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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

____

Dr. Michael J. Licari
Dean of the Graduate College

Hassan A. Alsultan

University of Northern Iowa

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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Dr. Ali E. Kashef, Chair

____

Dr. Julie Zhang, Co-Chair

____

Dr. Andrew R Gilpin, Committee Member

____

Dr. Scott Greenhalgh, Committee Member

____

Dr. Radhi Al-Mabuk, Committee Member

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.

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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; Tarí, 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 *quality* means. Notably, the term *quality* has no single definition, because various quality gurus and organizations have different interpretations of it. For instance, Crosby (1984) defined *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 *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 *quality* is the most comprehensive:

> 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)

Feigenbaum's definition demonstrates that it is difficult to define *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

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

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

Common Tools Used in the Measure Phase		
Basic statistics	Histograms	Project tracking
Brainstorming	Hypothesis testing	Regression
Cause-and-effect diagrams	Measurement systems analysis (MSA)	Run charts
Check sheets	Meeting minutes	Scatter diagrams
Circle diagrams	Operational definitions	Spaghetti diagrams
Correlation	Pareto charts	Statistical process control (SPC)
Data collection	Probability	Supplier-input-process-output-customer (SIPOC)
Data collection plan	Process capability analysis	Taguchi loss function
Failure mode and effects analysis (FMEA)	Process flow metrics	Tollgate review
Flowcharts	Process maps	Value stream maps
Gage R&R	Process sigma	
Graphical methods	Project management	

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

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

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

Common Tools Used in the Improve Phase		
Activity network diagrams	Measurement systems analysis (MSA)	Project tracking
Analysis of variance (ANOVA)	Meeting minutes	Reliability analysis
Brainstorming	Mixture experiments	Response surface methodology (RSM)
Control chats	Multi-vari studies	Risk analysis
D-optimal designs	Multi-voting	Simulation
Design of experiments (DOE)	Normal group technique	Statistical tolerancing
Evolutionary operations (EVOP)	Pareto charts	Taguchi designs
Failure mode and effects analysis (FMEA)	Project evaluation and review technique (PERT)	Taguchi robustness concepts
Fault tree analysis (FTA)	Pilot	Tollgate review
Flowchart/process mapping (to be)	Prioritization matrix	Value stream maps
Gantt charts	Process sigma	Work breakdown structure
Histograms	Project management	Y=f(x)
Hypothesis testing		

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

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

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 measureable 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

Quantitative	Non-Quantitative
Pareto chart	Cause-and-effect diagram
Control charts	Flowchart
Check sheet	
Scatter diagram	
Histogram	

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

Identifying Tools	Prioritizing & Communicating Tools	Analyzing Tools
Check sheet	Histogram	Cause-and-effect diagram
Flowchart	Pareto chart	Scatter diagram
		Control charts

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

Graphical Tools	Flow Diagrams
Histograms	Cause-and-effect diagram
Pareto charts	Scatter diagram
Control charts	Flowchart

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

Defect Type		Total
1. Assembly	II	2
2. Print quality	IIIIIIIIIIIII	13
3. Print detail	IIII	4
4. Edge flaw	IIIIIIIIIIIIIIIIIIIIII	22
5. Cosmetic	IIIII	5
Customer Complaints		**Total**
1. Missing ring	II	2
2. Print quality	IIIIIIIIIIIIIIIIIIIIIII	23
3. Misplace print	IIII	4
4. Rough edge	III	3
5. Type error	IIIIII	6
6. Excess flash	IIIIIIIIIIIII	13
7. Late shipment	IIIIII	6
8. Bad count	IIII	4

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

Division	x	y
1	10	80
2	19	65
3	30	68
4	45	55
5	50	35
6	65	10
7	80	12

Source: Brase and Brase (2011, p. 134)

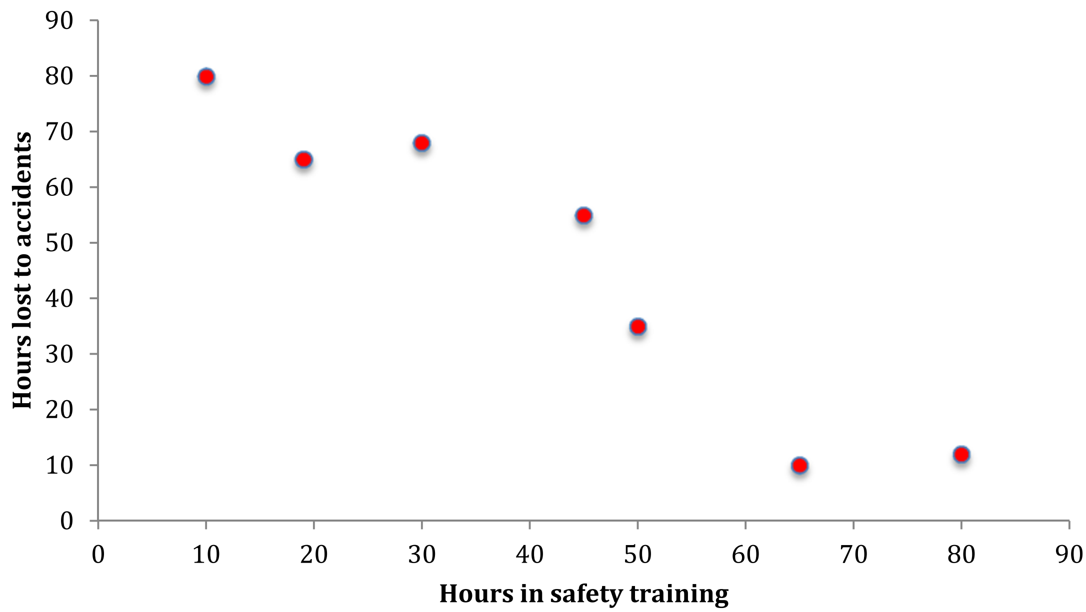

Figure 1. Scatter diagram for safety report. Source: Brase and Brase (2011, p. 134).

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.

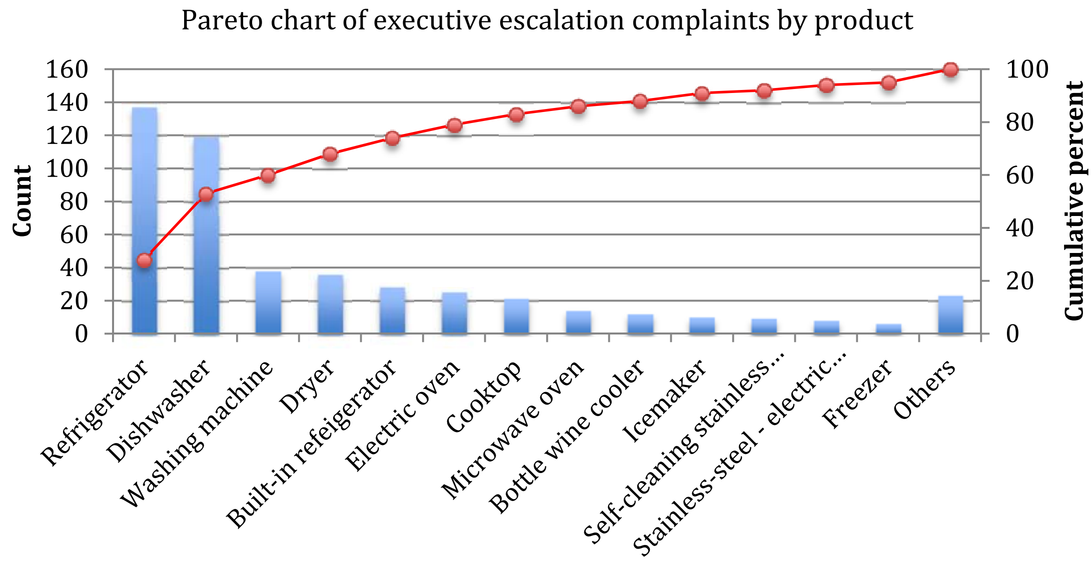

Figure 2. Pareto chart of executive escalation complaints by product. Source: Harry et al. (2010, p. 221).

Table 11

Pareto Chart Product Count

Count	137	119	38	36	28	25	21	14	12	10	9	8	6	23
Percent	28	24	8	7	6	5	4	3	2	2	2	2	1	5
Cum %	28	53	60	68	74	79	83	86	88	91	92	94	95	100

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 -3σ and +3σ (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.

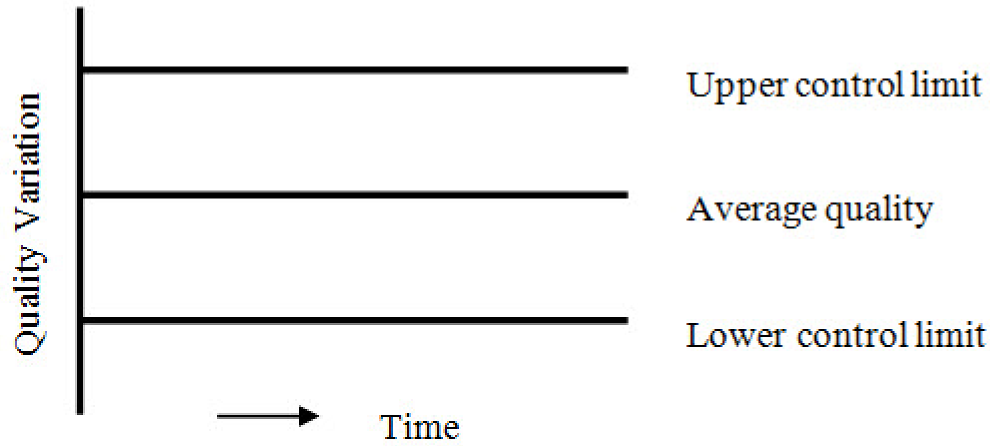

Figure 3. Control chart limits. Source: Rastogi (2010, p. 66).

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.

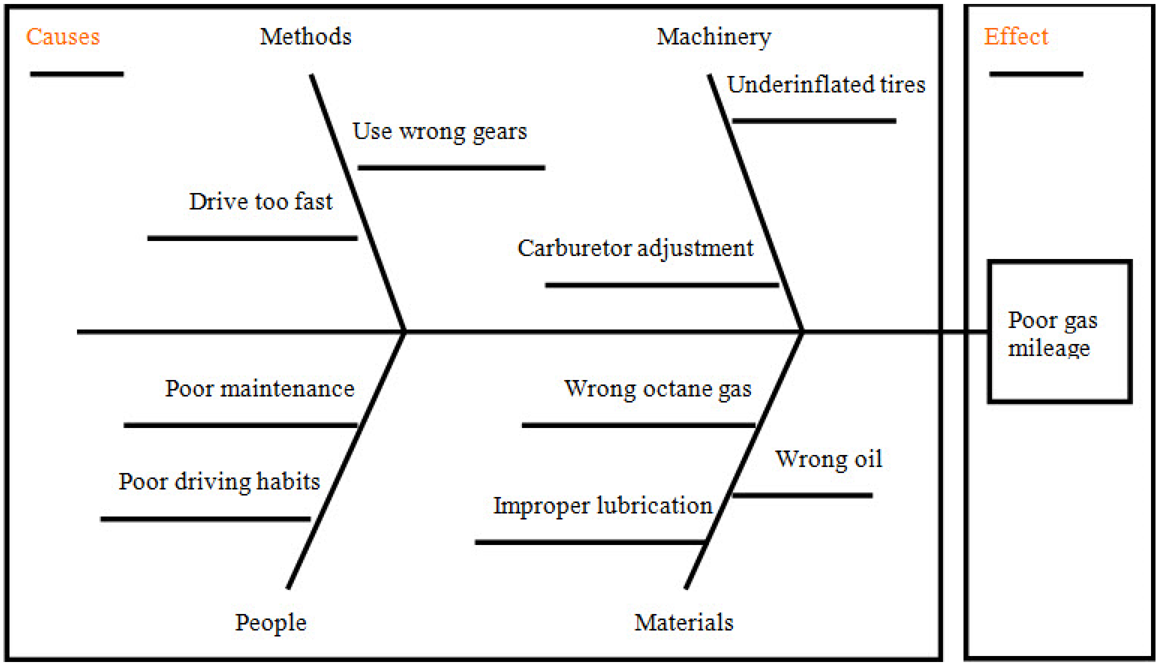

Figure 4. A cause-and-effect diagram for poor gas mileage. Source: Drozda and Wick (1998, p. 27).

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.

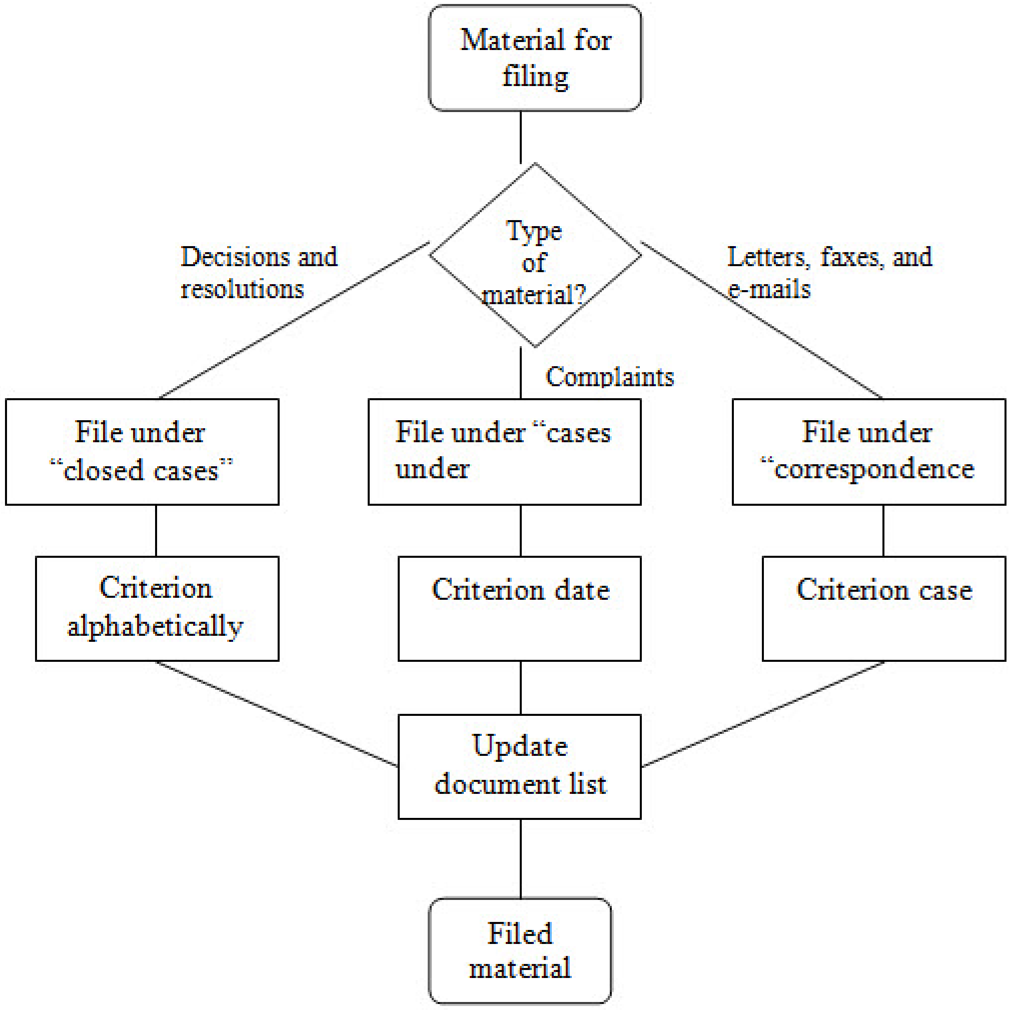

Figure 5. Flowchart for the filing process. Source: Andersen (2007, p. 49).

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.

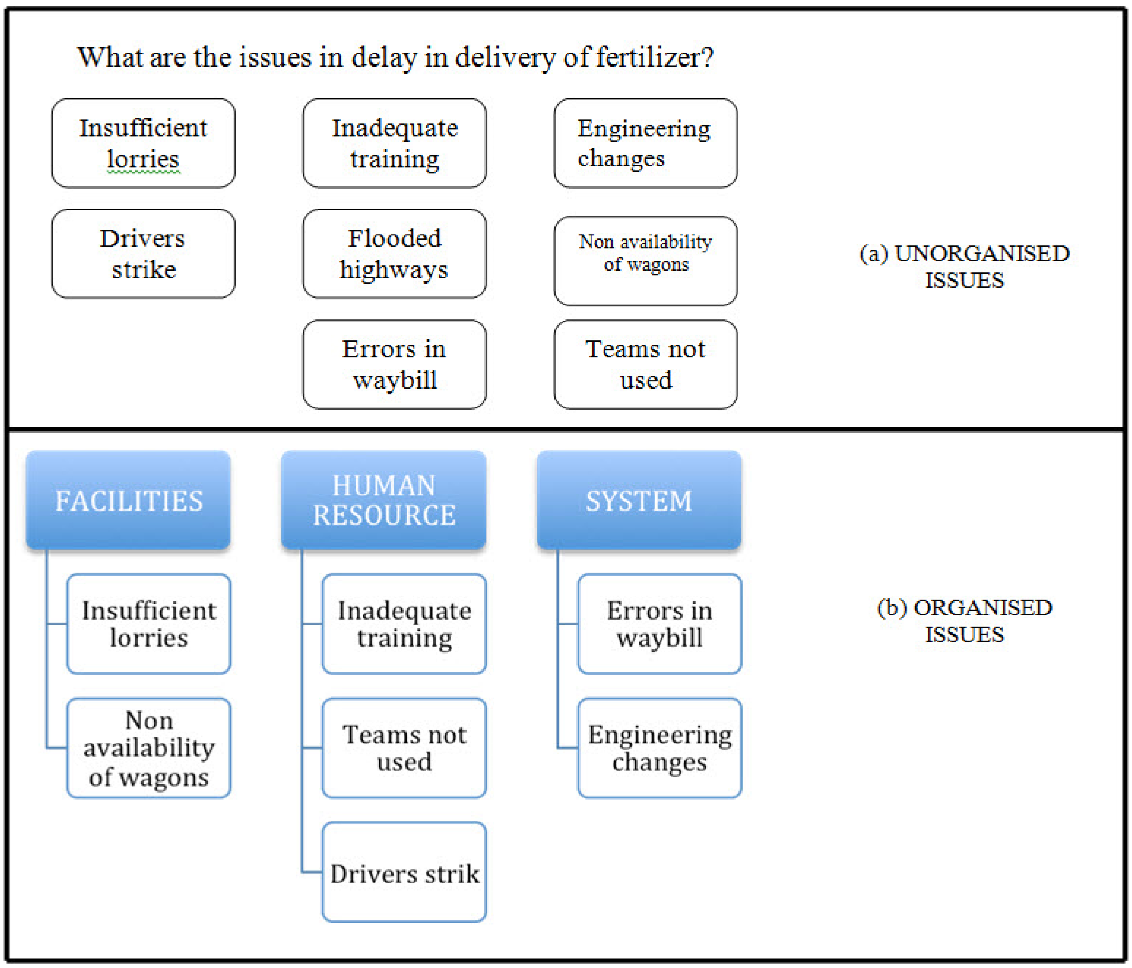

Figure 6. Example of an affinity diagram. Source: Naagarazan and Arivalagar (2005, p. 85).

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)

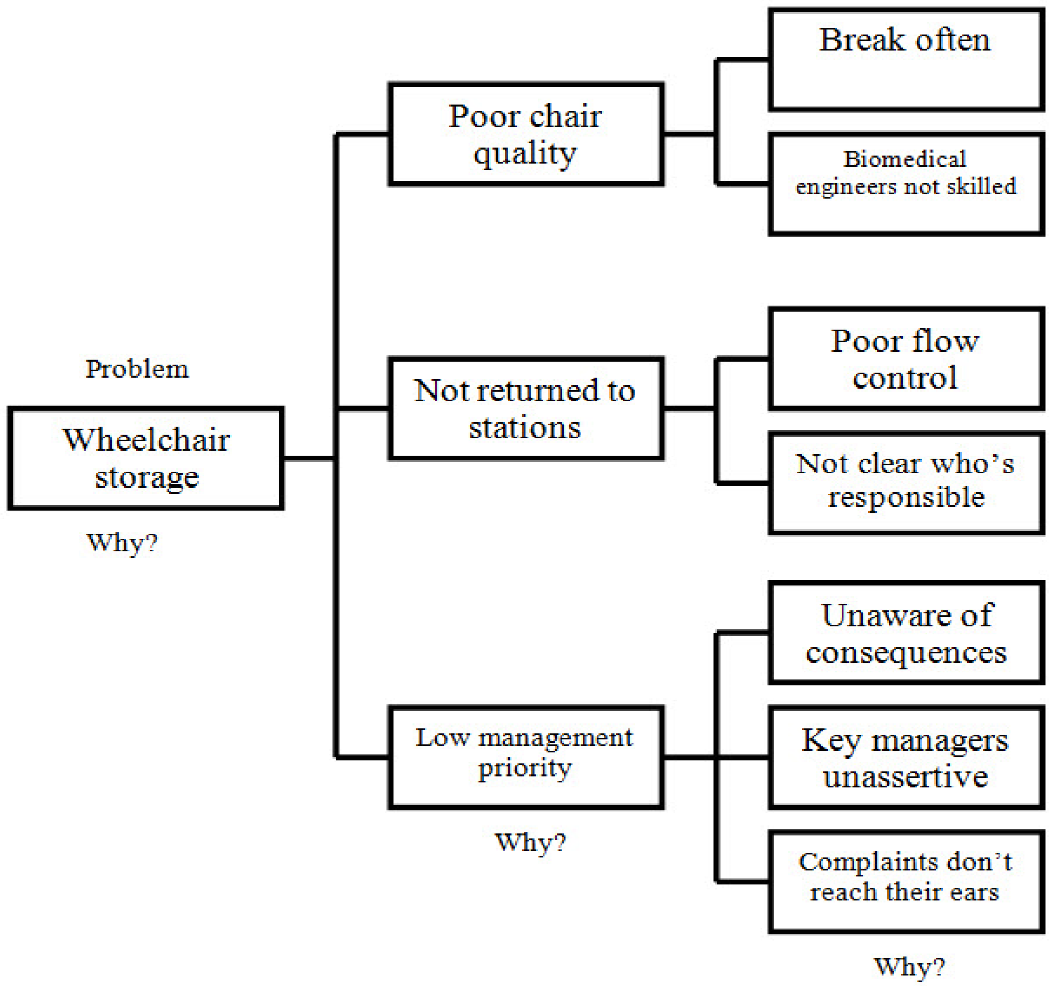

Figure 7. Example "Why Why" tree diagram. Source: Leebov (2003, p. 175).

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.

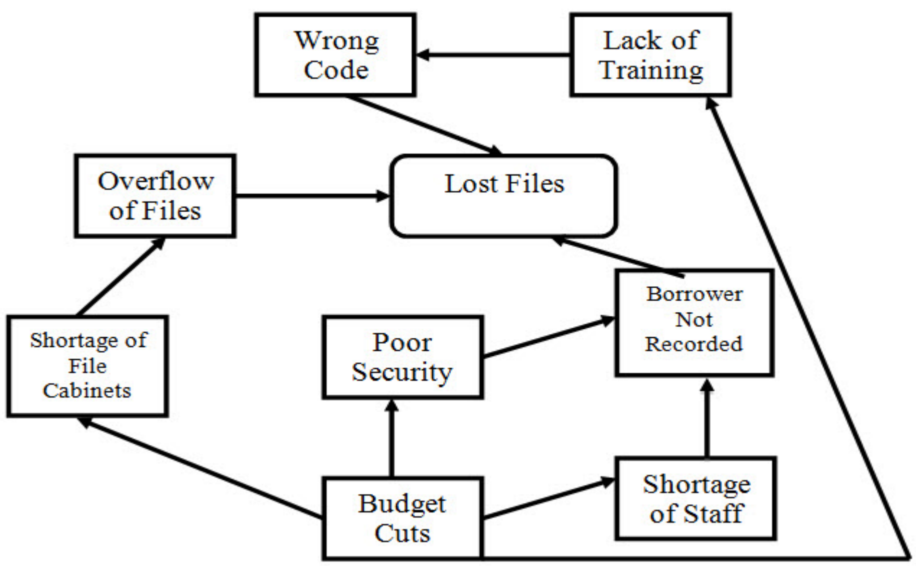

Figure 8. Example relations diagram for causes of lost files. Source: Allison (1996, p. 47).

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.

Goals \ Actions	Improve Work Environment	Improve Manufacturing Technology	Develop New Products
Cost Effectiveness	●	○	
High Quality	●	●	
Shareholder Value		△	●

● = Strong relationship ○ = Medium relationship △ = Weak relationship

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

<u>Matrix data analysis diagram</u>. 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

Requirement	Importance Weight	Best Competitor Evaluation	MicroTech Evaluation	Difference
Price	2	6	8	+2
Reliability	4	7	8	+1
Delivery	1	8	5	-3
Technical support	3	7	5	-2

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.

