran et al. (2010) to find the most frequently applied quality tools among Malaysian SMEs, they discovered that the new seven management tools are ranked among the least used. The same finding appeared in a study conducted by Hyland, Milia, and Sun (2005) to compare the application of quality tools and techniques among manufacturers in Hong Kong and Australia. According to Levesque and Walker (2008), these tools are primary effective in the conceptualization and ideation stages early in the process, and less relevant directly to process improvement.
work. This may depict reasons behind the limited use of the new seven management tools among quality practitioners. Also, there is a common misperception among many senior managers that these tools are complex and too difficult to practically implement (Bose, 2010). This misconception is not true, since the only tool that incorporates statistical analysis is the matrix data analysis diagram. Overall, Bose (2010) indicated that the application of the new seven management tools contributes significantly in cost reduction and product quality improvement among many other common applications. He also noted that the new seven management tools contribute the most, however, because they combine with each other and with the seven basic quality control tools (QC7). Figure 12 illustrates a combination flow diagram of the new seven management tools.

Figure 12. Flow diagram for the new seven management tools. Source: Bose (2010, p. 356).
Advanced Quality Techniques

A quality technique, as defined earlier, is a broader application than a tool and requires more specialized knowledge. Quality techniques are mostly used for high measurement to produce significant results, once applied correctly (Basu, 2004). Table 13 shows a short list of quality techniques, categorized in two groups.

Table 13

Short List of Quality Techniques

<table>
<thead>
<tr>
<th>Quantitative Techniques</th>
<th>Qualitative Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure mode and effects analysis (FMEA)</td>
<td>Benchmarking</td>
</tr>
<tr>
<td>Statistical process control (SPC)</td>
<td>The balance scorecard</td>
</tr>
<tr>
<td>Quality function deployment (QFD)</td>
<td>Sales and operations planning (S&amp;OP)</td>
</tr>
<tr>
<td>Design of experiment (DOE)</td>
<td>Kanban</td>
</tr>
<tr>
<td>Design for Six Sigma (DFSS)</td>
<td>Activity based costing (ABC)</td>
</tr>
<tr>
<td>Monte Carlo techniques (MCT)</td>
<td>Quality management system (ISO 9000)</td>
</tr>
</tbody>
</table>

Adapted from Basu (2004).

According to Clegg et al. (2010), non-expert, quality practitioners tend to undervalue the importance of these advanced techniques. Thus, training on utilizing techniques must be incorporated in a way that practitioners could see the potential benefits of techniques for current and future processes.

Selecting the Right Quality Tools

As stated earlier, the successful implementation of quality management cannot be achieved without the appropriate selection of different tools and techniques; thus various
elements that contribute directly and indirectly to such success must be identified. An investigation about implementing quality engineering tools and techniques in Malaysia’s and Indonesia’s automotive industries, conducted by Putri and Yusof (2009) revealed that usefulness and user-friendliness (i.e., ease of use) are the most significant internal factors for adopting quality tools and techniques, while necessity and the industry itself are the most external factors. The researchers also revealed that the most hindering factors for implementing these tools and techniques are a lack of knowledge about the tools, a poor measurement system and data handling, a lack of statistical knowledge, and a lack of managerial commitment.

Moreover, a study conducted by Burcher, Lee, and Waddell (2006) found that although quality managers in Britain and Australia have very limited skills in many quality tools and techniques, they do not pay a major effort to enhance their knowledge in that area. They do not use the most current quality tools and techniques, and they are perhaps not even aware of them. Quality managers in these two countries mostly employed a very narrow collection of tools and techniques, which consisted of brainstorming, control charts, and Pareto analysis.

In another study conducted by Psomas, Fotopoulos, and Kafetzopoulos (2011), unexpected finding was that some companies that have implemented a quality management system, such as ISO-9001, had very limited use of quality tools and techniques. The researchers discovered that although their samples of ISO-9001-certified manufacturing companies in Greece adopted high levels of core process management practices, these companies had low usage of proposed quality tools and techniques. This
study clearly indicates that quality tools and techniques are not a requirement for ISO-9001 certification as part of core process management practices. However, this implication does not indicate that quality tools and techniques are not critical: The study also revealed that quality tools and techniques had a significant, indirect impact on quality improvement. Researchers concluded that because the improvement efforts of the sample companies were not based on data analysis, true causes of problems, and fact-based managerial decisions, there will always be defects in the system, even in small margins. It is important to emphasize that achieving a zero defects level cannot be made without integrating the appropriate quality tools and techniques.

Here are some of questions that managers must address in selecting the right quality tools and techniques:

1. What is the fundamental purpose of the technique?
2. What will it achieve?
3. Will it produce benefits if applied on its own?
4. Is the technique right for the company’s product, processes, people, and culture?
5. How will the technique facilitate improvement?
6. How will it fit in with, complement, or support other techniques, methods?
7. What is the best method of introducing and then using the technique?
8. What are the potential difficulties in using the technique?
9. What are the limitations, if any, of the technique? (Dale, 2003, p.310)

In a nutshell, the more experienced an organization with the application of quality management, the more tendency it has to use different quality tools and techniques, particularly advanced ones (Revuelto-Taboada, Canet-Giner, & Balbastre-Benavent, 2011); and, the more an organization uses quality tools and techniques, the better performance it acquires, regardless of its size (Ahmed & Hassan, 2003).
Review of Studies on the Application of Quality Tools and Techniques

Several studies have been conducted to verify the priority and importance of different tools and techniques for quality improvement. For instance, a study by Tari and Sabater (2004) found that the most frequent tools and techniques used within 106 ISO-certified firms in Spain are audits, graphs, SPC, and flow charts, respectively. On the other hand, the least used tools and techniques in the firms studied were the basic tools. Another study by Drew and Healy (2006) of Irish organizations discovered that the most and widely used quality tools were customer surveys, followed by competitive benchmarking. In the study by Fotopoulos and Psomas (2009), it was found that two-thirds of the organizations studied used easy to understand tools, which included check sheets, flow charts, and data collection, while the remaining tools and techniques had very limited implementation. Also, a study conducted with Swedish quality professionals by Lagrosen and Lagrosen (2005) revealed that the application of all quality tools and techniques was generally limited, expect for flowcharts, which were used extensively. Although quality tools and techniques were used significantly more often in larger organizations (Fotopoulos & Psomas, 2009), they could be implemented in all organizations, regardless of size or type (Basu & Wright, 2012).

Small and Large Organizations

Tari and Sabater (2004) stated in their study that large organizations tend to use cause-and-effect diagrams, flow charts, problem-solving methods, and benchmarking more than smaller organizations. Also, a study of large companies in Turkey by Bayazit (2003) indicated that the most commonly used quality tools and techniques are statistical
process control, process charts, Pareto charts, cause-and-effect diagrams, quality control circles, just-in-time, quality audits, and total productivity maintenance.

On the other hand, Sahran et al. (2010) discovered in their study that small and medium enterprises (SME) are more applicable for safety team, 5S, house-keeping, and 5M checklists, respectively, for the basic tools, while quality function deployment and design of experiment are most used for advanced techniques. Also, Ahmed and Hassan (2003) revealed that the most common basic tools for SMEs are (in order) check sheets, process flow diagrams, histograms, cause-and-effective diagrams, and Pareto analysis; and the most common advanced techniques are inspection sampling, benchmarking, and SPC. Overall, Ahmed and Hassan suggested that the application of different quality tools and techniques is very limited for SMEs than for large firms.

**Manufacturing and Service Organizations**

Although few researchers indicated no significant difference in the application of tools and techniques between manufacturing and service industries (Fotopoulos & Psomas, 2009; Sousa et al., 2005), several other studies clearly showed the difference between the two industries based on the priority selection of different tools and techniques (Antony et al., 2007; Antony & Banuelas, 2002; Nicols, 2006).

In a study conducted by Yau (2000), the researcher found that the manufacturing industry more frequently used the seven basic quality control tools, acceptance sampling, and process capability, whereas the service industry used benchmarking, Gantt charts, and quality circles the most often. In another study conducted in the Saudi food industry
by Alsaleh (2007), the researcher revealed that control charts, histograms, and run charts were the tools and techniques used most often.

In general, manufacturing organizations more often apply quality improvement tools and techniques than do service organizations (Tari & Sabater, 2004). The following tables summarize studies about the application priorities for different tools and techniques, from different countries, and from different company types and sizes. Table 14 illustrates the rankings of basic quality tools. Table 15 illustrates the rankings of advanced techniques. Table 16 illustrates the rankings of both quality tools and techniques.

Table 14

*Rankings of Basic Quality Tools*

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<thead>
<tr>
<th>Source</th>
<th>Rankings</th>
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<tr>
<td></td>
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</table>
|                        | 2. Process flow diagram  
|                        | 3. Histogram  
|                        | 4. Cause-and-effect diagram  
|                        | 5. Pareto analysis  
|                        | 6. P-chart  
|                        | 7. X-bar chat  
|                        | 8. R-Chart  
|                        | 9. Scatter diagram  
|                        | 10. C-chart  
|                 | 2. Process charts  
|                 | 3. Pareto charts  
|                 | 4. Cause-and-effect diagram  
| Alsaleh (2007) | 1. Control chart  
|                 | 2. Histogram  
|                 | 3. Run chart  
|                 | 4. Cause-and-effect diagram  
|                 | 5. Pareto chart  
|                 | 6. Flow diagram  |
Table 15

*Rankings of Advanced Techniques*

<table>
<thead>
<tr>
<th>Source</th>
<th>Rankings</th>
<th>Source</th>
<th>Rankings</th>
</tr>
</thead>
</table>
| Sahran, Zeinalnezhad & Mukhtar (2010)       | 1. Quality function deployment  
2. Design of experiment  
3. Statistic method  
4. Motion study and time study  
5. Work design for Ergonomics  
2. Benchmarking  
3. SPC  
4. Capability measures  
5. TQM practice  
6. House of quality  
7. Concurrent engineering  
8. QFD  
9. Taguchi Methods                  |
| Bayazit (2003)                               | 1. Quality control circles  
2 Statistical process control  
3. Just-in-time  
4. Total productivity maintenance  
5. Quality audit |


**Table 16**

*Overall Rankings of Quality Tools and Techniques*

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*(table continues)*
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|---|---|---|---|---|---|

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<td></td>
<td></td>
<td></td>
<td>25. Departmental purpose analysis</td>
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</tr>
</tbody>
</table>
History of Inventive Problem Solving

Genrich S. Altshuller developed the Theory of Inventive Problem Solving in the Soviet Union in 1946 (Yang & El-Haik, 2003). After originally studying around 200,000 patents, Altshuller came up with inventive solutions based on 40,000 patents. He categorized inventive solutions into five major levels, derived from their scale of innovation. He discovered that there is at least one contradiction in all invention problems and, from this, determined invention levels as based on how in-depth and advanced the solutions of the contradictions were: “A contradiction is a conflict in the system” (as cited in Rantanen & Domb, 2008, p. 12). Contradiction is the best single word to describe the idea of TRIZ, which operates under the principal that if we try to improve or increase one part of a system, the other is forced to deteriorate or reduce.

The Need for TRIZ

TRIZ is a systematic approach that assists in solving difficult problems by using a collection of tools, principles, and techniques that were established by Altshuller and his colleagues who reviewed more than 2.5 million patents (Tennant, 2003). TRIZ guides problems to their resolution without having to use trial and error methods or by struggling to re-invent a new solution for a problem that has already been solved in a similar way. Since most industries search for solutions to problems from within their fields, the power of TRIZ lays in its ability to break boundaries between industries by providing solutions that may come from entirely distinct situations or unrelated fields (Gadd, 2011). The basic process of the TRIZ problem-solving method is depicted in Figure 13.
Main Elements of TRIZ

TRIZ has numerous components that range from different tools and methods to lists of patterns and principles. The most common principles of TRIZ are considered and described briefly in the sections that follow.

Function Modeling and Functional Analysis

Developing a model for a problem being investigated is one of the most important steps toward solving the actual problem. A picture is worth a thousand words; this is the case for modeling, which helps lay out the contradictions in any system (Silverstein et al., 2008). A system usually processes by using various functions, such as assisting functions, correcting functions, secondary useful functions, etc. Among these functions, the “Main Basic Function” is the most critical, because it drives the actual performance of any product or service. The Main Basic Function exists all the time in every process, while other functions may vary based on the methods used for the design. Any function that
does not add benefit or support to the Main Basic Function is considered harmful. For instance, while an internal-combustion engine provides power, it also provides harmful functions like noise, heat, and pollution. Ultimately, we should attempt to eliminate or reduce any harmful functions (Yang & El-Haik, 2003).

Modeling and function analysis are powerful TRIZ tools that used to identify problems. These tools help to find destructive relationships that are caused by various contradictions, as indicated by the negative and positive functions around the system (Tseng & Piller, 2003). Because of functionality, sharing knowledge becomes possible among large companies and SMEs, and across different boundaries. For example, general functions such as moving people and removing a solid object both have specific solutions (which are motor cars and washing powders, respectively), and by organizing knowledge by general functions, companies could examine specific solutions achieved across industries where general functions do not change among them. Thus, TRIZ emphasizes flexibility as the key for problem-solving techniques. There is no need for engineers or scientists to research problems only from within their limited fields, when solutions can be found somewhere that is similar or close.

**Ideality (Ideal Final Results)**

Rantanen and Domb (2008) defined ideality as “the measure of how close the system is to the ideal final result” (p.15). Ideality is basically the sum of all benefits, divided by the sum of all harms, plus their cost. Therefore, if the useful features or functions improve, ideality improves; also, if harmful features and costs reduce, ideality also improves. The ideality equation is a critical gauge of an innovative system. For an
effective problem-solving tool, costs and harmful functions should be minimized as much as possible while, at the same time, maximizing the benefits of useful features.

Resources

Using various resources effectively and creatively is a fundamental part of TRIZ. Rantanen and Domb (2008) wrote that “Resources are information, energy, properties, and such, available for solving contradictions. They are often invisible at first because we are accustomed to not seeing them when we look at the problem situation” (p.14). Many inventions have been achieved because their inventors realized that there were many, unused resources that should be utilized. The goal is to use all available resources to accomplish a better rate of ideality (Jugulum & Samuel, 2008). Yang (2008) divided resources into six categories:

1. Substance resources, such as raw materials and products, waste, and system elements;
2. Field resources, such as energy in the system and energy from the environment;
3. Space resources, such as empty space and space at the interfaces of different systems;
4. Time resources, such as pre-work periods, post-work periods, and time slots created by efficient scheduling;
5. Information/ knowledge resources, such as knowledge about all available substances, past knowledge, and knowledge of other people; and
6. Functional resources, such as un-utilized or under-utilized existing system main functions, and un-utilized or under-utilized existing system harmful functions.

Contradiction Matrix

Contradiction is the heart of TRIZ. As noted in the definition of inventive problem, “resolution of the contradiction is an indispensable condition of the removal of the relevant inventive problem” (Orloff, 2012, p 23). Contradiction occurs in a system whenever there is a conflict between different characteristics. For instance, enhancing one element causes the decrease of another. A simple example of contradiction from a daily life is driving a car: Driving faster gets us to our destination in less time, but we usually consume more gas in doing so. In this scenario, we make a compromise that does not solve the real problem. In TRIZ, problems are solved creatively by finding ways to eliminate contradictions while not compromising (San, Jin, & Li, 2009).

TRIZ divides contradiction into either a technical or a physical contradiction. According to Rodman (2005), “Technical contradictions, where the improvement of one characteristic degrades a different characteristic (strength vs. weight, speed vs. size, et cetera). Traditionally, this contradiction results in a system compromise. TRIZ attempts to eliminate the contradiction, and avoid the compromise” (p. 299). On the other hand, physical contradictions are “where a system characteristic [is in] conflict itself (i.e., it must be both higher and lower, present and absent, et cetera). TRIZ attempts to convert physical contradictions to technical contradictions” (p. 299).
Yang and El-Haik (2003) explained that physical contradictions could be solved by applying one or more of four separation principles, which are:

- Separation in time;
- Separation in space;
- Separation between components; and
- Separation between components and the set of the components.

While, technical contradictions could be solved by applying one or more of the forty inventive principles, as shown in Table 17.

### Table 17

*The Forty Inventive Principles*

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Segmentation</td>
</tr>
<tr>
<td>2.</td>
<td>Takeout</td>
</tr>
<tr>
<td>3.</td>
<td>Local quality</td>
</tr>
<tr>
<td>4.</td>
<td>Asymmetry</td>
</tr>
<tr>
<td>5.</td>
<td>Merging</td>
</tr>
<tr>
<td>6.</td>
<td>Universality</td>
</tr>
<tr>
<td>7.</td>
<td>Nested doll</td>
</tr>
<tr>
<td>8.</td>
<td>Anti-weight</td>
</tr>
<tr>
<td>9.</td>
<td>Preliminary anti-action</td>
</tr>
<tr>
<td>10.</td>
<td>Preliminary action</td>
</tr>
<tr>
<td>11.</td>
<td>Beforehand cushioning</td>
</tr>
<tr>
<td>12.</td>
<td>Equipotentiality</td>
</tr>
<tr>
<td>13.</td>
<td>“The other way around”</td>
</tr>
<tr>
<td>14.</td>
<td>Spheroidality</td>
</tr>
<tr>
<td>15.</td>
<td>Dynamics</td>
</tr>
<tr>
<td>16.</td>
<td>Partial or excessive actions</td>
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<tr>
<td>17.</td>
<td>Another dimension</td>
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<tr>
<td>18.</td>
<td>Mechanical vibration</td>
</tr>
<tr>
<td>19.</td>
<td>Periodic actions</td>
</tr>
<tr>
<td>20.</td>
<td>Continuity of useful action</td>
</tr>
<tr>
<td>21.</td>
<td>Skipping</td>
</tr>
<tr>
<td>22.</td>
<td>“Blessing in disguise”</td>
</tr>
<tr>
<td>23.</td>
<td>Feedback</td>
</tr>
<tr>
<td>24.</td>
<td>Intermediary</td>
</tr>
<tr>
<td>25.</td>
<td>Self-service</td>
</tr>
<tr>
<td>26.</td>
<td>Copying</td>
</tr>
<tr>
<td>27.</td>
<td>Cheap short-living</td>
</tr>
<tr>
<td>28.</td>
<td>Mechanical substitution</td>
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<tr>
<td>29.</td>
<td>Pneumatics and hydraulics</td>
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<tr>
<td>30.</td>
<td>Flexible shells and thin films</td>
</tr>
<tr>
<td>31.</td>
<td>Porous materials</td>
</tr>
<tr>
<td>32.</td>
<td>Color changes</td>
</tr>
<tr>
<td>33.</td>
<td>Homogeneity</td>
</tr>
<tr>
<td>34.</td>
<td>Discarding and recovering</td>
</tr>
<tr>
<td>35.</td>
<td>Parameter changes</td>
</tr>
<tr>
<td>36.</td>
<td>Phase transitions</td>
</tr>
<tr>
<td>37.</td>
<td>Thermal expansion</td>
</tr>
<tr>
<td>38.</td>
<td>Strong oxidants</td>
</tr>
<tr>
<td>39.</td>
<td>Inert atmosphere</td>
</tr>
<tr>
<td>40.</td>
<td>Composite materials</td>
</tr>
</tbody>
</table>

As indicated earlier, technical contradictions typically is the state where strength or increase in one element in a system leads to the loss or decrease in another. People tend to compromise to solve problems of this type. Altshuller extracted 39 parameters from over 40,000 patents, concluding that technical or innovative problems must have a pair of parameters: one parameter that is improving, while the other is deteriorating (Childs, 2013). A list of the 39 parameters is illustrated in Table 18. Altshuller also concluded that any problem that consists at least one pair of the 39 parameters could be resolved, without compromise, by using one of the 40 inventive principles. For practical implementation, the Contradiction Matrix is used to identify the correct principles for the appropriate problem so that the first column represents 39 improving parameters, while the first row represents 39 deteriorating parameters. The intersecting area lists the 40 principles that are recommended for the problem. A small sample of the TRIZ contradiction matrix is illustrated in Table 19.
Table 18

The 39 Technical Parameters for the Contradiction Matrix

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th></th>
<th>Description</th>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weight of moving object</td>
<td>14</td>
<td>Strength</td>
<td>27</td>
<td>Reliability</td>
</tr>
<tr>
<td>2</td>
<td>Weight of stationary object</td>
<td>15</td>
<td>Duration of action by moving object</td>
<td>28</td>
<td>Measurement Accuracy</td>
</tr>
<tr>
<td>3</td>
<td>Length of moving object</td>
<td>16</td>
<td>Duration of action by stationary object</td>
<td>29</td>
<td>Manufacturing precision</td>
</tr>
<tr>
<td>4</td>
<td>Length of stationary object</td>
<td>17</td>
<td>Temperature</td>
<td>30</td>
<td>Object-affected harmful factors</td>
</tr>
<tr>
<td>5</td>
<td>Area of moving object</td>
<td>18</td>
<td>Illumination intensity</td>
<td>31</td>
<td>Object-generated harmful factors</td>
</tr>
<tr>
<td>6</td>
<td>Area of stationary object</td>
<td>19</td>
<td>Use of energy by moving object</td>
<td>32</td>
<td>Ease of manufacture</td>
</tr>
<tr>
<td>7</td>
<td>Volume of moving object</td>
<td>20</td>
<td>Use of energy by stationary object</td>
<td>33</td>
<td>Convenience of use</td>
</tr>
<tr>
<td>8</td>
<td>Volume of stationary object</td>
<td>21</td>
<td>Power</td>
<td>34</td>
<td>Ease of repair</td>
</tr>
<tr>
<td>9</td>
<td>Speed</td>
<td>22</td>
<td>Loss of energy</td>
<td>35</td>
<td>Adaptability or versatility</td>
</tr>
<tr>
<td>10</td>
<td>Force</td>
<td>23</td>
<td>Loss of substance</td>
<td>36</td>
<td>Device complexity</td>
</tr>
<tr>
<td>11</td>
<td>Stress or Pressure</td>
<td>24</td>
<td>Loss of information</td>
<td>37</td>
<td>Difficult of detecting and measuring</td>
</tr>
<tr>
<td>12</td>
<td>Shape</td>
<td>25</td>
<td>Loss of time</td>
<td>38</td>
<td>Extent of automation</td>
</tr>
<tr>
<td>13</td>
<td>Stability of object’s composition</td>
<td>26</td>
<td>Quantity of substance</td>
<td>39</td>
<td>Productivity</td>
</tr>
</tbody>
</table>

Source: Gadd (2011, p.110)
Table 19

*Portion of the TRIZ Contradiction Matrix*

<table>
<thead>
<tr>
<th>39 Parameters</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of moving object</td>
<td>-</td>
<td>15 8</td>
<td>-</td>
<td>29 34</td>
<td>-</td>
<td>29 17</td>
<td>38 34</td>
</tr>
<tr>
<td>Weight of stationary object</td>
<td>-</td>
<td>-</td>
<td>10 1</td>
<td>29 35</td>
<td>-</td>
<td>35 30</td>
<td>13  2</td>
</tr>
<tr>
<td>Length of moving object</td>
<td>8 15</td>
<td>-</td>
<td>-</td>
<td>15 4</td>
<td>-</td>
<td>7 17</td>
<td>4 35</td>
</tr>
<tr>
<td>Length of stationary object</td>
<td>35 8</td>
<td>40 29</td>
<td>-</td>
<td>-</td>
<td>17 7</td>
<td>10 40</td>
<td>-</td>
</tr>
<tr>
<td>Area of moving object</td>
<td>2 17</td>
<td>29 4</td>
<td>14 15</td>
<td>-</td>
<td>-</td>
<td>7 14</td>
<td>17 4</td>
</tr>
<tr>
<td>Area of stationary object</td>
<td>30 2</td>
<td>14 18</td>
<td>26 7</td>
<td>9 39</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Volume of moving object</td>
<td>2 26</td>
<td>29 40</td>
<td>-</td>
<td>1 7 4</td>
<td>1 7 4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Volume of stationary object</td>
<td>35 10</td>
<td>19 14</td>
<td>19 15</td>
<td>35 2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Adapted from Gadd (2011, p.109)

**Non-Technical Application of TRIZ**

Because the initial users of TRIZ were engineers, the application of TRIZ has been classified into two categories: technical and non-technical. Engineers labeled any problem not from production or design as a non-technical problem (Domb, 2003). Zlotin
et al. (2001) extensively reviewed the application of TRIZ for non-technical problems, and indicated that the successful implementation of TRIZ for non-technical problems has been demonstrated many times since 1980s. Although the TRIZ approach is designed primarily for technical problems, it has been demonstrated by different researchers that TRIZ could also be applied successfully for non-technical problems. The 40 principles of the contradiction matrix have been exemplified thoroughly in quality management (Retsepor, 2003), service operations management (Zhang, Tan, & Chai, 2003), finance (Dourson, 2004), social life (Terninko, Zusman & Zlotin; 2001), marketing, sales and advertising (Retsepor, 2005), school administration (Hopper, Aaron, Dale & Domb; 1998), and many areas. In situations where the 40 principles cannot be applied directly, investigators have developed a new or modified the contradiction matrix. Examples include the modified contradiction matrix developed for health-care service (Altuntas & Yener; 2012) and the new contradiction matrices developed for business environment (Mann, 2001) and for construction (Chang, Yu, Cheng, & Lee, 2010).

Domb (2003) illustrated good examples of contradictions in non-technical problems. For instance, in physical contradictions, managers seek consistently to train their employees for specific tasks, but at the same time, they don’t want them to be away from their routinely tasks. In technical contradictions, the liberty of empowering employees leads to the deterioration of standardization.

TRIZ and Quality Management

Many quality engineers and production experts looking for innovation and ideal solutions find TRIZ a very helpful technique once it is integrated with other quality tools,
such as Quality Function Deployment, Taguchi, Lean, Six Sigma, and Value Engineering (Gadd, 2011; Tague, 2005). Using such quality tools individually does not cover the entire problem-solving process; these tools are more helpful for a specific part of a problem. Thus, a package of different tools and methods that can tackle an entire problem, and find the ultimate solution, is needed. TRIZ serves as a systematic and universal approach for solving problems that is more efficient with quality improvements related to cost and time (Rumane, 2010).

**TRIZ and Six Sigma**

TRIZ and Six Sigma can be integrated into an effective, single procedure that combines innovation with analytical tools. The ultimate goal of this method is to generate superior results by reducing the cycle time and targeting to a zero-defect process delivery. Although Six Sigma is well-known for achieving success—especially in improving existing processes that are failing—it does have deficiencies in designing and introducing new products or services (Zhao, 2005). Six Sigma needs TRIZ: Six Sigma is a process-centered technique that may fail to recognize the entire system. Six Sigma, DAMIC projects typically avoid conflict, and do not adopt contradictory ideas; this leaves room for enhancements that can be carried out by TRIZ. For instance, TRIZ contradiction techniques (i.e., the 40 inventive principles) add value particularly in the improvement and measurement stages. Also, the concept of an Ideal Final Result is a very helpful tool in the Define stage, among others. Design for Six Sigma (DFSS) is another methodology that could gain substantial benefits from TRIZ, where designers can reduce work activities through fewer compromises. TRIZ also offers advantages for DFSS in New
Product Introduction (NPI) by empowering the concept of Ideal Final Results (Tennant, 2003).

**TRIZ, QFD, and Taguchi**

Integrating TRIZ with QFD and Taguchi methods provides customer-driven, robust innovation (Jayaswal & Patton, 2007). Although these methods all come from separate procedures, they relate to each other through a robust design process. This process starts with QFD, which is then followed by TRIZ, and ends with Taguchi. QFD is a systematic approach that transforms the needs of customers into engineering requirements. TRIZ, then, is linked in to provide creative solutions, while Taguchi sets parameter values for the designed product or service.

**Conclusion**

With the current, competitive market, organizations must seek innovation alongside improvement. Quality improvement has been already well-established by many quality gurus while innovation is not yet a fully structured domain. There is a need for a framework that combines improvement and innovation systematically. Thus, TRIZ, which is an inventive technique, serves as a powerful tool for quality management, despite its origins outside the field. Due to the importance and advantages of the TRIZ technique, several studies have extended the benefits of TRIZ to non-technical areas. However, more studies are needed to enlighten the potential benefit of TRIZ in the quality field where the link between innovation and improvement can be thoroughly defined.
 CHAPTER 3

METHODOLOGY

This chapter presents a summary of the steps used as a research methodology in this study, including the research design, method, data analysis, matrix development, and matrix validation. Figure 14 illustrates the overall process of the research.

Figure 14. The overall research process.
Research Design

This research followed a cross-sectional research design, and examined different patterns of quality tools and techniques. In this study, the researcher attempted to extend the applicability of the TRIZ contradiction matrix to the area of quality management to develop a roadmap for selecting various quality tools and techniques. A matrix model based on the TRIZ methodology was proposed, and several case studies were used to verify the applicability of the matrix in the area of quality management.

Cross-Sectional Design

A cross-sectional design was the framework used in this study for collecting and analyzing quantitative and qualitative data from various cases at a single point in time to uncover related patterns (Bryman & Bell, 2007). A cross-sectional design was appropriate for the study because of the nature and purpose of the study, where analyzing the variation and complexity involved in selecting quality tools and techniques requires studying a large sample of cases. This design is effective because it can be conducted for a limited time, and at minimum cost (Wilson, 2010). One important point to highlight here is that a cross-sectional design does not determine causal relationships (as an experimental design does) because of its descriptive nature; however, it does provide the basic grounds for decision-making. Also, the cross-sectional design is a more practical choice than an experimental design where there are a large number of variables under investigation, which makes a cross-sectional design a good fit for complex models (Lee & Lings, 2008).
Validity and Reliability

Cross-sectional designs are typically weak for internal validity, because they do not determine strong cause-and-effect relationships (Bryman & Bell, 2007). This limitation, however, was not an issue for this proposed study, since the study was focused more on the associations of different quality tools and techniques than on revealing causation. In terms of external validity, this study employed matrix validation to confirm outcomes. This validation offset the limitation of using a non-random sampling method in selecting the case studies. The researcher selected as large a sample as possible and carefully selected peer-reviewed case studies based on specific criteria to reduce bias that may occur from the non-random sampling. According to Lee and Lings (2007), selecting a large and suitable sample in cross-sectional designs leads to stronger external validity over experimental designs. As far as reliability is concerned, cluster analysis was employed to increase the reliability of this study, as quantitative measurements are considered more reliable than qualitative measurements (Briggs, Morrison, & Coleman, 2012). Also, an organized database from various cases was presented in this research so that other researchers are able to retrieve and re-examine the original data (Yin, 2009).

Research Method

The purpose of this study was to develop a contradiction matrix that serves as an aid for individuals or organizations in quality management. Building the contradiction matrix was requiring large sets of data, collected from many cases, to find patterns of similarities; thus, a cross-sectional design and a secondary data analysis were ideally
suited for this research. Published case studies were the method used for collecting data for this study.

Secondary Data

Secondary data is defined as data that have been collected primarily by other investigators than the researcher himself during literature review (Wilson, 2010). Data could be several types, such as: newspaper reports, magazine articles, annual reports, company documents, published case descriptions, printed government sources, and many others. Although primary data are often considered the best for conducting research, it can sometimes be impractical or impossible if large sets of data need to be obtained (Vartanian, 2011). Alternatively, secondary data provide researchers with access to a broad range of data, which is why this study was designed entirely using secondary data from published case descriptions. This research study was requiring large sets of data concerning the application of quality tools and techniques in real-life settings, making it economically impractical to gather primary data, especially, when useful primary data have already been collected by other researchers.

Case Selection

This study aimed to collect a minimum sample of 100 cases that were purposely selected and examined. The main criteria for selecting case studies for this research were based on the following five points:

1. Case studies of tools and techniques in DMAIC were only considered.
2. The tools and techniques must had been implemented successfully. Success was reviewed in the case description and measured as achieving financial reward or any sort of improvement.

3. Cases published in journal articles, proceedings papers, and books were only considered.

4. The dates of published cases were only considered to be between 2000 and 2014.

5. Case studies within the domain of quality management were only considered. The domain of quality management was measured by having at least one quality dimension of a product or service included in the case study.

Data Collection

While published case studies were the data for this study, various databases were used for collecting the data. Google scholar was the primary source of data collection followed by many major databases such as EBSCOhost, Emerald, ScienceDirect, Emerald, and ProQuest. The data collected were limited to tools and techniques implemented within quality dimensions that consist of the eight Garvin dimensions of product quality (Garvin, 1988) and the five SERVQUAL dimensions of service quality (Parasuraman, Berry, & Zeithaml, 1991). Table 20 illustrates the list of quality dimensions in this study.
Table 20

*List of Quality Dimensions*

<table>
<thead>
<tr>
<th>Service Quality Dimensions</th>
<th>Product Quality Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tangibles</td>
<td>Performance</td>
</tr>
<tr>
<td>Reliability</td>
<td>Features</td>
</tr>
<tr>
<td>Responsiveness</td>
<td>Reliability</td>
</tr>
<tr>
<td>Assurance</td>
<td>Conformance</td>
</tr>
<tr>
<td>Empathy</td>
<td>Durability</td>
</tr>
<tr>
<td></td>
<td>Serviceability</td>
</tr>
<tr>
<td></td>
<td>Aesthetics</td>
</tr>
<tr>
<td></td>
<td>Perceived Quality</td>
</tr>
</tbody>
</table>

Each case from the selected sample was represented in a binary code—as a linear combination of the 13 dimensions (dependent variables). Each dimension was either given a value of one (1) if it was used in the case problem, or a value of zero (0) if it was not (Kim & Park, 2008). Overall data were collected and organized in a “rectangle” of data (Marsh, 1998; as cited in Bryman & Bell, 2007). Table 21 illustrates the data collection for manufacturing and Table 22 illustrates the data collection for service, while Table 23 represents the list of DMAIC quality tools and techniques (independent variables) in each case for both manufacturing and service.
Table 21

*Table of Data Collection for Manufacturing*

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Case Reference</th>
<th>Performance</th>
<th>Features</th>
<th>Reliability</th>
<th>Conformance</th>
<th>Durability</th>
<th>Serviceability</th>
<th>Aesthetics</th>
<th>Perceived Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Case 2</td>
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<td></td>
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<tr>
<td>Case 3</td>
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<tr>
<td>Case 4</td>
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<tr>
<td>Case 5</td>
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<td></td>
</tr>
</tbody>
</table>
Table 22

Table of Data Collection for Service Quality

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Case Reference</th>
<th>Tangibles</th>
<th>Reliability</th>
<th>Responsiveness</th>
<th>Assurance</th>
<th>Empathy</th>
<th>Serviceability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Case 2</td>
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<td></td>
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<td></td>
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<tr>
<td>Case 3</td>
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</tr>
<tr>
<td>Case 4</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Case 5</td>
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</tr>
</tbody>
</table>
Table 23

*DMAIC Quality Tools and Techniques in Each Case*

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Case Reference</th>
<th>DMAIC Phase</th>
<th>Tools &amp; Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td></td>
<td>Define</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analyze</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improve</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>Case 2</td>
<td></td>
<td>Define</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analyze</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improve</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>Case n</td>
<td></td>
<td>Define</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Analyze</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improve</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td></td>
</tr>
</tbody>
</table>

**Data Analysis**

The research was seeking to uncover homogenous patterns of different quality case studies, ultimately providing the optimal groups of quality tools and techniques used in certain circumstances. Cluster analysis was therefore selected as the best fit for the study.

**Cluster Analysis**

Cluster analysis is an exploratory technique that seeks to classify large data sets into small, homogeneous groups (Everitt, Landau, Leese, & Stahl, 2011). This classification serves as an aid for researchers so that they can easily comprehend large amounts of data precisely by recognizing patterns of similarity and differences that can
be found in the data. The primary purpose in conducting cluster analysis is to find out if cases (i.e., the data set) can be grouped into smaller clusters that share similar values (Todman & Dugard, 2007).

According to Blattberg, Kim, and Neslin (2008), the clustering process follows five steps:

1. Choosing the clustering variables.
2. Choosing a measurement for similarity.
4. Decide upon the ultimate number of clusters to be analyzed.
5. Perform and analyze the clustering outcome.

In the first step of the cluster analysis, cluster variables is determined; however, in cluster analysis, there is no distinction between dependent and independent variables, because the purpose of the cluster analysis is to group cases into random, homogenous clusters based on the selected clustering variables (Blattberg et al., 2008). The variables selected for this study were the eight Garvin dimensions of product quality (Garvin, 1988) and the five SERVQUAL dimensions of service quality.