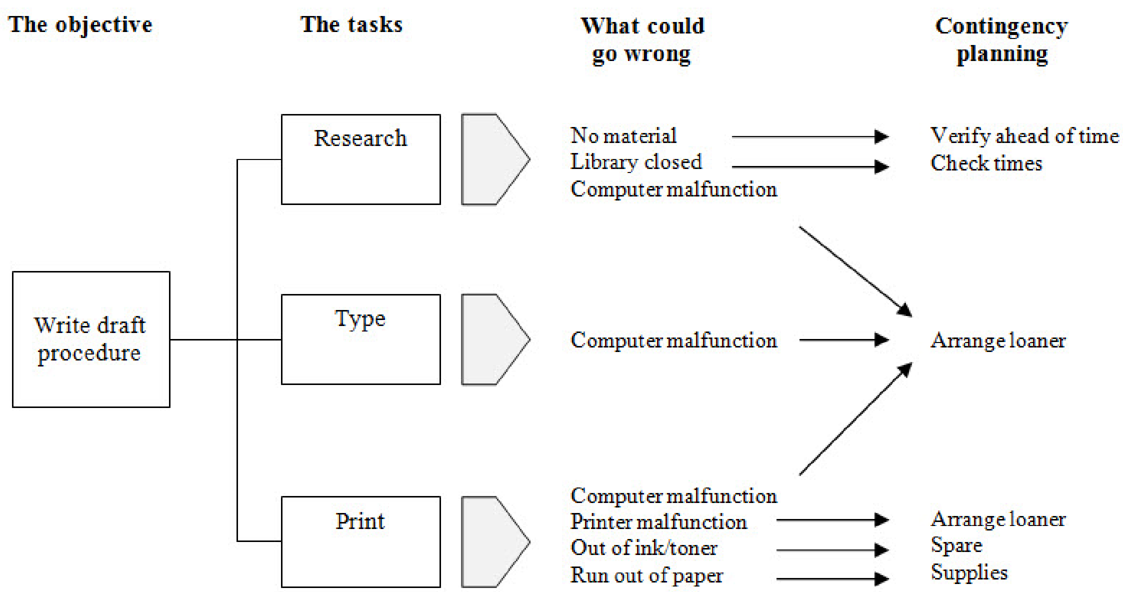

Figure 10. Example process decision program chart. Source: Westcott (2006, p. 343).

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.

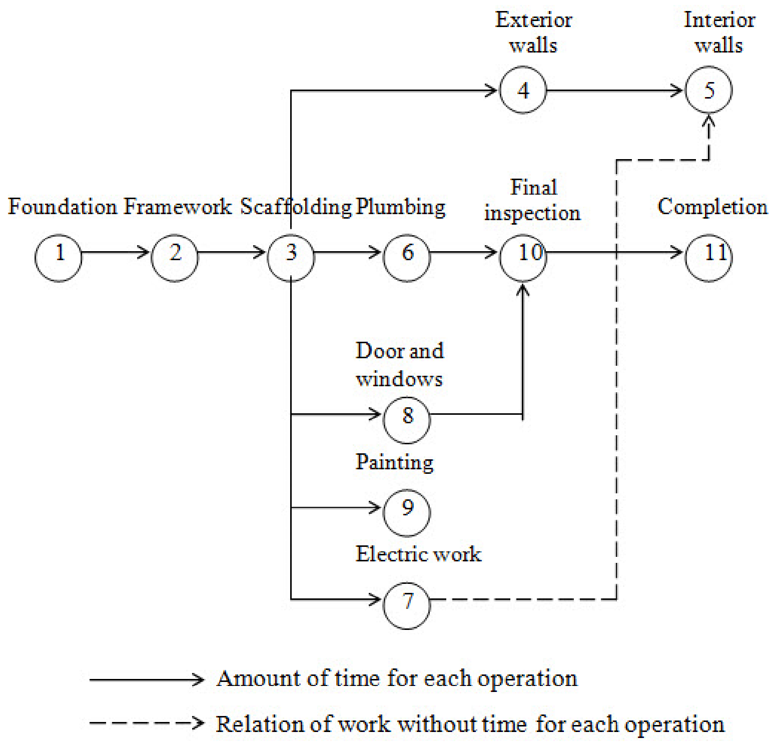

Figure 11. Example arrow diagram. Source: Kanji and Asher (1996, p. 25).

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.

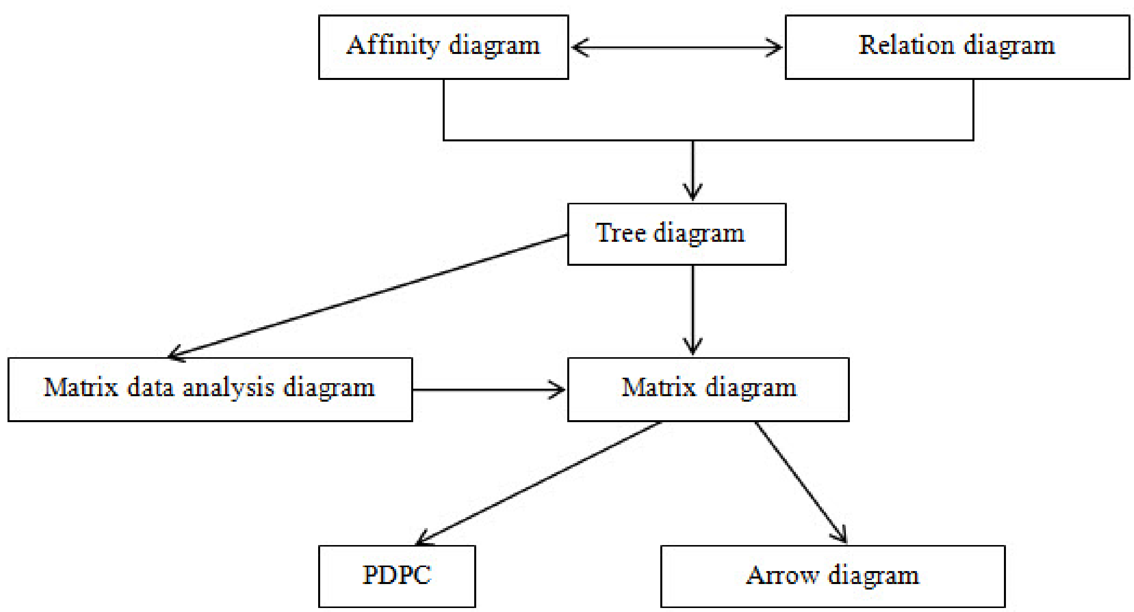

Figure 12. Flow diagram for the new seven management tools. Source: Bose (2010, p. 356).

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

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

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

Rankings of Basic Quality Tools (from High to Low)			
Source	Ahmed & Hassan (2003)	Bayazit (2003)	Alsaleh (2007)
Rankings	1. Check sheet 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	1. Statistical process control 2. Process charts 3. Pareto charts 4. Cause-and-effect diagram	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

Rankings of Advanced Techniques (from High to Low)			
Source	Sahran, Zeinalnezhad & Mukhtar (2010)	Ahmed & Hassan (2003)	Bayazit (2003)
Rankings	1. Quality function deployment 2. Design of experiment 3. Statistic method 4. Motion study and time study 5. Work design for Ergonomics 6. New seven tools of quality control	1. Inspection sampling 2. Benchmarking 3. SPC 4. Capability measures 5. TQM practice 6. House of quality 7. Concurrent engineering 8. QFD 9. Taguchi Methods	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

Overall Rankings of Quality Tools and Techniques (from High to Low)					
Tari & Sabater (2004)	Sahran, Zeinalnezhad & Mukhtar (2010)	Fotopoulos & Psomas (2009)	Rowland-Jones, Thomas, & Page-Thomas (2008) *In SME	Rowland-Jones, Thomas, & Page-Thomas (2008) *In large firms	Clegg, Rees, & Titchen (2010)
1. Internal audits	1. Safety teams	1. Check sheet	1. Brainstorming	1. Process capability	1. Sampling plans
2. Graphics	2. 5S and house-keeping	2. Flow chart	2. Bar charts	2. Just-in-time	2. Monte Carlo simulation
3. SPC	3. 5M checklist	3. Data collection forms	3. Improve internal process (IIP)	3. Productivity improvement	3. Survey design and analysis
4. Flow chart	4. Statistical Process Control (SPC)	4. Graph	4. Check Sheets	4. Lean	4. CTQ trees
5. Problem-solving methodology	5. Waste elimination	5. Benchmarking	5. ISO 9001:2000	5. Statistical process control	5. IDEFO modeling
6. Quality costs	6. Brainstorming	6. Histogram	6. Flow charts	6. ISO 9001:2000	6. Stratification
7. Histograms	7. Quality circle or small group activities	7. Brainstorming	7. Lean	7. Total Quality Management	7. Simulation discrete
8. Benchmarking	8. Visible management	8. Tree diagram	8. Process capability	8. Self-assessments	8. Moments of truth
9. FMEA	9. Basic seven quality control tools	9. Cause-and-effect diagram	9. Self-assessments	9. Material requirements planning	9. Histogram
10. Pareto diagrams	10. 5 Whys	10. Pareto diagram	10. Statistical process control	10. Improve internal process (IIP)	10. Quality function deployment
11. Cause-and-effect diagrams	11. TPM team	11. Quality function deployment	11. Material requirements planning	11. Kanban	11. Personality profiling
12. Scatter diagram	12. Suggestion system	12. Design of experiments	12. Plan, do, check, act, cycle	12. Matrix data analysis	12. Pareto
	13. Poka-yoke	13. Run chart	13. Matrix data analysis	13. Bar charts	13. Scatter plots
		14. Failure mode and effect analysis	14. Just-in-time	14. Plan, do, check, act, cycle	14. TRIZ
		15. Stem and leaf diagram	15. Kanban		15. 5S
		16. Control charts	16. Suggestion schemes		16. Input/output analysis
					17. Kano

(table continues)

Tari & Sabater (2004)	Sahran, Zeinalnezhad, & Mukhtar (2010)	Fotopoulos & Psomas (2009)	Rowland-Jones, Thomas, & Page-Thomas (2008) *In SME	Rowland-Jones, Thomas, & Page-Thomas (2008) *In large firms	Clegg, Rees, & Titchen (2010)
		17. Relations diagram 18. Force-field analysis 19. Affinity diagram	17. Tally charts 18. Productivity improvement 19. Tree diagrams 20. Total quality management	15. Brainstorming 16. Flow charts 17. Suggestion schemes 18. Tally charts 19. Check sheets 20. Tree diagrams	18. Pilot testing 19. Dashboards 20. Brainstorming 21. Hoshin planning 22. Force field analysis 23. Correlation 24. KPIs 25. Quality loss function
Drew & Healy (2006)	**Lagrosen & Lagrosen (2005)**	**Lam (1996)**	**Miguel, Satolo, Andrietta, & Calarge (2012)**	**Sousa, Aspinwall, Sampaio, & Rodrigues (2005)**	**Tarí (2005)**
1. Customer surveys 2. Competitive benchmarking 3. Self-assessment models 4. Statistical process control 5. Just-in-time manufacturing 6. Quality circles 7. Cause-and-effect diagrams 8. PDCA cycle	1. Flowcharts 2. FMEA 3. The seven quality control tools 4. SPC 5. Quality circles 6. Design of experiments 7. Quality function deployment 8. The seven management tools 9. Poka-Yoke	1. Brain storming 2. Control chart 3. Cause-and-effect analysis 4. Histogram 5. Flowchart 6. PDCA cycle 7. Pareto analysis 8. Statistical sampling 9. Run chart 10. Scatter diagram 11. System audit	1. Data collection techniques 2. Histogram 3. Pareto diagram 4. Brainstorming 5. Control charts 6. Capacity index 7. Flow charts 8. Process map 9. Evaluation of the measurement/ inspection system 10. SPC	1. Graphs 2. Check sheet 3. Process flowchart 4. Histogram 5. Questionnaires 6. Surveys 7. Pareto analysis 8. Brainstorming 9. Group interviews 10. Cause-and-effect diagram	1. Internal audit 2. Graphics 3. SPC 4. Flow chart 5. Problem-solving methodology 7. Quality costs 8. Histograms 9. Benchmarking 10. FMEA 11. Pareto diagrams 12. Cause-and-effect diagram

(table continues)

Drew & Healy (2006)	Lagrosen & Lagrosen (2005)	Lam (1996)	Miguel, Satolo, Andrietta, & Calarge (2012)	Sousa, Aspinwall, Sampaio, & Rodrigues (2005)	Tarí (2005)
9. Quality function deployment	10. Taguchi methods 11. Conjoint analysis	12. Quality control circle 13. Stratification 14. Standard time 15. Just-in-time 16. Design of experiment 17. Cost of quality 18. Benchmarking 19. Quality function deployment 20. Diagnostic matrix 21. KJ method 22. Hoshin planning 23. Fault tree analysis 24. Taguchi method 25. Departmental purpose analysis			13. Scatter diagram

Theory of Inventive Problem Solving (TRIZ)

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 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.

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.

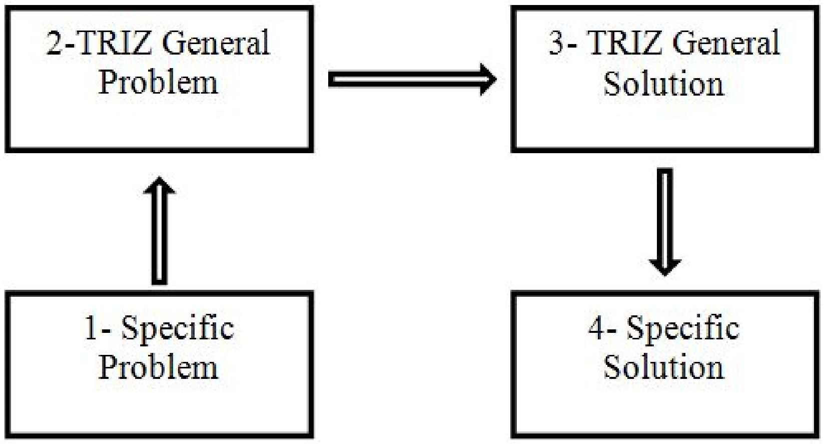

Figure 13. Basic TRIZ problem-solving process. Adapted from Silverstein et al. (2008, p. 57).

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

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

Source: Rantanen and Domb (2008, pp. 123-124).

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

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

Source: Gadd (2011, p.110)

Table 19

Portion of the TRIZ Contradiction Matrix

39 Parameters	39 Parameters	1 Weight of moving object	2 Weight of stationary object	3 Length of moving object	4 Length of stationary object	5 Area of moving object	6 Area of stationary object	7 Volume of moving object
1	Weight of moving object		-	15 8 29 34	-	29 17 38 34	-	29 2 40 28
2	Weight of stationary object	-		-	10 1 29 35	-	35 30 13 2	-
3	Length of moving object	8 15 29 34	-		-	15 17 4	-	7 17 4 35
4	Length of stationary object		35 28 40 29	-		-	17 7 10 40	-
5	Area of moving object	2 17 29 4	-	14 15 18 4	-		-	7 14 17 4
6	Area of stationary object	-	30 2 14 18	-	26 7 9 39	-		-
7	Volume of moving object	2 26 29 40	-	1 7 4 35	-	1 7 4 17	-	
8	Volume of stationary object	-	35 10 19 14	19 14	35 8 2 14	-		-

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 (Retseptor, 2003), service operations management (Zhang, Tan, & Chai, 2003), finance (Dourson, 2004), social life (Terninko, Zusman & Zlotin; 2001), marketing, sales and advertising (Retseptor, 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 filed 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. Figure14 illustrates the overall process of the research.

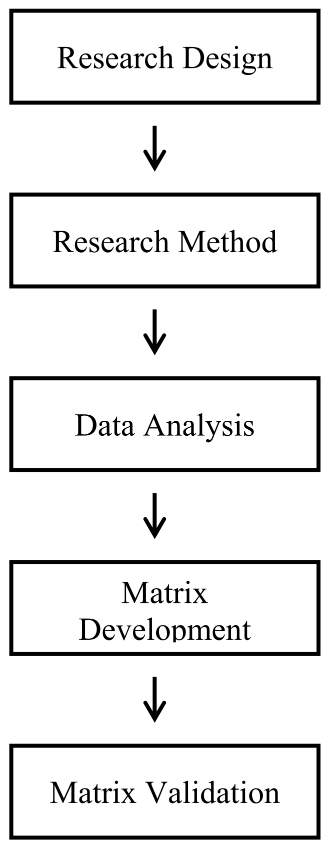

Figure 14. The overall research process.

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).

<u>Validity and Reliability</u>

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

List of Quality Dimensions	
Service Quality Dimensions	**Product Quality Dimensions**
Tangibles	Performance
Reliability	Features
Responsiveness	Reliability
Assurance	Conformance
Empathy	Durability
	Serviceability
	Aesthetics
	Perceived Quality

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

Product Quality Dimensions									
Case Number	Case Reference	Performance	Features	Reliability	Conformance	Durability	Serviceability	Aesthetics	Perceived Quality
Case 1									
Case 2									
Case 3									
Case 4									
Case 5									
…									
Case n									

Table 22

Table of Data Collection for Service

Service Quality Dimensions							
Case Number	Case Reference	Tangibles	Reliability	Responsiveness	Assurance	Empathy	Serviceability
Case 1							
Case 2							
Case 3							
Case 4							
Case 5							
…							
Case n							

Table 23

DMAIC Quality Tools and Techniques in Each Case

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
Case 1		*Define*	
		Measure	
		Analyze	
		Improve	
		Control	
Case 2		*Define*	
		Measure	
		Analyze	
		Improve	
		Control	
Case n		*Define*	
		Measure	
		Analyze	
		Improve	
		Control	

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.
3. Choosing a method for clustering.
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

Cluster Number	DMAIC Phase	Tools & Techniques
Cluster 1	*Define*	
	Measure	
	Analyze	
	Improve	
	Control	
Cluster 2	*Define*	
	Measure	
	Analyze	
	Improve	
	Control	
Cluster n	*Define*	
	Measure	
	Analyze	
	Improve	
	Control	

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

Contradiction Matrix for Manufacturing								
	Performance	***Features***	***Reliability***	***Conformance***	***Durability***	***Serviceability***	***Aesthetics***	***Perceived Quality***
Performance								
Features								
Reliability								
Conformance								
Durability								
Serviceability								
Aesthetics								
Perceived Quality								

Table 26

Contradiction Matrix for Service Industry

Contradiction Matrix for Service					
	Tangibles	***Reliability***	***Responsiveness***	***Assurance***	***Empathy***
Tangibles					
Reliability					
Responsiveness					
Assurance					
Empathy					

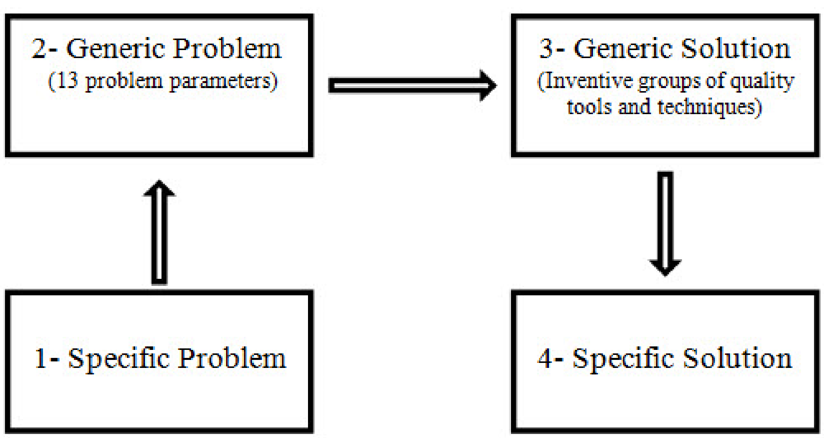

Figure 15. The problem-solving process for the research. Adapted from Silverstein, DeCarlo, & Slocum (2008, p. 57).

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

Case Number	Case Reference	Performance	Features	Reliability	Conformance	Durability	Serviceability	Aesthetics	Perceived Quality
1	(Barone & Franco, 2012; p. 296)	0	0	0	1	0	0	0	0
2	(Barone & Franco, 2012; p. 350)	0	0	0	1	0	1	0	0
3	(Barone & Franco, 2012; p. 365)	0	0	0	1	0	1	0	0
4	(Antony, Gijo, & Childe, 2012)	0	0	1	1	0	0	0	0
5	(Bakshi, Singh, Singh, & Singla, 2012)	1	0	0	0	0	0	0	0
6	(Banuelas, Antony, & Brace, 2005)	1	0	1	0	0	0	0	0
7	(Bharti, Khan, & Singh, 2011)	0	0	0	1	0	0	0	0
8	(Bilgen, & Şen, 2012)	0	0	0	1	0	0	0	0
9	(Valles, Sanchez, Noriega, & Nuñez, 2009)	1	0	1	1	0	0	0	0
10	(Chinbat, & Takakuwa, 2008)	0	0	0	1	0	0	0	0
11	(Christyanti, 2012)	0	0	0	1	0	0	0	0
12	(Cloete & Bester, 2012)	0	0	1	0	0	0	0	0
13	(Das & Gupta, 2012)	1	0	0	1	0	0	0	0
14	(Dietmüller & Spitler, 2009)	0	0	1	0	0	0	0	0
15	(Ditahardiyani, Ratnayani, & Angwar, 2009)	0	0	0	1	0	0	0	0
16	(Falcón, Alonso, Fernández, & Pérez-Lombard, 2012)	1	0	0	0	0	0	0	0
17	(Ghosh & Maiti, 2012)	0	0	0	1	0	0	0	0
18	(Gijo, Scaria, & Antony, 2011)	0	0	0	1	0	0	0	0
19	(Gnanaraj, Devadasan, Murugesh, & Sreenivasa, 2012)	0	0	0	1	0	1	0	0
20	(Goriwondo & Maunga, 2012)	1	0	0	1	0	1	0	0
21	(Hung, Wu, & Sung, 2011)	0	0	0	1	0	0	0	0
22	(Jin, Janamanchi, & Feng, 2011)	0	0	1	0	0	0	0	0
23	(Jirasukprasert, Garza-Reyes, Soriano-Meier, & Rocha-Lona, 2012)	0	0	0	1	0	0	0	0
24	(Kaushik, & Khanduja, 2009)	1	0	0	0	0	0	0	0
25	(Knowles, Johnson, & Warwood, 2004)	0	0	1	1	0	0	0	0
26	(Kumar, & Sosnoski, 2009)	0	0	0	1	0	0	0	0
27	(Kumaravadivel & Natarajan, 2011)	0	0	0	1	0	0	0	0

(table continues)

Case Number	Case Reference	Performance	Features	Reliability	Conformance	Durability	Serviceability	Aesthetics	Perceived Quality
28	(Lee & Wei, 2010)	1	0	0	0	0	0	0	0
29	(Lee, Wei, & Lee, 2009)	0	0	0	1	0	0	0	0
30	(Ladani, Das, Cartwright, & Yenkner, 2006; Case 1)	0	0	0	1	0	0	0	0
31	(Ladani, Das, Cartwright, & Yenkner, 2006; Case 2)	0	0	0	1	0	0	0	0
32	(Kumar, Antony, Singh, Tiwari, & Perry, 2006)	0	1	0	1	0	0	0	0
33	(Kumar, Antony, Antony, & Madu, 2007)	0	0	0	1	0	0	0	0
34	(Chen & Lyu, 2009)	1	0	0	0	0	0	1	0
35	(Mukhopadhyay & Ray, 2006)	0	0	0	1	0	0	1	0
36	(Zhuravskaya, Tarba, & Mach, 2012)	1	0	0	0	0	0	0	0
37	(Pranckevicius, Diaz, & Gitlow, 2008)	0	0	1	1	0	0	0	0
38	(Ray & Das, 2011)	0	0	0	1	0	1	0	0
39	(Reddy & Reddy, 2010)	0	0	0	1	0	0	0	0
40	(Sahoo, Tiwari, & Mileham, 2008)	1	0	1	0	1	0	0	0
41	(Saravanan, Mahadevan, Suratkar, & Gijo, 2012)	1	0	0	0	0	0	0	0
42	(Sekhar & Mahanti, 2006)	1	0	0	0	0	0	0	0
43	(Singh & Bakshi, 2012)	0	0	0	1	0	0	0	0
44	(Soković, Pavletić, & Krulčić, 2006)	0	0	0	1	0	0	0	0
45	(Kumar, Satsangi, & Prajapati, 2011)	1	0	0	0	0	0	0	0
46	(Lo, Tsai, & Hsieh, 2009)	0	0	0	1	0	0	0	0
47	(Vinodh, Kumar, & Vimal, 2014)	0	0	0	1	0	0	0	0
48	(Zaman, Pattanayak, & Paul, 2013)	0	0	0	1	0	0	0	0
49	(Aggogeri & Mazzola, 2008)	1	0	0	1	0	1	0	0
50	(Aksoy & Orbak, 2009)	0	0	0	1	0	0	0	0
51	(Artharn & Rojanarowan, 2013)	0	0	0	1	0	0	1	0
52	(Belokar & Singh, 2013)	0	0	0	1	0	0	0	0
53	(Chowdhury, Deb, & Das, 2014)	0	0	0	1	0	0	0	0
54	(Desai & Shrivastava, 2008)	1	0	0	1	0	1	0	1
55	(Enache, Simion, Chiscop, & Adrian, 2014)	1	0	0	0	0	0	1	0
56	(Farahmand, Marquez Grajales, & Hamidi, 2010)	0	0	0	1	0	0	0	0
57	(Hayajneh, Bataineh, & Al-tawil, 2013)	1	0	0	1	0	0	0	0
58	(Ruthaiputpong & Rojanarowan, 2013)	1	0	0	0	0	0	0	0

(table continues)

Case Number	Case Reference	Performance	Features	Reliability	Conformance	Durability	Serviceability	Aesthetics	Perceived Quality
59	(Sambhe, 2012)	0	0	1	1	0	0	0	0
60	(Chung, Yen, Hsu, Tsai, & Chen, 2008)	1	0	0	0	0	0	0	0
61	(Tong, Tsung, & Yen, 2004)	1	0	0	0	0	0	0	0
62	(Abbas, Ming-Hsien, Al-Tahat, & Fouad, 2011)	1	0	0	0	0	0	1	0
63	(Al-Refaie, Li, Jalham, Bata, & Al-Hmaideen, 2013)	0	1	0	0	0	0	0	0
64	(Nair, 2011)	0	0	1	0	0	0	0	0
65	(Dambhare, Aphale, Kakade, Thote, & Jawalkar, 2013)	1	0	0	1	0	0	0	0
66	(Dambhare, Aphale, Kakade, Thote, & Borade, 2013)	1	0	1	1	0	0	0	0
67	(Hahn, Piller, & Lessner, 2006)	1	0	1	0	0	0	0	0
68	(Puvanasvaran, Ling, Zain, & Al-Hayali, 2012)	0	0	1	0	1	0	0	0
69	(Al-Mishari & Suliman 2008)	0	0	1	0	1	0	0	0
70	(Kumar, Jawalkar, & Vaishya, 2014)	0	0	0	1	0	0	1	0
71	(Sajeev & M, 2013)	0	0	0	1	0	1	0	0
72	(Jie, Kamaruddin, & Azid, 2014)	1	0	0	0	0	1	0	0

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

Dimensions	Total Number of Cases
Conformance	47
Performance	26
Reliability	15
Serviceability	9
Aesthetics	6
Durability	3
Features	2
Perceived Quality	1

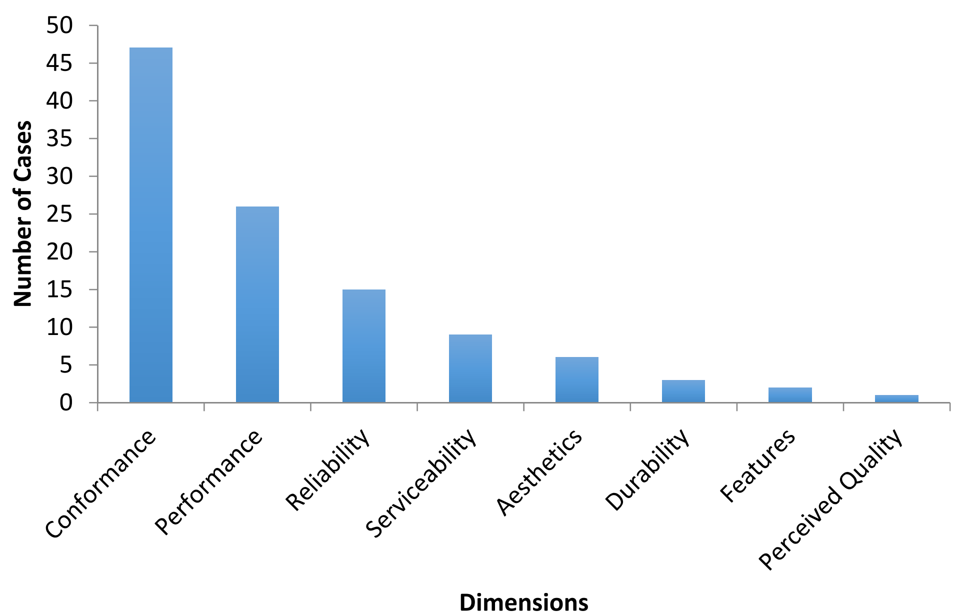

Figure 16. Eight Garvin dimensions of product quality and their case numbers

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.

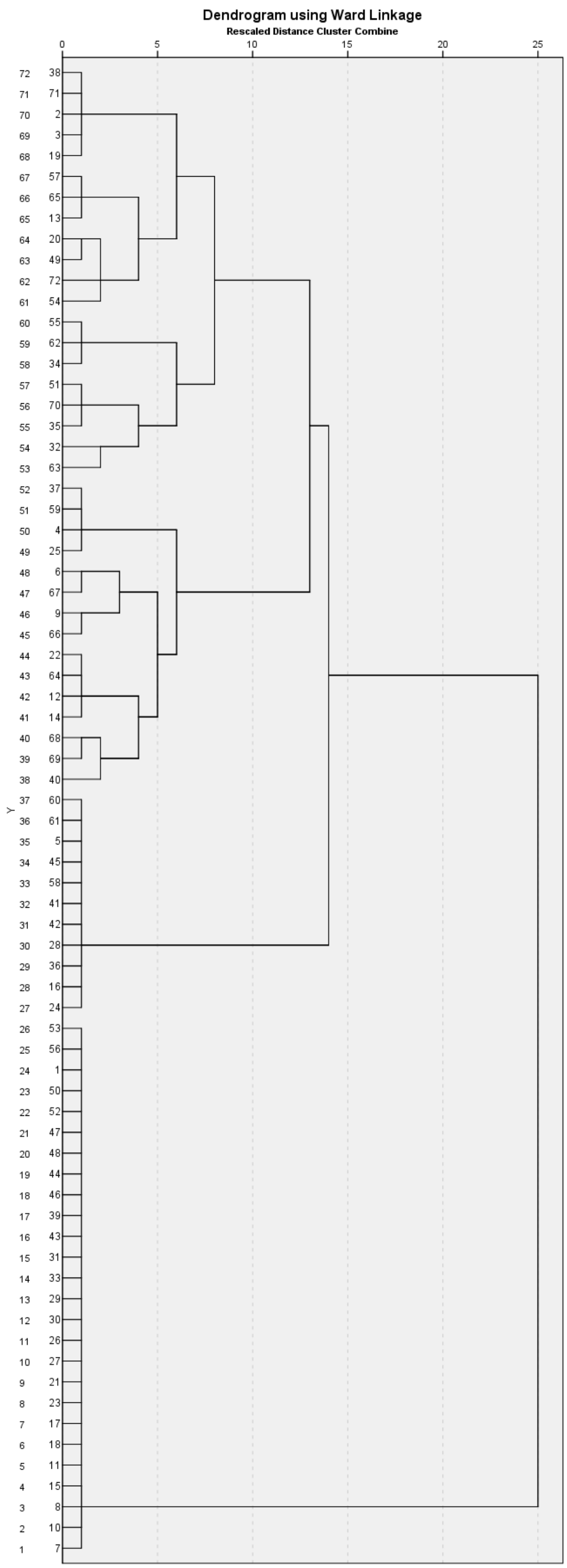

Figure 17. Dendrogram diagram for the 72 case studies.

Table 29

Cluster Membership for the Manufacturing Industry

Case Number	Cluster	Case Number	Cluster
1	1	37	4
2	2	38	2
3	2	39	1
4	4	40	11
5	5	41	5
6	6	42	5
7	1	43	1
8	1	44	1
9	9	45	5
10	1	46	1
11	1	47	1
12	12	48	1
13	13	49	3
14	12	50	1
15	1	51	10
16	5	52	1
17	1	53	1
18	1	54	14
19	2	55	8
20	3	56	1
21	1	57	13
22	12	58	5
23	1	59	4
24	5	60	5
25	4	61	5
26	1	62	8
27	1	63	15
28	5	64	12
29	1	65	13
30	1	66	9
31	1	67	6
32	7	68	16
33	1	69	16
34	8	70	10
35	10	71	2
36	5	72	17

Table 30

Cases Number and Dimensions Used in Each Cluster of Manufacturing

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

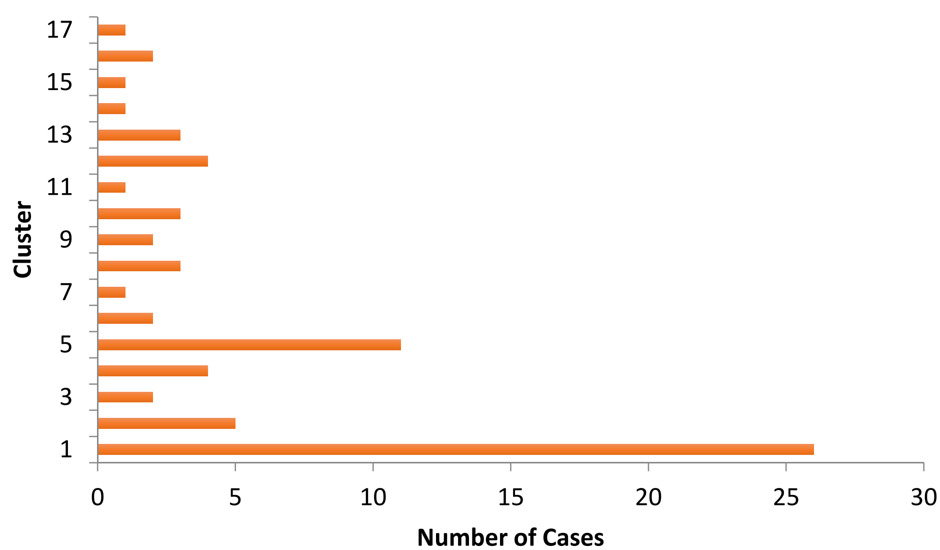

Figure 18. Number of cases used in each cluster.

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

Tools & Techniques for Cluster Cases		
Cluster 1	*Define*	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)
	Measure	Cause-and-Effect Diagram, Interview, Gauge R&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)
	Analyze	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
	Improve	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&R, 5S, Kanban, Total Productive Maintenance (TPM), Value Stream Mapping (VSM), Dot Plot, Pareto Chart
	Control	Control Plan, I-Chart, Control Chart, Sigma Calculation (DPMO), Run Chart, Standardization, Auditing, Statistical Process Control (SPC), Process Capability Analysis, Pareto Chart

(table continues)

Tools & Techniques for Cluster Cases		
Cluster 2	*Define*	Project Charter, Gantt Chart, Y and y definitions, Cause-and-Effect Diagram, Business Case, Log book on meetings, SIPOC Diagram, Process Mapping, Cause-and-Effect Diagram, Brainstorming, Critical to Quality (CTQ)
	Measure	Interview, Observation, Drawings, Work Sheet, Histogram, Gauge R&R, Brainstorming, Cause-and-Effect Diagram, Geometric Optical Measurements, Check Sheets, Sigma Calculation (DPMO), ANOVA Test, Process Capability Analysis, Control Chart, Pareto Diagram
	Analyze	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
	Improve	Flow Diagram, Brainstorming, Bar Chart, Matrix Diagram, Design of Experiments (DOE),, ANOVA Test, Process Capability Analysis
	Control	Flowchart, Checklists, Control Plan
Cluster 3	*Define*	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)
	Measure	Value Stream Mapping, Brainstorming, Gage R&R, Process Capability Analysis, Time Value Map Diagram, Value-added Analysis
	Analyze	Pareto Chart, Cause-and-Effect Diagram, Run Chart, Box Plot, Control Chart, Histogram, ANOVA Test
	Improve	Value Stream Mapping (VSM), Kanban, Brainstorming, Cost-benefit Analysis, Process Capability Analysis, Single Minute Exchange of Die (SMED)
	Control	Control Plan

(table continues)

Tools & Techniques for Cluster Cases		
Cluster 4	*Define*	Project Charter, Flowchart, SIPOC Diagram, Process Mapping, Cause-and-Effect Diagram, Gantt Chart, Voice of Customer (VOC), Critical to Quality (CTQ)
	Measure	Gauge R&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)
	Analyze	Brainstorming, Cause-and-Effect Diagram, Regression Analysis, GEMBA, Flowchart, Failure Mode and Effect Analysis (FMEA), Gauge R&R, Process Capability Analysis, Descriptive Statistics, Box Plot, Process Mapping, Six Thinking Hat
	Improve	Design of Experiments (DOE), Taguchi Methods, ANOVA Test, Risk Analysis, Process Capability Analysis, 5S, Flowchart, Pilot Plan, Control Chart, Pareto Chart
	Control	Checklist, Auditing, Control Chart, Documentation, Control Plan, Statistical Process Control (SPC), Poka-yoke
Cluster 5	*Define*	SIPOC Diagram, Project Charter, Voice of Customer (VOC), Critical to Quality (CTQ), Brainstorming, Process Mapping
	Measure	Cause-and-Effect Matrix, Pareto Chart, Block Step, Gauge R&R, Process Mapping, Tact Time, Overall Equipment Efficiency (OEE), Process Capability Analysis, Normal Probability Plot, Critical to Quality (CTQ), Brainstorming, Statistical Process Control (SPC)
	Analyze	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
	Improve	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
	Control	Control Plan, Standardization, Control Chart, Run Chart, Pareto Chart, Benchmark, Hypothesis Testing, Check Sheets, Process Capability Analysis
Cluster 6	*Define*	Project Charter, Critical to Quality (CTQ), Quality Function Deployment (QFD)
	Measure	Process Mapping, Process Capability Analysis, Run Chart, Pareto Chart, Box Plot, Hypothesis Testing, Gauge R&R, Cause-and-Effect Diagram, Brainstorming, Simulation, Probability Plot
	Analyze	Multi-vari Chart, Hypothesis Testing, Process Mapping
	Improve	ANOVA Test, Anderson–Darling Test, Ryan–Joiner Test, Design of Experiments (DOE), Normal Probability Plot, Control Chart, Process Capability Analysis, Hypothesis Testing
	Control	Process capability Analysis, Control Plan, Control Chart

(table continues)

Tools & Techniques for Cluster Cases		
Cluster 7	*Define*	Critical to Quality (CTQ), Voice of Customer (VOC), Value Stream Mapping (VSM)
	Measure	Gauge R&R
	Analyze	Pareto Chart, Brainstorming, Cause-and-Effect Diagram
	Improve	Design of Experiments (DOE), 5S, Total Productive Maintenance (TPM)
	Control	Control Chart, Standardization, Mistake Proofing, Failure Mode and Effect Analysis (FMEA)
Cluster 8	*Define*	Critical to Quality (CTQ), Voice of Customer (VOC), SIPOC Diagram, Cause-and-Effect Diagram, Project Charter, Flowchart, Process Mapping, Control Chart
	Measure	Cause-and-Effect Matrix, Gauge R&R, Control Chart, Process Capability Analysis
	Analyze	ANOVA Test, Process capability Analysis, Cause-and-Effect Diagram
	Improve	Design of Experiments (DOE), Regression Analysis, Process Capability Analysis, Pareto Chart, Taguchi Method, ANOVA Test
	Control	Statistical Process Control (SPC), Control Plan
Cluster 9	*Define*	Box plot, Critical to Quality (CTQ), Critical to Cost (CTC)
	Measure	Process Capability Analysis, Gauge R&R, Control Chart
	Analyze	Brainstorming, Hypotheses Testing, Pareto Chart, Cause-and-Effect Matrix, ANOVA Test, Box Plot, Fault Tree Analysis, Multi-vari Analysis, Regression Analysis, Gage R&R, Normal Probability Plot, Histogram
	Improve	Box plot, control chart
Cluster 10	*Define*	Pareto chart, SIPOC Diagram
	Measure	Sigma Calculation (DPMO), Pareto Chart, key Process Input Variable (KPIVs), Cause-and-Effect Diagram, Failure Mode and Effect Analysis (FMEA), Process Capability Analysis
	Analyze	Regression Analysis, Control Chart, Gauge R&R, Chi-square Test, Cause-and-Effect Diagram, Pareto Chart
	Control	Control Plan, Control Chart, Process Capability Analysis, Sigma Calculation (DPMO)

(table continues)

Tools & Techniques for Cluster Cases		
Cluster 11	*Measure*	Brainstorming, Control Chart, Cause-and-Effect Diagram
	Analyze	Taguchi Methods, ANOVA Test
Cluster 12	*Define*	Pareto Chart, Value Stream Mapping, Cause-and-Effect Diagram
	Measure	Value Stream Mapping (VSM), Simulation, Pareto Chart, Quality Function Deployment (QFD)
	Analyze	Statistical Process Control (SPC), ANOVA Test, Regression Analysis, Process Capability Analysis, Control Chart, Scatter Plot, Cost-benefit Analysis, Hypothesis Testing, Cause-and-Effect Diagram
	Improve	Kaizen, Non-parametric test
	Control	Failure Mode and Effect Analysis (FMEA), Statistical Tests, Control Plan, Control Chart
Cluster 13	*Define*	Project Charter, Process Mapping, Prioritization Matrix
	Measure	Sigma Calculation (DPMO), Pareto Chart, Flowchart, Cause-and-Effect Diagram, Gage R&R
	Analyze	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
	Improve	Action plan, Sigma Calculation (DPMO), 5S
	Control	Standardization, Control Plan, Flowchart
Cluster 14	*Define*	Pareto Chart, Project Charter, SIPOC Diagram, Critical to Quality (CTQ), Voice of Customer (VOC)
	Measure	Process Mapping, Sigma Calculation (DPMO)
	Analyze	Pareto Chart, Failure Mode and Effect Analysis (FMEA), Cause-and-Effect Diagram, Why-Why Analysis
	Improve	Matrix Diagram
	Control	Control Plan

(table continues)

Tools & Techniques for Cluster Cases		
Cluster 15	*Define*	Process Mapping
	Measure	Control Chart, Process Capability Analysis
	Analyze	Taguchi Methods
	Improve	Taguchi Methods
	Control	Control Chart
Cluster 16	*Define*	Process Capability Analysis
	Measure	Gage R&R, Process Mapping, Cause-and-Effect Diagram, Weibull Analysis, Survey
	Analyze	Hypothesis Testing, Box Plot, Regression Analysis
	Improve	Hypothesis Testing
	Control	Control Chart
Cluster 17	*Define*	Value Stream Mapping (VSM), Flowchart
	Measure	Pareto Chart
	Analyze	5 Whys Analysis
	Control	5S, Standard Operating Procedure (SOP)

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

Cluster	Number of Cases	Dimensions
6	2	Performance, Reliability
9	2	Performance, Reliability, Conformance
11	1	Performance, Reliability, Durability

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

Contradiction Matrix for Manufacturing								
	Performance	***Features***	***Reliability***	***Conformance***	***Durability***	***Serviceability***	***Aesthetics***	***Perceived Quality***
Performance	3, 5, 6, 8, 9, 11, 13, 14 (DMAIC LIST 1)	NONE	6, 9, 11 (DMAIC LIST 2)	3, 9, 13, 14 (DMAIC LIST 3)	11 (DMAIC LIST 4)	3, 14, 17 (DMAIC LIST 5)	8 (DMAIC LIST 6)	14 (DMAIC LIST 7)
Features	NONE	7, 15 (DMAIC LIST 8)	NONE	7 (DMAIC LIST 9)	NONE	NONE	NONE	NONE
Reliability	6, 9, 11 (DMAIC LIST 2)	NONE	4, 6, 9, 11, 12 (DMAIC LIST 10)	4, 9 (DMAIC LIST 11)	11, 16 (DMAIC LIST 17)	NONE	NONE	NONE
Conformance	3, 9, 13, 14 (DMAIC LIST 3)	7 (DMAIC LIST 9)	4, 9 (DMAIC LIST 11)	1, 2, 3, 4, 7, 9, 10, 13, 14 (DMAIC LIST 12)	NONE	2, 14 (DMAIC LIST 13)	10 (DMAIC LIST 16)	14 (DMAIC LIST 7)
Durability	11 (DMAIC LIST 4)	NONE	11, 15 (DMAIC LIST 17)	NONE	11 (DMAIC LIST 4)	NONE	NONE	NONE
Serviceability	3, 14, 17 (DMAIC LIST 5)	NONE	NONE	2, 14 (DMAIC LIST 13)	NONE	2, 3, 14 (DMAIC LIST 14)	NONE	14 (DMAIC LIST 7)
Aesthetics	8 (DMAIC LIST 6)	NONE	NONE	10 (DMAIC LIST 16)	NONE	NONE	8, 10 (DMAIC LIST 15)	NONE
Perceived Quality	14 (DMAIC LIST 7)	NONE	NONE	14 (DMAIC LIST 7)	NONE	14 (DMAIC LIST 7)	NONE	14 (DMAIC LIST 7)

Table 34

Seventeen DMAIC Lists for the Contradiction Matrix for Manufacturing

		DMAIC List for The Contradiction Matrix
DMAIC LIST 1	*Define*	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
	Measure	Value Stream Mapping (VSM), Brainstorming, Gage R&R, Process Capability Analysis, Time Value Map Diagram, Value-added Analysis, Cause-and-Effect Matrix, Pareto Chart, Block Step, Process Mapping, Tact Time, Overall Equipment Efficiency (OEE), Normal Probability Plot, Critical to Quality (CTQ), Statistical Process Control (SPC), Run Chart, Box Plot, Hypothesis Test, Cause-and-Effect Diagram, Control Chart, Sigma Calculation (DPMO), Flowchart, Simulation
	Analyze	Pareto Chart, Cause-and-Effect Diagram, Run Chart, Box plot, Control Chart, Histogram, ANOVA Test, Brainstorming, Multi-vari Analysis, Regression Analysis, Process Capability Analysis, Bar Chart, Correlation Analysis, Failure Mode and Effect Analysis (FMEA), Taguchi Methods, Design of Experiments (DOE), Normal Probability Plot, Simulation, Hypotheses Testing, Cause-and-Effect Matrix, Fault Tree Analysis, Tree diagram, Key Input Variables (KIVs), Why-Why Analysis, Gage R&R, Process Mapping
	Improve	Value Stream Map (VSM), Kanban, Brainstorming, Cost-benefit Analysis, Process Capability Analysis, Single Minute Exchange of Die (SMED), Design of Experiments (DOE), Failure Mode and Effect Analysis (FMEA), 5S, Total Productive Maintenance (TPM), Taguchi Methods, Simulation, Flowchart, Regression Analysis, ANOVA Test, Anderson–Darling Test, Ryan–Joiner Test, Pareto Chart, Box Plot, Action Plan, Sigma Calculation (DPMO), Matrix Diagram, Control Chart, Probability Plot, Hypothesis Testing
	Control	Control Plan, Standardization, Control Chart, Run Chart, Pareto Diagram, Benchmark, Hypothesis Testing, Check Sheet, Process Capability Analysis, Statistical Process Control (SPC), Flowchart
DMAIC LIST 2	*Define*	Project Charter, Critical to Quality (CTQ), Box plot, Critical to Cost (CTC)
	Measure	Process Mapping, Process Capability Analysis, Run Chart, Pareto Chart, Box Plot, Hypothesis Testing, Gauge R&R, Cause-and-Effect Diagram, Brainstorming, Control Chart
	Analyze	Multi-vari Chart, Taguchi Methods, ANOVA Test, Brainstorming, Hypotheses Testing, Pareto Chart, Cause-and-Effect Matrix, Box Plot, Fault Tree Analysis, Regression Analysis, Gage R&R, Normal Probability Plot, Histogram
	Improve	ANOVA Test, Anderson–Darling Test, Ryan–Joiner Test, Box Plot, Control Chart
	Control	Process capability Analysis, Control Plan

(table continues)

		DMAIC List for The Contradiction Matrix
DMAIC LIST 3	*Define*	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), Box Plot, Critical to Cost (CTC), Project Charter, Prioritization Matrix, SIPOC Diagram
	Measure	Value Stream Mapping, Brainstorming, Gage R&R, Process Capability Analysis, Time Value Map diagram, Value-added Analysis, Sigma Calculation (DPMO), Pareto Chart, Flowchart, cause-and-effect Diagram, Process Mapping, Control Chart
	Analyze	Pareto Chart, Cause-and-Effect Diagram, Run chart, Box Plot, Control Chart, Histograms, ANOVA Test, Brainstorming, Hypotheses Testing, Cause-and-Effect Matrix, Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis, Tree Diagram, Key Input Variables (KIVs), Multi-vari Chart, Regression Analysis, Why-Why Analysis, Regression Analysis, Gage R&R, Normal Probability Plot
	Improve	Value Stream Mapping (VSM), Kanban, Brainstorming, Cost-benefit Analysis, Process Capability Analysis, Single Minute Exchange of Die (SMED), Box Plot, Action Plan, Sigma Calculation (DPMO), 5S, Matrix Diagram, Control Chart
	Control	Control Plan, Standardization, Flowchart
DMAIC LIST 4	*Measure*	Brainstorming, Control Chart, Cause-and-Effect Diagram
	Analyze	Taguchi Methods, ANOVA Test
DMAIC LIST 5	*Define*	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), Project Charter, SIPOC Diagram, Value Stream Mapping (VSM), Flowchart
	Measure	Value Stream Mapping, Brainstorming, Gage R&R, Process Capability Analysis, Time Value Map Diagram, Value-added Analysis, Process Mapping, Sigma Calculation (DPMO), Pareto Chart
	Analyze	Pareto Chart, Cause-and-Effect Diagram, Run Chart, Box Plot, Control Chart, Histogram, ANOVA Test, Failure Mode and Effect Analysis (FMEA), Why-Why Analysis, 5 Whys Analysis
	Improve	Value Stream Mapping (VSM), Kanban, Brainstorming, Cost-benefit Analysis, Process Capability Analysis, Single Minute Exchange of Die (SMED), Failure Mode and Effect Analysis (FMEA), Why-Why Analysis
	Control	Control Plan, 5S, Standard Operating Procedure (SOP)

(table continues)