In the second step of the clustering process, and after selecting variables on which to cluster, a measurement for variable similarities is selected, such as distance type, matching type, scaling, and weighting (Blattberg et al., 2008). In this study, Euclidean—the most popular distance type—was used.

After selecting a measurement for similarity, the researcher must specify the clustering method to be followed—either hierarchical clustering or non-hierarchical
clustering. Researchers commonly select both methods to complement the analysis (Feinberg, Kinnear, & Taylor, 2012). Thus, this study started with hierarchical clustering to determine appropriate cluster numbers, and then assigned different cases of the study into clusters using non-hierarchical, k-means clustering. Within the hierarchical clustering approach, the Agglomerative method was applied, since it is applicable to the research area and because it is the most commonly used method (Govaert, 2010). Within the Agglomerative method, there are several Agglomerative criteria that a researcher must select. Ward’s criterion was applied because it is among the best methods indicated by many studies (Rencher & Christensen, 2012).

In the fourth step of the clustering process, a dendrogram, which is a tree-like diagram, was used as an illustration and to determine the number of clusters (Blattberg et al., 2008).

In the fifth step of the clustering process, the analysis of the hierarchical and k-means clustering methods were conducted. The total number of case studies collected in the study were assigned into different clusters. Ultimately, each cluster provided cumulated list of tools and techniques as shown in Table 24.

Last, since this method is an exploratory technique, and because several cluster steps and choices influence the outcome, conclusions should not be made until verified by other methods (Todman & Dugard, 2007). Thus, the role of the last stage for this research process, which is matrix validation, was to confirm the outcome of this exploratory technique.
### Table 24

**Cumulated Tools and Techniques for Clusters**

<table>
<thead>
<tr>
<th>Cluster Number</th>
<th>DMAIC Phase</th>
<th>Tools &amp; Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster 1</td>
<td>Define</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Measure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td></td>
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**Matrix Development**

Constructing a contradiction matrix was the primary goal of this research. This contradiction matrix provides a framework for selecting numerous quality tools and techniques, which is a critical issue in the field of quality control (Dale, 2003). Inspired from the TRIZ contradiction matrix, the researcher developed collective matrices constructed from real cases that had already successfully applied different quality tools and techniques. The purpose was to not reinvent the wheel, since many firms have already solved similar quality problems by using specific tools and techniques.

The TRIZ contradiction matrix is a comprehensive methodology for solving technical problems that has been used effectively for years (Cameron, 2010). Because the
TRIZ contradiction matrix is constructed from thousands of patent problems and applied
directly to technical problems (Childs, 2013), several studies have developed a modified
or new version of matrix for specific, non-technical problems (Altuntas & Yener, 2012;
Chang et al., 2010; Mann, 2001). Thus, this research was seeking to construct a new
version of the TRIZ contradiction matrix that is tailored to the field of quality
management, and specifically to appropriately select different quality tools and
techniques.

The basic concept of the TRIZ contradiction matrix relies upon the principle of
solving more than 1,000 different contradictions in a technical system without
compromise (Altshuller, Shulyak, & Rodman, 1998). In order to develop a new version
of the contradiction matrix, a new set of contradicting parameters are needed first to
replace the 39 technical parameters. Second, new inventive groups of tools and
techniques are needed to replace the 40 inventive principles. Therefore, as new
parameters within the quality domain, the researcher selected the eight Garvin
dimensions of product quality and the five SERVQUAL dimensions of service quality to
replace the 39 technical parameters. These dimensions were selected because they vary
relatively in terms of importance (Garvin, 1988; Parasuraman et al., 1991), and, in many
occasions, and as Garvin indicated, a compromise must be made between quality
dimensions once two or more dimensions need to be improved together. For this reason,
very few products or services shine in all dimensions. For instance, Japanese cars in the
1970s were distinguished as having high quality based on only three dimensions
(Besterfield, 2009). Because there are always tradeoffs that must be considered among
quality dimensions, a practical framework for effective implementation of all dimensions is needed.

To replace the 40 inventive principles, the developed clusters for quality tools and techniques in the previous stage of this research were cumulated to produce optimal DMAIC lists. Table 25 illustrates the contradiction matrix developed for manufacturing industry based on the eight Garvin dimensions of product quality and Table 26 illustrates the contradiction matrix developed for service industry based on the five SERVQUAL dimensions of service quality. Figure 15 illustrates the process of problem-solving process for this research, in comparison with the TRIZ problem-solving process.
Table 25

Contradiction Matrix for Manufacturing Industry

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<td>Perceived Quality</td>
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Table 26

Contradiction Matrix for Service Industry

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<td>Tangibles</td>
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<td>Responsiveness</td>
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<td>Assurance</td>
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<td>Empathy</td>
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*Figure 15. The problem-solving process for the research. Adapted from Silverstein, DeCarlo, & Slocum (2008, p. 57).*
Matrix Validation

In this phase of the research, the constructed matrices were validated by several case studies that had been already published. Thus, in order to provide a strong validation for the new developed matrix, a selected sample (i.e., optimal DMAIC lists of tools and techniques) from the intersection matrix cells were verified by real case studies different from the ones used to build the matrix. The validation process took place once the selected sample (i.e., optimal DMAIC lists of tools and techniques), from the developed matrix, was matched with an example from a case study.
CHAPTER 4

RESULTS

This chapter presents the analysis and results of the two groups of manufacturing and service industries, with the goal of developing an innovative and diagnostic matrix that imitates the contradiction matrix of TRIZ. Results from the two groups are analyzed and grouped categorically. The analysis begins by presenting the collected data. A cluster analysis follows by grouping the homogenous cases, which helps to construct the final matrix. Finally, after constructing the matrix model, the validation process is illustrated.

Manufacturing Industry

Data Collection

Seventy-two cases from the manufacturing industry were carefully selected to meet the five specific criteria identified in choosing cases for this study. These cases were represented in a binary code as a linear combination of the eight Garvin dimensions of product quality (i.e., dependent variables), which are: Performance, Features, Reliability, Conformance, Durability, Serviceability, Aesthetics, and Perceived Quality. Each dimension was either given a value of one (1) if it was used in the case problem, or a value of zero (0) if it was not. Table 27 shows a summary of the collected data. The sets of quality tools and techniques (i.e., independent variables) in each case were categorized for further analysis in the clustering step. A full list of DMAIC tools and techniques for each of the 72 cases can be found in Appendix A.
Table 27

Summary of Collected Data for the Manufacturing Industry

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<td>(Farahmand, Marquez Grajales, &amp; Hamidi, 2010)</td>
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<td>Durability</td>
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<td>Perceived Quality</td>
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<td>(Abbas, Ming-Hsien, Al-Tahat, &amp; Fouad, 2011)</td>
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<td>(Al-Refaie, Li, Jalham, Bata, &amp; Al-Hmaideen, 2013)</td>
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<td>(Dambhare, Aphale, Kakade, Thote, &amp; Jawalkar, 2013)</td>
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<td>68</td>
<td>(Puvanasvaran, Ling, Zain, &amp; Al-Hayali, 2012)</td>
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<td>69</td>
<td>(Al-Mishari &amp; Suliman 2008)</td>
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<td>70</td>
<td>(Kumar, Jawalkar, &amp; Vaishya, 2014)</td>
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<td>(Sajeev &amp; M, 2013)</td>
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<td>72</td>
<td>(Jie, Kamaruddin, &amp; Azid, 2014)</td>
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</table>

From the 72 case studies listed in Table 27, the distribution of the eight Garvin dimensions of product quality (i.e., dependent variables) is illustrated in Table 28 in terms of their total number of cases. For further illustration, Figure 16 provides a graphical representation of the eight Garvin dimensions of product quality in terms of number of cases.
Table 28

*Number of Cases in each Dimension of Manufacturing*

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Total Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conformance</td>
<td>47</td>
</tr>
<tr>
<td>Performance</td>
<td>26</td>
</tr>
<tr>
<td>Reliability</td>
<td>15</td>
</tr>
<tr>
<td>Serviceability</td>
<td>9</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>6</td>
</tr>
<tr>
<td>Durability</td>
<td>3</td>
</tr>
<tr>
<td>Features</td>
<td>2</td>
</tr>
<tr>
<td>Perceived Quality</td>
<td>1</td>
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</tbody>
</table>

*Figure 16.* Eight Garvin dimensions of product quality and their case numbers

**Data Analysis**

After the data were collected, the researcher used cluster analysis to categorize the case studies in homogenous groups. The cluster analysis process identified by Blattberg
et al. (2008) was followed in this step of the study. In the first step of the cluster analysis, the eight Garvin dimensions of product quality were determined for the following cluster variables: Performance, Features, Reliability, Conformance, Durability, Serviceability, Aesthetics, and Perceived Quality. In the second step, Euclidean distance type was used to measure similarities. Following this, hierarchical and k-means clustering approaches were selected to conduct the cluster analysis. SPSS software was used to run the two types of clustering techniques. The number of clusters was determined to be 17. From the hierarchical clustering method that used Ward's linkage type, the output of the dendrogram diagram was used to clarify the determined number of clusters, as shown in Figure 17. Then, the 17 clusters were analyzed using the k-means clustering method. Each of the 72 manufacturing industry cases was assigned one of the 17 clusters. Table 29 shows the cluster membership of each case. Table 30 shows the number of cases and dimensions (i.e., variables) used in each cluster. Figure 18 provides a graphical representation of the 17 clusters and their case numbers.
Figure 17. Dendrogram diagram for the 72 case studies.
Table 29

*Cluster Membership for the Manufacturing Industry*

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Cluster</th>
<th>Case Number</th>
<th>Cluster</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>37</td>
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<td>36</td>
<td>5</td>
<td>72</td>
<td>17</td>
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Table 30

*Cases Number and Dimensions Used in Each Cluster of Manufacturing*

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Number of Cases</th>
<th>Dimensions</th>
</tr>
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<tr>
<td>1</td>
<td>26</td>
<td>Conformance</td>
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<tr>
<td>2</td>
<td>5</td>
<td>Conformance, Serviceability</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Performance, Conformance, Serviceability</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Reliability, Conformance</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>Performance</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>Performance, Reliability</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Features, Conformance</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>Performance, Aesthetics</td>
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<tr>
<td>9</td>
<td>2</td>
<td>Performance, Reliability, Conformance</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>Conformance, Aesthetics</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>Performance, Reliability, Durability</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
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<tr>
<td>13</td>
<td>3</td>
<td>Performance, Conformance</td>
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<tr>
<td>14</td>
<td>1</td>
<td>Performance, Conformance, Serviceability, Perceived Quality</td>
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<tr>
<td>15</td>
<td>1</td>
<td>Features</td>
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<tr>
<td>16</td>
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<td>Reliability, Durability</td>
</tr>
<tr>
<td>17</td>
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<td>Performance, Serviceability</td>
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</table>

*Figure 18. Number of cases used in each cluster.*
After assigning each of the 72 manufacturing industry cases into the 17 clusters, tools and techniques (i.e., independent variables) were cumulated in each cluster. Table 31 shows the cumulated tools and techniques for each cluster.

**Table 31**

*Cumulated Tools and Techniques for Clusters in Manufacturing*

<table>
<thead>
<tr>
<th>Cluster 1</th>
<th>Tools &amp; Techniques for Cluster Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define</td>
<td>Project Charter, Gantt Chart, Y and y definitions, SIPOC Diagram, Process Mapping, Product Flow-down Tree, Voice of Customer (VOC), Brainstorming, Pareto Chart, Critical to Quality (CTQ), Tree Diagram, Prioritization Matrix, Flowchart, Key Performance Indicators (KPIs), Multi-Voting, Cost of Poor Quality (COPQ), Checklist, Failure Mode and Effect Analysis (FMEA)</td>
</tr>
<tr>
<td>Measure</td>
<td>Cause-and-Effect Diagram, Interview, Gauge R&amp;R, Process Capability Analysis, Histogram, Control Chart, Sigma Calculation (DPMO), Pareto Chart, Fault Tree Analysis, Brainstorming, Flowchart, Cause-and-Effect Matrix, Basic Statistics, Histogram, Process Mapping, Failure Mode and Effect Analysis (FMEA), Critical to Quality (CTQ), Value stream mapping (VSM), The Seven Wastes (Muda), Value-added Analysis, Probability Plot, key Process Input Variable (KPIVs), Key Process Output Variables (KPOVs)</td>
</tr>
<tr>
<td>Analyze</td>
<td>Process Capability Analysis, Control Chart, Cause-and-Effect Diagram, Taguchi Methods, ANOVA Test, Regression Analysis, Box plot, Failure Mode and Effect Analysis (FMEA), Scatter Plot, Brainstorm, Multi-Voting, 5 Whys Analysis, Decision Tree, Process Capability Analysis, Chi-square Test, Design of Experiments (DOE), Logistic Regression, Flowchart, Value Stream Mapping (VSM), Pareto Chart, Hypothesis Testing, Why-Why Analysis, Multi-vary Analysis</td>
</tr>
<tr>
<td>Improve</td>
<td>Histogram, Hypothesis testing, Simulation, Design of Experiments (DOE), Failure Mode and Effect Analysis (FMEA), Standard Operating Procedure (SOP), Sigma Calculation (DPMO), Brainstorming, Taguchi Methods, ANOVA Test, Box Plot, Survey, Normal Probability Plot, Poka-yoke, Kaizen, Process Capability Analysis, Gage R&amp;R, 5S, Kanban, Total Productive Maintenance (TPM), Value Stream Mapping (VSM), Dot Plot, Pareto Chart</td>
</tr>
<tr>
<td>Control</td>
<td>Control Plan, I-Chart, Control Chart, Sigma Calculation (DPMO), Run Chart, Standardization, Auditing, Statistical Process Control (SPC), Process Capability Analysis, Pareto Chart</td>
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* (table continues)
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<thead>
<tr>
<th>Cluster 3</th>
<th>Define</th>
<th>Key Performance Indicators (KPIs), Voice of Customer (VOC), Voice of the Process (VOP), Critical to Customer (CTCs), Pareto Diagram, Process Mapping, Costs of Poor Quality (COPQs), Critical to Quality (CTQ), Quality Function Deployment (QFD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure</td>
<td>Value Stream Mapping, Brainstorming, Gage R&amp;R, Process Capability Analysis, Time Value Map Diagram, Value-added Analysis</td>
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<tr>
<td>Analyze</td>
<td>Pareto Chart, Cause-and-Effect Diagram, Run Chart, Box Plot, Control Chart, Histogram, ANOVA Test</td>
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<tr>
<td>Improve</td>
<td>Value Stream Mapping (VSM), Kanban, Brainstorming, Cost-benefit Analysis, Process Capability Analysis, Single Minute Exchange of Die (SMED)</td>
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<tr>
<td>Control</td>
<td>Control Plan</td>
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<tbody>
<tr>
<td>Measure</td>
<td>Interview, Observation, Drawings, Work Sheet, Histogram, Gauge R&amp;R, Brainstorming, Cause-and-Effect Diagram, Geometric Optical Measurements, Check Sheets, Sigma Calculation (DPMO), ANOVA Test, Process Capability Analysis, Control Chart, Pareto Diagram</td>
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</tr>
<tr>
<td>Analyze</td>
<td>Correlation Analysis, Regression Analysis, Process Mapping, Cause-and-Effect Matrix, Failure Mode and Effect Analysis (FMEA), VMEA, Normal Probability Plot, Process Capability Analysis, Control Chart, Brainstorming, Cause-and-Effect Diagram, Bar Chart, Pareto Chart, Tree Diagram, ANOVA Test, GEMBA</td>
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<tr>
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<td>Flow Diagram, Brainstorming, Bar Chart, Matrix Diagram, Design of Experiments (DOE), ANOVA Test, Process Capability Analysis</td>
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<td>Flowchart, Checklists, Control Plan</td>
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<table>
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<tr>
<th>Tools &amp; Techniques for Cluster Cases</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Measure</td>
<td>Gauge R&amp;R, Anderson–Darling Normality Test, Process Capability Analysis, Normal Probability Plot, Histogram, R Chart, Scatter Plot, Brainstorm, Cause-and-Effect Diagram, Control Chart, Pareto Chart, Failure Mode and Effect Analysis (FMEA)</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>Brainstorming, Cause-and-Effect Diagram, Regression Analysis, GEMBA, Flowchart, Failure Mode and Effect Analysis (FMEA), Gauge R&amp;R, Process Capability Analysis, Descriptive Statistics, Box Plot, Process Mapping, Six Thinking Hat</td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td>Design of Experiments (DOE), Taguchi Methods, ANOVA Test, Risk Analysis, Process Capability Analysis, 5S, Flowchart, Pilot Plan, Control Chart, Pareto Chart</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>Checklist, Auditing, Control Chart, Documentation, Control Plan, Statistical Process Control (SPC), Poka-yoke</td>
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<table>
<thead>
<tr>
<th>Cluster 5</th>
<th>Define</th>
<th>SIPOC Diagram, Project Charter, Voice of Customer (VOC), Critical to Quality (CTQ), Brainstorming, Process Mapping</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Analyze</td>
<td>Cause-and-effect Diagram, Brainstorming, Multi-vari Analysis, Regression Analysis, Process Capability Analysis, Run Chart, Histogram, Bar Chart, ANOVA Test, Correlation Analysis, Failure Mode and Effect Analysis (FMEA), Taguchi Methods, Design of Experiments (DOE), Normal Probability Plot, Simulation</td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td>Design of Experiments (DOE), Process Capability Analysis, Brainstorming, Failure Mode and Effect Analysis (FMEA), 5S, Total Productive Maintenance (TPM), Taguchi Methods, Simulation, Flowchart, Regression Analysis, ANOVA Test</td>
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<tr>
<td></td>
<td>Control</td>
<td>Control Plan, Standardization, Control Chart, Run Chart, Pareto Chart, Benchmark, Hypothesis Testing, Check Sheets, Process Capability Analysis</td>
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<table>
<thead>
<tr>
<th>Cluster 6</th>
<th>Define</th>
<th>Project Charter, Critical to Quality (CTQ), Quality Function Deployment (QFD)</th>
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<td></td>
<td>Measure</td>
<td>Process Mapping, Process Capability Analysis, Run Chart, Pareto Chart, Box Plot, Hypothesis Testing, Gauge R&amp;R, Cause-and-Effect Diagram, Brainstorming, Simulation, Probability Plot</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>Multi-vari Chart, Hypothesis Testing, Process Mapping</td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td>ANOVA Test, Anderson–Darling Test, Ryan–Joiner Test, Design of Experiments (DOE), Normal Probability Plot, Control Chart, Process Capability Analysis, Hypothesis Testing</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>Process capability Analysis, Control Plan, Control Chart</td>
</tr>
</tbody>
</table>

(table continues)
<table>
<thead>
<tr>
<th>Cluster</th>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Critical to Quality (CTQ), Voice of Customer (VOC), Value Stream Mapping (VSM)</td>
<td>Gauge R&amp;R</td>
<td>Pareto Chart, Brainstorming, Cause-and-Effect Diagram</td>
<td>Design of Experiments (DOE), 5S, Total Productive Maintenance (TPM)</td>
<td>Control Chart, Standardization, Mistake Proofing, Failure Mode and Effect Analysis (FMEA)</td>
</tr>
<tr>
<td>9</td>
<td>Box plot, Critical to Quality (CTQ), Critical to Cost (CTC)</td>
<td>Process Capability Analysis, Gauge R&amp;R, Control Chart</td>
<td>Brainstorming, Hypotheses Testing, Pareto Chart, Cause-and-Effect Matrix, ANOVA Test, Box Plot, Fault Tree Analysis, Multi-vari Analysis, Regression Analysis, Gage R&amp;R, Normal Probability Plot, Histogram</td>
<td>Box plot, control chart</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Pareto chart, SIPOC Diagram</td>
<td>Sigma Calculation (DPMO), Pareto Chart, key Process Input Variable (KPIVs), Cause-and-Effect Diagram, Failure Mode and Effect Analysis (FMEA), Process Capability Analysis</td>
<td>Regression Analysis, Control Chart, Gauge R&amp;R, Chi-square Test, Cause-and-Process Diagram, Pareto Chart</td>
<td>Control Plan, Control Chart, Process Capability Analysis, Sigma Calculation (DPMO)</td>
<td></td>
</tr>
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</table>

(table continues)
<table>
<thead>
<tr>
<th>Cluster 11</th>
<th>Measure</th>
<th>Brainstorming, Control Chart, Cause-and-Effect Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Analyze</td>
<td>Taguchi Methods, ANOVA Test</td>
</tr>
<tr>
<td>Cluster 12</td>
<td>Define</td>
<td>Pareto Chart, Value Stream Mapping, Cause-and-Effect Diagram</td>
</tr>
<tr>
<td></td>
<td>Measure</td>
<td>Value Stream Mapping (VSM), Simulation, Pareto Chart, Quality Function Deployment (QFD)</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>Statistical Process Control (SPC), ANOVA Test, Regression Analysis, Process Capability Analysis, Control Chart, Scatter Plot, Cost-benefit Analysis, Hypothesis Testing, Cause-and-Effect Diagram</td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td>Kaizen, Non-parametric test</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>Failure Mode and Effect Analysis (FMEA), Statistical Tests, Control Plan, Control Chart</td>
</tr>
<tr>
<td>Cluster 13</td>
<td>Define</td>
<td>Project Charter, Process Mapping, Prioritization Matrix</td>
</tr>
<tr>
<td></td>
<td>Measure</td>
<td>Sigma Calculation (DPMO), Pareto Chart, Flowchart, Cause-and-Effect Diagram, Gage R&amp;R</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>Cause-and-Effect Diagram, Failure Mode and Effect Analysis (FMEA), Pareto Chart, Fault Tree Analysis, Tree diagram, Key Input Variables (KIVs), Multi-vari Chart, Regression Analysis</td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td>Action plan, Sigma Calculation (DPMO), 5S</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>Standardization, Control Plan, Flowchart</td>
</tr>
<tr>
<td>Cluster 14</td>
<td>Define</td>
<td>Pareto Chart, Project Charter, SIPOC Diagram, Critical to Quality (CTQ), Voice of Customer (VOC)</td>
</tr>
<tr>
<td></td>
<td>Measure</td>
<td>Process Mapping, Sigma Calculation (DPMO)</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>Pareto Chart, Failure Mode and Effect Analysis (FMEA), Cause-and-Effect Diagram, Why-Why Analysis</td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td>Matrix Diagram</td>
</tr>
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<td></td>
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<table>
<thead>
<tr>
<th>Cluster 15</th>
<th>Define</th>
<th>Process Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measure</td>
<td>Control Chart, Process Capability Analysis</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>Taguchi Methods</td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td>Taguchi Methods</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>Control Chart</td>
</tr>
<tr>
<td>Cluster 16</td>
<td>Define</td>
<td>Process Capability Analysis</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>Hypothesis Testing, Box Plot, Regression Analysis</td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td>Hypothesis Testing</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>Control Chart</td>
</tr>
<tr>
<td>Cluster 17</td>
<td>Define</td>
<td>Value Stream Mapping (VSM), Flowchart</td>
</tr>
<tr>
<td></td>
<td>Measure</td>
<td>Pareto Chart</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>5 Whys Analysis</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>5S, Standard Operating Procedure (SOP)</td>
</tr>
</tbody>
</table>

Matrix Development

The researcher used the 17 clusters as the basis for developing the ultimate goal of the first part of this research: Constructing the contradiction matrix of manufacturing. To build the new matrix, the original 39 technical parameters of TRIZ were replaced by the eight Garvin dimensions of product quality. Each cell in the matrix was constructed by combining two dimensions in each row and column; thus, the outcome of each cell must contain all clusters that shared at least the two dimensions. For instance, the intersection
of Performance and Reliability shares the following clusters: 6, 9, and 11. All of these clusters share the two dimensions of Performance and Reliability, as illustrated in Table 32.

Table 32

*Performance and Reliability Dimensions*

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Number of Cases</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2</td>
<td>Performance, Reliability</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>Performance, Reliability, Conformance</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>Performance, Reliability, Durability</td>
</tr>
</tbody>
</table>

After constructing each cell of the matrix, the cumulated tools and techniques in all clusters in the cell produced the 17 DMAIC lists, which are the optimal list of tools and techniques for each pair of the matrix. Table 33 shows the developed contradiction matrix for manufacturing, and Table 34 shows the 17 DMAIC lists of tools and techniques for the matrix. For further clarification, Table 35 demonstrates the total number of cases used to build each DMAIC list in the contradiction matrix.
### Table 33

**Contradiction Matrix for Manufacturing**

<table>
<thead>
<tr>
<th>Performance</th>
<th>Features</th>
<th>Reliability</th>
<th>Conformance</th>
<th>Durability</th>
<th>Serviceability</th>
<th>Aesthetics</th>
<th>Perceived Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance</strong></td>
<td>3, 5, 6, 8, 9, 11, 13, 14 (DMAIC LIST 1)</td>
<td>NONE</td>
<td>6, 9, 11 (DMAIC LIST 2)</td>
<td>3, 9, 13, 14 (DMAIC LIST 3)</td>
<td>11 (DMAIC LIST 4)</td>
<td>3, 14, 17 (DMAIC LIST 5)</td>
<td>8 (DMAIC LIST 6)</td>
</tr>
<tr>
<td><strong>Features</strong></td>
<td>NONE</td>
<td>7, 15 (DMAIC LIST 8)</td>
<td>NONE</td>
<td>7 (DMAIC LIST 9)</td>
<td>NONE</td>
<td>NONE</td>
<td>NONE</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>6, 9, 11 (DMAIC LIST 2)</td>
<td>NONE</td>
<td>4, 6, 9, 11, 12 (DMAIC LIST 10)</td>
<td>4, 9 (DMAIC LIST 11)</td>
<td>11, 16 (DMAIC LIST 17)</td>
<td>NONE</td>
<td>NONE</td>
</tr>
<tr>
<td><strong>Conformance</strong></td>
<td>3, 9, 13, 14 (DMAIC LIST 3)</td>
<td>7 (DMAIC LIST 9)</td>
<td>4, 9 (DMAIC LIST 11)</td>
<td>1, 2, 3, 4, 7, 9, 10, 13, 14 (DMAIC LIST 12)</td>
<td>NONE</td>
<td>2, 14 (DMAIC LIST 13)</td>
<td>10 (DMAIC LIST 16)</td>
</tr>
<tr>
<td><strong>Durability</strong></td>
<td>11 (DMAIC LIST 4)</td>
<td>NONE</td>
<td>11, 15 (DMAIC LIST 17)</td>
<td>NONE</td>
<td>11 (DMAIC LIST 4)</td>
<td>NONE</td>
<td>NONE</td>
</tr>
<tr>
<td><strong>Serviceability</strong></td>
<td>3, 14, 17 (DMAIC LIST 5)</td>
<td>NONE</td>
<td>NONE</td>
<td>2, 14 (DMAIC LIST 13)</td>
<td>NONE</td>
<td>2, 3, 14 (DMAIC LIST 14)</td>
<td>NONE</td>
</tr>
<tr>
<td><strong>Aesthetics</strong></td>
<td>8 (DMAIC LIST 6)</td>
<td>NONE</td>
<td>NONE</td>
<td>10 (DMAIC LIST 16)</td>
<td>NONE</td>
<td>NONE</td>
<td>8, 10 (DMAIC LIST 15)</td>
</tr>
<tr>
<td><strong>Perceived Quality</strong></td>
<td>14 (DMAIC LIST 7)</td>
<td>NONE</td>
<td>NONE</td>
<td>14 (DMAIC LIST 7)</td>
<td>NONE</td>
<td>14 (DMAIC LIST 7)</td>
<td>NONE</td>
</tr>
</tbody>
</table>
Table 34

**Seventeen DMAIC Lists for the Contradiction Matrix for Manufacturing**

<table>
<thead>
<tr>
<th>DMAIC List 1</th>
<th>Define</th>
<th>DMAIC List 2</th>
<th>Define</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Define</strong></td>
<td>Key Performance Indicators (KPIs), Voice of Customer (VOC), Voice of the Process (VOP), Critical to Customer (CTCs), Pareto Diagram, Process Mapping, Costs of Poor Quality (COPQs), Critical to Quality (CTQ), Quality Function Deployment (QFD), SIPOC Diagram, Project Charter, Brainstorming, Cause-Effect-Diagram, Flowchart, Control Chart, Box plot, Critical to Cost (CTC), Prioritization Matrix</td>
<td>Project Charter, Critical to Quality (CTQ), Box plot, Critical to Cost (CTC)</td>
<td></td>
</tr>
<tr>
<td><strong>Improve</strong></td>
<td>Process Mapping, Process Capability Analysis, Run Chart, Pareto Chart, Box Plot, Hypothesis Testing, Gauge R&amp;R, Cause-and-Effect Diagram, Brainstorming, Control Chart</td>
<td>ANOVA Test, Anderson–Darling Test, Ryan–Joiner Test, Box Plot, Control Chart</td>
<td></td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>Control Plan, Standardization, Control Chart, Run Chart, Pareto Diagram, Benchmark, Hypothesis Testing, Check Sheet, Process Capability Analysis, Statistical Process Control (SPC), Flowchart</td>
<td>Process capability Analysis, Control Plan</td>
<td></td>
</tr>
</tbody>
</table>
### DMAIC List for The Contradiction Matrix

<table>
<thead>
<tr>
<th>DMAIC List</th>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>List 4</strong></td>
<td>Brainstorming, Control Chart, Cause-and-Effect Diagram</td>
<td></td>
<td>Taguchi Methods, ANOVA Test</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(table continues)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DMAIC LIST 6</td>
<td>Measure</td>
<td>Cause-and-Effect Matrix, Gauge R&amp;R, Control Chart, Process Capability Analysis</td>
</tr>
<tr>
<td>DMAIC LIST 6</td>
<td>Analyze</td>
<td>ANOVA Test, Process Capability Analysis, Cause-and-Effect Diagram</td>
</tr>
<tr>
<td>DMAIC LIST 6</td>
<td>Improve</td>
<td>Design of Experiment (DOE), Regression Analysis, Process Capability Analysis, Pareto Chart, Taguchi Methods, ANOVA Test</td>
</tr>
<tr>
<td>DMAIC LIST 6</td>
<td>Control</td>
<td>Statistical Process Control (SPC), Control Plan</td>
</tr>
<tr>
<td>DMAIC LIST 7</td>
<td>Define</td>
<td>Pareto Chart, Project Charter, Voice of Customer (VOC), SIPOC Diagram, Critical to Quality (CTQ)</td>
</tr>
<tr>
<td>DMAIC LIST 7</td>
<td>Measure</td>
<td>Process Mapping, Sigma Calculation (DPMO)</td>
</tr>
<tr>
<td>DMAIC LIST 7</td>
<td>Analyze</td>
<td>Pareto Chart, Failure Mode and Effect Analysis (FMEA), Cause-and-Effect Diagram, Why-Why Analysis</td>
</tr>
<tr>
<td>DMAIC LIST 7</td>
<td>Improve</td>
<td>Matrix Diagram</td>
</tr>
<tr>
<td>DMAIC LIST 7</td>
<td>Control</td>
<td>Control Plan</td>
</tr>
<tr>
<td>DMAIC LIST 8</td>
<td>Define</td>
<td>Process Mapping, Critical to Quality (CTQ), Voice of Customer (VOC), Value Stream Mapping</td>
</tr>
<tr>
<td>DMAIC LIST 8</td>
<td>Measure</td>
<td>Control Chart, Process Capability Analysis, Gauge R&amp;R</td>
</tr>
<tr>
<td>DMAIC LIST 8</td>
<td>Analyze</td>
<td>Taguchi Methods, Pareto Chart, Brainstorming, Cause-and-Effect Diagram</td>
</tr>
<tr>
<td>DMAIC LIST 8</td>
<td>Improve</td>
<td>Taguchi Methods, Design of Experiment (DOE), 5S, Total Productive Maintenance (TPM)</td>
</tr>
<tr>
<td>DMAIC LIST 8</td>
<td>Control</td>
<td>Control Chart, Control Chart, Standardization, Mistake Proofing, Failure Mode and Effect Analysis (FMEA)</td>
</tr>
<tr>
<td>DMAIC LIST 9</td>
<td>Define</td>
<td>Critical to Quality (CTQ), Voice of Customer (VOC), Value Stream Mapping (VSM)</td>
</tr>
<tr>
<td>DMAIC LIST 9</td>
<td>Measure</td>
<td>Gauge R&amp;R</td>
</tr>
<tr>
<td>DMAIC LIST 9</td>
<td>Analyze</td>
<td>Pareto Chart, Brainstorming, Cause-and-Effect Diagram</td>
</tr>
<tr>
<td>DMAIC LIST 9</td>
<td>Improve</td>
<td>Design of Experiment (DOE), 5S, Total Productive Maintenance (TPM)</td>
</tr>
<tr>
<td>DMAIC LIST 9</td>
<td>Control</td>
<td>Control Chart, Standardization, Mistake Proofing, Failure Mode and Effect Analysis (FMEA)</td>
</tr>
</tbody>
</table>

(table continues)
<table>
<thead>
<tr>
<th>DMAIC List for The Contradiction Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Define</strong></td>
</tr>
<tr>
<td>Project Charter, Flowchart, SIPOC Diagram, Process Mapping, Cause-and-Effect Diagram, Gantt Chart, Critical to Quality (CTQ), Voice of Customer (VOC), Box Plot, Critical to Cost (CTC), Pareto Chart, Value Stream Mapping, Quality Function Deployment (QFD)</td>
</tr>
<tr>
<td><strong>Measure</strong></td>
</tr>
<tr>
<td><strong>Analyze</strong></td>
</tr>
<tr>
<td><strong>Improve</strong></td>
</tr>
<tr>
<td>Design of experiments (DOE), Taguchi Methods, ANOVA Test, Risk Analysis, Process Capability Analysis, 5S, Flowchart, Pilot Plan, Control Chart, Pareto Chart, Anderson–Darling Test, Ryan–Joiner Test, Box Plot, Kaizen, Non-parametric Test, Normal Probability Plot, Hypothesis Testing</td>
</tr>
<tr>
<td><strong>Control</strong></td>
</tr>
<tr>
<td>Checklist, Auditing, Control Chart, Documentation, Control Plan, Statistical Process Control (SPC), Poka-yoke, Process capability Analysis, Failure Mode and Effect Analysis (FMEA), Statistical Test</td>
</tr>
</tbody>
</table>

<p>| <strong>Define</strong>                              |
| Project Charter, Flow chart, SIPOC Diagram, Process Mapping, Cause-and-Effect Diagram, Gantt Chart, Critical to Quality (CTQ), Voice of Customer (VOC), Box Plot, Critical to Cost (CTC) |
| <strong>Measure</strong>                             |
| Gauge R&amp;R, Anderson–Darling Normality Test, Process Capability Analysis, Normal Probability Plot, Histogram, R Charts, Scatter Plot, Brainstorming, Cause-and-Effect Diagram, Control Chart, Pareto Chart, Failure Mode and Effect Analysis (FMEA) |
| <strong>Analyze</strong>                             |
| <strong>Improve</strong>                             |
| Design of Experiments (DOE), Taguchi Methods, ANOVA Test, Risk Analysis, Process Capability Analysis, 5S, Flowchart, Pilot Testing, Control Chart, Pareto Chart, Box Plot |
| <strong>Control</strong>                             |
| Checklist, Auditing, Control Chart, Documentation, Control Plan, Statistical Process Control (SPC), Poka-yoke |</p>
<table>
<thead>
<tr>
<th>DMAIC List for The Contradiction Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Define</strong></td>
</tr>
<tr>
<td>Project Charter, Gantt Chart, Y and y definitions, SIPOC Diagram, Process Mapping, Product flow-down Tree, Voice of Customer (VOC), Brainstorming, Pareto Chart, Critical to Quality (CTQ), Tree Diagram, Prioritization Matrix, Flowchart, Key Performance Indicators (KPIs), Multi-Voting, Cost of Poor Quality (COPQ), Checklist, Failure Mode and Effect Analysis (FMEA), Cause-and-Effect Diagram, Business Case, Log book on meetings, Voice of the Process (VOP), Critical to Customer (CTCs), Quality Function Deployment (QFD), Box Plot, Critical to Cost (CTC), Value Stream Mapping</td>
</tr>
<tr>
<td><strong>Measure</strong></td>
</tr>
<tr>
<td><strong>Analyze</strong></td>
</tr>
<tr>
<td>Process Capability Analyses, Control Charts, Cause-and-Effect Diagram, Taguchi Methods, ANOVA Test, Regression Analysis, Box Plot, Failure Mode and Effect Analysis (FMEA), Scatter Plot, Brainstorm, Multi-voting, 5 Whys Analysis, Decision Tree, Chi-square Test, Design of Experiments (DOE), Logistic Regression, Flowchart, Value Stream Mapping (VSM), Pareto Chart, Hypothesis Testing, Multi Regression, Why-Why Analysis, Multi-vari Chart, Correlation Analysis, Process Mapping, Cause-and-Effect Matrix, VMEA, Normal Probability Plot, Bar Chart, Tree Diagram, Run Chart, Histogram, GEMBA, Gauge R&amp;R, Descriptive Statistics, Six Thinking Hat, Cause-and-Effect Matrix, Fault Tree Analysis, Key Input Variables (KIVs)</td>
</tr>
<tr>
<td><strong>Improve</strong></td>
</tr>
<tr>
<td><strong>Control</strong></td>
</tr>
<tr>
<td>Control plan, I-Chart, Control Chart, Sigma Calculation (DPMO), Run Chart, Standardization, Auditing, Statistical Process Control (SPC), Process Capability Analysis, Pareto Chart, Flowchart, Checklists, Documentation, Poka-yoke, Mistake Proofing, Failure Mode and Effect Analysis (FMEA)</td>
</tr>
</tbody>
</table>