		DMAIC List for The Contradiction Matrix
DMAIC LIST 6	*Define*	Voice of Customer (VOC), SIPOC Diagram, Critical to Quality (CTQ), Cause-and-Effect Diagram, Project Charter, Flowchart, Process Mapping, Control Chart
	Measure	Cause-and-Effect Matrix, Gauge R&R, Control Chart, Process Capability Analysis
	Analyze	ANOVA Test, Process Capability Analysis, Cause-and-Effect Diagram
	Improve	Design of Experiment (DOE), Regression Analysis, Process Capability Analysis, Pareto Chart, Taguchi Methods, ANOVA Test
	Control	Statistical Process Control (SPC), Control Plan
DMAIC LIST 7	*Define*	Pareto Chart, Project Charter, Voice of Customer (VOC), SIPOC Diagram, Critical to Quality (CTQ)
	Measure	Process Mapping, Sigma Calculation (DPMO)
	Analyze	Pareto Chart, Failure Mode and Effect Analysis (FMEA), Cause-and-Effect Diagram, Why-Why Analysis
	Improve	Matrix Diagram
	Control	Control Plan
DMAIC LIST 8	*Define*	Process Mapping, Critical to Quality (CTQ), Voice of Customer (VOC), Value Stream Mapping
	Measure	Control Chart, Process Capability Analysis, Gauge R&R
	Analyze	Taguchi Methods, Pareto Chart, Brainstorming, Cause-and-Effect Diagram
	Improve	Taguchi Methods, Design of Experiment (DOE), 5S, Total Productive Maintenance (TPM)
	Control	Control Chart, Control Chart, Standardization, Mistake Proofing, Failure Mode and Effect Analysis (FMEA)
DMAIC LIST 9	*Define*	Critical to Quality (CTQ), Voice of Customer (VOC), Value Stream Mapping (VSM)
	Measure	Gauge R&R
	Analyze	Pareto Chart, Brainstorming, Cause-and-Effect Diagram
	Improve	Design of Experiment (DOE), 5S, Total Productive Maintenance (TPM)
	Control	Control Chart, Standardization, Mistake Proofing, Failure Mode and Effect Analysis (FMEA)

(table continues)

		DMAIC List for The Contradiction Matrix
DMAIC LIST 10	*Define*	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)
	Measure	Gauge R&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), Process Mapping, Run Chart, Box Plot, Hypothesis Testing, Brainstorming, Value Stream Mapping, Simulation, Quality Function Deployment (QFD)
	Analyze	Brainstorming, Cause-and-Effect Diagram, Regression Analysis, GEMBA, Flowchart, Failure Mode and Effect Analysis (FMEA), Gauge R&R, Process Capability Analysis, Descriptive Statistics, Box Plot, Process Mapping, Six Thinking Hat, Multi-vari Chart, Hypotheses Testing, Pareto Charts, Cause-and-Effect Matrix, ANOVA Test, Taguchi Methods, Statistical Process Control (SPC), Control Chart, Statistical Test, Scatter Plot, Cost-benefit Analysis, Hypothesis Testing
	Improve	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
	Control	Checklist, Auditing, Control Chart, Documentation, Control Plan, Statistical Process Control (SPC), Poka-yoke, Process capability Analysis, Failure Mode and Effect Analysis (FMEA), Statistical Test
DMAIC LIST 11	*Define*	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)
	Measure	Gauge R&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)
	Analyze	Brainstorming, Cause-and-Effect Diagram, Regression Analysis, GEMBA, Flowchart, Failure Mode and Effect Analysis (FMEA), Gauge R&R, Process Capability Analysis, Descriptive Statistics, Box Plot, Process Mapping, Six Thinking Hat, Hypotheses Testing, Cause-and-Effect Matrix, ANOVA Test, Fault Tree Analysis, Multi-vari Analysis, Normal Probability Plot, Histogram
	Improve	Design of Experiments (DOE), Taguchi Methods, ANOVA Test, Risk Analysis, Process Capability Analysis, 5S, Flowchart, Pilot Testing, Control Chart, Pareto Chart, Box Plot
	Control	Checklist, Auditing, Control Chart, Documentation, Control Plan, Statistical Process Control (SPC), Poka-yoke

(table continues)

DMAIC List for The Contradiction Matrix		
DMAIC LIST 12	*Define*	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
	Measure	Cause-and-Effect Diagram, Interview, Gauge R&R, Process Capability Analysis, Histogram, Control Chart, Sigma Calculation (DPMO), Pareto Chart, Fault Tree, Brainstorming, Flowchart, Cause-and-Effect Matrix, Basic Statistics, Histogram, Process Mapping, Failure Mode and Effect Analysis (FMEA), Critical to Quality (CTQ), Value Stream Mapping, The Seven Wastes (Muda), Value-added Analysis, Normal Probability Plot, key Process Input Variable (KPIVs), Key Process Output Variables (KPOVs), Observation, Drawings, Work Sheet, Geometric Optical Measurements, Check Sheets, ANOVA Test, Time Value Map Diagram, Anderson–Darling Normality Test, R Charts, Scatter Plot
	Analyze	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&R, Descriptive Statistics, Six Thinking Hat, Cause-and-Effect Matrix, Fault Tree Analysis, Key Input Variables (KIVs)
	Improve	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&R, 5S, Kanban, Total Productive Maintenance (TPM), Value Stream Mapping (VSM), Dot Plot, Pareto Chart, Flow Diagram, Bar Chart, Matrix Diagram, Cost-benefit Analysis, Single Minute Exchange of Die (SMED), Risk Analysis, Process Capability Analysis, Pilot Plan, Control Chart, Action Plan
	Control	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)

(table continues)

		DMAIC List for The Contradiction Matrix
DMAIC LIST 13	*Define*	Project Charter, Gantt Chart, Y and y definitions, Cause-and-Effect Diagram, Business Case, Log book on meetings, SIPOC Diagram, Process Mapping, Cause-and-Effect Diagram, Brainstorming, Critical to Quality (CTQ), Pareto Chart, Voice of Customer (VOC)
	Measure	Interview, Observation, Drawings, Work Sheets, Histograms, Gauge R&R, Brainstorming, Cause-and-Effect Diagram, Geometric Optical Measurements, Check Sheets, Sigma Calculation (DPMO), ANOVA Test, Process Capability Analysis, Control Chart, Process Mapping, Pareto Chart
	Analyze	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, Why-Why Analysis, GEMBA
	Improve	Flowchart, Brainstorming, Bar Chart, Matrix Diagram, Design of Experiments (DOE), ANOVA Test, Process Capability Analysis
	Control	Flowchart, Checklists, Control Plan
DMAIC LIST 14	*Define*	Project Charter, Gantt Chart, Y and y definitions, Cause-and-Effect Diagram, Business Case, Log book on meetings, SIPOC Diagram, Process Mapping, Cause-and-Effect Diagram, Brainstorming, Critical to Quality (CTQ), Key Performance Indicators (KPIs), Voice of Customer (VOC), Voice of the Process (VOP), Critical to Customer (CTCs), Pareto Diagram, Costs of Poor Quality (COPQs), Quality Function Deployment (QFD)
	Measure	Interview, Observation, Drawings, Work Sheets, Histograms, Gauge R&R, Brainstorming, Cause-and-Effect Diagram, Geometric Optical Measurements, Check Sheets, Sigma Calculation (DPMO), ANOVA Test, Process Capability Analysis, Control Charts, Value Stream Mapping, Time Value Map Diagram, Value-added Analysis, Process Mapping, Pareto Chart
	Analyze	Correlation, Regression Analysis, Process Mapping, Cause-and-Effect Matrix, Failure Mode and Effect Analysis (FMEA), VMEA, Normal Probability Plot, Process Capability Analyses, Control Chart, Brainstorming, Cause-and-Effect Diagram, Bar Chart, Pareto Chart, Tree Diagram, ANOVA Test, Run Chart, Box Plot, Histogram, Why-Why Analysis, GEMBA
	Improve	Flowchart, Brainstorming, Bar Chart, Matrix Diagram, Design of Experiments (DOE), ANOVA Test, Process Capability Analysis, Value Stream Mapping (VSM), Kanban, Cost-benefit Analysis, Single Minute Exchange of Die (SMED)
	Control	Flowchart, Checklists, Control Plan

(table continues)

DMAIC List for The Contradiction Matrix		
DMAIC LIST 15	*Define*	Voice of Customer (VOC), SIPOC Diagram, Critical to Quality (CTQ), Cause-and-Effect Diagram, Project Charter, Flowchart, Process Mapping, Control Chart, Pareto Chart
	Measure	Cause-and-Effect Matrix, Gauge R&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)
	Analyze	ANOVA Test, Process Capability Analysis, Cause-and-Effect Diagram, Regression Analysis, Control Chart, Gauge R&R, Chi-square test, Pareto Chart
	Improve	Design of Experiments (DOE), Regression Analysis, Process Capability Analysis, Pareto Chart, Taguchi Methods, ANOVA Test
	Control	Statistical Process Control (SPC), Control Plan, Control Chart, Process Capability Analysis, Sigma Calculation (DPMO)
DMAIC LIST 16	*Define*	Pareto Chart, SIPOC Diagram
	Measure	Sigma Calculation (DPMO), Pareto chart, key Process Input Variable (KPIVs), Cause-and-Effect Diagram, Failure Mode and Effect Analysis (FMEA, Process Capability Analysis
	Analyze	Regression Analysis, Control Chart, Gauge R&R, Chi-square Test, Cause-and-Effect Diagram, Pareto Chart
	Control	Control Plan, Control Chart, Process Capability Analysis, Sigma Calculation (DPMO)
DMAIC LIST 17	*Define*	Process Capability Analysis
	Measure	Brainstorming, Control Chart, Cause-and-Effect Diagram, Gage R&R, Process Mapping, Weibull Analysis, Survey
	Analyze	Taguchi Methods, ANOVA Test, Hypothesis Testing, Box plot, Regression Analysis
	Improve	Hypothesis Testing
	Control	Control Chart

Table 35

Number of Cases Used in each DMAIC List of Manufacturing

DMAIC LIST	Number of Cases
DMAIC LIST 1	25
DMAIC LIST 2	5
DMAIC LIST 3	8
DMAIC LIST 4	1
DMAIC LIST 5	4
DMAIC LIST 6	3
DMAIC LIST 7	1
DMAIC LIST 8	2
DMAIC LIST 9	1
DMAIC LIST 10	13
DMAIC LIST 11	6
DMAIC LIST 12	47
DMAIC LIST 13	6
DMAIC LIST 14	8
DMAIC LIST 15	6
DMAIC LIST 16	3
DMAIC LIST 17	3

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

Contradiction Matrix for Manufacturing								
	Performance	***Features***	***Reliability***	***Conformance***	***Durability***	***Serviceability***	***Aesthetics***	***Perceived Quality***
Performance	3, 5, 6, 8, 9, 11, 13, 14 (DMAIC LIST 1)	NONE	6, 9, 11 (DMAIC LIST 2)	3, 9, 13, 14 (DMAIC LIST 3)	11 (DMAIC LIST 4)	3, 14, 17 (DMAIC LIST 5)	8 (DMAIC LIST 6)	14 (DMAIC LIST 7)
Features	NONE	7, 15 (DMAIC LIST 8)	NONE	7 (DMAIC LIST 9)	NONE	NONE	NONE	NONE
Reliability	6, 9, 11 (DMAIC LIST 2)	NONE	4, 6, 9, 11, 12 (DMAIC LIST 10)	4, 9 (DMAIC LIST 11)	11, 16 (DMAIC LIST 17)	NONE	NONE	NONE
Conformance	3, 9, 13, 14 (DMAIC LIST 3)	7 (DMAIC LIST 9)	4, 9 (DMAIC LIST 11)	1, 2, 3, 4, 7, 9, 10, 13, 14 (DMAIC LIST 12)	NONE	2, 14 (DMAIC LIST 13)	10 (DMAIC LIST 16)	14 (DMAIC LIST 7)
Durability	11 (DMAIC LIST 4)	NONE	11, 15 (DMAIC LIST 17)	NONE	11 (DMAIC LIST 4)	NONE	NONE	NONE
Serviceability	3, 14, 17 (DMAIC LIST 5)	NONE	NONE	2, 14 (DMAIC LIST 13)	NONE	2, 3, 14 (DMAIC LIST 14)	NONE	14 (DMAIC LIST 7)
Aesthetics	8 (DMAIC LIST 6)	NONE	NONE	10 (DMAIC LIST 16)	NONE	NONE	8, 10 (DMAIC LIST 15)	NONE
Perceived Quality	14 (DMAIC LIST 7)	NONE	NONE	14 (DMAIC LIST 7)	NONE	14 (DMAIC LIST 7)	NONE	14 (DMAIC LIST 7)

Table 37

Validation Cases for Manufacturing

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

Table 38

Validated DMAIC Lists Based on the Number of Cases in Manufacturing

DMAIC LIST	**Number of Cases**	**Validation**
DMAIC LIST 12	47	*Validated*
DMAIC LIST 1	25	*Validated*
DMAIC LIST 10	13	*Validated*
DMAIC LIST 3	8	*Validated*
DMAIC LIST 14	8	*Validated*
DMAIC LIST 11	6	*None*
DMAIC LIST 13	6	*None*
DMAIC LIST 15	6	*Validated*
DMAIC LIST 2	5	*None*
DMAIC LIST 5	4	*Validated*
DMAIC LIST 6	3	*None*
DMAIC LIST 16	3	*Validated*
DMAIC LIST 17	3	*None*
DMAIC LIST 8	2	*None*
DMAIC LIST 4	1	*None*
DMAIC LIST 7	1	*None*
DMAIC LIST 9	1	*None*

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

Case Number	Case Reference	Tangibles	Reliability	Responsiveness	Assurance	Empathy
1	(Barone & Franco, 2012; p. 269)	0	1	0	0	0
2	(Barone & Franco, 2012; p. 283)	0	1	1	0	0
3	(Barone & Franco, 2012; p .314)	0	1	1	1	0
4	(Al-Bashir & Al-Tawarah, 2012)	0	1	0	0	0
5	(Allen, Tseng, Swanson, & McClay, 2009)	0	1	1	0	0
6	(Antony, Bhuller, Kumar, Mendibil, & Montgomery, 2012)	0	1	0	0	0
7	(Cash, 2013)	0	1	0	0	0
8	(Drenckpohl, Bowers, & Cooper, 2007)	0	1	0	1	0
9	(Eldridge et al., 2006)	0	0	0	1	0
10	(Feng & Antony, 2009)	0	1	0	0	0
11	(Furterer & Elshennawy, 2005)	0	1	1	0	0
12	(Goodman, Kasper, & Leek, 2007)	0	1	1	0	0
13	(Heuvel, Does, & Vermaat, 2004; case 1)	0	1	1	0	0
14	(Heuvel, Does, & Vermaat, 2004, case 2)	0	1	0	0	0
15	(Heuvel, Does, & Vermaat, 2004; case 3)	0	1	0	0	0
16	(Chen, Shyu, & Kuo, 2010)	0	1	0	0	0
17	(Kapoor, Bhaskar, & Vo, 2012)	0	1	0	0	0
18	(Kaushik, Shokeen, Kaushik, & Khanduja, 2007)	0	1	0	0	0
19	(Kukreja, Ricks, & Meyer, 2009)	0	1	0	0	0
20	(Murphy, 2009)	0	1	1	0	0
21	(Nabhani & Shokri, 2009)	0	1	0	0	0
22	(Kumar, Wolfe, & Wolfe, 2008)	0	1	1	0	0
23	(Kumar, Choe, & Venkataramani, 2012)	0	1	0	0	0
24	(Kumar, Strandlund, & Thomas, 2008)	0	1	0	0	0

(table continues)

Case Number	Case Reference	Tangibles	Reliability	Responsiveness	Assurance	Empathy
25	(Kumi & Morrow, 2006)	0	1	0	0	0
26	(Laureani & Antony, 2010)	0	1	0	0	0
27	(Martinez & Gitlow, 2011)	0	1	0	0	0
28	(Martinez, Chavez-Valdez, Holt, Grogan, Khalifeh, Slater, Winner, Moyer, & Lehmann, 2011)	0	1	1	1	0
29	(Franchetti & Bedal, 2009)	0	1	1	1	0
30	(O'Neill & Duvall, 2005)	1	1	1	1	0
31	(Pan, Ryu, & Baik, 2007)	0	1	1	0	0
32	(Pandey, 2007)	0	1	0	0	0
33	(Prasad, Subbaiah, & Padmavathi, 2012)	1	1	0	1	0
34	(Redzic & Baik, 2006)	0	1	0	0	0
35	(Rivera & Marovich, 2001)	0	1	1	0	0
36	(Salzarulo, Krehbiel, Mahar, & Emerson, 2012)	0	1	0	0	1
37	(Furterer, 2011)	0	1	0	0	0
38	(Ray, Das, & Bhattachrya, 2011)	0	1	1	0	0
39	(Li, Wu, Yen, & Lee, 2011)	0	1	1	0	0
40	(Silich, Wetz, Riebling, Coleman, Khoueiry, Bagon, & Szerszen, 2012)	0	1	1	1	0
41	(Southard, Chandra, & Kumar, 2012)	1	1	1	1	0
42	(Taner, Sezen, & Atwat, 2012)	0	1	0	1	0
43	(Taner & Sezen, 2009)	0	1	0	0	0
44	(Wei, Sheen, Tai, & Lee, 2010)	1	1	1	0	0
45	(McAdam, Davies, Keogh, & Finnegan, 2009)	0	1	1	1	1
46	(Cheng & Chang, 2012)	0	1	1	0	0
47	(Chiarini, 2012)	0	1	0	1	0
48	(Das & Hughes, 2006)	0	0	1	0	0
49	(Desai, 2006)	0	1	0	0	0
50	(Ng, Tsung, So, & Li, 2005)	0	0	0	1	0
51	(Kapadia, Hemanth, & Sharda, 2003)	0	0	1	0	0
52	(Nanda, 2010)	0	0	0	1	0
53	(Kumar, Jensen, & Menge, 2008)	0	0	0	1	0
54	(Al-Qatawneh, Abdallah, & Zalloum, 2013)	1	1	0	0	0
55	(Baddour & Saleh, 2013)	0	0	0	1	0

(table continues)

Case Number	Case Reference	Tangibles	Reliability	Responsiveness	Assurance	Empathy
56	(Kumar, Phillips, & Rupp, 2009)	0	1	1	0	1
57	(Hagg, El-Harit, Vanni, & Scott, 2007)	1	0	0	0	1
58	(Kanakana, Pretorius, & van Wyk, 2012)	1	0	0	0	1
59	(Lokkerbol, Schotman, & Does, 2012)	1	0	0	1	0
60	(Lokkerbol, Molenaar, & Does, 2012)	1	1	1	0	0
61	(Miski, 2014)	0	1	0	0	1
62	(Pranoto & Nurcahyo, 2014)	1	1	0	1	0
63	(Cheng, 2013)	0	0	0	1	1
64	(Barone & Franco, 2012; p. 330)	0	1	0	0	0
65	(Elberfeld, Goodman, & Mark Van Kooy, 2004)	0	1	1	1	0
66	(Wang & Chen, 2010)	0	1	1	0	0
67	(Kim, Kim, & Chung, 2010)	0	1	1	0	0
68	(Laureani, Antony, & Douglas, 2010)	0	1	1	0	0

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

Dimensions	Total Number of Cases
Reliability	57
Responsiveness	28
Assurance	20
Tangibles	10
Empathy	7

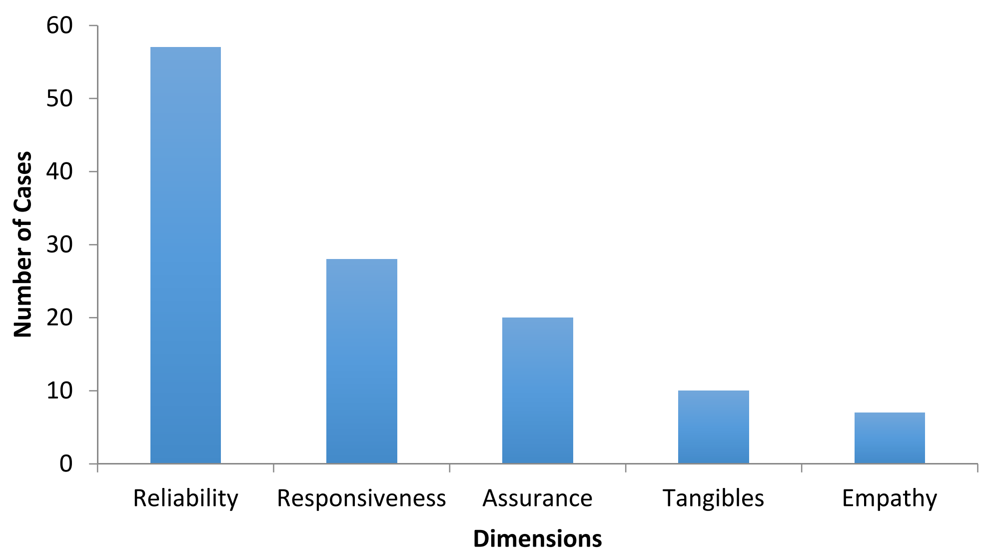

Figure 19. Five SERVQUAL dimensions of service quality and their case numbers.

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.

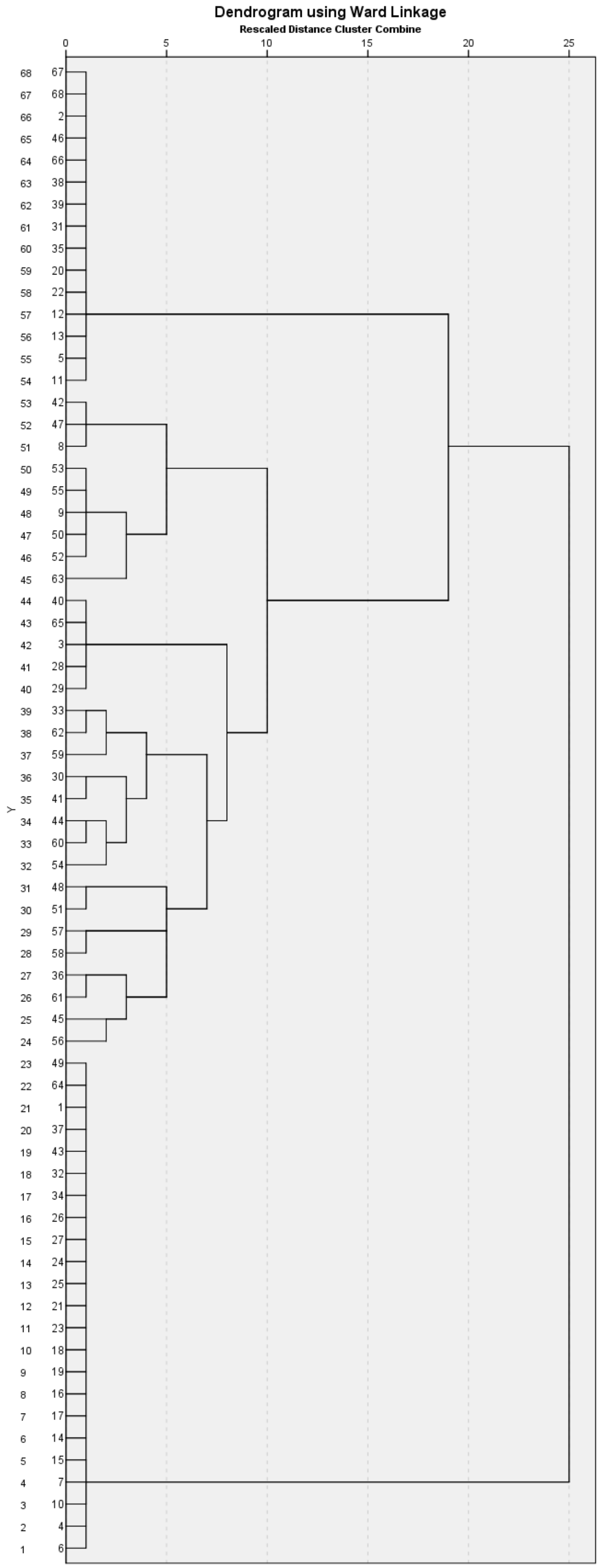

Figure 20. Dendrogram diagram for the 68 case studies

Table 41

Cluster Membership for the Service Industry

Case Number	Cluster	Case Number	Cluster
1	1	35	2
2	2	36	6
3	3	37	1
4	1	38	2
5	2	39	2
6	1	40	3
7	1	41	4
8	8	42	8
9	9	43	1
10	1	44	7
11	2	45	10
12	2	46	2
13	2	47	8
14	1	48	11
15	1	49	1
16	1	50	9
17	1	51	11
18	1	52	9
19	1	53	9
20	2	54	12
21	1	55	9
22	2	56	13
23	1	57	14
24	1	58	14
25	1	59	15
26	1	60	7
27	1	61	6
28	3	62	5
29	3	63	16
30	4	64	1
31	2	65	3
32	1	66	2
33	5	67	2
34	1	68	2

Table 42

Cases Number and Dimensions Used in Each Cluster of Service

Cluster	Number of Cases	Dimensions
1	23	Reliability
2	15	Reliability, Responsiveness
3	5	Reliability, Responsiveness, Assurance
4	2	Tangibles, Reliability, Responsiveness, Assurance
5	2	Tangibles, Reliability, Assurance
6	2	Reliability, Empathy
7	2	Tangibles, Reliability, Responsiveness
8	3	Reliability, Assurance
9	5	Assurance
10	1	Reliability, Responsiveness, Assurance, Empathy
11	2	Responsiveness
12	1	Tangibles, Reliability
13	1	Reliability, Responsiveness, Empathy
14	2	Tangibles, Empathy
15	1	Tangibles, Assurance
16	1	Assurance, Empathy

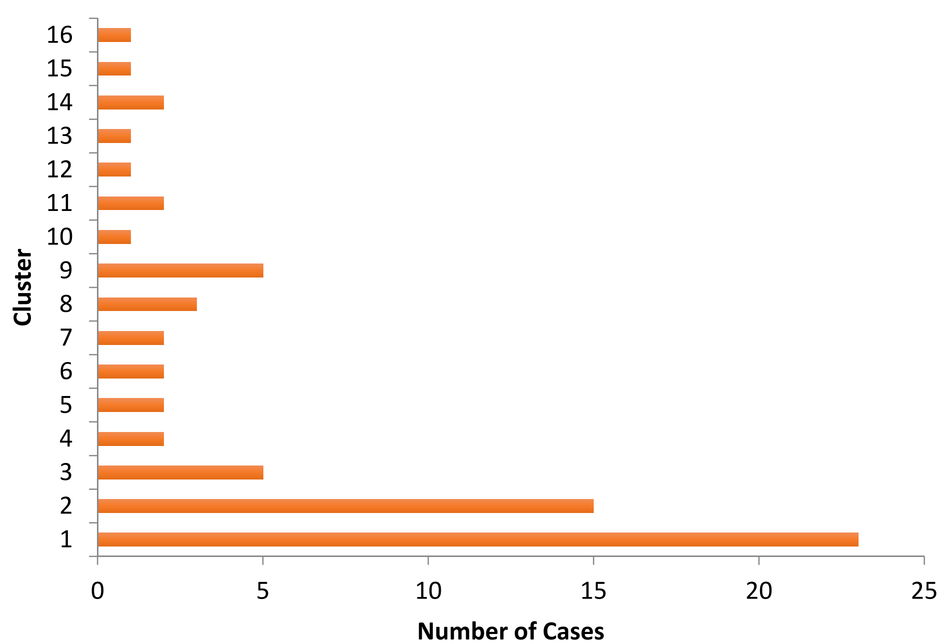

Figure 21. Number of cases used in each cluster.

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

Tools & Techniques for Cluster Cases		
Cluster 1	*Define*	Project Charter, 5 Whys Analysis, Gantt Chart, SIPOC, Process Mapping, Voice of Customer (VOC), Affinity Diagram, Brainstorm, Critical to Quality (CTQ), Cause-and-Effect Diagram, Key Performance Indicators (KPIs), Survey, Pareto Diagram, Benchmarking, Prioritization Matrix, Kano Analysis, Balanced Scorecard, Interview, Value Stream Mapping (VSM)
	Measure	Interviews, Observation, Histograms, Flowchart, Brainstorm, Cause-and-Effect Diagram, Critical to Quality (CTQ), Key output variable (KPOV), Gage R&R, Pareto Chart, Radar Diagram, Auditing, Process Mapping, Cause-and-Effect Matrix, Process Capability Analysis, Sigma Calculation (DPMO), Regression Analysis, Scatter diagram, Anderson-Darling normality test, Survey, Control Chart.
	Analyze	ANOVA test, Cause-and-Effect Diagram, Pareto Chart, Sigma Calculation (DPMO), Multi-voting, Survey, Process Mapping, Flowchart, Basic Statistics, Brainstorm, Failure Mode and Effects Analysis (FMEA), Chi-square test, Hypothesis Testing, Voice of Customer (VOC), Affinity Diagram, Cause-and-Effect Matrix, Histograms, Normal Probability Plot, Scatter Diagram, Pie Charts, Kanban, Paynter Chart, Why-Why Diagram, Regression Analysis, Gage R&R
	Improve	Action Plan, Control Chart, Matrix Diagram, Brainstorming, Poka-yoke, Process Capability Analysis, Cause-and-Effect Diagram, Cause-and-Effect Matrix, Pilot Plan, Prioritization Matrix diagram, Cost-Benefits Analysis, Analytic Hierarchy Process (AHP), Affinity diagram, Kaizen, 5S, Operator Balance Charts, Cell Design, Material Replenishment, Standard Work, QCPC/Turnbacks, Visual Management, Takt Time Analysis, Regression Analysis, Flowchart, Process Mapping
	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)

Tools & Techniques for Cluster Cases		
Cluster 2	*Define*	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)
	Measure	Interviews, Observation, Process Mapping, Standard Operating Procedure (SOP), Control Chart, Benchmark, Flowchart, Waste elimination, 5S, Housekeeping, Brainstorming, Cause-and-Effect diagram, Gage R&R, Sigma Calculation (DPMO), Process Capability Analysis, Survey, Pareto Diagram, Histograms, Tally Check Sheet, Run chart, Frequency Table, SIPOC diagram
	Analyze	Histograms, Time Series Plot, Box plot, Kawakita Jiro (KJ) Method, Cause-and-Effect Diagram, ANOM, Pareto Chart, Process Capability Analyses, Correlation Analysis, key Input Variables (KIVs), Pareto Chart, Cause-and-Effect Matrix, Brainstorming, Flowchart, Statistical Process Control (SPC), Kanban, Waste elimination, One Piece Flow, Cost–Benefit Analysis, Chi-square test, Failure Mode and Effect Analysis (FMEA), ANOVA test, Simulation, Tree diagram, Regression analysis, 5 Whys Analysis, EMEA (Error Modes and Effects Analysis), Window Analysis, Mann-Whitney Test, Kruskal-Wallis Test, Hypothesis Testing
	Improve	Brainstorm, ANOVA test, Poka-yoke, Prioritization Matrix, Cost-Benefit Analysis, Pilot Plan, TRIZ, Value Stream Mapping (VSM), Process Capability Analysis, Survey, Simulation, Cause-and-effect diagram, Flowchart
	Control	Binomial Test, Survey, Flowchart, Standardization, Control Plan, Control Chart, Risk Evaluation Matrix, Survey, Sigma Calculation (DPMO)
Cluster 3	*Define*	Project charter, Gantt Chart, Y and y definitions, P-diagram, SIPOC Diagram, Process Mapping, Auditing
	Measure	Interview, Observation, Kawakita Jiro (KJ) Method, Cause-and-Effect Diagram, Voting, Pareto Chart, VMEA, Force Field Analysis, Survey, Process Mapping, Sigma calculation (DPMO), SIPOC Diagram, Brainstorming, Process Capability Analysis, Control Charts, Gage R&R
	Analyze	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
	Improve	Process Capability Analysis, Hypothesis Testing, Histogram, Survey, Chi-square Test
	Control	Process Capability Analysis, Flowchart, Control Chart, Failure Mode and Effect Analysis (FMEA)

(table continues)

Tools & Techniques for Cluster Cases		
Cluster 4	*Define*	Critical to Quality (CTQ), Project Charter, Key Performance Indicators (KPIs)
	Measure	Value Stream Mapping (VSM), Survey
	Analyze	Process Mapping, simulation, Poka-yoke, Flowchart, Statistical Process Control (SPC)
	Improve	Cost-benefit Analysis, Control Chart
	Control	Survey
Cluster 5	*Define*	Critical to Quality (CTQ), SIPOC Diagram, Project Charter, Voice of Customer (VOC)
	Measure	Process Capability Analysis, Sigma Calculation (DPMO), Cause-and-Effect Diagram
	Analyze	Cause-and-Effect Diagram, Pareto Diagram, Failure Mode Effects Analysis (FMEA)
	Improve	Failure Mode Effect Analysis (FMEA)
	Control	Control Charts, Survey
Cluster 6	*Define*	Project Charter, SIPOC Diagram, Voice of Customer (VOC), Critical to Quality (CTQ)
	Measure	Survey, Frequency Table, Benchmarking, Kano Model
	Analyze	Scatter Diagram, Frequency Tables, Basic Statistics, Cause-and-Effect Diagram, Pareto Chart, 5 Whys Analysis
	Improve	Brainstorming, Affinity Diagram
	Control	Control Charts
Cluster 7	*Define*	Project Charter, Voice of Customer (VOC), Critical to Quality (CTQ), SIPOC Diagram, Process Mapping
	Measure	Process Mapping, Cause-and-Effect Diagram, Cause-and-Effect matrix, Failure Mode Effect Analysis (FMEA), Critical to Quality (CTQ), Brainstorming
	Analyze	ANOVA Test, Process Mapping, Value Stream Mapping (VSM)
	Control	Control Plan, Value Stream Mapping (VSM)

(table continues)

Tools & Techniques for Cluster Cases		
Cluster 8	*Define*	Process Mapping, Cause-and-Effect Diagram, Voice of Customer (VOC), Critical to Quality (CTQ)
	Measure	Value Stream Mapping (VSM), Process Mapping, Mode Effect Analysis (FMEA), Pareto Chart
	Analyze	Cause-and-effect Diagram, 5 Whys Analysis, Mode Effect Analysis (FMEA), Tree Diagram. Survey, Process Capability Analysis
	Improve	Sigma Calculation (DPMO)
	Control	Mode Effect Analysis (FMEA), Balanced Scorecards
Cluster 9	*Define*	Project Charter, Interview
	Measure	Process Mapping, Cause-and-Effect Matrix, Observation, Survey, Tree Diagram, Correlation Analysis, Cause-and-Effect Diagram, Flowchart
	Analyze	Failure Modes and Effects Analysis (FMEA), Multi-vari Chart, Cause-and-Effect Diagram, Relations Diagram, Process Mapping, Brainstorming, Histogram, poka-yoke, Survey, Pareto Diagram
	Improve	Brainstorming, Process Mapping, Gant Chart, Pilot Plan
	Control	Control Plan, Checklist
Cluster 10	*Define*	Focus Group
	Measure	Frequency Table
	Analyze	Frequency Table
	Improve	Process Mapping
	Control	Run Chart
Cluster 11	*Measure*	Process Mapping, Dashboard
	Analyze	Pareto Chart, Brainstorming
	Improve	Control Chart
	Control	Control Chart, Flow Chart, Control Plan

(table continues)

Tools & Techniques for Cluster Cases		
Cluster 12	*Define*	Voice of Customer (VOC), Critical to Quality (CTQ), Survey
	Measure	Process Mapping
	Analyze	Value-added analysis, Brainstorming, Cause-and-Effect Diagram
Cluster 13	*Define*	Process mapping
	Measure	Survey
	Analyze	Cause-and-Effect Diagram
	Improve	Process Mapping, Poka-yoke
Cluster 14	*Define*	Voice of Customer (VOC), Project Charter
	Measure	Process map, Critical to Quality (CTQ), Sigma Calculation (DPMO), Gage R&R
	Analyze	Spaghetti Diagram, Pareto Chart, Cause-and-Effect Diagram, 5 Why Analysis, Survey, Hypothesis Testing
	Improve	Box Plot, Control Chart
	Control	Pilot Plan, Control Chart, Action plan, Auditing
Cluster 15	*Define*	SIPOC, Diagram, Critical to Quality (CTQ)
	Analyze	Brainstorming
	Improve	Frequency Table
Cluster 16	*Measure*	Hypothesis testing, Survey
	Analyze	Cause-and-effect Diagram
	Improve	Matrix Diagram

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

Cluster	Number of Cases	Dimensions
2	15	Reliability, Responsiveness
3	5	Reliability, Responsiveness, Assurance
4	2	Tangibles, Reliability, Responsiveness, Assurance
7	2	Tangibles, Reliability, Responsiveness
10	1	Reliability, Responsiveness, Assurance, Empathy
13	1	Reliability, Responsiveness, Empathy

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

Contradiction Matrix for Service					
	Tangibles	***Reliability***	***Responsiveness***	***Assurance***	***Empathy***
Tangibles	4, 5, 7, 12, 14, 15 (DMAIC LIST 14)	4, 5, 7, 12 (DMAIC LIST 1)	4, 7 (DMAIC LIST 2)	4, 5, 15 (DMAIC LIST 3)	14 (DMAIC LIST 13)
Reliability	4, 5, 7, 12 (DMAIC LIST 1)	1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 13 (DMAIC LIST 10)	2, 3, 4, 7, 10, 13 (DMAIC LIST 4)	3, 4, 5, 8 10 (DMAIC LIST 5)	6, 10, 13 (DMAIC LIST 6)
Responsiveness	4, 7 (DMAIC LIST 2)	2, 3, 4, 7, 10, 13 (DMAIC LIST 4)	2, 3, 4, 7, 10 11, 13 (DMAIC LIST 11)	3, 4, 10 (DMAIC LIST 7)	10, 13 (DMAIC LIST 8)
Assurance	4, 5, 15 (DMAIC LIST 3)	3, 4, 5, 8, 10 (DMAIC LIST 5)	3, 4, 10 (DMAIC LIST 7)	3, 4, 5, 8, 9, 10, 15, 16 (DMAIC LIST 12)	10, 16 (DMAIC LIST 9)
Empathy	14 (DMAIC LIST 13)	6, 10, 13 (DMAIC LIST 6)	10, 13 (DMAIC LIST 8)	10, 16 (DMAIC LIST 9)	6, 10, 13, 14, 16 (DMAIC LIST 15)

Table 46

Fifteen DMAIC Lists for the Contradiction Matrix of Service

DMAIC Lists for The Contradiction Matrix		
DMAIC LIST 1	*Define*	Voice of Customer (VOC), Critical to Quality (CTQ), Project Charter, Key Performance Indicators (KPIs), Survey, SIPOC Diagram, Process Mapping
	Measure	Value Stream Mapping (VSM), Survey, Process Mapping, Cause-and-Effect Diagram, Cause-and-Effect Matrix, Failure Mode Effect Analysis (FMEA), Process Capability Analysis, Critical to Quality (CTQ), Brainstorming, Sigma Calculation (DPMO)
	Analyze	Process Mapping, Simulation, Poka-yoke, Flowchart, Statistical Process Control (SPC), ANOVA Test, Value-added Analysis, Brainstorming, Cause-and-Effect Diagram, Pareto Diagram, Value Stream Mapping (VSM), Failure Mode Effect Analysis (FMEA)
	Improve	Cost-benefit Analysis, Control Chart, Failure Mode Effect Analysis (FMEA)
	Control	Survey, Control Plan, Control Chart, Value Stream Mapping (VSM)
DMAIC LIST 2	*Define*	Critical to Quality (CTQ), Project Charter, Key Performance Indicators (KPIs), Voice of Customer (VOC), SIPOC Diagram, Process Mapping
	Measure	Value Stream Mapping (VSM), Survey, Process Mapping, Cause-and-Effect Diagram, Cause-and-Effect Matrix, Failure Mode Effect Analysis (FMEA), Critical to Quality (CTQ), Brainstorming
	Analyze	Process Mapping, Simulation, Poka-yoke, Flowchart, Statistical Process Control (SPC), ANOVA Test, Value Stream Mapping (VSM)
	Improve	Cost-benefit Analysis, Control Chart
	Control	Survey, Control plan, Value Stream Mapping (VSM)
DMAIC LIST 3	*Define*	Critical to Quality (CTQ), Project Charter, Key Performance Indicators (KPIs), SIPOC Diagram, Voice of Customer (VOC)
	Measure	Value Stream Mapping (VSM), Survey, Process Capability Analysis, Sigma Calculation (DPMO), Cause-and-Effect Diagram
	Analyze	Process Mapping, Simulation, Poka-yoke, Flowchart, Statistical Process Control (SPC), Cause-and-Effect Diagram, Pareto Diagram, Brainstorming, Failure Mode Effect Analysis (FMEA)
	Improve	Cost-benefit Analysis, Control Chart, Failure Mode Effect Analysis (FMEA), Frequency Table
	Control	Survey, Control Chart

(table continues)

DMAIC Lists for The Contradiction Matrix		
DMAIC LIST 4	*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	Interview, Observation, Process Mapping, Standard Operating Procedure (SOP), Control Chart, Benchmark, Flowchart, Waste elimination, 5S, Housekeeping, Brainstorming, Cause-and-Effect diagram, Gage R&R, Sigma Calculation DPMO, Process Capability Analysis, Survey, Pareto Diagram, Histograms, Tally Check Sheet, Run Chart, Frequency Table, SIPOC Diagram, Kawakita Jiro (KJ) Method, Voting, VMEA, Force Field Analysis, Value Stream Mapping (VSM), Cause-and-Effect Matrix, Failure Mode Effect Analysis (FMEA), Critical to Quality (CTQ)
	Analyze	Histograms, Time series plot, Box Plot, Kawakita Jiro (KJ) Method, Cause-and-Effect Diagram, ANOM, Pareto Charts, Process Capability Analyses, Correlation Analysis, key Input Variables (KIVs), Pareto Chart, Cause-and-Effect Matrix, Brainstorming, Flowchart, Statistical Process Control (SPC), Kanban, Waste elimination, One Piece Flow, Cost–benefit Analysis, Chi-square Test, Failure Mode and Effect Analysis (FMEA), ANOVA Test, Simulation, Tree Diagram, Regression Analysis, 5 Whys Analysis, Error Modes and Effects Analysis (EMEA), Window Analysis, Mann-Whitney Test, Kruskal-Wallis Test, Hypothesis testing, Value Stream Mapping (VSM), Sampling, Process Mapping, Poka-yoke, Frequency Table
	Improve	Brainstorm, ANOVA Test, Poka-yoke, Prioritization Matrix, Cost-benefit Analysis, Pilot Plan, TRIZ, Value Stream Mapping, Process Capability Analysis, Survey, Simulation, Cause-and-effect Diagram, Flowchart, Hypothesis testing, Histogram, Chi-square Test, Control Chart, Process Mapping
	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)

DMAIC Lists for The Contradiction Matrix		
DMAIC LIST 5	*Define*	Project Charter, Gantt Chart, Y and y definitions, P-diagram, SIPOC Diagram, Process Mapping, Auditing, Cause-Effect Diagram, Voice of Customer (VOC), Critical to Quality (CTQ), Key Performance Indicators (KPIs), Focus Group
	Measure	Interview, Observation, Kawakita Jiro (KJ) Method, Cause-and-Effect Diagram, Voting, Pareto Chart, VMEA, Force Field Analysis, Survey, Process Map, Sigma Calculation (DPMO), SIPOC Diagram, Brainstorming, Process Capability Analysis, Control Chart, Gage R&R, Value Stream Mapping (VSM), Failure Mode and Effect Analysis (FMEA), Frequency Table
	Analyze	Kruskal-Wallis Test, Chi-square Test, Process Capability Analysis, Pareto Diagram, 5 Whys Analysis, Regression Analysis, Failure Mode and Effects Analysis (FMEA), Value Stream Mapping, Sampling, Cause-and-Effect Diagram, Hypothesis Testing, Brainstorm, Tree Analysis Diagram, Survey, Process Mapping, Simulation, Poka-yoke, Flowchart, Statistical Process Control (SPC), Frequency Table
	Improve	Process Capability Analysis, Hypothesis Testing, Histogram, Survey, Chi-square Test, Sigma calculation (DPMO), Cost-benefit Analysis, Control Chart, Failure Mode and Effect Analysis (FMEA), Process Mapping
	Control	Process capability Analysis, Flowchart, Control Chart, Failure Mode and Effect Analysis (FMEA), Balanced Scorecards, Survey, Run Chart
DMAIC LIST 6	*Define*	Project Charter, Process Mapping, Focus Group, SIPOC Diagram, Voice of Customer (VOC), Critical to Quality (CTQ)
	Measure	Survey, Frequency Table, Interview, Benchmarking, Kano Model
	Analyze	Scatter Diagram, Frequency Table, Basic Statistics, Cause-and-Effect Diagram, Pareto Chart, 5 Whys Analysis
	Improve	Process Mapping, Poka-yoke, Brainstorming, Affinity Diagram
	Control	Run Chart, Control Chart

(table continues)

DMAIC Lists for The Contradiction Matrix		
DMAIC LIST 7	*Define*	Project Charter, Gantt Chart, Y and y definitions, P-diagram, SIPOC Digram, Process Mapping, Auditing, Focus Group, Critical to Quality (CTQ), Key Performance Indicators (KPIs)
	Measure	Interview, Observation, Kawakita Jiro (KJ) Method, Cause-and-Effect Diagram, Voting, Pareto Chart, VMEA, Force Field Analysis, Survey, Process Mapping, Sigma Calculation (DPMO), SIPOC Diagram, Brainstorming, Process Capability Analysis, Control Chart, Gage R&R, Frequency Table, Value Stream Mapping (VSM)
	Analyze	Kruskal-Wallis testing, Chi-square Test, Process Capability Analysis, Pareto Chart, 5 Whys Analysis, Regression Analysis, Failure Mode and Effects Analysis (FMEA), Value Stream Mapping, Sampling, Cause-and-Effect Diagram, Hypothesis Testing, Brainstorm, Frequency Table, Process Mapping, Simulation, Poka-yoke, Flowchart, Statistical Process Control (SPC)
	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		
DMAIC LIST 10	*Define*	Project Charter, 5 Whys Analysis, Gantt Chart, SIPOC Diagram, Process mapping, Voice of Customer (VOC), Affinity Diagram, Brainstorm, Critical to Quality (CTQ), Cause-and-Effect Diagram, Key Performance Indicators (KPIs), Survey, Pareto Diagram, Benchmarking, Prioritization Matrix, Kano Analysis, Balanced Scorecard, Interview, Value Stream Mapping, P-diagram, Tollgate Checklist, key Output Variables (KOVs), Flowchart, Cause-and-Effect Matrix, The Seven Wastes (Muda), Y and y definitions, Auditing, Focus group
	Measure	Interview, Observation, Histograms, Flowchart, Brainstorm, Cause-and-Effect Diagram, Critical to Quality (CTQ), Key Output Variable (KPOV), Gage R&R, Pareto Chart, Radar Diagram, Auditing, Process Mapping, Cause-and-Effect Matrix, Process Capability Analysis, Sigma calculation (DPMO), Regression Analysis, Scatter Diagram, I-MR chart, Anderson-Darling Normality Test, Survey, Control Chart, Standard Operating Procedure (SOP), Benchmark, Waste elimination, 5S, Housekeeping, Tally Check Sheet, Run Chart, Frequency Table, SIPOC diagram, Kawakita Jiro (KJ) Method, Voting, VMEA, Force Field Analysis, Process Mapping, Value Stream Mapping (VSM), Failure Mode and Effects Analysis (FMEA), Kano Model
	Analyze	ANOVA Test, Cause-and-Effects Diagram, Pareto Charts, Sigma Calculation (DPMO), Multi-voting, Survey, Process Mapping, Flowchart, Basic Statistics, Brainstorm, Failure Mode and Effects Analysis (FMEA), Chi-square Test, Hypothesis testing, Voice of Customer (VOC), Affinity Diagram, Cause-and-Effect Matrix, Histogram, Probability Plot, Scatter plot, Pie chart, kanban, Paynter Chart, Why-Why Diagram, Regression Analysis, Gage R&R, Time Series plot, Box Plot, Kawakita Jiro (KJ) Method, ANOM, Process Capability Analyses, Correlation Analysis, key Input Variables (KIVs), Statistical Process Control (SPC), Waste elimination, One Piece Flow, Cost–benefit Analysis, Simulation, Tree diagram, 5 Whys Analysis, Error Modes and Effects Analysis (EMEA), Window Analysis, Mann-Whitney Test, Kruskal-Wallis Test, Value Stream Mapping (VSM), Sampling, Hypothesis Testing, Scatter Diagram, Frequency Tables, Basic Statistics, Poka-yoke
	Improve	Action plan, Control Chart, Matrix Diagram, Brainstorming, Poka-yoke, Process Capability Analysis, Cause-and-Effect Diagram, Cause-and-Effect Matrix, Pilot Plan, Prioritization Matrix Diagram, Cost-benefits Analysis, Analytic Hierarchy Process (AHP), Affinity Diagram, kaizen, 5S, Operator Balance Chart, Cell Design, Material Replenishment, Standard Work, QCPC/Turnbacks, Visual Management, Takt Time Analysis, Regression Analysis, Flowchart, Process Mapping, ANOVA Test, TRIZ, Value Stream Mapping, Survey, Simulation, Hypothesis Testing, Histogram, Chi-square Test, Sigma Calculation (DPMO), Failure Mode and Effect Analysis (FMEA)
	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), Binomial Test, Flowchart, Standardization, Risk Evaluation Matrix, Failure Mode and Effect Analysis (FMEA), Balanced Scorecards, Run Chart, Value Stream Mapping (VSM)

(table continues)

DMAIC Lists for The Contradiction Matrix		
DMAIC LIST 11	*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 (VSM), Cause-and-Effect Matrix, The Seven Wastes (Muda), Auditing, Y and y definition, Key Performance Indicators (KPIs), Focus Group
	Measure	Interview, Observation, Process Mapping, Standard Operating Procedure (SOP), Control Chart, Benchmark, Flowchart, Waste elimination, 5S, Housekeeping, Brainstorming, Cause-and-Effect diagram, Gage R&R, Sigma Calculation (DPMO), Process Capability Analysis, Survey, Pareto Diagram, Histogram, Tally Check Sheet, Run Chart, Frequency Table, SIPOC Diagram, Kawakita Jiro (KJ) Method, Voting, VMEA, Force Field Analysis, Value Stream Mapping (VSM), Cause-and-Effect Matrix, Failure Mode and Effect Analysis (FMEA), Dashboards, Critical to Quality (CTQ)
	Analyze	Histogram, Time Series Plot, Box Plot, Kawakita Jiro (KJ) Method, Cause-and-Effect Diagram, ANOM, Pareto Chart, Process Capability Analyses, Correlation Analysis, key Input Variables (KIVs), Pareto Chart, Cause-and-Effect Matrix, Brainstorming, Flowchart, Statistical Process Control (SPC), Kanban, Waste elimination, One Piece Flow, Cost–benefit Analysis, Chi-square Test, Failure Mode and Effect Analysis (FMEA), ANOVA test, Simulation, Tree Diagram, Regression Analysis, 5 Whys Analysis, Error Modes and Effects Analysis (EMEA), Window Analysis, Mann-Whitney Test, Kruskal-Wallis Test, Hypothesis testing, Value Stream Mapping, Sampling, Process Mapping, Poka-yoke, Frequency Table
	Improve	Brainstorm, ANOVA Test, Poka-yoke, Prioritization Matrix, Cost-benefit Analysis, Pilot Plan, TRIZ, Value Stream Mapping, Process Capability Analysis, Survey, Simulation, Cause-and-effect Diagram, Flowchart, Hypothesis testing, Histogram, Chi-square Test, Control Chart, Process Mapping
	Control	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)