(table continues)
### DMAIC List for The Contradiction Matrix

<table>
<thead>
<tr>
<th>DMAIC LIST 13</th>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>**DMAIC LIST 14</td>
<td>Define</td>
<td>Measure</td>
<td>Analyze</td>
<td>Improve</td>
<td>Control</td>
</tr>
</tbody>
</table>

(table continues)
<table>
<thead>
<tr>
<th>DMAIC LIST 15</th>
<th>Define</th>
<th>Voice of Customer (VOC), SIPOC Diagram, Critical to Quality (CTQ), Cause-and-Effect Diagram, Project Charter, Flowchart, Process Mapping, Control Chart, Pareto Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measure</td>
<td>Cause-and-Effect Matrix, Gauge R&amp;R, Control Chart, Process Capability Analysis, Sigma Calculation (DPMO), Pareto Chart, key Process Input Variable (KPIVs), Cause-Effect-Diagram, Failure Mode and Effect Analysis (FMEA)</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>ANOVA Test, Process Capability Analysis, Cause-and-Effect Diagram, Regression Analysis, Control Chart, Gauge R&amp;R, Chi-square test, Pareto Chart</td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td>Design of Experiments (DOE), Regression Analysis, Process Capability Analysis, Pareto Chart, Taguchi Methods, ANOVA Test</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>Statistical Process Control (SPC), Control Plan, Control Chart, Process Capability Analysis, Sigma Calculation (DPMO)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DMAIC LIST 16</th>
<th>Define</th>
<th>Pareto Chart, SIPOC Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measure</td>
<td>Sigma Calculation (DPMO), Pareto chart, key Process Input Variable (KPIVs), Cause-and-Effect Diagram, Failure Mode and Effect Analysis (FMEA, Process Capability Analysis)</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>Regression Analysis, Control Chart, Gauge R&amp;R, Chi-square Test, Cause-and-Effect Diagram, Pareto Chart</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>Control Plan, Control Chart, Process Capability Analysis, Sigma Calculation (DPMO)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DMAIC LIST 17</th>
<th>Define</th>
<th>Process Capability Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measure</td>
<td>Brainstorming, Control Chart, Cause-and-Effect Diagram, Gage R&amp;R, Process Mapping, Weibull Analysis, Survey</td>
</tr>
<tr>
<td></td>
<td>Analyze</td>
<td>Taguchi Methods, ANOVA Test, Hypothesis Testing, Box plot, Regression Analysis</td>
</tr>
<tr>
<td></td>
<td>Improve</td>
<td>Hypothesis Testing</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>Control Chart</td>
</tr>
</tbody>
</table>
Table 35

Number of Cases Used in each DMAIC List of Manufacturing

<table>
<thead>
<tr>
<th>DMAIC LIST</th>
<th>Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMAIC LIST 1</td>
<td>25</td>
</tr>
<tr>
<td>DMAIC LIST 2</td>
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<td>DMAIC LIST 15</td>
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<tr>
<td>DMAIC LIST 16</td>
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</tr>
<tr>
<td>DMAIC LIST 17</td>
<td>3</td>
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</table>

Matrix Validation

To validate the contradiction matrix for manufacturing, the researcher selected samples from the 17 DMAIC lists, and verified these samples in relation to case studies different from the ones used to build the matrix. Validation took place because the selected samples—DMAIC lists 1, 3, 5, 10, 12, 14, 15 and 16 developed from the matrix—matched with the tools and techniques discussed in case studies from Mandahawi, Fouad, and Obeidat (2012); Junankar, Gupta, Sayed, and Bhende (2014); Soni, Mohan, Bajpai, and Katare (2013); Shrivastava, Ahmad, and Desai (2008); Kaushik, Khanduja, Mittal, and Jaglan (2012); and Dwivedi, Anas, and Siraj (2014). The shaded cells in Table 36 represent the validated DMAIC lists in the contradiction matrix.
for manufacturing. Table 37 illustrates the tools and techniques used in the six case studies to validate the selected DMAIC lists. For further clarification, Table 38 demonstrates the validated DMAIC lists from large to small, based on the number of cases used in each list.
Table 36

Validated DMAIC Lists in the Contradiction Matrix for Manufacturing

<table>
<thead>
<tr>
<th>Contradiction Matrix for Manufacturing</th>
<th>Performance</th>
<th>Features</th>
<th>Reliability</th>
<th>Conformance</th>
<th>Durability</th>
<th>Serviceability</th>
<th>Aesthetics</th>
<th>Perceived Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>3, 5, 6, 8, 9, 11, 13, 14 (DMAIC LIST 1)</td>
<td>NONE</td>
<td>6, 9, 11 (DMAIC LIST 2)</td>
<td>3, 9, 13, 14 (DMAIC LIST 3)</td>
<td>11</td>
<td>3, 14, 17 (DMAIC LIST 4)</td>
<td>8</td>
<td>14 (DMAIC LIST 7)</td>
</tr>
<tr>
<td>Features</td>
<td>NONE</td>
<td>7, 15 (DMAIC LIST 8)</td>
<td>NONE</td>
<td>7 (DMAIC LIST 9)</td>
<td>NONE</td>
<td>NONE</td>
<td>NONE</td>
<td>NONE</td>
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<tr>
<td>Reliability</td>
<td>6, 9, 11 (DMAIC LIST 2)</td>
<td>NONE</td>
<td>4, 6, 9, 11, 12 (DMAIC LIST 10)</td>
<td>4, 9 (DMAIC LIST 11)</td>
<td>11, 16 (DMAIC LIST 17)</td>
<td>NONE</td>
<td>NONE</td>
<td>NONE</td>
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<tr>
<td>Conformance</td>
<td>3, 9, 13, 14 (DMAIC LIST 3)</td>
<td>7 (DMAIC LIST 9)</td>
<td>4, 9 (DMAIC LIST 11)</td>
<td>1, 2, 3, 4, 7, 9, 10, 13, 14 (DMAIC LIST 12)</td>
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<td>2, 14 (DMAIC LIST 13)</td>
<td>10</td>
<td>14 (DMAIC LIST 7)</td>
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<tr>
<td>Durability</td>
<td>11 (DMAIC LIST 4)</td>
<td>NONE</td>
<td>11, 15 (DMAIC LIST 17)</td>
<td>NONE</td>
<td>11 (DMAIC LIST 4)</td>
<td>NONE</td>
<td>NONE</td>
<td>NONE</td>
</tr>
<tr>
<td>Serviceability</td>
<td>3, 14, 17 (DMAIC LIST 5)</td>
<td>NONE</td>
<td>NONE</td>
<td>2, 14 (DMAIC LIST 13)</td>
<td>NONE</td>
<td>2, 3, 14 (DMAIC LIST 14)</td>
<td>NONE</td>
<td>14 (DMAIC LIST 7)</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>8 (DMAIC LIST 6)</td>
<td>NONE</td>
<td>NONE</td>
<td>10 (DMAIC LIST 16)</td>
<td>NONE</td>
<td>NONE</td>
<td>8, 10 (DMAIC LIST 15)</td>
<td>NONE</td>
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<tr>
<td>Perceived Quality</td>
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<td>NONE</td>
<td>14 (DMAIC LIST 7)</td>
<td>NONE</td>
<td>14 (DMAIC LIST 7)</td>
<td>NONE</td>
<td>14 (DMAIC LIST 7)</td>
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### Table 37

**Validation Cases for Manufacturing**

<table>
<thead>
<tr>
<th>Case Study</th>
<th>DMAIC Tools &amp; Techniques</th>
<th>Validated DMAIC LIST</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mandahawi, Fouad, &amp; Obeidat, 2012)</td>
<td><strong>Define</strong> Project Charter, Process Mapping, Brainstorming</td>
<td>DMAIC LIST 1</td>
</tr>
<tr>
<td></td>
<td><strong>Analyze</strong> Cause-and-Effect Diagram, Brainstorming</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Improve</strong> Brainstorming</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>DMAIC LIST</strong></td>
<td></td>
</tr>
<tr>
<td>(Junankar, Gupta, Sayed, &amp; Bhende, 2014)</td>
<td><strong>Define</strong> Project Charter</td>
<td>DMAIC LIST 3</td>
</tr>
<tr>
<td></td>
<td><strong>Measure</strong> Sigma Calculation (DPMO)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Analyze</strong> Cause-and Effect Diagram, Pareto Chart</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Improve</strong> Sigma Calculation (DPMO)</td>
<td></td>
</tr>
<tr>
<td>(Soni, Mohan, Bajpai, &amp; Katare, 2013)</td>
<td><strong>Define</strong> Pareto Chart, Project Charter, SIPOC Diagram, Critical to Quality (CTQ), Voice of Customer (VOC)</td>
<td>DMAIC LIST 5 &amp; DMAIC LIST 14</td>
</tr>
<tr>
<td></td>
<td><strong>Measure</strong> Process Mapping</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Analyze</strong> Why-Why Analysis, Pareto Analysis, Causes-and-Effect Diagram</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Improve</strong> Brainstorming</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Control</strong> Control Plan</td>
<td></td>
</tr>
<tr>
<td>(Shrivastava, Ahmad, &amp; Desai, 2008)</td>
<td><strong>Define</strong> Project Charter, Process Mapping, Flowchart</td>
<td>DMAIC LIST 10</td>
</tr>
<tr>
<td></td>
<td><strong>Measure</strong> Cause-and-Effect Diagram</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Analyze</strong> Pareto Chart, Failure Mode and Effect Analysis (FMEA)</td>
<td></td>
</tr>
<tr>
<td>(Kaushik, Khanduja, Mittal, &amp; Jaglan, 2012)</td>
<td><strong>Define</strong> Process Mapping, SIPOC Diagram</td>
<td>DMAIC LIST 12</td>
</tr>
<tr>
<td></td>
<td><strong>Measure</strong> Gauge R&amp;R</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Analyze</strong> Process capability Analysis, Causes-and-Effect Diagram, Hypothesis Testing</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Improve</strong> Design of Experiments (DOE)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Control</strong> Control Chart</td>
<td></td>
</tr>
<tr>
<td>(Dwivedi, Anas, &amp; Siraj, 2014)</td>
<td><strong>Define</strong> SIPOC Diagram</td>
<td>DMAIC LIST 15 &amp; DMAIC LIST 16</td>
</tr>
<tr>
<td></td>
<td><strong>Measure</strong> Sigma Calculation (DPMO)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Analyze</strong> Cause-and-Effect Diagram</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Control</strong> Sigma Calculation (DPMO)</td>
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</table>
Table 38

*Validated DMAIC Lists Based on the Number of Cases in Manufacturing*

<table>
<thead>
<tr>
<th>DMAIC LIST</th>
<th>Number of Cases</th>
<th>Validation</th>
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<tr>
<td>DMAIC LIST 12</td>
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</tr>
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</tr>
<tr>
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<td>Validated</td>
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<tr>
<td>DMAIC LIST 14</td>
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<td>DMAIC LIST 7</td>
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<td>None</td>
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<tr>
<td>DMAIC LIST 9</td>
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</tbody>
</table>

Service Industry

Data Collection

In the service industry, 68 case studies were carefully selected to meet the five specific criteria identified in choosing case studies. These cases were also represented in a binary code as a linear combination of the five SERVQUAL dimensions of service quality (i.e., dependent variables), which are: Tangibles, Reliability, Responsiveness, Assurance, and Empathy. Each dimension was given either a value of one (1) if it was used in the case problem, or a value of zero (0) if it was not. Table 39 shows a summary of the collected data. The sets of quality tools and techniques (i.e., independent variables)
in each case were categorized for further analysis in the clustering step. A full list of DMAIC tools and techniques for each of the 68 cases can be found in Appendix B.

Table 39

Summary of Collected Data for the Service Industry

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Case Reference</th>
<th>Tangibles</th>
<th>Reliability</th>
<th>Responsiveness</th>
<th>Assurance</th>
<th>Empathy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(Barone &amp; Franco, 2012; p. 269)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>(Barone &amp; Franco, 2012; p. 314)</td>
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<td>1</td>
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<td>1</td>
<td>0</td>
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<tr>
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<td>(Al-Bashir &amp; Al-Tawarah, 2012)</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>(Allen, Tseng, Swanson, &amp; McClay, 2009)</td>
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<tr>
<td>6</td>
<td>(Antony, Bhuller, Kumar, Mendibil, &amp; Montgomery, 2012)</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>(Cash, 2013)</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>8</td>
<td>(Drenckpohl, Bowers, &amp; Cooper, 2007)</td>
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<td>1</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>9</td>
<td>(Eldridge et al., 2006)</td>
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<tr>
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<td>(Feng &amp; Antony, 2009)</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>11</td>
<td>(Furterer &amp; Elshennawy, 2005)</td>
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<tr>
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<td>(Goodman, Kasper, &amp; Leek, 2007)</td>
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<tr>
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<td>(Heuvel, Does, &amp; Vermaat, 2004; case 1)</td>
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<td>Assurance</td>
<td>Empathy</td>
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<tr>
<td>43</td>
<td>(Taner &amp; Sezen, 2009)</td>
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</tr>
<tr>
<td>44</td>
<td>(Wei, Sheen, Tai, &amp; Lee, 2010)</td>
<td>1</td>
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</tr>
<tr>
<td>45</td>
<td>(McAdam, Davies, Keogh, &amp; Finnegan, 2009)</td>
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<td>1</td>
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<td>1</td>
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</tr>
<tr>
<td>46</td>
<td>(Cheng &amp; Chang, 2012)</td>
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<td>1</td>
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</tr>
<tr>
<td>47</td>
<td>(Chiarini, 2012)</td>
<td>0</td>
<td>1</td>
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</tr>
<tr>
<td>48</td>
<td>(Das &amp; Hughes, 2006)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>49</td>
<td>(Desai, 2006)</td>
<td>0</td>
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<tr>
<td>50</td>
<td>(Ng, Tsung, So, &amp; Li, 2005)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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</tr>
<tr>
<td>51</td>
<td>(Kapadia, Hemanth, &amp; Sharda, 2003)</td>
<td>0</td>
<td>0</td>
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<td>(Nanda, 2010)</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>53</td>
<td>(Kumar, Jensen, &amp; Menge, 2008)</td>
<td>0</td>
<td>0</td>
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<tr>
<td>54</td>
<td>(Al-Qatawneh, Abdallah, &amp; Zalloum, 2013)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>55</td>
<td>(Baddour &amp; Saleh, 2013)</td>
<td>0</td>
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</tr>
<tr>
<td>Case Number</td>
<td>Case Reference</td>
<td>Tangibles</td>
<td>Reliability</td>
<td>Responsiveness</td>
<td>Assurance</td>
<td>Empathy</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------</td>
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<td>-------------</td>
<td>----------------</td>
<td>-----------</td>
<td>---------</td>
</tr>
<tr>
<td>56</td>
<td>(Kumar, Phillips, &amp; Rupp, 2009)</td>
<td>0</td>
<td>1</td>
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</tr>
<tr>
<td>57</td>
<td>(Hagg, El-Harit, Vanni, &amp; Scott, 2007)</td>
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<td>0</td>
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<tr>
<td>58</td>
<td>(Kanakana, Pretorius, &amp; van Wyk, 2012)</td>
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<tr>
<td>59</td>
<td>(Lokkerbol, Schotman, &amp; Does, 2012)</td>
<td>1</td>
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<tr>
<td>60</td>
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<tr>
<td>61</td>
<td>(Miski, 2014)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>62</td>
<td>(Pranoto &amp; Nurcahyo, 2014)</td>
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<td>1</td>
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<td>1</td>
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</tr>
<tr>
<td>63</td>
<td>(Cheng, 2013)</td>
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<td>0</td>
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<td>1</td>
</tr>
<tr>
<td>64</td>
<td>(Barone &amp; Franco, 2012; p. 330)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>65</td>
<td>(Elberfeld, Goodman, &amp; Mark Van Kooy, 2004)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>66</td>
<td>(Wang &amp; Chen, 2010)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>67</td>
<td>(Kim, Kim, &amp; Chung, 2010)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>68</td>
<td>(Laureani, Antony, &amp; Douglas, 2010)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

From the 68 case studies listed in Table 39, the distribution of the five SERVQUAL dimensions of service quality (i.e., dependent variables) is illustrated in Table 40 in terms of their total number of cases. For further illustration, Figure 19 provides a graphical representation of the five SERVQUAL dimensions of service quality in terms of the number of cases.
Table 40

*Number of Cases in each Dimension of Service*

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Total Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>57</td>
</tr>
<tr>
<td>Responsiveness</td>
<td>28</td>
</tr>
<tr>
<td>Assurance</td>
<td>20</td>
</tr>
<tr>
<td>Tangibles</td>
<td>10</td>
</tr>
<tr>
<td>Empathy</td>
<td>7</td>
</tr>
</tbody>
</table>

*Figure 19.* Five SERVQUAL dimensions of service quality and their case numbers.

**Data Analysis**

After the data were collected, the researcher used cluster analysis to categorize the case studies into homogenous groups. The same cluster analysis process as identified earlier was followed in this step of the study. In the first step of the cluster analysis, the
five SERVQUAL dimensions of service quality were determined for the following cluster variables: Tangibles, Reliability, Responsiveness, Assurance, and Empathy. In the second step, Euclidean distance type was used to measure similarities. Following this, both hierarchical and k-means clustering approaches were selected to conduct the cluster analysis. SPSS software was used to run the two types of clustering techniques.