(table continues)

DMAIC Lists for The Contradiction Matrix		
DMAIC LIST 12	*Define*	Project Charter, Gantt Chart, Y and y definitions, P-diagram, SIPOC Diagram, Process Mapping, Auditing, Cause-and-Effect Diagram, Voice of Customer (VOC), Critical to Quality (CTQ), Key Performance Indicators (KPIs), Focus Group, Interview
	Measure	Interviews, Observation, Kawakita Jiro (KJ) Method, Cause-and-Effect Diagram, Voting, Pareto Chart, VMEA, Force Field Analysis, Survey, Process Mapping, Sigma Calculation (DPMO), SIPOC Diagram, Brainstorming, Process Capability Analysis, Control Chart, Gage R&R, Value Stream Mapping (VSM), Failure Mode and Effect Analysis (FMEA), Frequency Table, Tree Diagram, Correlation Analysis, Flowchart, Hypothesis Testing
	Analyze	Kruskal-Wallis Test, Chi-square Test, Process Capability Analysis, Pareto Chart, 5 Whys Analysis, Regression Analysis, Failure Mode and Effects Analysis (FMEA), Value Stream Mapping (VSM), Sampling, Cause-and-Effect Diagram, Hypothesis Testing, Brainstorm, Tree Analysis Diagram, Survey, Process Mapping, Simulation, Poka-yoke, Flowchart, Statistical Process Control (SPC), Frequency Table, Multi-vari Chart, Relations Diagram, Histogram, 5S
	Improve	Process Capability Analysis, Hypothesis Testing, Histogram, Survey, Chi-square Test, Sigma Calculation (DPMO), Cost-benefit Analysis, Control Chart, Failure Mode and Effect Analysis (FMEA), Process Mapping, Brainstorming, Gant Chart, Pilot Plan, Frequency Table, Matrix Diagram
	Control	Process capability Analysis, Flow Chart, Control Chart, Failure Mode and Effect Analysis (FMEA), Balanced Scorecards, Survey, Run Chart, Control Plan, Checklist
DMAIC LIST 13	*Define*	Voice of Customer (VOC), Project Charter
	Measure	Process Mapping, Critical to Quality (CTQ), Sigma Calculation (DPMO), Gage R&R
	Analyze	Spaghetti Diagram, Pareto Chart, Cause-and-Effect Diagram, 5 Whys Analysis, Survey, Hypothesis Testing
	Improve	Box Plot, Control Chart
	Control	Pilot Plan, Control Chart, Action plan, Auditing

(table continues)

DMAIC Lists for The Contradiction Matrix		
DMAIC LIST 14	*Define*	Critical to Quality (CTQ), Project Charter, Key Performance Indicators (KPIs), Voice of Customer (VOC), Survey, SIPOC Diagram, Sigma Calculation (DPMO), Gage R&R, Process Mapping
	Measure	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)
	Analyze	Process Mapping, Simulation, Poka-yoke, Flowchart, Statistical Process Control (SPC), ANOVA Testing, Value-added Analysis, Brainstorming, Cause-and-Effect Diagram, Pareto Diagram, Spaghetti Diagram, 5 Whys Analysis, Survey, Hypothesis Testing, Value Stream Mapping (VSM), Failure Mode and Effect Analysis (FMEA)
	Improve	Cost-benefit Analysis, Control Chart, Failure Mode and Effect Analysis (FMEA), Box Plot, Frequency Table
	Control	Survey, Control Plan, Control Chart, Pilot Plan, Action Plan, Auditing, Value Stream Mapping (VSM)
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

Table 47

Number of Cases Used in each DMAIC List of Service

DMAIC LIST	Number of Cases
DMAIC LIST 1	7
DMAIC LIST 2	4
DMAIC LIST 3	5
DMAIC LIST 4	26
DMAIC LIST 5	13
DMAIC LIST 6	4
DMAIC LIST 7	8
DMAIC LIST 8	2
DMAIC LIST 9	2
DMAIC LIST 10	57
DMAIC LIST 11	28
DMAIC LIST 12	20
DMAIC LIST 13	2
DMAIC LIST 14	10
DMAIC LIST 15	7

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

Contradiction Matrix for Service					
	Tangibles	***Reliability***	***Responsiveness***	***Assurance***	***Empathy***
Tangibles	4, 5, 7, 12, 14, 15 (DMAIC LIST 14)	4, 5, 7, 12 (DMAIC LIST 1)	4, 7 (DMAIC LIST 2)	4, 5, 15 (DMAIC LIST 3)	14 (DMAIC LIST 13)
Reliability	4, 5, 7, 12 (DMAIC LIST 1)	1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 13 (DMAIC LIST 10)	2, 3, 4, 7, 10, 13 (DMAIC LIST 4)	3, 4, 5, 8 10 (DMAIC LIST 5)	6, 10, 13 (DMAIC LIST 6)
Responsiveness	4, 7 (DMAIC LIST 2)	2, 3, 4, 7, 10, 13 (DMAIC LIST 4)	2, 3, 4, 7, 10 11, 13 (DMAIC LIST 11)	3, 4, 10 (DMAIC LIST 7)	10, 13 (DMAIC LIST 8)
Assurance	4, 5, 15 (DMAIC LIST 3)	3, 4, 5, 8, 10 (DMAIC LIST 5)	3, 4, 10 (DMAIC LIST 7)	3, 4, 5, 8, 9, 10, 15, 16 (DMAIC LIST 12)	10, 16 (DMAIC LIST 9)
Empathy	14 (DMAIC LIST 13)	6, 10, 13 (DMAIC LIST 6)	10, 13 (DMAIC LIST 8)	10, 16 (DMAIC LIST 9)	6, 10, 13, 14, 16 (DMAIC LIST 15)

Table 49

Validation Cases for Service

Case Study	DMAIC Tools & Techniques		Validated DMAIC LIST
(Wang & Chen, 2010)	*Define*	SIPOC Diagram, Value Stream Mapping (VSM), Process Mapping	DMAIC LIST 4 & DMAIC LIST 11
	Measure	Process Capability Analysis, Control Chart	
	Analyze	Cause-and-Effect Matrix, Pareto Diagram, Failure Mode and Effect Analysis (FMEA)	
	Improve	TRIZ, Value Stream Mapping (VSM), Process Capability	
	Control	Control Plan, Control Chart	
(Bao, Chen, Shang, Fang, Xu, Guo, & Wang, 2013)	*Measure*	Process Capability Analysis, Frequency Table	DMAIC LIST 5
	Analyze	Brainstorming, Cause-and-Effect Diagram	
	Control	Survey	
(Rohini & Mallikarjun, 2011)	*Define*	Project Charter, Process Mapping	DMAIC LIST 10
	Measure	Sigma Calculation (DPMO)	
	Analyze	Cause-and-Effect Diagram, Brainstorm	
	Improve	Brainstorm	
	Control	Sigma Calculation (DPMO)	
(Ateekh-ur-Rehman, 2012)	*Measure*	Survey, Causes-and-Effect Diagram	DMAIC LIST 12
	Analyze	Cause-and-Effect Diagram	
	Control	Control Plan	

Table 50

Validated DMAIC Lists Based on The Number of Cases in Service

DMAIC LIST	Number of Cases	Validation
DMAIC LIST 10	57	*Validated*
DMAIC LIST 11	28	*Validated*
DMAIC LIST 4	26	*Validated*
DMAIC LIST 12	20	*Validated*
DMAIC LIST 5	13	*Validated*
DMAIC LIST 14	10	*None*
DMAIC LIST 7	8	*None*
DMAIC LIST 1	7	*None*
DMAIC LIST 15	7	*None*
DMAIC LIST 3	5	*None*
DMAIC LIST 2	4	*None*
DMAIC LIST 6	4	*None*
DMAIC LIST 8	2	*None*
DMAIC LIST 9	2	*None*
DMAIC LIST 13	2	*None*

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

Abbas, A. R., Ming-Hsien, L., Al-Tahat, M. D., & Fouad, R. H. (2011). Applying DMAIC procedure to improve performance of LGP printing progress companies. *Advances in Production Engineering & Management, 6*(1), 45-56. Retrieved from https://eis.hu.edu.jo/deanshipfiles/pub102022885.pdf

Aggogeri, F., & Mazzola, M. (2008). Combining six sigma with lean production to increase the performance level of a manufacturing system. *Proceedings of International Mechanical Engineering Congress and Exposition, 4*, 425-434. doi:10.1115/IMECE2008-67275

Ahmed, S., & Hassan, M. (2003). Survey and case investigations on application of quality management tools and techniques in SMIs. *International Journal of Quality & Reliability Management, 20*(7), 795-826. doi:10.1108/02656710310491221

Aksoy, B., & Orbak, Â. Y. (2009). Reducing the quantity of reworked parts in a robotic arc welding process. *Quality and Reliability Engineering International, 25*(4), 495-512. doi:10.1002/qre.985

Al-Bashir, A., & Al-Tawarah, A. (2012). Implementation of Six Sigma on corrective maintenance case study at the directorate of biomedical engineering in the Jordanian ministry of health. *Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management,* 2508- 2516. Retrieved from http://iieom.org/ieom2012/pdfs/586.pdf

Al-Mishari, S. T., & Suliman, S. (2008). Integrating Six-Sigma with other reliability improvement methods in equipment reliability and maintenance applications. *Journal of Quality in Maintenance Engineering, 14*(1), 59-70. doi:10.1108/13552510810861941

Al-Qatawneh, L., Abdallah, A., & Zalloum, S. (2013). Reducing stock-out incidents at a hospital using Six Sigma. *World Academy of Science, Engineering and Technology, 7*(5), 404-411. Retrieved from http://www.waset.org/publications /14055

Al-Refaie, A., Li, M. H., Jalham, I., Bata, N., & Al-Hmaideen, K. (2013). Improving performance of tableting process using DMAIC and grey relation analysis. *Proceedings of the International MultiConference of Engineers and Computer Scientists, 2*. Retrieved from http://www.iaeng.org/publication/IMECS2013 /IMECS2013_pp1088-1093.pdf

Allen, T. T., Tseng, S. H., Swanson, K., & McClay, M. A. (2009). Improving the hospital discharge process with Six Sigma methods. *Quality Engineering, 22*(1), 13-20. doi:10.1080/08982110903344812

Allison, M. (1996). *The problem buster's guide.* Hampshire, England: Gower Publishing, Ltd.

Alsaleh, N.A. (2007). Application of quality tools by the Saudi food industry. *The TQM Magazine, 19*(2), 150-161. doi:10.1108/09544780710729999

Altshuller, G., Shulyak, L., & Rodman, S. (1998). *40 principles: TRIZ keys to technical innovation.* Worcester, MA: Technical Innovation Center.

Altuntas, S., & Yener, E. (2012). An approach based on TRIZ methodology and SERVQUAL scale to improve the quality of health-care service: A case study. *Ege Academic Review, 12*(1), 97-106.

Andersen, B. (2007). *Business process improvement toolbox*. Milwaukee, WI: ASQ Quality Press.

Antony, J., Antony, F.J., Kumar, M. & Cho, B.R. (2007). Six Sigma in service organizations: Benefits, challenges and difficulties, common myths, empirical observations and success factors. *International Journal of Quality & Reliability Management, 24*(3), 294-311. doi:10.1108/02656710710730889

Antony, J., & Banuelas, R. (2002). Key ingredients for the effective implementation of Six Sigma program. *Measuring Business Excellence, 6*(4), 20-27. doi:10.1108/13683040210451679

Antony, J., Bhuller, A. S., Kumar, M., Mendibil, K., & Montgomery, D. C. (2012). Application of Six Sigma DMAIC methodology in a transactional environment. *International Journal of Quality & Reliability Management, 29*(1), 31-53. doi:10.1108/02656711211190864

Antony, J., Gijo, E. V., & Childe, S. J. (2012). Case study in Six Sigma methodology: Manufacturing quality improvement and guidance for managers. *Production Planning & Control, 23*(8), 624-640. doi:10.1080/09537287.2011.576404

Artharn, P., & Rojanarowan, N. (2013). Defective reduction on dent defects in flexible printed circuits manufacturing process. *IOSR Journal of Engineering (IOSRJEN), 3*(5), 23-28. Retrieved from http://www.iosrjen.org/Papers/vol3_issue5%20(part-2)/E03522328.pdf

Arthur, J. (2001). *Six Sigma simplified: Breakthrough improvement made easy*. Denver, CO: LifeStar.

Ateekh-ur-Rehman, L. U. R. (2012). Safety management in a manufacturing company: Six Sigma approach. *Engineering, 4*(7), 400-407. doi:10.4236/eng.2012.47053

Baddour, A. A., & Saleh, H. A. (2013). Use Six Sigma approach to improve healthcare workers safety. *International Journal of Pure & Applied Sciences & Technology, 18*(1), 54-68. Retrieved from http://www.ijopaasat.in/yahoo_site_admin/assets /docs/7_IJPAST-610-V18N1.283102216.pdf

Bakshi, Y., Singh, B. J., Singh, S. S., & Singla, R. (2012). Performance optimization of backup power system through Six Sigma: A case study. *International Journal of Applied Engineering Research, 7*(11). Retrieved from http://gimt.edu.in/ clientFiles/FILE_REPO/2012/NOV/23/1353646609614/94.pdf

Bamford, D.R., & Greatbanks, R.W. (2005). The use of quality management tools and techniques: A study of application in everyday situations. *International Journal of Quality & Reliability Management, 22*(4), 376-392. doi:10.1108/02656710510591219

Banuelas, R., Antony, J., & Brace, M. (2005). An application of Six Sigma to reduce waste. *Quality and Reliability Engineering International, 21*(6), 553-570. doi:10.1002/qre.669

Bao, L., Chen, N., Shang, T., Fang, P., Xu, Z., Guo, W., & Wang, Y. (2013). A multicenter study of the application of Six Sigma management in clinical rational drug use via pharmacist intervention. *Turkish Journal of Medical Sciences, 43*(3), 362-367. doi:10.3906/sag-1205-38

Barnes, D. (2008). *Operations management: An international perspective*. London, England: Thomson Learning.

Barone, S., & Franco, E. L. (2012). *Statistical and managerial techniques for Six Sigma methodology: Theory and application.* West Sussex, UK: John Wiley & Sons.

Basu, R. (2004). *Implementing quality: A practical guide to tools and techniques*. London, England: Thomson Learning.

Basu, R. (2009). *Implementing Six Sigma and lean: A practical guide to tools and techniques*. New York, NY: Butterworth-Heinemann.

Basu, R., & Wright, J.N.N. (Eds.). (2012). *Quality beyond Six Sigma*. New York, NY: Routledge.

Bayazit, O. (2003). Total quality management (TQM) practices in Turkish manufacturing organizations. *The TQM Magazine, 15*(5), 345-350. doi:10.1108/09544780310502435

Bejan, A., & Moran, M. J. (1996). *Thermal design and optimization*. Hoboken, NJ: John Wiley & Sons.

Belokar, R. M., & Singh, J. (2013). Strategic enhancement of quality through 6σ: A case study. *International Journal of Engineering Trends and Technology (IJETT), 4*(6), 2468- 2472.

Besterfield, D.H. (2009). *Quality control*. Upper Saddle River, NJ: Pearson Education.

Bharti, P. K., Khan, M. I., & Singh, H. (2011). Six Sigma approach for quality management in plastic injection molding process: A case study and review. *International Journal of Applied Engineering Research, 6*(3), 303-314.

Bialek, R.G., Duffy, G.L., & Moran, J.W. (2009). *The public health quality improvement handbook*. Milwaukee, WI: ASQ Quality Press.

Bilgen, B., & Şen, M. (2012). Project selection through fuzzy analytic hierarchy process and a case study on Six Sigma implementation in an automotive industry. *Production Planning & Control, 23*(1), 2-25. doi:10.1080/09537287.2010.537286

Blattberg, R., Kim, B. & Neslin, S. (2008). *Database marketing: Analyzing and managing customers.* New York, NY: Springer.

Bose, T. (2010). *Total quality of management*. New York, NY: Pearson Education.

Brady, J.E., & Allen, T.T. (2006). Six Sigma literature: A review and agenda for future research. *Quality and Reliability Engineering International, 22*(3), 335-367. doi:10.1002/qre.769

Brase, C.H., & Brase, C.P. (2011). *Understanding basic statistics* (6th ed.). Boston, MA: Cengage Learning.

Briggs, A.R., Morrison, M., & Coleman, M. (2012). *Research methods in educational leadership and management*. Thousand Oaks, CA: Sage Publications.

Bryman, A., & Bell, E. (2007). *Business research methods*. New York, NY: Oxford University Press.

Burcher, P., Lee, G.L., & Waddell, D. (2006). The roles, responsibilities, and development needs of quality managers in Britain and Australia. *POMS 2006 17th Annual Conference*. Boston, MA: POMS.

Burton, T.T. (2011). *Accelerating lean Six Sigma results: How to achieve improvement excellence in the new economy.* Fort Lauderdale, FL: J. Ross Publishing.

Cameron, G. (2010). *Trizics: Teach yourself TRIZ, how to invent, innovate and solve "impossible" technical problems systematically*. Lexington, KY: CreateSpace.

Cano, E.L., Moguerza, J.M., & Redchuk, A. (2012). *Six Sigma with R: Statistical engineering for process improvement.* New York, NY: Springer.

Carmona, M., & Sieh, L. (2004). *Measuring quality in planning: Managing the performance process*. New York, NY: Routledge.

Cash, B. (2013, February). Getting it all. *Six Sigma Forum Magazine,12*(2), 9-14.

Chang, P. L., Yu, W. D., Cheng, S. T., & Lee, S. M. (2010). Exploring underlying patterns of emergent problem-solving in construction with TRIZ. *27th International Symposium on Automation and Robotics in Construction.* Bratislava, Slovakia: IAARC.

Charantimath, P.M. (2003). *Total quality management*. Boston, MA: Pearson Education.

Charantimath, P.M. (2011). *Total quality management* (2nd ed.). Boston, MA: Pearson Education.

Chen, K. S., Shyu, C. S., & Kuo, M. T. (2010). An application of Six Sigma methodology to reduce shoplifting in bookstores. *Quality & Quantity, 44*(6), 1093-1103. doi:10.1007/s11135-009-9260-9

Chen, M., & Lyu, J. (2009). A lean Six-Sigma approach to touch panel quality improvement. *Production Planning and Control, 20*(5), 445-454. doi:10.1080/09537280902946343

Cheng, C. Y., & Chang, P. Y. (2012). Implementation of the lean Six Sigma framework in non-profit organisations: A case study. *Total Quality Management & Business Excellence, 23*(3-4), 431-447. doi:10.1080/14783363.2012.663880

Cheng, K. M. (2013). On applying Six Sigma to improving the relationship quality of fitness and health clubs. *Journal of Service Science, 6(*1), 127- 138.

Chiarini, A. (2012). Risk management and cost reduction of cancer drugs using lean Six Sigma tools. *Leadership in Health Services, 25*(4), 318-330. doi:10.1108/17511871211268982

Childs, P. (2013). *Mechanical design engineering handbook*. Waltham, MA: Butterworth-Heinemann.

Chinbat, U., & Takakuwa, S. (2008). Using operation process simulation for a Six Sigma project of mining and iron production factory. *Proceedings of the 2008 Winter Simulation Conference.* Miami, FL: WSC. doi:10.1109/WSC.2008.4736351

Chowdhury, B., Deb, S. K., & Das, P. C. (2014). Managing and analyzing manufacturing defects: A case of refrigerator liner manufacturing. *International Journal of Current Engineering and Technology*, 54-61. doi:http://dx.doi.org/10.14741/ijcet/spl.2.2014.11

Christensen, E.H., Coombes-Betz, K.M., & Stein, M.S. (2007). *The certified quality process analyst handbook.* Milwaukee, WI: ASQ Quality Press.

Christyanti, J. (2012). Improving the quality of asbestos roofing at PT BBI using Six Sigma methodology. *Procedia-Social and Behavioral Sciences, 65*, 306-312. doi:10.1016/j.sbspro.2012.11.127

Chung, Y. C., Yen, T. M., Hsu, Y. W., Tsai, C. H., & Chen, C. P. (2008). Research on using Six Sigma tool to reduce the core process time. *Asian Journal on Quality, 9*(1), 94-102. doi:10.1108/15982688200800006

Clegg, B., Rees, C., & Titchen, M. (2010). A study into the effectiveness of quality management training: A focus on tools and critical success factors. *The TQM Journal, 22*(2), 188-208. doi:10.1108/17542731011024291

Cloete, B. C., & Bester, A. (2012). A lean Six Sigma approach to the improvement of the selenium analysis method. *Onderstepoort Journal of Veterinary Research, 79*(1), 1-13. doi:10.4102/http://www.ojvr.org ojvr.v79i1.407

Crosby, P. (1984). *Quality without tears: The art of hassle free management*. New York, NY: McGraw-Hill.

Dahlgaard, J.J., Khanji, G.K., & Kristensen, K. (2007). *Fundamentals of total quality management.* London, England: Routledge.

Dale, B. (2003). *Managing quality* (4th ed.). Oxford, UK: Blackwell Publishers.

Dale, B.G., & McQuater, R.E. (1998). *Managing business improvement and quality: Implementing key tools and techniques*. Oxford, UK: Blackwell Publishers.

Dambhare, S., Aphale, S., Kakade, K., Thote, T., & Borade, A. (2013). Productivity improvement of a special purpose machine using DMAIC principles: A case study. *Journal of Quality and Reliability Engineering, 2013*. doi:10.1155/2013/752164

Dambhare, S., Aphale, S., Kakade, K., Thote, T., & Jawalkar, U. (2013). Reduction in rework of an engine step bore depth variation using DMAIC and Six Sigma approach: A case study of engine manufacturing industry. *International Journal of Advanced Scientific and Technical Research, 3*(2), 252- 263. Retrieved from http://rspublication.com/ijst/april13/24.pdf

Das, P., & Gupta, A. (2012, August). Molding a solution. *Six Sigma Forum Magazine 11*(4), 27-31.

Das, S. K., & Hughes, M. (2006). Improving aluminum can recycling rates: A Six Sigma study in Kentucky. *JOM, 58*(8), 27-31. doi:10.1007/s11837-006-0049-1

Desai, D. A. (2006). Improving customer delivery commitments the Six Sigma way: Case study of an Indian small scale industry. *International Journal of Six Sigma and Competitive Advantage, 2*(1), 23-47. doi:10.1504/IJSSCA.2006.009368

Desai, T. N., & Shrivastava, R. L. (2008). Six Sigma: A new direction to quality and productivity management. *Proceedings of the World Congress on Engineering and Computer Science.* San Francisco, CA.

Dietmüller, T., & Spitler, B. (2009, November). A plan for the master plan. *Six Sigma Forum Magazine, 9*(1), 8-13.

Ditahardiyani, P., Ratnayani, R., & Angwar, M. (2009). The quality improvement of primer packaging process using Six Sigma methodology. *Jurnal Teknik Industri, 10*(2), 177-184. Retrieved from http://cpanel.petra.ac.id/ejournal/index.php/ind/article/viewFile/16985/16968

Domb, E. (2003). TRIZ for non-technical problem solving. *Keynote Address at the 3d European TRIZ Congress*. Zurich, Switzerland. Retrieved from http://www.triz-journal.com/archives/2003/04/a/01.pdf

Dourson, S. (2004). The 40 inventive principles of TRIZ applied to finance. *The TRIZ Journal*, *1*, 1-23.

Drenckpohl, D., Bowers, L., & Cooper, H. (2007). Use of the Six Sigma methodology to reduce incidence of breast milk administration errors in the NICU. *Neonatal Network: The Journal of Neonatal Nursing, 26*(3), 161-166. doi:10.1891/0730-0832.26.3.161

Drew, E., & Healy, C. (2006). Quality management approaches in Irish organizations. *The TQM Magazine, 18*(4), 358-371. doi:10.1108/09544780610671039

Drozda, T., & Wick, C. (1998). *Tool and manufacturing engineers' handbook: Material and part handling in manufacturing*. Dearborn, MI: Society of Manufacturing Engineers (SME).

Duffy, G. (2013). *The ASQ quality improvement pocket guide: Basic history, concepts, tools and relationships*. Milwaukee, WI: ASQ Quality Press.

Dwivedi, V., Anas, M., & Siraj, M. (2014). Six Sigma: As applied in quality improvement for injection moulding process. *International Review of Applied Engineering Research, 4*(4), 317-324. Retrieved from http://www.ripublication.com/iraer-spl/iraerv4n4spl_04.pdf

Elberfeld, A., Goodman, K., & Mark Van Kooy, M. D. (2004). Using the Six Sigma approach to meet quality standards for cardiac medication administration. *JCOM, 11*(8), 510-516. Retrieved from http://www.turner-white.com/pdf/jcom_aug04_sigma.pdf

Eldridge, N. E., Woods, S. S., Bonello, R. S., Clutter, K., Ellingson, L., Harris, M. A., ... & Wright, S. M. (2006). Using the Six Sigma process to implement the centers for disease control and prevention guideline for hand hygiene in 4 intensive care units. *Journal of General Internal Medicine, 21*(2), 35-42. doi:10.1111/j.15251497.2006.00361.x

Enache, I. C., Simion, I., Chiscop, F., & Adrian, M. (2014). Injection process improvement using Six Sigma. *U.P.B. Sci. Bull, 76(*1), 161-170. Retrieved from http://www.scientificbulletin.upb.ro/rev_docs_arhiva/rez4ed_676222.pdf

Evans, J. (2011). *Quality and performance excellence: Management, organization, and strategy* (6th ed.). Mason, OH: Cengage Learning.

Evans, J., & Lindsay, W. (2012). *Managing for quality and performance excellence* (9th ed.). Mason, OH: Cengage Learning.

Everitt, B.S., Landau, S., Leese, M., & Stahl, D. (2011). *Cluster analysis* (5th ed.). Chichester, UK: John Wiley & Sons.

Falcón, R. G., Alonso, D. V., Fernández, L. M., & Pérez-Lombard, L. (2012). Improving energy efficiency in a naphtha reforming plant using Six Sigma methodology. *Fuel Processing Technology, 103,* 110-116. doi:10.1016/j.fuproc.2011.07.010

Farahmand, K., Marquez Grajales, J. V., & Hamidi, M. (2010). Application of Six Sigma to gear box manufacturing. *International Journal of Modern Engineering, 11*(1), 12-19. Retrieved from http://archive.ijme.us/issues/ fall2010/ IJME_Vol11_N1_Fall2010%20(PDW%20final3).pdf#page=14

Feinberg, F.M., Kinnear, T.C., & Taylor, J.R. (2012). *Modern marketing research: Concepts, methods, and cases* (2nd ed.). Boston, MA: Cengage Learning.

Feng, Q., & Antony, J. (2009). Integrating DEA into Six Sigma methodology for measuring health service efficiency. *Journal of the Operational Research Society, 61*(7), 1112-1121. doi:10.1057/jors.2009.61

Ficalora, J.P., & Cohen, L. (2009). *Quality function deployment and Six Sigma: A QFD handbook.* Boston, MA: Pearson Education.

Field, S.W., & Swift, K.G. (2012). *Effecting a quality change*. New York, NY: Routledge.

Fotopoulos, C., & Psomas, E. (2009). The use of quality management tools and techniques in ISO 9001: 2000 certified companies: The Greek case. *International Journal of Productivity and Performance Management, 58*(6), 564-580. doi:10.1108/17410400910977091

Franchetti, M., & Bedal, K. (2009, August). Perfect match. *Six Sigma Forum Magazine, 8*(4), 10-17.

Frigon, N.L. (1997). *Practical guide to experimental design*. Hoboken, NJ: John Wiley & Sons.

Furterer, S. L. (2011). Applying lean Six Sigma to reduce linen loss in an acute care hospital. *International Journal of Engineering, Science and Technology, 3*(7), 39-55. doi:http://dx.doi.org/10.4314/ijest.v3i7.4S

Furterer, S., & Elshennawy, A. K. (2005). Implementation of TQM and lean Six Sigma tools in local government: A framework and a case study. *Total Quality Management & Business Excellence, 16*(10), 1179-1191. doi:10.1080/14783360500236379

Gadd, K. (2011). *TRIZ for engineers: Enabling inventive problem solving*. Chichester, UK: John Wiley & Sons.

Gardner, D.L. (2004). *The supply chain vector: Methods for linking the execution of global business models with financial performance*. Fort Lauderdale, FL: J. Ross Publishing.

Garvin, D. (1988). *Managing quality: The strategic and competitive edge*. New York, NY: The Free Press.

Ghosh, S., & Maiti, J. (2012). Data mining driven DMAIC framework for improving foundry quality: A case study. *Production Planning & Control*, 1-16. doi:10.1080/09537287.2012.709642

Gijo, E. V., Scaria, J., & Antony, J. (2011). Application of Six Sigma methodology to reduce defects of a grinding process. *Quality and Reliability Engineering International, 27*(8), 1221-1234. doi:10.1002/qre.1212

Gnanaraj, S. M., Devadasan, S. R., Murugesh, R., & Sreenivasa, C. G. (2012). Sensitisation of SMEs towards the implementation of lean Six Sigma: An initialisation in a cylinder frames manufacturing Indian SME. *Production Planning & Control, 23*(8), 599-608. doi:10.1080/09537287.2011.572091

Goodman, K. J., Kasper, S. A., & Leek, K. (2007, November). When project termination is the beginning. *Six Sigma Forum Magazine, 7*(1), 20-26.

Gopalakrishnan, N. (2012). *Simplified Six Sigma: Methodology, tools, and implementation.* New Delhi, India: PHI Learning.

Goriwondo, W. M., & Maunga, N. (2012). Lean Six Sigma application for sustainable production: A case study for margarine production in Zimbabwe. *International Journal of Innovative Technology and Exploring Engineering (IJITEE), 1*(5), 87-96. Retrieved from http://www.ijitee.org/attachments/File/v1i5/E0302091512.pdf

Govaert, G. (2010). *Data analysis*. Hoboken, NJ: John Wiley & Sons.

Hagemeyer, C., Gershenson, J.K., & Johnson, D.M. (2006). Classification and application of problem solving quality tools: A manufacturing case study. *The TQM Magazine, 18*(5), 455-483. doi:10.1108/09544780610685458

Hagg, H. W., El-Harit, J., Vanni, C., & Scott, P. (2007). "All bundled out"-application of lean Six Sigma techniques to reduce workload impact during implementation of patient care bundles within critical care: A case study. *Proceedings of the Spring 2007 American Society for Engineering Education Illinois-Indiana Section Conference*. Indianapolis, IN.

Hahn, R., Piller, J., & Lessner, P. (2006). Improved SMT performance of tantalum conductive polymer capacitors with very low ESR. *Carts Conference.* Arlington, VA.

Hambleton, L. (2007). *Treasure chest of Six Sigma growth methods, tools, and best practices.* Upper Saddle River, NJ: Prentice Hall.

Harry, M., Mann, P.S., De Hodgins, O.C., Hulbert, R.L., & Lacke, C.J. (2010). *The practitioner's guide to statistics and lean Six Sigma for process improvements.* Hoboken, NJ: John Wiley & Sons.

Hayajneh, M., Bataineh, O., & Al-tawil, R. (2013). Applying Six Sigma methodology based on "DMAIC" tools to reduce production defects in textile manufacturing. *Proceedings of the 1st International Conference on Industrial and Manufacturing Technologies (INMAT '13*). Vouliagmeni, Athens, Greece.

Hennessy, R. (2005). Quality management: More pay, more challenges. *Quality Magazine*. Retrieved from http://www.qualitymag.com/articles/84610-quality-management-more-pay-more-challenges

Heuvel, J., Does, R. J., & Vermaat, M. B. (2004). Six Sigma in a Dutch hospital: Does it work in the nursing department?. *Quality and Reliability Engineering International, 20*(5), 419-426. doi:10.1002/qre.656

Hopper, D., Aaron, K., Dale, H., & Domb, E. (1998). TRIZ in school district administration. *The TRIZ Journal*, *3*.

Hung, H. C., Wu, T. C., & Sung, M. H. (2011). Application of Six Sigma in the TFT-LCD Industry: A case study. *International Journal of Organizational Innovation, 4*(1), 74-127. Retrieved from http://www.ijoi-online.org/attachments/article/27/VOL_4_NUM_1_SUMMER%20_2011.pdf#page=74

Hyland, P.W., Milia, L., & Sun, H. (2005). CI tools and techniques: Are there any differences between firms? In *7th International Research Conference on Quality, Innovation, and Knowledge Management*. Kuala Lumpur, Malaysia.

Imler, K. (2006). *Get it right: A guide to strategic quality systems*. Milwaukee, WI: ASQ Quality Press.

Jafari, S. & Setak, M. (2010). Total quality management tools and techniques: The quest for an implementation roadmap. In *AGBA 7th World Congress*. Putrajaya, Malaysia.

Jayaswal, B., & Patton, P. (2007). *Design for trustworthy software: Tools, techniques, and methodology of developing robust software*. Upper Saddle River, NJ: Pearson.

Jie, J. C. R., Kamaruddin, S., & Azid, I. A. (2014). Implementing the lean Six Sigma framework in a small medium enterprise (SME): A case study in a printing company. *Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management*. Bali, Indonesia.

Jin, T., Janamanchi, B., & Feng, Q. (2011). Reliability deployment in distributed manufacturing chains via closed-loop Six Sigma methodology. *International Journal of Production Economics, 130*(1), 96-103. doi:10.1016/j.ijpe.2010.11.020

Jirasukprasert, P., Garza-Reyes, J. A., Soriano-Meier, H., & Rocha-Lona, L. (2012) A case study of defects reduction in a rubber gloves manufacturing process by applying Six Sigma principles and DMAIC problem solving methodology. *Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management.* Istanbul, Turkey.

Jugulum, R., & Samuel, P. (2008). *Design for lean Six Sigma: A holistic approach to design and innovation*. Hoboken, NJ: John Wiley & Sons.

Junankar, A. A., Gupta, P. M., Sayed, A. R., & Bhende, N. V. (2014). Six Sigma technique for quality improvement in valve industry. *IJREAT International Journal of Research in Engineering & Advanced Technology, 2*(1). Retrieved from http://www.ijreat.org/Papers%202014/Issue7/IJREATV2I1012.pdf

Juran, J.M. (1989). *Juran on leadership for quality: An executive handbook*. New York, NY: Free Press.

Kanakana, M. G., Pretorius, J. H., & van Wyk, B. J. (2012). Applying lean Six Sigma in engineering education at Tshwane University of Technology. *Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management.* Istanbul, Turkey.

Kanji, G.K., & Asher, M. (1996). *100 methods for total quality management*. Thousand Oaks, CA: Sage Publications.

Kapadia, M. M., Hemanth, S., & Sharda, B. (2003). Six Sigma: The critical link between process improvements and business results. *American Society for Quality*. Retrieved from http://mail.asq.org/sixsigma/six-sigma-the-critical-link-between-process-improvements-and-business-results.pdf

Kapoor, A., Bhaskar, R., & Vo, A. (2012). Pioneering the health care quality improvement in India using Six Sigma: A case study of a northern India hospital. *Journal of Cases on Information Technology (JCIT), 14(*4), 41-55. doi:10.4018/jcit.2012100104

Kaushik, C., Shokeen, A., Kaushik, P., & Khanduja, D. (2007). Six Sigma application for library services. *DESIDOC Journal of Library & Information Technology, 27*(5), 35-39.

Kaushik, P., & Khanduja, D. (2009). Application of Six Sigma DMAIC methodology in thermal power plants: A case study. *Total Quality Management, 20*(2), 197-207. doi:10.1080/14783360802622995

Kaushik, P., Khanduja, D., Mittal, K., & Jaglan, P. (2012). A case study: Application of Six Sigma methodology in a small and medium-sized manufacturing enterprise. *The TQM Journal, 24*(1), 4-16. doi:10.1108/17542731211191186

Kim, J., & Park, Y. (2008). Systematic clustering of business problems. *The TRIZ Journal.* Retrieved from http://www.triz-journal.com/archives/2008/12/03/

Kim, Y., Kim, E. J., & Chung, M. G. (2010). A Six Sigma-based method to renovate information services: Focusing on information acquisition process. *Library Hi Tech, 28*(4), 632-647. doi 10.1108/07378831011096286

Knowles, G., Johnson, M., & Warwood, S. (2004). Medicated sweet variability: A Six Sigma application at a UK food manufacturer. *The TQM Magazine, 16*(4), 284-292. doi:10.1108/09544780410541936

Kubiak, T.M. (2012). *The certified Six Sigma master black belt handbook.* Milwaukee, WI: ASQ Quality Press.

Kukreja, A., Ricks, J. M., & Meyer, J. A. (2009). Using Six Sigma for performance improvement in business curriculum: A case study. *Performance Improvement, 48*(2), 9-25. doi:10.1002/pfi.20042

Kumar, G., Jawalkar, C. S., & Vaishya, R. O. (2014). Six Sigma-an innovative approach for improving Sigma level: A case study of a brick company. *International Journal of Engineering and Innovative Technology (IJEIT), 3*(8), 187-195. Retrieved from http://ijeit.com/Vol%203/Issue%208/IJEIT1412201402_34.pdf

Kumar, M., Antony, J., Antony, F. J., & Madu, C. N. (2007). Winning customer loyalty in an automotive company through Six Sigma: A case study. *Quality and Reliability Engineering International, 23*(7), 849-866. doi:10.1002/qre.840

Kumar, M., Antony, J., Singh, R. K., Tiwari, M. K., & Perry, D. (2006). Implementing the lean Sigma framework in an Indian SME: A case study. *Production Planning and Control, 17*(4), 407-423. doi:10.1080/09537280500483350

Kumar, S., Choe, D., & Venkataramani, S. (2012). Achieving customer service excellence using lean pull replenishment. *International Journal of Productivity and Performance Management, 62*(1), 5-5. doi:10.1108/17410401311285318

Kumar, S., Jensen, H., & Menge, H. (2008). Analyzing mitigation of container security risks using Six Sigma DMAIC approach in supply chain design. *Transportation Journal, 47*(2), 54-66.

Kumar, S., Phillips, A., & Rupp, J. (2009). Using Six Sigma DMAIC to design a high-quality summer lodge operation. *Journal of Retail & Leisure Property, 8*(3), 173-191. doi:10.1057/rlp.2009.8

Kumar, S., Satsangi, P. S., & Prajapati, D. R. (2011). Six Sigma an excellent tool for process improvement: A case study. *International Journal of Scientific & Engineering Research, 2*(9), 1-10. Retrieved from http://www.ijser.org/researchpaper/Six-Sigma-an-Excellent-Tool-for-Process-Improvement-A-Case-Study.pdf

Kumar, S., & Sosnoski, M. (2009). Using DMAIC Six Sigma to systematically improve shopfloor production quality and costs. *International journal of productivity and performance management, 58*(3), 254-273. doi:10.1108/17410400910938850

Kumar, S., Strandlund, E., & Thomas, D. (2008). Improved service system design using Six Sigma DMAIC for a major US consumer electronics and appliance retailer. *International Journal of Retail & Distribution Management, 36*(12), 970-994. doi:10.1108/09590550810919388

Kumar, S., Wolfe, A. D., & Wolfe, K. A. (2008). Using Six Sigma DMAIC to improve credit initiation process in a financial services operation. *International Journal of Productivity and Performance Management, 57*(8), 659-676. doi:10.1108/17410400810916071

Kumaravadivel, A., & Natarajan, U. (2011). Empirical study on employee job satisfaction upon implementing six sigma DMAIC methodology in Indian foundry: A case study. *International Journal of Engineering, Science and Technology, 3*(4), 164-184. Retrieved from http://www.ijest-ng.com/vol3_no4/ijest-ng-vol3-no4-pp164-184.pdf

Kumi, S., & Morrow, J. (2006). Improving self service the Six Sigma way at Newcastle university library. *Program: electronic library and information systems, 40*(2), 123-136. doi:10.1108/00330330610669253

Kwok, K.Y. & Tummala, V.M.R. (1998). A quality control and improvement system based on total control methodology (TCM). *International Journal of Quality & Reliability Management, 15*(1), 13-48. doi:10.1108/02656719810197288

Ladani, L. J., Das, D., Cartwright, J. L., & Yenkner, R. (2006). Implementation of Six Sigma quality system in Celestica with practical examples. *International Journal of Six Sigma and Competitive Advantage, 2*(1), 69-88. doi:10.1504/IJSSCA.2006.009370

Lagrosen, Y., & Lagrosen, S. (2005). The effects of quality management: A survey of Swedish quality professionals. *International Journal of Operations & Production Management, 25*(10), 940-952. doi:10.1108/01443570510619464

Lam, S.S. (1996). Applications of quality improvement tools in Hong Kong: An empirical analysis. *Total Quality Management, 7*(6), 675-680. doi:10.1080/09544129610559

Laureani, A., & Antony, J. (2010). Reducing employees' turnover in transactional services: A lean Six Sigma case study. *International Journal of Productivity and Performance Management, 59*(7), 688-700. doi:10.1108/17410401011075666

Laureani, A., Antony, J., & Douglas, A. (2010). Lean Six Sigma in a call centre: A case study. *International Journal of Productivity and Performance Management, 59*(8), 757-768. doi:10.1108/17410401011089454

Lee, K. L., & Wei, C. C. (2010). Reducing mold changing time by implementing lean Six Sigma. *Quality and Reliability Engineering International, 26*(4), 387-395. doi:10.1002/qre.1069

Lee, K. L., Wei, C. C., & Lee, H. H. (2009). Reducing exposed copper on annular rings in a PCB factory through implementation of a Six Sigma project. *Total Quality Management, 20*(8), 863-876. doi:10.1080/14783360903128322

Lee, N., & Lings, I. (2008). *Doing business research: A guide to theory and practice.* Thousand Oaks, CA: Sage Publications.

Leebov, E.D.W. (2003). *The health care manager's guide to continuous quality improvement*. Lincoln, NE: iUniverse.

Levesque, J., & Walker, H.F. (2008). The innovation process and quality tools. *Quality Control and Applied Statistics, 53*(3), 275.

Li, S. H., Wu, C. C., Yen, D. C., & Lee, M. C. (2011). Improving the efficiency of IT help-desk service by Six Sigma management methodology (DMAIC): A case study of C company. *Production Planning & Control, 22*(7), 612-627. doi:10.1080/09537287.2010.503321

Lighter, D., & Fair, D.C. (2004). *Quality management in health care: Principles and methods.* Sudbury, MA: Jones & Bartlett Publishers.

Lo, W. C., Tsai, K. M., & Hsieh, C. Y. (2009). Six Sigma approach to improve surface precision of optical lenses in the injection-molding process. *The International Journal of Advanced Manufacturing Technology, 41*(9-10), 885-896. doi:10.1007/s00170-008-1543-0

Lokkerbol, J., Molenaar, M. F., & Does, R. J. (2012). Quality quandaries: An efficient public sector. *Quality Engineering, 24*(3), 431-435. doi:10.1080/08982112.2012.680226

Lokkerbol, J., Schotman, M. A., & Does, R. J. (2012). Quality quandaries: Personal injuries: A case study. *Quality Engineering, 24*(1), 102-106. doi:10.1080/08982112.2011.625521

Longenecker, J.G., Moore, C.W., Petty, J.W., & Palich, L.E. (2008). *Small business management: Launching and growing entrepreneurial ventures* (14th ed.). Mason, OH: Thomson South-Western.

Mahadevan, B. (2010). *Operations management: Theory and practice*. Boston, MA: Pearson Education.

Mandahawi, N., Fouad, R. H., & Obeidat, S. (2012). An application of customized lean Six Sigma to enhance productivity at a paper manufacturing company. *Jordan Journal of Mechanical & Industrial Engineering, 6*(1), 103-109. Retrieved from https://eis.hu.edu.jo/Deanshipfiles/pub107024481.pdf#page=112

Mann, D. (2001). Systematic win-win problem solving in a business environment. *The TRIZ Journal*. Retrieved from http://www.triz-journal.com/archives /2002/05/f/

Marsh, J. (1998). *The continuous improvement toolkit: A practical resource for achieving organizational excellence*. London, UK: BT Batsford, Ltd.

Martinez, D., & Gitlow, H. S. (2011). Optimizing employee time in a purchasing department: A Six Sigma case study. *International Journal of Lean Six Sigma, 2*(2), 180-190. Doi:10.1108/20401461111135046

Martinez, E. A., Chavez-Valdez, R., Holt, N. F., Grogan, K. L., Khalifeh, K. W., Slater, T., ... & Lehmann, C. U. (2011). Successful implementation of a perioperative glycemic control protocol in cardiac surgery: Barrier analysis and intervention using lean Six Sigma. *Anesthesiology research and practice, 2011*. doi:10.1155/2011/565069

McAdam, R., Davies, J., Keogh, B., & Finnegan, A. (2009). Customer-orientated Six Sigma in call centre performance measurement. *International Journal of Quality & Reliability Management, 26*(6), 516-545. doi:10.1108/02656710910966110

Mears, M. (2009). *Leadership elements: A guide to building trust.* Bloomington, IN: iUniverse.

Miguel, P.A.C., Satolo, E., Andrietta, J. M., & Calarge, F.A. (2012). Benchmarking the use of tools and techniques in the Six Sigma programme based on a survey conducted in a developing country. *Benchmarking: An International Journal, 19*(6), 690-708. doi:10.1108/14635771211284279

Miski, A. (2014). Improving customers service at IKEA using Six Sigma methodology. *International Journal of Scientific & Engineering Research, 5*(1), 1712- 1720. Retrieved from http://www.ijser.org/researchpaper%5CImproving-Customers-Service-at-IKEA-Using-Six-Sigma-Methodology.pdf

Mitra, A. (2012). *Fundamentals of quality control and improvement*. Hoboken, NJ: John Wiley & Sons.

Mohanty, R.P. (2009). *Quality management practices*. New Delhi, India: Excel Books.

Morris, M.H., Pitt, L.F., & Honeycutt, E.D. (2001). *Business-to-business marketing: A strategic approach.* Thousand Oaks, CA: Sage Publications.

Morrow, R. (2012). *Utilizing the 3Ms of process improvement: A step-by-step guide to better outcomes leading to performance excellence*. Boca Raton, FL: CRC Press.

Mukhopadhyay, A. R., & Ray, S. (2006). Reduction of yarn packing defects using six sigma methods: A case study. *Quality Engineering, 18*(2), 189-206. doi:10.1080/08982110600567533

Murphy, S. A. (2009). Leveraging lean Six Sigma to culture, nurture, and sustain assessment and change in the academic library environment. *College & Research Libraries, 70*(3), 215-226. Retrieved from http://crl.acrl.org/content/70/3/215. full.pdf

Naagarazan, R. & Arivalagar, A. (2005). *Total quality management*. New Delhi, India: New Age International.

Nabhani, F., & Shokri, A. (2009). Reducing the delivery lead time in a food distribution SME through the implementation of Six Sigma methodology. *Journal of Manufacturing Technology Management, 20*(7), 957-974. doi:10.1108/17410380910984221

Nair, A. C. (2011). Assuring quality using 6 Sigma tools-DMAIC technique. *International Journal of Research in Commerce, IT and Management, 1*(4), 34-38.

Nanda, V. (2010, February). Preempting problems. *Six Sigma Forum Magazine, 9*(2), 9-18.

Ng, E., Tsung, F., So, R., & Li, T. S. (2005). Six Sigma approach to reducing fall hazards among cargo handlers working on top of cargo containers: A case study. *International Journal of Six Sigma and Competitive Advantage, 1*(2), 188-209. doi:10.1504/IJSSCA.2005.006424

Nicols, M. (2006). Quality tools in a service environment. *ASQ Six Sigma Forum Magazine, 6*(1). Retrieved from: http://www.nicholsqualityassociates.com/ files/MikeNicholsGuestEditorial.pdf

Novak, S. (2005). *The small manufacturer's toolkit: A guide to selecting the techniques and systems to help you win*. Boca Raton, FL: CRC Press.

Oakland, J.S. (2004). *Oakland on quality management*. New York, NY: Routledge.

Omachonu, V. & Ross, J. (2004). *Principles of total quality* (3rd ed.). Boca Raton, FL: CRC Press.

O'Neill, M., & Duvall, C. (2005). A Six Sigma quality approach to workplace evaluation. *Journal of Facilities Management, 3*(3), 240-253. doi:10.1108/14725960510808509

Orloff, M.A. (2012). *Modern TRIZ: A practical course with EASyTRIZ technology*. New York, NY: Springer.

Pan, Z., Ryu, H., & Baik, J. (2007). A case study: CRM adoption success factor analysis and Six Sigma DMAIC application. *Fifth International Conference on Software Engineering Research, Management and Applications.* Busan, South Korea. doi:10.1109/SERA.2007.6

Pandey, A. (2007). Strategically focused training in Six Sigma way: A case study. *Journal of European Industrial Training, 31*(2), 145-162. doi:10.1108/03090590710734363

Parasuraman, A., Berry, L. L., & Zeithaml, V. A. (1991). Refinement and reassessment of the SERVQUAL scale. *Journal of Retailing, 67*(4), 420-50.

Persse, J.R. (2008). *Process improvement essentials: CMMI, Six Sigma, and ISO 9001*. Sebastopol, CA: O'Reilly Media.

Pongracic, I. (2009). *Employees and entrepreneurship: Co-ordination and spontaneity in non-hierarchical business organizations*. Northampton, Massachusetts: Edward Elgar Publishing.

Pranckevicius, D., Diaz, D. M., & Gitlow, H. (2008). A lean Six Sigma case study: An application of the “5s” techniques. *Journal of advances in Management Research, 5*(1), 63-79. doi:10.1108/97279810880001268

Pranoto, S., & Nurcahyo, R. (2014). Implementation of integrated system Six Sigma and importance performance analysis for quality improvement of HSDPA telecommunication network and customer satisfaction. *Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management.* Bali, Indonesia.