The number of clusters was determined to be 16. From the hierarchical clustering method that used Ward's linkage type, the output of the dendrogram diagram was used to clarify the determined number of clusters, as shown in Figure 20. Then, the 16 clusters were analyzed using the k-means clustering method. Each of the 68 service industry cases was assigned one of the 16 clusters. Table 41 shows the cluster membership of each case. Table 42 shows the number of cases and dimensions (i.e., variables) used in each cluster. Figure 21 provides a graphical representation of the 16 clusters and their case numbers.
Figure 20. Dendrogram diagram for the 68 case studies
Table 41

*Cluster Membership for the Service Industry*

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Cluster</th>
<th>Case Number</th>
<th>Cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>35</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>36</td>
<td>6</td>
</tr>
<tr>
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<td>3</td>
<td>37</td>
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</tr>
<tr>
<td>4</td>
<td>1</td>
<td>38</td>
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<td>39</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>40</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>41</td>
<td>4</td>
</tr>
<tr>
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<td>42</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>44</td>
<td>7</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>45</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>46</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
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</tr>
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<td>53</td>
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</tr>
<tr>
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<td>2</td>
<td>54</td>
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</tr>
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<td>61</td>
<td>6</td>
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<td>28</td>
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<td>62</td>
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<td>29</td>
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<td>63</td>
<td>16</td>
</tr>
<tr>
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<td>64</td>
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</tr>
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<td>65</td>
<td>3</td>
</tr>
<tr>
<td>32</td>
<td>1</td>
<td>66</td>
<td>2</td>
</tr>
<tr>
<td>33</td>
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<td>67</td>
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</tr>
<tr>
<td>34</td>
<td>1</td>
<td>68</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 42

*Cases Number and Dimensions Used in Each Cluster of Service*

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Number of Cases</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23</td>
<td>Reliability</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>Reliability, Responsiveness</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>Reliability, Responsiveness, Assurance</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Tangibles, Reliability, Responsiveness, Assurance</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>Tangibles, Reliability, Assurance</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>Reliability, Empathy</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>Tangibles, Reliability, Responsiveness</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>Reliability, Assurance</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>Assurance</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>Reliability, Responsiveness, Assurance, Empathy</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>Responsiveness</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>Tangibles, Reliability</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>Reliability, Responsiveness, Empathy</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>Tangibles, Empathy</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>Tangibles, Assurance</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>Assurance, Empathy</td>
</tr>
</tbody>
</table>

*Figure 21. Number of cases used in each cluster.*
After assigning each of the 68 service industry cases into the 16 clusters, tools and techniques (i.e., independent variables) were cumulated in each cluster. Table 43 shows the cumulated tools and techniques for each cluster.

Table 43

*Cumulated Tools and Techniques for Clusters in Service*

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Tools &amp; Techniques for Cluster Cases</th>
</tr>
</thead>
</table>
| 1       | **Define**  
**Measure**  
**Analyze**  
**Improve**  
**Control**  
Quality Function Deployment (QFD), Control Plan, RACI Matrix (Responsible Accountable Consulted and Informed), Survey, Control Chart, Sigma Calculation (DPMO), Process Capability Analysis, ISO 9000, Plan-Do-Study-Act (PDSA). |

(table continues)
<table>
<thead>
<tr>
<th>Cluster 2</th>
<th>Define</th>
<th>Project Charter, Gantt Chart, P-diagram, SIPOC Diagram, Process Map, Critical to Quality (CTQ), Tollgate Checklist, Key Output Variables (KOVs), Voice of Customer (VOC), Flowchart, Value Stream Mapping (VSM), Cause-and-Effect Matrix, The Seven Wastes (Muda)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Binomial Test, Survey, Flowchart, Standardization, Control Plan, Control Chart, Risk Evaluation Matrix, Survey, Sigma Calculation (DPMO)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cluster 3</th>
<th>Define</th>
<th>Project charter, Gantt Chart, Y and y definitions, P-diagram, SIPOC Diagram, Process Mapping, Auditing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyze</td>
<td>Kruskal-Wallis Test, Chi-square Test, Process capability analysis, Pareto Analysis, 5 Whys Analysis, Regression Analysis, Failure Mode Effects Analysis (FMEA), Value Stream Mapping (VSM), Sampling, Cause-and-Effect Diagram, Hypothesis Testing, Brainstorming</td>
<td></td>
</tr>
<tr>
<td>Improve</td>
<td>Process Capability Analysis, Hypothesis Testing, Histogram, Survey, Chi-square Test</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>Process Capability Analysis, Flowchart, Control Chart, Failure Mode and Effect Analysis (FMEA)</td>
<td></td>
</tr>
</tbody>
</table>

(table continues)
<table>
<thead>
<tr>
<th>Cluster</th>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4</strong></td>
<td>Critical to Quality (CTQ), Project Charter, Key Performance Indicators (KPIs)</td>
<td>Value Stream Mapping (VSM), Survey</td>
<td>Process Mapping, simulation, Poka-yoke, Flowchart, Statistical Process Control (SPC)</td>
<td>Cost-benefit Analysis, Control Chart</td>
<td>Survey</td>
</tr>
<tr>
<td><strong>6</strong></td>
<td>Project Charter, SIPOC Diagram, Voice of Customer (VOC), Critical to Quality (CTQ)</td>
<td>Survey, Frequency Table, Benchmarking, Kano Model</td>
<td>Scatter Diagram, Frequency Tables, Basic Statistics, Cause-and-Effect Diagram, Pareto Chart, 5 Whys Analysis</td>
<td>Brainstorming, Affinity Diagram</td>
<td>Control Charts</td>
</tr>
<tr>
<td>Cluster</td>
<td>Define</td>
<td>Measure</td>
<td>Analyze</td>
<td>Improve</td>
<td>Control</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
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</tr>
<tr>
<td>10</td>
<td>Focus Group</td>
<td>Frequency Table</td>
<td>Frequency Table</td>
<td>Process Mapping</td>
<td>Run Chart</td>
</tr>
<tr>
<td>11</td>
<td>Frequency Table</td>
<td>Process Mapping, Dashboard</td>
<td>Pareto Chart, Brainstorming</td>
<td>Control Chart</td>
<td>Control Chart, Flow Chart, Control Plan</td>
</tr>
<tr>
<td>Cluster</td>
<td>Define</td>
<td>Measure</td>
<td>Analyze</td>
<td>Improve</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>Cluster 12</td>
<td>Voice of Customer (VOC), Critical to Quality (CTQ), Survey</td>
<td>Process Mapping</td>
<td>Value-added analysis, Brainstorming, Cause-and-Effect Diagram</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster 14</td>
<td>Voice of Customer (VOC), Project Charter</td>
<td>Process map, Critical to Quality (CTQ), Sigma Calculation (DPMO), Gage R&amp;R</td>
<td>Spaghetti Diagram, Pareto Chart, Cause-and-Effect Diagram, 5 Why Analysis, Survey, Hypothesis Testing</td>
<td>Box Plot, Control Chart</td>
<td></td>
</tr>
<tr>
<td>Cluster 15</td>
<td>SIPOC, Diagram, Critical to Quality (CTQ)</td>
<td>Brainstorming</td>
<td>Frequency Table</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster 16</td>
<td>Hypothesis testing, Survey</td>
<td>Cause-and-effect Diagram</td>
<td>Matrix Diagram</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Matrix Development**

The researcher used the 16 clusters as the basis for developing the ultimate goal of the second part of this research: Constructing the contradiction matrix of service. To
build the new matrix, the original 39 technical parameters of TRIZ were replaced by the five SERVQUAL dimensions of service quality. Each cell in the matrix was constructed by combining two dimensions in each row and column; thus, the outcome of each cell must contain all clusters that shared at least the two dimensions. For instance, the intersection of Responsiveness and Reliability shares the following clusters: 2, 3, 4, 7, 10, and 13. All of these clusters share the two dimensions of Responsiveness and Reliability, as illustrated in Table 44.

Table 44

*Responsiveness and Reliability Dimensions*

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Number of Cases</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>15</td>
<td>Reliability, Responsiveness</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>Reliability, Responsiveness, Assurance</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Tangibles, Reliability, Responsiveness, Assurance</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>Tangibles, Reliability, Responsiveness</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>Reliability, Responsiveness, Assurance, Empathy</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>Reliability, Responsiveness, Empathy</td>
</tr>
</tbody>
</table>

After constructing each cell of the matrix, the cumulated tools and techniques in all clusters in the cell produced the 15 DMAIC lists, which are the optimal list of tools and techniques for each pair of the matrix. Table 45 shows the developed contradiction matrix for service, and Table 46 shows the 15 DMAIC lists of tools and techniques for the matrix. Table 47 illustrates the total number of cases used to build each DMAIC list in the contradiction matrix.
Table 45

Contradiction Matrix for Service

<table>
<thead>
<tr>
<th></th>
<th>Tangibles</th>
<th>Reliability</th>
<th>Responsiveness</th>
<th>Assurance</th>
<th>Empathy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tangibles</strong></td>
<td>4, 5, 7, 12, 14, 15 (DMAIC LIST 14)</td>
<td>4, 5, 7, 12 (DMAIC LIST 1)</td>
<td>4, 7 (DMAIC LIST 2)</td>
<td>4, 5, 15 (DMAIC LIST 3)</td>
<td>14 (DMAIC LIST 13)</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>4, 5, 7, 12 (DMAIC LIST 1)</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 13 (DMAIC LIST 10)</td>
<td>2, 3, 4, 7, 10, 13 (DMAIC LIST 4)</td>
<td>3, 4, 5, 8, 10 (DMAIC LIST 5)</td>
<td>6, 10, 13 (DMAIC LIST 6)</td>
</tr>
<tr>
<td><strong>Responsiveness</strong></td>
<td>4, 7 (DMAIC LIST 2)</td>
<td>2, 3, 4, 7, 10, 13 (DMAIC LIST 4)</td>
<td>2, 3, 4, 7, 10, 11, 13 (DMAIC LIST 11)</td>
<td>3, 4, 10 (DMAIC LIST 7)</td>
<td>10, 13 (DMAIC LIST 8)</td>
</tr>
<tr>
<td><strong>Assurance</strong></td>
<td>4, 5, 15 (DMAIC LIST 3)</td>
<td>3, 4, 5, 8, 10 (DMAIC LIST 5)</td>
<td>3, 4, 10 (DMAIC LIST 7)</td>
<td>3, 4, 5, 8, 9, 10, 15, 16 (DMAIC LIST 12)</td>
<td>10, 16 (DMAIC LIST 9)</td>
</tr>
<tr>
<td><strong>Empathy</strong></td>
<td>14 (DMAIC LIST 13)</td>
<td>6, 10, 13 (DMAIC LIST 6)</td>
<td>10, 13 (DMAIC LIST 8)</td>
<td>10, 16 (DMAIC LIST 9)</td>
<td>6, 10, 13, 14, 16 (DMAIC LIST 15)</td>
</tr>
</tbody>
</table>
### Table 46

**Fifteen DMAIC Lists for the Contradiction Matrix of Service**

<table>
<thead>
<tr>
<th>DMAIC Lists for The Contradiction Matrix</th>
<th>DMAIC LIST 1</th>
<th>DMAIC LIST 2</th>
<th>DMAIC LIST 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define</td>
<td>Voice of Customer (VOC), Critical to Quality (CTQ), Project Charter, Key Performance Indicators (KPIs), Survey, SIPOC Diagram, Process Mapping</td>
<td>Critical to Quality (CTQ), Project Charter, Key Performance Indicators (KPIs), Voice of Customer (VOC), SIPOC Diagram, Process Mapping</td>
<td>Critical to Quality (CTQ), Project Charter, Key Performance Indicators (KPIs), SIPOC Diagram, Voice of Customer (VOC)</td>
</tr>
<tr>
<td>Improve</td>
<td>Cost-benefit Analysis, Control Chart, Failure Mode Effect Analysis (FMEA)</td>
<td>Cost-benefit Analysis, Control Chart</td>
<td>Cost-benefit Analysis, Control Chart</td>
</tr>
<tr>
<td>Control</td>
<td>Survey, Control Plan, Control Chart, Value Stream Mapping (VSM)</td>
<td>Survey, Control plan, Value Stream Mapping (VSM)</td>
<td>Survey, Control Chart</td>
</tr>
</tbody>
</table>

(table continues)
### DMAIC Lists for The Contradiction Matrix

**Define**
- Project Charter, Gantt Chart, P-diagram, SIPOC Diagram, Process Mapping, Critical to Quality (CTQ), Tollgate Checklist, Key Output Variables (KOVs), Voice of Customer (VOC), Flowchart, Value Stream Mapping, Cause-and-Effect Matrix, The Seven Wastes (Muda), Auditing, Y and y definition, Key Performance Indicators (KPIs), Focus Group

**Measure**

**Analyze**

**Improve**

**Control**
- Binomial test, Survey, Flowchart, Standardization, Control Plan, Control Chart, Risk Evaluation Matrix, Survey, Sigma Calculation (DPMO), Process Capability Analysis, Failure Mode and Effect Analysis (FMEA), Run Chart, Value Stream Mapping (VSM)

(table continues)
<table>
<thead>
<tr>
<th>DMAIC Lists for The Contradiction Matrix</th>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DMAIC LIST 5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DMAIC LIST 6</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Define</strong></td>
<td>Project Charter, Process Mapping, Focus Group, SIPOC Diagram, Voice of Customer (VOC), Critical to Quality (CTQ)</td>
<td>Survey, Frequency Table, Interview, Benchmarking, Kano Model</td>
<td>Scatter Diagram, Frequency Table, Basic Statistics, Cause-and-Effect Diagram, Pareto Chart, 5 Whys Analysis</td>
<td>Process Mapping, Poka-yoke, Brainstorming, Affinity Diagram</td>
<td>Run Chart, Control Chart</td>
</tr>
</tbody>
</table>

(table continues)
<table>
<thead>
<tr>
<th>DMAIC Lists for The Contradiction Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Define</strong></td>
</tr>
<tr>
<td>DMAIC LIST 7</td>
</tr>
<tr>
<td><strong>Define</strong></td>
</tr>
<tr>
<td>DMAIC LIST 8</td>
</tr>
<tr>
<td><strong>Define</strong></td>
</tr>
<tr>
<td>DMAIC LIST 9</td>
</tr>
<tr>
<td><strong>Define</strong></td>
</tr>
</tbody>
</table>

### DMAIC LIST 7

**Define**
- Project Charter, Gantt Chart, Y and y definitions, P-diagram, SIPOC Diagram, Process Mapping, Auditing, Focus Group, Critical to Quality (CTQ), Key Performance Indicators (KPIs)

**Measure**

**Analyze**

**Improve**
- Process Capability Analysis, Hypothesis Testing, Histogram, Survey, Chi-square Test, Process Mapping, Cost-benefit Analysis, Control Chart

**Control**
- Process Capability Analysis, Flowchart, Control Chart, Failure Mode and Effects Analysis (FMEA), Run Chart, Survey

### DMAIC LIST 8

**Define**
- Process Mapping, Focus Group

**Measure**
- Survey, Frequency Table

**Analyze**
- Cause-and-Effect Diagram, Frequency Table

**Improve**
- Process Mapping, Poka-yoke

**Control**
- Run Chart

### DMAIC LIST 9

**Define**
- Focus Group

**Measure**
- Frequency Table, Hypothesis testing, Survey

**Analyze**
- Frequency Table, Cause-and-Effect Diagram

**Improve**
- Process Mapping, Matrix Diagram

**Control**
- Run Chart

*(table continues)*
DMAIC Lists for The Contradiction Matrix

<table>
<thead>
<tr>
<th>DMAIC LIST 10</th>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
</table>

(table continues)
### DMAIC Lists for The Contradiction Matrix

<table>
<thead>
<tr>
<th>DMAIC LIST 11</th>
<th>Define</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Define</strong></td>
<td>Project Charter, Gantt Chart, P-diagram, SIPOC Diagram, Process Mapping, Critical to Quality (CTQ), Tollgate Checklist, Key Output Variables (KOVs), Voice of Customer (VOC), Flowchart, Value Stream Mapping (VSM), Cause-and-Effect Matrix, The Seven Wastes (Muda), Auditing, Y and y definition, Key Performance Indicators (KPIs), Focus Group</td>
<td></td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>Binomial Test, Survey, Flowchart, Standardization, Control Plan, Control Chart, Risk Evaluation Matrix, Survey, Sigma Calculation (DPMO), Process Capability, Failure Mode and Effect Analysis (FMEA), Run Chart, Value Stream Mapping (VSM)</td>
<td></td>
</tr>
</tbody>
</table>

*table continues*
### DMAIC Lists for The Contradiction Matrix

<table>
<thead>
<tr>
<th>DMAIC LIST 12</th>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMAIC LIST 13</td>
<td><strong>Define</strong> Voice of Customer (VOC), Project Charter</td>
<td><strong>Measure</strong> Process Mapping, Critical to Quality (CTQ), Sigma Calculation (DPMO), Gage R&amp;R</td>
<td><strong>Analyze</strong> Spaghetti Diagram, Pareto Chart, Cause-and-Effect Diagram, 5 Whys Analysis, Survey, Hypothesis Testing</td>
<td><strong>Improve</strong> Box Plot, Control Chart</td>
<td><strong>Control</strong> Pilot Plan, Control Chart, Action plan, Auditing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table continues...*
<table>
<thead>
<tr>
<th>DMAIC Lists for The Contradiction Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Define</strong></td>
</tr>
<tr>
<td>Critical to Quality (CTQ), Project Charter, Key Performance Indicators (KPIs), Voice of Customer (VOC), Survey, SIPOC Diagram, Sigma Calculation (DPMO), Gage R&amp;R, Process Mapping</td>
</tr>
<tr>
<td><strong>Measure</strong></td>
</tr>
<tr>
<td>Value Stream Mapping (VSM), Survey, Process Mapping, Cause-and-Effect Diagram, Cause-and-Effect Matrix, Failure Mode and Effect Analysis (FMEA), Process Capability Analysis, Critical to Quality (CTQ), Brainstorming, Sigma Calculation (DPMO)</td>
</tr>
<tr>
<td><strong>Analyze</strong></td>
</tr>
<tr>
<td><strong>Improve</strong></td>
</tr>
<tr>
<td>Cost-benefit Analysis, Control Chart, Failure Mode and Effect Analysis (FMEA), Box Plot, Frequency Table</td>
</tr>
<tr>
<td><strong>Control</strong></td>
</tr>
<tr>
<td>Survey, Control Plan, Control Chart, Pilot Plan, Action Plan, Auditing, Value Stream Mapping (VSM)</td>
</tr>
</tbody>
</table>

**DMAIC LIST 15**

| **Define**                             |
| Project Charter, Process Mapping, Focus Group, Voice of Customer (VOC), SIPOC Diagram, Critical to Quality (CTQ) |
| **Measure**                            |
| Survey, Frequency Table, Process Mapping, Critical to Quality (CTQ), Sigma Calculation (DPMO), Gage R&R, Interviews, Benchmarking, Kano Model, Hypothesis Testing |
| **Analyze**                            |
| Scatter Diagram, Frequency Table, Basic Statistics, Spaghetti Diagram, Pareto Chart, Cause-and-Effect Diagram, 5 whys Analysis, Survey, Hypothesis Testing |
| **Improve**                            |
| Process Mapping, Poka-yoke, Box Plot, Control Chart, Brainstorming, Affinity Diagram, Matrix Diagram |
| **Control**                            |
| Run Chart, Pilot Plan, Control Chart, Action Plan, Auditing |
Matrix Validation

To validate the contradiction matrix for service, the researcher used selected samples from the 15 DMAIC lists, and verified these sample in relation to case studies different from the ones used to build the matrix. Validation took place because the selected samples—DMAIC lists 4, 5, 10, 11, and 12 developed from the matrix—matched with the tools and techniques discussed in case studies from Wang and Chen (2010); Bao et al. (2013); Rohini and Mallikarjun (2011); and Ateekh-ur-Rehman (2012). The shaded cells in Table 48 represent the validated DMAIC lists in the contradiction matrix for service. Table 49 illustrates the tools and techniques used in the four case studies to validate the selected DMAIC lists. Lastly, Table 50 demonstrates the validated DMAIC lists from large to small, based on the number of cases used in each list.
Table 48

Validated DMAIC Lists in the Contradiction Matrix for Service

<table>
<thead>
<tr>
<th>Contradiction Matrix for Service</th>
<th>Tangibles</th>
<th>Reliability</th>
<th>Responsiveness</th>
<th>Assurance</th>
<th>Empathy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tangibles</strong></td>
<td>4, 5, 7, 12, 14, 15 (DMAIC LIST 14)</td>
<td>4, 5, 7, 12 (DMAIC LIST 1)</td>
<td>4, 7 (DMAIC LIST 2)</td>
<td>4, 5, 15 (DMAIC LIST 3)</td>
<td>14 (DMAIC LIST 13)</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>4, 5, 7, 12 (DMAIC LIST 1)</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 13 (DMAIC LIST 10)</td>
<td>2, 3, 4, 7, 10, 13 (DMAIC LIST 4)</td>
<td>3, 4, 5, 8 10 (DMAIC LIST 5)</td>
<td>6, 10, 13 (DMAIC LIST 6)</td>
</tr>
<tr>
<td><strong>Responsiveness</strong></td>
<td>4, 7 (DMAIC LIST 2)</td>
<td>2, 3, 4, 7, 10, 11, 13 (DMAIC LIST 11)</td>
<td>3, 4, 10 (DMAIC LIST 7)</td>
<td>10, 13 (DMAIC LIST 8)</td>
<td></td>
</tr>
<tr>
<td><strong>Assurance</strong></td>
<td>4, 5, 15 (DMAIC LIST 3)</td>
<td>3, 4, 5, 8, 10 (DMAIC LIST 5)</td>
<td>3, 4, 10 (DMAIC LIST 7)</td>
<td>3, 4, 5, 8, 9, 10, 15, 16 (DMAIC LIST 12)</td>
<td>10, 16 (DMAIC LIST 9)</td>
</tr>
<tr>
<td><strong>Empathy</strong></td>
<td>14 (DMAIC LIST 13)</td>
<td>6, 10, 13 (DMAIC LIST 6)</td>
<td>10, 13 (DMAIC LIST 8)</td>
<td>10, 16 (DMAIC LIST 9)</td>
<td>6, 10, 13, 14, 16 (DMAIC LIST 15)</td>
</tr>
</tbody>
</table>
Table 49

Validation Cases for Service

<table>
<thead>
<tr>
<th>Case Study</th>
<th>DMAIC Tools &amp; Techniques</th>
<th>Validated DMAIC LIST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measure: Process Capability Analysis, Control Chart</td>
<td>DMAIC LIST 4 &amp; DMAIC LIST 11</td>
</tr>
<tr>
<td></td>
<td>Analyze: Cause-and-Effect Matrix, Pareto Diagram, Failure Mode and Effect Analysis (FMEA)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improve: TRIZ, Value Stream Mapping (VSM), Process Capability</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control: Control Plan, Control Chart</td>
<td></td>
</tr>
<tr>
<td>(Bao, Chen, Shang, Fang, Xu, Guo, &amp; Wang, 2013)</td>
<td>Measure: Process Capability Analysis, Frequency Table</td>
<td>DMAIC LIST 5</td>
</tr>
<tr>
<td></td>
<td>Analyze: Brainstorming, Cause-and-Effect Diagram</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control: Survey</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Measure: Sigma Calculation (DPMO)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analyze: Cause-and-Effect Diagram, Brainstorm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improve: Brainstorm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control: Sigma Calculation (DPMO)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analyze: Cause-and-Effect Diagram</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control: Control Plan</td>
<td></td>
</tr>
</tbody>
</table>
Table 50

Validated DMAIC Lists Based on The Number of Cases in Service

<table>
<thead>
<tr>
<th>DMAIC LIST</th>
<th>Number of Cases</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMAIC LIST 10</td>
<td>57</td>
<td>Validated</td>
</tr>
<tr>
<td>DMAIC LIST 11</td>
<td>28</td>
<td>Validated</td>
</tr>
<tr>
<td>DMAIC LIST 4</td>
<td>26</td>
<td>Validated</td>
</tr>
<tr>
<td>DMAIC LIST 12</td>
<td>20</td>
<td>Validated</td>
</tr>
<tr>
<td>DMAIC LIST 5</td>
<td>13</td>
<td>Validated</td>
</tr>
<tr>
<td>DMAIC LIST 14</td>
<td>10</td>
<td>None</td>
</tr>
<tr>
<td>DMAIC LIST 7</td>
<td>8</td>
<td>None</td>
</tr>
<tr>
<td>DMAIC LIST 1</td>
<td>7</td>
<td>None</td>
</tr>
<tr>
<td>DMAIC LIST 15</td>
<td>7</td>
<td>None</td>
</tr>
<tr>
<td>DMAIC LIST 3</td>
<td>5</td>
<td>None</td>
</tr>
<tr>
<td>DMAIC LIST 2</td>
<td>4</td>
<td>None</td>
</tr>
<tr>
<td>DMAIC LIST 6</td>
<td>4</td>
<td>None</td>
</tr>
<tr>
<td>DMAIC LIST 8</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>DMAIC LIST 9</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>DMAIC LIST 13</td>
<td>2</td>
<td>None</td>
</tr>
</tbody>
</table>

Summary

This chapter presented the result of the steps used in the research methodology of the study. The included manufacturing and service industries were analyzed to develop the proposed innovative matrices. The study collected 72 case studies for the manufacturing industry, producing 17 different clusters that were used to develop the contradiction matrix for manufacturing, which ultimately includes the optimal 17 DMAIC lists of tools and techniques. The eight Garvin dimensions of product quality were used as variables for the developed contradiction matrix for the manufacturing industry, including: Performance, Features, Reliability, Conformance, Durability, Serviceability, Aesthetics, and Perceived Quality. For the service industry, the study collected 68 case studies, which produced 16 different clusters to develop the
contradiction matrix for service, which ultimately includes the optimal 15 DMAIC lists of tools and techniques. The five SERVQUAL dimensions of service quality were used as variables for the developed contradiction matrix for the service industry, including: Tangibles, Reliability, Responsiveness, Assurance, and Empathy.
CHAPTER 5
CONCLUSION, DISCUSSION, AND RECOMMENDATION

Conclusion

An extensive review of the literature indicated that today, competition plus innovation is the equation of success for any business. Quality—the first part of the equation, linked to competition—has been established by quality experts like W. Edwards Deming, Joseph M. Juran, and Philip B. Crosby for more than five decades. Innovation, the second part of the equation, has not yet been established or followed systematically. Therefore, a method of applying innovation and improvement systematically is needed. To achieve this objective, the researcher used TRIZ to solve problems concerning quality control and management systematically, effectively, efficiently, and innovatively.

There are more than 400 tools and techniques in the quality management area. These tools and techniques provide significant benefits, but they could create more problems in the quality system if applied inappropriately. Quality tools and techniques need to be applied sequentially, and be embedded within a systematic problem-solving approach, to be implemented effectively. Thus, the researcher developed innovative and diagnostic matrices that mimicked the contradiction matrix of TRIZ in order to help individuals or teams in different industries select the correct quality tools and techniques. This study asked three questions, each of which is answered below.
Research Question 1

Research question 1 asked, “What are the optimal tools and techniques for quality management in the manufacturing and service industries?” Based on the results of this study, Table 34 summarizes the optimal tools and techniques for quality management in the manufacturing industry, which are depicted in 17 DMAIC lists. These optimal tools and techniques cumulated initially from 17 clusters composed of 72 case studies. Table 46 summarizes the optimal tools and techniques for quality management in the service industry, which are depicted in 15 DMAIC lists. These optimal tools and techniques cumulated initially from 16 clusters composed of 68 case studies. In total, the optimal tools and techniques for the manufacturing and service industries cumulated from 140 case studies that were carefully selected based on the specific five criteria indicated in the methodology of this study.

Research Question 2

Research question 2 asked, “How does one diagnose which quality tools and techniques are more applicable in specific circumstances related to quality dimensions?” Based on the results of this study, the contradiction matrices developed for the manufacturing and service industries—as identified in Table 33 and Table 45—provided a diagnostic methodology that could be applied for quality dimensions. The eight Garvin dimensions of product quality were determined as the specific circumstances that helped to select the appropriate tools and techniques in the contradiction matrix of manufacturing. The dimensions include: Performance, Features, Reliability, Conformance, Durability, Serviceability, Aesthetics, and Perceived Quality. The five
SERVQUAL dimensions of service quality were determined as the specific circumstances that helped to select the appropriate tools and techniques in the contradiction matrix of service. The dimensions include: Tangibles, Reliability, Responsiveness, Assurance, and Empathy.

Research Question 3

Research question 3 asked, “How does one maximize the benefits of all quality dimensions of products and services while tradeoffs have to be made between them?” Based on the literature review, compromises are commonly made between quality dimensions when two or more dimensions need to be improved together; thus, very few products or services shine in all dimensions. The researcher used the concept of the TRIZ contradiction matrix to solve this research question. In TRIZ, problems are solved creatively by finding ways to eliminate contradictions while not compromising. The developed contradiction matrices in Table 33 and Table 45 mimic the TRIZ contradiction matrix. There were no compromises made between any two dimensions, which led to a maximization of the benefits of all quality dimensions for products and services. Each cell in the matrix has two dimensions that share cumulated tools and techniques that were collected from similar case studies. For instance, the intersection of Responsiveness and Reliability in the contradiction matrix of service shares DMAIC list 4, which cumulated tools and techniques from 26 similar case studies.

Discussion

This study has several strengths and limitations. In terms of strengths, the current study used a cross-sectional design as the framework to collect and analyze quantitative
and qualitative data from various cases at a single point in time to uncover related patterns. This design provided significant assistance in gathering data from many case studies from all over the world within a limited time, at minimum cost. The study sample was initially set to be at least 100 cases for both the manufacturing and service industries; however, the actual total collected sample was 140 case studies, which include 72 cases for the manufacturing industry, and 68 cases for the service industry. Another strength of the study is its comprehensive approach. The contradiction matrices developed in this study cover both the manufacturing and service industries, as an inclusive application of quality tools and techniques was a notable gap in the literature review. The developed contradiction matrices of manufacturing and service filtered more than 400 tools and techniques in the area of quality management to be more appropriately diagnosed in an innovative way, with the ultimate goal of ensuring that no compromise is made between different dimensions in need of improvement. Finally, the contradiction matrices were developed to be used with a pair of dimensions—the goal of which was to eliminate compromises. This is similar to the TRIZ contradiction matrix. In addition to the pair of dimensions, a single dimension was added in this study.

In terms of limitations, the 13 dimensions (i.e., dependent variables) used in the contradiction matrices developed for this study are not equally distributed: Some had very large number of cases, while others were very few, as shown in Table 28 and Table 40. The variation in number of cases in each dimension occurred because of the lack of availability of case studies, which used certain dimensions. Some dimensions are commonly used in practice, while others are atypical. For instance, Conformance was the
most common issue used in the manufacturing industry. There were 47 case studies used for Conformance in the DMAIC process, while there was only one case study used for Perceived Quality. Also, in the contradiction matrix of service, Reliability was the most common issue used in the service industry. There were 57 case studies used for Reliability in the DMAIC process, while there were only 7 case studies used for Empathy. The variation of the number of cases used in the 13 dimensions affected the overall robustness of the developed contradiction matrices, as some of the optimal DMAIC lists were constructed by many cases, while others were developed using very few. A few intersecting cells in the contradiction matrix of manufacturing contained no data due to the lack of a case study for that specific pair of dimensions. Also, the variation of the number of cases in the 13 dimensions limited the availability of case studies for validating the developed contradiction matrices. Furthermore, the selected sample from the optimal DMAIC lists could not be done randomly, because the chance of finding new case studies to validate the DMAIC lists, which cumulated from few case studies, was too low. Table 38 and Table 50 show that all of the validated DMAIC lists have large number of cases.

Selecting a non-random sampling method for the 140 case studies was another limitation of the study because the sample case studies had to be selected based on specific criteria. Although the selected case studies are assumed to be accurate, there is always room for errors, since this study is primarily based on secondary data analysis.

Another limitation is the broad coverage for the category of industries used in this study. Manufacturing and service industries are general domains, and could be
categorized into more specific fields. For instance, the manufacturing industry could include the petroleum, automobile, furniture, and food industries; the service industry could include the health, education, finance, and insurance industries. The application of tools and techniques may vary to some degree for these more narrow categories. The same could apply for differently sized organizations, as indicated in the literature.

Moreover, although the researcher used an innovative and unique approach (i.e., TRIZ methodology) to build the developed contradiction matrices, no previous studies had been found to follow a similar procedure. Thus, there was no strong way to assess the outcome of the study for its reliability during various phases of the research.

Lastly, the developed contradiction matrices are only applied for a single or a pair of dimensions; in practice, the application of these dimensions could take place with three or more variables at the same time, as shown in the few cases described in Table 27 and Table 39. The reason behind this limitation is that the current study mimics the contradiction matrix of TRIZ, where only a pair of technical parameters is used.

**Recommendations**

The current study could serve as a significant starting point for many future investigations in the field of quality management and innovation. Based on the literature review, the results of the current study, and the current study’s strengths and limitations, several recommendations can be made, including:

1. Replication of the current study in the future using more case studies, especially for those dimensions that have no or very few case studies, could make the developed contradiction matrices more robust. Also,
replicating the current study with more case studies would increase the reliability of the developed contradiction matrices by increasing the availability of more validated case studies.

2. Replication of the applicability of different tools and techniques used in the current study with different problem-solving processes, such as DMADV, PDCA cycle, the seven-step process, 8D, and Lean.

3. Increasing the reliability of the current study with additional, validated examples from primary data collected and implemented by the researcher from real case studies.

4. Extending the developed contradiction matrices to be more applicable to specific fields within the manufacturing and service industries, and to differently sized organizations.

5. Developing an extended matrix to include applying more than two dimensions at the same time.

6. Creating an inclusive contradiction matrix by validating the conjunction of the optimal DMAIC lists developed in this study with the 40 Inventive Principles of TRIZ.
REFERENCES


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read/write area in hard disk drive assembly process. *Uncertain Supply Chain 


optimize radial forging operation variables. *Journal of Materials Processing 


## APPENDIX A

### DMAIC TOOLS AND TECHNIQUES IN MANUFACTURING

#### Table A1

**DMAIC Tools and Techniques for the 72 Cases in Manufacturing**

<table>
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<tr>
<th>Case Number</th>
<th>Case Reference</th>
<th>DMAIC Phase</th>
<th>Tools &amp; Techniques</th>
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<tbody>
<tr>
<td>1</td>
<td>(Barone &amp; Franco, 2012; p. 296)</td>
<td>Define</td>
<td>Project Charter, Gantt Chart, Y and y Definitions, SIPOC Diagram, Process Mapping, Product Flow-down Tree</td>
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<td>Analyze</td>
<td>Process Capability Analyses, Control Chart</td>
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<td>Measure</td>
<td>Interview, Observation, Drawings, Work Sheets, Histogram, Gauge R&amp;R</td>
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<td>(Barone &amp; Franco, 2012; p. 365)</td>
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<td>Correlation Analysis, Regression Analysis, Normal Probability Plot, Process Capability Analyses, Control Chart</td>
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<td>Anderson–Darling Normality Test, Process Capability Analysis, Normal Probability Plot</td>
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<td>Checklist, Auditing, Control Chart</td>
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<tr>
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<td>(Bakshi, Singh, Singh, &amp; Singla, 2012)</td>
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<td>Cause-and-Effect Diagram, Brainstorming</td>
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<td>Design of experiments (DOE)</td>
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<td>(Banuelas, Antony, &amp; Brace, 2005)</td>
<td>Define</td>
<td>Project Charter, Critical to Quality (CTQ)</td>
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<td>ANOVA Test, Anderson–Darling and Ryan–Joiner Tests</td>
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<td>Process Capability Analysis, Control Plan</td>
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<td>7</td>
<td>(Bharti, Khan, &amp; Singh, 2011)</td>
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<td>Voice of Customer (VOC), Brainstorming, Pareto chart, Critical to Quality (CTQ)</td>
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<td>Box Plot, Critical to Quality (CTQ), Critical to Cost (CTC).</td>
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<tr>
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<td>(Christyanti, 2012)</td>
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<td>Cause-and-Effect Diagram, Failure Mode and Effect Analysis (FMEA)</td>
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<td>(Dietmüller &amp; Spitler, 2009)</td>
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<td>(Ditahardiyani, Ratnayani, &amp; Angwar, 2009)</td>
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<td>Failure Mode and Effect Analysis (FMEA), Standard Operating Procedure (SOP), Sigma Calculation (DPMO)</td>
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<td>(Falcón, Alonso, Fernández, &amp; Pérez-Lombard, 2012)</td>
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<td>SIPOC Diagram</td>
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<td>Measure</td>
<td>Cause-and-Effect Matrix, Pareto Chart, Block Step</td>
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<td>Multi-vari Analysis, Regression Analysis, Process Capability Analysis</td>
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<td>Improve</td>
<td>Process Capability Analysis</td>
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<tr>
<td>17</td>
<td>(Ghosh &amp; Maiti, 2012)</td>
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<td>(Gijo, Scaria, &amp; Antony, 2011)</td>
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<td>(Gnanaraj, Devadasan, Murugesh, &amp; Sreenivasa, 2012)</td>
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<td>(Goriwondo &amp; Maunga, 2012)</td>
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<td>Improve</td>
<td>Value Stream Mapping (VSM), Kanban, Brainstorming, Cost/Benefit Analysis</td>
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<td>(Hung, Wu, &amp; Sung, 2011)</td>
<td>Define</td>
<td>Voice of Customer (VOC), Key Performance Indicators (KPIs)</td>
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<td>(Jin, Janamanchi, &amp; Feng, 2011)</td>
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<td>(Kumar, &amp; Sosnoski, 2009)</td>
<td>Define</td>
<td>Pareto Chart, Project Charter</td>
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<td>(Ladani, Das, Cartwright, &amp; Yenkner, 2006; case 1)</td>
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<td>Hypothesis Testing, Regression Analysis</td>
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<td>(Ladani, Das, Cartwright, &amp; Yenkner, 2006; case 2)</td>
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<td>Hypothesis Testing</td>
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<td>(Kumar, Antony, Singh, Tiwari, &amp; Perry, 2006)</td>
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<td>Critical to Quality (CTQ), Voice of Customer (VOC), Value stream mapping (VSM)</td>
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<td>Design of Experiments (DOE), 5S, Total Productive Maintenance (TPM)</td>
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<tbody>
<tr>
<td>33</td>
<td>(Kumar, Antony, Antony, &amp; Madu, 2007)</td>
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<td>Control chart, Run Chart</td>
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<tr>
<td>34</td>
<td>(Chen &amp; Lyu, 2009)</td>
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<td>Voice of Customer (VOC), SIPOC Diagram, Critical to Quality (CTQ), Cause-and-Effect Diagram</td>
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<td>Statistical Process Control (SPC), Control Plan</td>
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<td>35</td>
<td>(Mukhopadhyay &amp; Ray, 2006)</td>
<td>Define</td>
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</tr>
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<td>Regression Analysis, Control Chart, Gauge R&amp;R</td>
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<td>36</td>
<td>(Zhuravskaya, Tarba, &amp; Mach, 2012)</td>
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<td>37</td>
<td>(Pranckevicius, Diaz, &amp; Gitlow, 2008)</td>
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(table continues)
<table>
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<tr>
<td>40</td>
<td>(Sahoo, Tiwari, &amp; Mileham, 2008)</td>
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<td>Brainstorming, Control Chart, Cause-and-Effect Diagram</td>
</tr>
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<td>Taguchi Methods, ANOVA Test</td>
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<td>41</td>
<td>(Saravanaan, Mahadevan, Suratkar, &amp; Gijo, 2012)</td>
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<td>(Sekhar &amp; Mahanti, 2006)</td>
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<th>Tools &amp; Techniques</th>
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<td>(Singh &amp; Bakshi, 2012)</td>
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<td>(Soković, Pavletić, &amp; Krulčić, 2006)</td>
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<td>(Kumar, Satsangi, &amp; Prajapati, 2011)</td>
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<td>46</td>
<td>(Lo, Tsai, &amp; Hsieh, 2009)</td>
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<td>47</td>
<td>(Vinodh, Kumar, &amp; Vimal, 2014)</td>
<td><strong>Define</strong></td>
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<td>48</td>
<td>(Zaman, Pattanayak, &amp; Paul, 2013)</td>
<td><strong>Define</strong></td>
<td>SIPOC Diagram</td>
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<tr>
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<td>Control Charts, Pareto Chart</td>
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<tr>
<td>49</td>
<td>(Aggogeri &amp; Mazzola, 2008)</td>
<td><strong>Define</strong></td>
<td>KPIs (Key Performance Indicators), Voice of Customer (VOC), Voice of the Process (VOP), Critical to Customer (CTC), Pareto Chart, Process Mapping, Costs of Poor Quality (COPQs), Critical to Quality (CTQ), Quality Function Deployment (QFD)</td>
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(table continues)
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<th>DMAIC Phase</th>
<th>Tools &amp; Techniques</th>
</tr>
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<td>51</td>
<td>(Artharn &amp; Rojanarowan, 2013)</td>
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<td>Pareto Chart, key Process Input Variable (KPIVs), Cause-and-Effect Diagram, Failure Mode and Effect Analysis (FMEA)</td>
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<td>52</td>
<td>(Belokar &amp; Singh, 2013)</td>
<td>Define</td>
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</tr>
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<td>53</td>
<td>(Chowdhury, Deb, &amp; Das, 2014)</td>
<td>Define</td>
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<td>54</td>
<td>(Desai &amp; Shrivastava, 2008)</td>
<td>Define</td>
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(table continues)
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<th>DMAIC Phase</th>
<th>Tools &amp; Techniques</th>
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<tbody>
<tr>
<td>56</td>
<td>(Farahmand, Marquez Grajales, &amp; Hamidi, 2010)</td>
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<td>(Hayajneh, Bataineh, &amp; Al-tawil, 2013)</td>
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<td>Control Plan, Flowchart</td>
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<td>(Ruthaiputpong &amp; Rojanarowan, 2013)</td>
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<td>Project Charter</td>
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<td>(Sambhe, 2012)</td>
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<th>Case Reference</th>
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<th>Tools &amp; Techniques</th>
</tr>
</thead>
<tbody>
<tr>
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<td>(Chung, Yen, Hsu, Tsai, &amp; Chen, 2008)</td>
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</tr>
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<td>(Tong, Tsung, &amp; Yen, 2004)</td>
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</tr>
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</tr>
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<td>(Al-Refaie, Li, Jalham, Bata, &amp; Al-Hmaideen, 2013)</td>
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</tr>
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</tr>
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<td>(Dambhare, Aphale, Kakade, Thote, &amp; Jawalkar, 2013)</td>
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<th>Case Reference</th>
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<th>Tools &amp; Techniques</th>
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</tr>
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<td>(Hahn, Piller, &amp; Lessner, 2006)</td>
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<td>Quality Function Deployment (QFD)</td>
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<td>Gage R&amp;R, Simulation, Normal Probability Plot</td>
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<td>Design of Experiments (DOE), Normal Probability Plot, Control Chart, Process Capability Analysis, Hypothesis Testing</td>
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<td>Control</td>
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<tr>
<td>68</td>
<td>(Puvanasvaran, Ling, Zain, &amp; Al-Hayali, 2012)</td>
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<td>Hypothesis Testing, Box Plot</td>
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<tr>
<td>69</td>
<td>(Al-Mishari &amp; Suliman 2008)</td>
<td>Define</td>
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<td></td>
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<td>Analyze</td>
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<td>Control Chart</td>
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<tr>
<td>70</td>
<td>(Kumar, Jawalkar, &amp; Vaishya, 2014)</td>
<td>Define</td>
<td>SIPOC Diagram</td>
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<td>Measure</td>
<td>Process Capability Analysis, Sigma Calculation (DPMO)</td>
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<td>Cause-and-Effect Diagram, Pareto Chart</td>
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<tr>
<td>71</td>
<td>(Sajeev &amp; M, 2013)</td>
<td>Define</td>
<td>Critical to Quality (CTQ), Project Charter</td>
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<td>Measure</td>
<td>Sigma Calculation (DPMO), Pareto Chart</td>
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<td>Analyze</td>
<td>Cause-and-Effect Diagram, Brainstorming, GEMBA</td>
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<td>72</td>
<td>(Jie, Kamaruddin, &amp; Azid, 2014)</td>
<td>Define</td>
<td>Value Stream Mapping (VSM), Flowchart</td>
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<td>Pareto Chart, Process Mapping</td>
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<td>Analyze</td>
<td>Cause-and-Effect Diagram, 5 Why Analysis</td>
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<td>Control</td>
<td>5S, Standard Operating Procedure (SOP)</td>
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### APPENDIX B

**DMAIC TOOLS AND TECHNIQUES IN SERVICE**

**Table B1**

**DMAIC Tools and Techniques for the 68 Cases in Service**

<table>
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<tr>
<th>Case Number</th>
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<tbody>
<tr>
<td>1</td>
<td>(Barone &amp; Franco, 2012; p.269)</td>
<td>Define</td>
<td>Project Charter, 5 whys Analysis, Gantt Chart, SIPOC Diagram, Process Mapping</td>
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<tr>
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<td>Measure</td>
<td>Interview, Observation, Histogram</td>
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<td>Analyze</td>
<td>ANOVA Test, Cause-and-Effects Diagram, Pareto Chart</td>
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<tr>
<td>2</td>
<td>(Barone &amp; Franco, 2012; p.283)</td>
<td>Define</td>
<td>Project Charter, Gantt Chart, P-diagram, SIPOC Diagram, Process Mapping, Critical to Quality (CTQ), Tollgate Checklist</td>
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<td>Measure</td>
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<td>Histogram, Time series plots, Box Plot, Interval plot, Kawakita Jiro (KJ) Method, Cause-and-Effect Diagram, ANOM, Pareto Chart, Process Capability Analysis, Correlation Analysis</td>
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<tr>
<td>3</td>
<td>(Barone &amp; Franco, 2012; p.314)</td>
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<td>Project Charter, Gantt Chart, Y and y definitions, P-diagram, SIPOC Diagram, Process Mapping</td>
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<td>Measure</td>
<td>Interview, Observation, Kawakita Jiro (KJ) Method, Cause-and-Effect Analysis, Voting, Pareto Chart, VMEA</td>
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<td>Analyze</td>
<td>Pareto Chart, Sigma Calculation (DPMO)</td>
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<tr>
<td>5</td>
<td>(Allen, Tseng, Swanson, &amp; McClay, 2009)</td>
<td>Define</td>
<td>Key Output Variables (KOVs)</td>
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<td>Key Input Variables (KIVs), Pareto Chart, Cause-and-Effect Matrix, Brainstorming, Process Mapping</td>
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<td>Critical to Quality (CTQ), Key Output Variable (KPOV), Gage R&amp;R, Pareto Chart</td>
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<td>7</td>
<td>(Cash, 2013)</td>
<td>Define</td>
<td>Project Charter, Critical to Quality (CTQ), Customer-needs Mapping</td>
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<td>Analyze</td>
<td>Root Cause Analysis</td>
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<tr>
<td>9</td>
<td>(Eldridge et al., 2006)</td>
<td>Define</td>
<td>Project Charter</td>
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<td>Measure</td>
<td>Process Map, Cause-and-Effect Matrix, Observation, Survey</td>
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<td>Failure Modes and Effects Analysis (FMEA), Multi-vari Analysis</td>
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<td>Control Plan, Checklist</td>
</tr>
<tr>
<td>10</td>
<td>(Feng &amp; Antony, 2009)</td>
<td>Define</td>
<td>Cause-and-Effect Diagram</td>
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<td></td>
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<td>Analyze</td>
<td>Pareto Chart, Statistical Process Control (SPC), Kanban, Waste elimination, One Piece Flow, Cost/benefit Analysis</td>
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<td>12</td>
<td>(Goodman, Kasper, &amp; Leek, 2007)</td>
<td>Define</td>
<td>Critical to Quality (CTQ), Voice of Customer (VOC), Process Mapping</td>
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<td>Measure</td>
<td>Gage R&amp;R, Sigma Calculation (DPMO), Control Chart, Cause-and-Effect Diagram</td>
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<td>Chi-square Test, Pareto Chart</td>
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<td>Improve</td>
<td>Brainstorming, ANOVA Test</td>
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<td>13</td>
<td>(Heuvel, Does, &amp; Vermaat, 2004, case 1)</td>
<td>Define</td>
<td>Critical to Quality (CTQ)</td>
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<td>Process Capability Analysis, Cause-and-Effect Diagram, Failure Modes and Effects Analysis (FMEA)</td>
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<td>14</td>
<td>(Heuvel, Does, &amp; Vermaat, 2004, case 2)</td>
<td>Define</td>
<td>Critical to Quality (CTQ)</td>
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<td>Brainstorming</td>
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<td>15</td>
<td>(Heuvel, Does, &amp; Vermaat, 2004, case 3)</td>
<td>Define</td>
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<td>Brainstorming</td>
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<td>16</td>
<td>(Chen, Shyu, &amp; Kuo, 2010)</td>
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<tr>
<td>17</td>
<td>(Kapoor, Bhaskar, &amp; Vo, 2012)</td>
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<td>Critical to Quality (CTQ), Voice of Customer (VOC)</td>
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<td>18</td>
<td>(Kaushik, Shokeen, Kaushik, &amp; Khanduja, 2007)</td>
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<td>Auditing, Interview</td>
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<td>Process Mapping, Cause-and-Effect Diagram</td>
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<td>19</td>
<td>(Kukreja, Ricks, &amp; Meyer, 2009)</td>
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<td>Process Mapping, Cause-and-Effect Matrix</td>
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<td>Responsible Accountable Consulted and Informed (RACI) Matrix</td>
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<td>(Murphy, 2009)</td>
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<td>Pareto Chart</td>
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<td>Balanced Score Card, Project Charter, SIPOC Diagram, Interview, Data Collection, Pareto Chart, Affinity Diagram</td>
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<td>Monitoring Chart, Sigma Calculation (DPMO), Data Collection</td>
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<td>22</td>
<td>(Kumar, Wolfe, &amp; Wolfe, 2008)</td>
<td>Measure</td>
<td>Flowchart</td>
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<tr>
<td>23</td>
<td>(Kumar, Choe, &amp; Venkataramani, 2012)</td>
<td>Define</td>
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<td>24</td>
<td>(Kumar, Strandlund, &amp; Thomas, 2008)</td>
<td>Define</td>
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<tr>
<td>25</td>
<td>(Kumi &amp; Morrow, 2006)</td>
<td>Define</td>
<td>Project Charter</td>
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<td>Failure Modes and Effects Analysis (FMEA), ANOVA Test</td>
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<tr>
<td>27</td>
<td>(Martinez &amp; Gitlow, 2011)</td>
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<td>SIPOC Diagram, Critical to Quality (CTQ), Voice of Customer (VOC)</td>
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<td>Regression Analysis, Flowchart, Cause-and-Effects Matrix</td>
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<td>ISO 9000, Control Plan, Plan-Do-Study-Act (PDSA)</td>
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<td>(Martinez, Chavez-Valdez, Holt, Grogan, Khalifeh, Slater, Winner, Moyer, &amp; Lehmann, 2011)</td>
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<td>(Pan, Ryu, &amp; Baik, 2007)</td>
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<td>Flowchart, Critical to Quality (CTQ), Project Charter</td>
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<td>32</td>
<td>(Pandey, 2007)</td>
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<td>Survey, Pareto Diagram, Benchmarking, Prioritization Matrix</td>
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<td>Hypothesis testing, Pareto Chart, Voice of Customer, Chi-square Test, ANOVA Test, Cause-and-Effect Diagram</td>
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<td>Process Capability Analysis</td>
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<td>33</td>
<td>(Prasad, Subbaiah, &amp; Padmavathi, 2012)</td>
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<td>Failure Mode and Effect Analysis (FMEA)</td>
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<td>Cause-and-Effect Diagram, Cause-and-Effect Matrix, Process Capability Analysis, Pilot Plan</td>
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<tr>
<td>35</td>
<td>(Rivera &amp; Marovich, 2001)</td>
<td>Define</td>
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<td>Survey, Process Mapping, Pareto Chart, Histogram, Tally Check Sheet</td>
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<td>Simulation, Pareto Chart</td>
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<td>Prioritization Matrix, Cost/Benefit Analysis, Pilot Plan</td>
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<td>36</td>
<td>(Salzarulo, Krehbiel, Mahar, &amp; Emerson, 2012)</td>
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<td>Scatter Diagram, Frequency Table, Basic Statistics</td>
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<td>37</td>
<td>(Furterer, 2011)</td>
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<td>Project Charter, Voice of Customer (VOC), SIPOC Diagram</td>
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<td>Brainstorming, Tree Diagram, ANOVA Test, Regression Analysis</td>
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<td>39</td>
<td>(Li, Wu, Yen, &amp; Lee, 2011)</td>
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<td>41</td>
<td>(Southard, Chandra, &amp; Kumar, 2012)</td>
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<td>42</td>
<td>(Taner, Sezen, &amp; Atwat, 2012)</td>
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<tr>
<td>43</td>
<td>(Taner &amp; Sezen, 2009)</td>
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<td>45</td>
<td>(McAdam, Davies, Keogh, &amp; Finnegan, 2009)</td>
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<tr>
<td>46</td>
<td>(Cheng &amp; Chang, 2012)</td>
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<td>(Chiarini, 2012)</td>
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<td>48</td>
<td>(Das &amp; Hughes, 2006)</td>
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<td>50</td>
<td>(Ng, Tsung, So, &amp; Li, 2005)</td>
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<td>51</td>
<td>(Kapadia, Hemanth, &amp; Sharda, 2003)</td>
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<tr>
<td>52</td>
<td>(Nanda, 2010)</td>
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<td>53</td>
<td>(Kumar, Jensen, &amp; Menge, 2008)</td>
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<td>54</td>
<td>(Al-Qatawneh, Abdallah, &amp; Zalloum, 2013)</td>
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<td>(Baddour &amp; Saleh, 2013)</td>
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<td>56</td>
<td>(Kumar, Phillips, &amp; Rupp, 2009)</td>
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<td>(Hagg, El-Harit, Vanni, &amp; Scott, 2007)</td>
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<td>Voice of Customer (VOC), Project Charter</td>
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<td>58</td>
<td>(Kanakana, Pretorius, &amp; van Wyk, 2012)</td>
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<td>(Lokkerbol, Schotman, &amp; Does, 2012)</td>
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<td>60</td>
<td>(Lokkerbol, Molenaar, &amp; Does, 2012)</td>
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<td>(Miski, 2014)</td>
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<td>63</td>
<td>(Cheng, 2013)</td>
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<tr>
<td>64</td>
<td>(Barone &amp; Franco, 2012; p. 330)</td>
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