Prasad, K. D., Subbaiah, K. V., & Padmavathi, G. (2012). Application of Six Sigma methodology in an engineering educational institution. *International Journal of Emerging Sciences, 2*(2), 210-221. Retrieved from http://ijes.info/2/2/42542204.pdf

Psomas, E.L., Fotopoulos, C.V., & Kafetzopoulos, D.P. (2011). Core process management practices, quality tools, and quality improvement in ISO 9001 certified manufacturing companies. *Business Process Management Journal, 17*(3), 437-460. doi:10.1108/14637151111136360

Putri, N.T., & Yusof, S.M. (2009). Critical success factors for implementing quality engineering tools and techniques in Malaysia's and Indonesia's automotive industries: An exploratory study. In S.I. Ao, O. Castillo, C. Douglas, D.D. Feng, & J. Lee (Eds.), *Proceedings of the International MultiConference of Engineers and Computer Scientists*, 18-20. Hong Kong, China: Newswood Publications.

Puvanasvaran, P., Ling, T. C., Zain, M. F. Y., & Al-Hayali, Z. A. (2012). A Study on the effect of different interconnection materials (wire and bond pad) on ball bond strength after temperature cycle stress. *International Conference on Design and Concurrent Engineering,* 223- 230. Melaka, Malaysia.

Pyzdek, T., & Keller, P.A. (2003). *Quality engineering handbook* (2nd ed.). Boca Raton, FL: CRC Press.

Rantanen, K., & Domb, E. (2008). *Simplified TRIZ : New problem solving applications for engineers and manufacturing professionals* (2nd ed.). Boca Raton, FL: Auerbach Publications.

Rastogi, M.K. (2010). *Production and operation management*. New Delhi, India: Laxmi Publications.

Ray, S., & Das, P. (2011). Improve machining process capability by using Six-Sigma. *International Journal for Quality Research, 5*(2), 901- 916. Retrieved from http://www.ijqr.net/journal/v5-n2/6a.pdf

Ray, S., Das, P., & Bhattachrya, B. K. (2011). Improve customer complaint resolution process using Six Sigma. *2nd International Conference on Industrial Engineering and Operations Management (IEOM 2011)*, 945-957. Kuala Lumpur, Malaysia.

Reddy, G. P., & Reddy, V. V. (2010). Process improvement using Six Sigma: A case study in small scale industry. *International Journal of Six Sigma and Competitive Advantage, 6*(1), 1-11. doi:10.1504/IJSSCA.2010.034853

Redzic, C., & Baik, J. (2006). Six sigma approach in software quality improvement. *Proceedings of the Fourth International Conference on Software Engineering Research, Management and Applications,* 396-406. Seattle, Washington.

Rencher, A. & Christensen, W. (2012). *Methods of multivariate analysis* (3rd ed.). Hoboken, NJ: John Wiley & Sons.

Retseptor, G. (2003). 40 inventive principles in quality management. *The TRIZ Journal, 3*. Retrieved from http://www.triz-journal.com/archives/2003/03/index.htm

Retseptor, G. (2005). 40 inventive principles in marketing, sales and advertising. *The TRIZ Journal*, 1-16.

Revuelto-Taboada, L., Canet-Giner, T., & Balbastre-Benavent, F. (2011). Quality tools and techniques, EFQM experience and strategy formation. Is there any relationship?: The particular case of Spanish service firms. *Innovar, 21*(42), 25-40.

Rivera, A., & Marovich, J. (2001). Use of Six Sigma to optimize cordis sales administration and order and revenue management process. *Proceeding of the 2001 Winter Simulation Conference,* 1252-1258. Arlington, VA.

Roberts, H. (1993). *Quality is personal: A foundation for total quality management*. New York, NY: Simon and Schuster.

Rodman, S. (2005). *Ballad of the stars: Stories of science fiction and TRIZ imagination*. Worcester, MA: Technical Innovation Center.

Rohini, R., & Mallikarjun, J. (2011). Six Sigma: Improving the quality of operation theatre. *Procedia-Social and Behavioral Sciences, 25*, 273-280. doi:10.1016/j.sbspro.2011.10.547

Rowland-Jones, R., Thomas, P.T., & Page-Thomas, K. (2008). Quality management tools & techniques: Profiling SME use & customer expectations. *The International Journal for Quality and Standards, 1*(1). Retrieved from http://www.bsieducation.org/Education/downloads/ijqs/paper6.pdf

Rumane, A.R. (2010). *Quality management in construction projects*. Boca Raton, FL: CRC Press.

Russell, J. P. (2013). *The ASQ auditing handbook* (4th ed). Milwaukee, WI: ASQ Quality Press.

Ruthaiputpong, P., & Rojanarowan, N. (2013). Improvement of track zero to increase read/write area in hard disk drive assembly process. *Uncertain Supply Chain Management, 1*(3), 165-176. doi:10.5267/j.uscm.2013.07.001

Sage, A.P., & Rouse, W.B. (2009). *Handbook of systems engineering and management*. Hoboken, NJ: John Wiley & Sons.

Sahoo, A. K., Tiwari, M. K., & Mileham, A. R. (2008). Six Sigma based approach to optimize radial forging operation variables. *Journal of Materials Processing Technology, 202*(1), 125-136. doi:10.1016/j.jmatprotec.2007.08.085

Sahran, S., Zeinalnezhad, M., & Mukhtar, M. (2010). Quality management in small and medium enterprises: Experiences from a developing country. *International Review of Business Research Papers, 6*(6), 164-173.

Sajeev, D. & M., V. (2013). Implementation of Six Sigma methodology in a blood bag manufacturing company. *International Journal of Innovative Research in Science, Engineering and Technology, 2*(1), 754-763. Retrieved from http://www.ijirset.com /upload/2013/special/energy/47_IMPLEMENTATION.pdf

Salzarulo, P. A., Krehbiel, T. C., Mahar, S., & Emerson, L. S. (2012). Six Sigma sales and marketing: Application to NCAA basketball. *American Journal of Business, 27*(2), 113-132. doi: 10.1108/19355181211274433

Sambhe, R. U. (2012). Six Sigma practice for quality improvement: A case study of Indian auto ancillary unit. *IOSR Journal of Mechanical and Civil Engineering, 4*(4), 26-42. Retrieved from http://www.iosrjournals.org/iosr-jmce/papers/vol4-issue4/E0442642.pdf

San, Y., Jin, Y., & Li, S. (2009). *TRIZ: Systematic innovation in manufacturing*. Petaling Jaya, Malaysia: Firstfruits Sdn. Bhd.

Saravanan, S., Mahadevan, M., Suratkar, P., & Gijo, E. V. (2012). Efficiency improvement on the multicrystalline silicon wafer through Six Sigma methodology. *International Journal of Sustainable Energy, 31*(3), 143-153. doi:10.1080/1478646X.2011.554981

Sekhar, H., & Mahanti, R. (2006). Confluence of Six Sigma, simulation and environmental quality: An application in foundry industries. *Management of Environmental Quality: An International Journal, 17*(2), 170-183. doi:10.1108/14777830610650483

Shahin, A., Arabzad, S.M., & Ghorbani, M. (2010). Proposing an integrated framework of seven basic and new quality management tools and techniques: A roadmap. *Research Journal of Internatıonal Studıes,* (17), 183-195.

Shankar, R. (2009). *Process improvement using Six Sigma: A DMAIC guide.* Milwaukee, WI: ASQ Quality Press.

Shrivastava, R. L., Ahmad, K. I., & Desai, T. N. (2008). Engine assembly process quality improvement using Six Sigma. *Proceedings of the World Congress on Engineering 3*, 2-4. London, UK.

Silich, S. J., Wetz, R. V., Riebling, N., Coleman, C., Khoueiry, G., Bagon, E., & Szerszen, A. (2012). Using Six Sigma methodology to reduce patient transfer times from floor to critical care beds. *Journal for Healthcare Quality, 34*(1), 44-54. doi:10.1111/j.1945-1474.2011.00184.x

Silverstein, D., DeCarlo, N., & Slocum, M. (2008). *Insourcing innovation: How to achieve competitive excellence using TRIZ.* Boca Raton, FL: Auerbach Publications.

Singh, B. J., & Bakshi, Y. (2012). Six Sigma for sustainable energy management: A case study. *SGI Reflections, 2*(2) 60-73. Retrieved from http://www.sgi.ac.in/colleges/newsletters/1146100720120618311.pdf#page=62

Snee, R.D. (2007). Use DMAIC to make improvement part of how we work. *Quality Progress*, September 2007, 52-54.

Soković, M., Pavletić, D., & Krulčić, E. (2006). Six Sigma process improvements in automotive parts production. *Journal of Achievements in Materials and Manufacturing Engineering, 19*(1), 96-102.

Soleimannejed, F. (2004). *Six Sigma, basic steps & implementation*. Bloomington, IN: AuthorHouse.

Soni, S., Mohan, R., Bajpai, L., & Katare, S. K. (2013). Reduction of welding defects using Six Sigma techniques. *International Journal of Mechanical Engineering and Robotics Research, 2*(3), 404-412. Retrieved from http://ijmerr.com/ijmerradmin/upload/ijmerr_51e808cb4e9af.pdf

Sousa, S.D., Aspinwall, E., Sampaio, P.A., & Rodrigues, A.G. (2005). Performance measures and quality tools in Portuguese small and medium enterprises: Survey results. *Total Quality Management and Business Excellence, 16*(2), 277-307.

Southard, P. B., Chandra, C., & Kumar, S. (2012). RFID in healthcare: A Six Sigma DMAIC and simulation case study. *International Journal of Health Care Quality Assurance, 25*(4), 291-321. doi:10.1108/09526861211221491

Sower, V.E. (2010). *Essentials of quality with cases and experiential exercises.* Hoboken, NJ: John Wiley & Sons.

Speegle, M. (2009). *Quality concepts for the process industry*. Clifton Park, NY: Delmar.

Stamatis, D.H. (1996). *Total quality service: Principles, practices, and implementation*. Boca Raton, FL: CRC Press.

Stamatis, D.H. (2002). *Six Sigma and beyond: Design for Six Sigma*. Boca Raton, FL: CRC Press.

Stamatis, D. H. (2004). *Six Sigma fundamentals: A complete guide to the system, methods and tools.* New York, NY: Productivity Press.

Stamatis, D. H. (2012). *Essential statistical concepts for the quality professional*. Boca Raton, FL: CRC Press.

Summers, D. (2010). *Quality* (5th ed.). Upper Saddle River, NJ: Prentice Hall.

Swanson, R.C. (1995). *The quality improvement handbook: Team guide to tools and techniques.* Boca Raton, FL: CRC Press.

Tague, N.R. (2005). *The quality toolbox* (2nd ed.). Milwaukee, WI: ASQ Quality Press.

Taner, M. T., & Sezen, B. (2009). An application of Six Sigma methodology to turnover intentions in health care. *International journal of health care quality assurance, 22*(3), 252-265. doi:10.1108/09526860910953520

Taner, M. T., Sezen, B., & Atwat, K. M. (2012). Application of Six Sigma methodology to a diagnostic imaging process. *International Journal of Health Care Quality Assurance, 25*(4), 274-290. doi:10.1108/09526861211221482

Tang, L. C., Goh, T. N., Yam, H. S., & Yoap, T. (2006). *Six Sigma: Advanced tools for black belts and master black belts.* West Sussex, UK: John Wiley & Sons.

Tarí, J.J. (2005). Components of successful total quality management. *The TQM magazine, 17*(2), 182-194. doi:10.1108/09544780510583245

Tarí, J.J., & Sabater, V. (2004). Quality tools and techniques: are they necessary for quality management? *International Journal of Production Economics, 92*(3), 267-280. doi:10.1016/j.ijpe.2003.10.018

Tennant, G. (2003). *Pocket TRIZ for Six Sigma: Systematic innovation and problem solving*. Bristol, England: Mulbury Consulting.

Terninko, J., Zusman, A., & Zlotin, B. (2001). 40 inventive principles with social examples. *The TRIZ Journal*. Retrieved from http://www.triz-journal.com /archives/2001/06/a/index.htm

Timans, W., Ahaus, K., & Van Solingen, R. (2009). A Delphi study on Six Sigma tools and techniques. *International Journal of Six Sigma and Competitive Advantage, 5*(3), 205-221.

Todman, J. & Dugard, P. (2007). *Approaching multivariate analysis: An introduction for psychology.* New York, NY: Psychology Press.

Tong, J. P. C., Tsung, F., & Yen, B. P. C. (2004). A DMAIC approach to printed circuit board quality improvement. *The International Journal of Advanced Manufacturing Technology, 23*(7-8), 523-531. doi:10.1007/s00170-003-1721-z

Tseng, M., & Piller, F. (2003). *The customer centric enterprise: Advances in mass customization and personalization*. New York, NY: Springer.

Valles, A., Sanchez, J., Noriega, S., & Nuñez, B. G. (2009). Implementation of Six Sigma in a manufacturing process: A case study. *International Journal of Industrial Engineering: Theory, Applications and Practice, 16*(3), 171-181. Retrieved from http://journals.sfu.ca/ijietap/index.php/ijie/article/viewFile /263/106

Vanzant-Stern, T. (2012). *Lean Six Sigma: International standards and global guidelines*. Palo Alto, CA: Fultus Corporation.

Vartanian, T. (2011). *Secondary data analysis: Pocket guides to social work research methods*. New York, NY: Oxford University Press.

Vasconcellos, J.A. (2003). *Quality assurance for the food industry: A practical approach*. Boca Raton, FL: CRC Press.

Vinodh, S., Kumar, S. V., & Vimal, K. E. K. (2014). Implementing lean sigma in an Indian rotary switches manufacturing organisation. *Production Planning & Control, 25*(4), 288-302. doi:10.1080/09537287.2012.684726

Voehl, F., Harrington, H., Mignosa, C., & Charron, R. (2013). *The lean Six Sigma black belt handbook: Tools and methods for process acceleration.* New York, NY: Productivity Press.

Walker, H.F., Elshennawy, A., Gupta, B., & McShane-Vaughn, M. (2012). *The certified quality inspector handbook.* Milwaukee, WI: ASQ Quality Press.

Wang, F. K., & Chen, K. S. (2010). Applying lean Six Sigma and TRIZ methodology in banking services. *Total Quality Management, 21*(3), 301-315. doi:10.1080/14783360903553248

Wei, C. C., Sheen, G. J., Tai, C. T., & Lee, K. L. (2010). Using Six Sigma to improve replenishment process in a direct selling company. *Supply Chain Management: An International Journal, 15*(1), 3-9. doi:10.1108/13598541011018076

Westcott, R. (2006). *The certified manager of quality/organizational excellence handbook* (3rd ed.). Milwaukee, WI: ASQ Quality Press.

Wilson, J. (2010). *Essentials of business research: A guide to doing your research project.* Thousand Oaks, CA: Sage Publications.

Yang, K. (2008). *Voice of the customer: Capture and analysis*. New York, NY: McGraw-Hill.

Yang, K., & El-Haik, B. (2003). *Design for Six Sigma: A roadmap for product development*. New York, NY: McGraw-Hill.

Yau, K.Y. (2000). *A multimedia system as an aid for selection of quality tools and techniques*. (Unpublished Master's thesis.). Department of Management, The Hong Kong Polytechnic University.

Yin, R.K. (2009). *Case study research: Design and methods* (4th ed.). Thousand Oaks, CA: Sage Publications.

Zaman, M., Pattanayak, S. K., & Paul, A. C. (2013). Study of feasibility of Six Sigma implementation in a manufacturing industry: A case study. *International Journal of Mechanical and Industrial Engineering (IJMIE), 3*(1), 96-100. Retrieved from http://www.interscience.in/IJMIE_Vol3Iss1/96-100.pdf

Zhang, J., Tan, K.C., & Chai, K.H. (2003), Systematic innovation in service design through TRIZ. *The TRIZ Journal, 9*. Retrieved from http://www.trizjournal.com/ archives/ 2003/09/index.htm

Zhao, X. (2005). Integrated TRIZ and six sigma theories for service/process innovation. *Proceedings of the International Conference on Services Systems and Services Management, 2*, 529-532. Chongqing, China.

Zhuravskaya, O. V., Tarba, L. V., & Mach, P. (2012). Contribution to the study of lean Six Sigma: A case study in automotive electronics. *Sworld*. Retrieved from http://www.sworld.com.ua/konfer28/480.pdf

Zlotin, B., Zusman, A., Kaplan, L., Visnepolschi, S., Proseanic, V., & Malkin, S. (2001). TRIZ beyond technology: The theory and practice of applying TRIZ to nontechnical areas. *The TRIZ Journal*. Retrieved from: http://www.triz-journal.com/archives/ 2001/01/f/

APPENDIX A

DMAIC TOOLS AND TECHNIQUES IN MANUFACTURING

Table A1

DMAIC Tools and Techniques for the 72 Cases in Manufacturing

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
1	(Barone & Franco, 2012; p. 296)	*Define*	Project Charter, Gantt Chart, Y and y Definitions, SIPOC Diagram, Process Mapping, Product Flow-down Tree
		Measure	Cause-and-Effect Diagram, Interview, Gauge R&R
		Analyze	Process Capability Analyses, Control Chart
2	(Barone & Franco, 2012; p. 350)	*Define*	Project Charter, Gantt chart, Y and y Definitions, Cause-and-Effect Diagram, Business Case, Log book on meetings, SIPOC Diagram, Process Mapping
		Measure	Interview, Observation, Drawings, Work Sheets, Histogram, Gauge R&R
		Analyze	Correlation Analysis, Regression Analysis, Process Mapping, Cause-and-Effect Matrix, Failure Mode and Effect Analysis (FMEA), VMEA
3	(Barone & Franco, 2012; p. 365)	*Define*	Project Charter, Gantt Chart, Y and y Definitions, Cause-and-Effect diagram, SIPOC Diagram
		Measure	Brainstorming, Observations, Pictures, Cause-and-Effect Diagram, Geometric Optical Measurements
		Analyze	Correlation Analysis, Regression Analysis, Normal Probability Plot, Process Capability Analyses, Control Chart

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
4	(Antony, Gijo, & Childe, 2012)	*Define*	Project Charter, Flowchart, SIPOC Diagram, Process Mapping.
		Measure	Gage R&R Anderson–Darling Normality Test, Process Capability Analysis, Normal Probability Plot
		Analyze	Brainstorming, Cause-and-Effect Diagram, Regression Analysis, GEMBA
		Improve	Design of Experiments (DOE), Taguchi Methods, ANOVA Test, Risk Analysis, Process Capability Analysis
		Control	Checklist, Auditing, Control Chart
5	(Bakshi, Singh, Singh, & Singla, 2012)	*Analyze*	Cause-and-Effect Diagram, Brainstorming
		Improve	Design of experiments (DOE)
6	(Banuelas, Antony, & Brace, 2005)	*Define*	Project Charter, Critical to Quality (CTQ)
		Measure	Process Mapping, Process Capability Analysis, Run Chart, Pareto Chart, Box Plot, Hypothesis Testing, Gauge R&R, Cause-and-Effect Diagram, Brainstorming
		Analyze	Multi-vari Chart
		Improve	ANOVA Test, Anderson–Darling and Ryan–Joiner Tests
		Control	Process Capability Analysis, Control Plan
7	(Bharti, Khan, & Singh, 2011)	*Define*	Voice of Customer (VOC), Brainstorming, Pareto chart, Critical to Quality (CTQ)
		Measure	Process Capability Analysis, Histogram
		Analyze	Cause-and-Effect Diagram, Taguchi Methods, ANOVA Test, Regression Analysis.
		improve	Histogram
		Control	Control plan

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
8	(Bilgen, & Şen, 2012)	*Define*	Project Charter, Critical to Quality (CTQ), Brainstorming, Voice of Customer (VOC), Tree Diagram, SIPOC Diagram, Process Mapping, Prioritization Matrix
		Analyze	Box Plot, Failure Mode and Effect Analysis (FMEA), Taguchi Methods, Scatter Plot.
		Improve	Hypothesis Testing
		Control	I-Chart
9	(Valles, Sanchez, Noriega, & Nuñez, 2009)	*Define*	Box Plot, Critical to Quality (CTQ), Critical to Cost (CTC).
		Measure	Process Capacity Analysis, Gauge R&R
		Analyze	Brainstorming, Hypotheses Testing, Pareto Charts, Cause-and-Effect Matrix, ANOVA Testing, Box Plot
		Improve	Box Plot
10	(Chinbat, & Takakuwa, 2008)	*Define*	Process Mapping
		Analyze	Brainstorm
		Improve	Simulation
11	(Christyanti, 2012)	*Define*	Pareto Chart, Project Charter, SIPOC Diagram
		Measure	Control Chart, Sigma Calculation (DPMO)
		Analyze	Cause-and-Effect Diagram, Failure Mode and Effect Analysis (FMEA)
		Improve	Design of Experiments (DOE)
		Control	Control Chart, Sigma Calculation (DPMO)
12	(Cloete & Bester, 2012)	*Define*	Pareto Chart, Value Stream Mapping (VSM), Cause-and-Effect Diagram
		Measure	Value Stream Mapping
		Analyze	Statistical Process Control (SPC), ANOVA Test, Regression Analysis, Process Capability Analysis, Control Chart
		Improve	Kaizen, Non-parametric Test
		Control	Failure Mode and Effect Analysis (FMEA)

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
13	(Das & Gupta, 2012)	*Define*	Project Charter, Process Mapping
		Measure	Sigma Calculation (DPMO), Pareto Chart
		Analyze	Cause-and-Effect Diagram, Failure Mode and Effect Analysis (FMEA)
		Improve	Action plan, Sigma Calculation (DPMO)
		Control	Standardization
14	(Dietmüller & Spitler, 2009)	*Define*	Cause-and-Effect Diagram
		Analyze	Regression Analysis, Statistical Tests, Scatter Plot, Cost-benefit Analysis
		Control	Statistical Tests
15	(Ditahardiyani, Ratnayani, & Angwar, 2009)	*Define*	Critical to Quality (CTQ)
		Measure	Sigma Calculation (DPMO)
		Analyze	Brainstorming, Cause-and-Effect Diagram, Multi-voting, 5 Whys Analysis
		Improve	Failure Mode and Effect Analysis (FMEA), Standard Operating Procedure (SOP), Sigma Calculation (DPMO)
16	(Falcón, Alonso, Fernández, & Pérez-Lombard, 2012)	*Define*	SIPOC Diagram
		Measure	Cause-and-Effect Matrix, Pareto Chart, Block Step
		Analyze	Multi-vari Analysis, Regression Analysis, Process Capability Analysis
		Improve	Process Capability Analysis
17	(Ghosh & Maiti, 2012)	*Define*	Process Mapping
		Measure	Pareto Chart, Fault tree, Cause-and-Effect Diagram, Brainstorming
		Analyze	Decision Tree
		Control	Run Chart

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
18	(Gijo, Scaria, & Antony, 2011)	*Define*	Project Charter, Critical to Quality (CTQ), SIPOC Diagram, Flowchart
		Measure	Gage R&R, Pareto Chart
		Analyze	Cause-and-Effect Diagram, Brainstorming, ANOVA Test, Process Capability Analysis, Chi-square Test, Design of Experiments (DOE)
		Improve	Brainstorming, Taguchi Methods
		Control	Standardization, Control Plan, Auditing, Control Chart
19	(Gnanaraj, Devadasan, Murugesh, & Sreenivasa, 2012)	*Define*	Project Charter, Brainstorming
		Measure	Brainstorming, Check Sheets, Sigma Calculation (DPMO)
		Analyze	Brainstorming, Cause-and-Effect Diagram, Bar Chart, Pareto Chart
		Improve	Flowchart, Brainstorming, Bar Chart, Matrix Diagram
		Control	Flowchart, Checklists.
20	(Goriwondo & Maunga, 2012)	*Define*	Key Performance Indicators (KPIs)
		Measure	Value Stream Mapping (VSM)
		Analyze	Pareto Chart, Cause-and-Effect Diagram
		Improve	Value Stream Mapping (VSM), Kanban, Brainstorming, Cost/Benefit Analysis
21	(Hung, Wu, & Sung, 2011)	*Define*	Voice of Customer (VOC), Key Performance Indicators (KPIs)
		Measure	Flowchart, Cause-and-Effect Diagram, Process Capability Analysis, Cause-and-Effect Matrix
		Analyze	Logistic Regression, ANOVA Test
		Improve	Design of Experiments (DOE)
		Control	Control Plan, Control Chart

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
22	(Jin, Janamanchi, & Feng, 2011)	*Measure*	Simulation, Pareto Chart
		Analyze	Hypothesis Testing
		Control	Control Plan, Control Chart
23	(Jirasukprasert, Garza-Reyes, Soriano-Meier, & Rocha-Lona, 2012)	*Define*	Voice of Customer (VOC), Project Charter
		Measure	Sigma Calculation (DPMO), Pareto Chart
		Analyze	Flowchart, Brainstorming, Cause-and-Effect Diagram
		Improve	Design of Experiments (DOE), ANOVA Test, Box Plot
24	(Kaushik, & Khanduja, 2009)	*Define*	SIPOC Diagram
		Measure	Gauge R&R
		Analyze	Run Chart, Histogram, Process Capability Analysis, Cause-and-Effect Diagram, Bar Chart
		Improve	Brainstorming
25	(Knowles, Johnson, & Warwood, 2004)	*Define*	Cause-and-Effect Diagram, Flowchart
		Measure	Histogram, R charts, Process Capability Analysis, Scatter Plot, Brainstorm, Cause-and-Effect Diagram
		Improve	Taguchi Methods, Process Capability Analysis
		Control	Documentation, Control Plan, Statistical Process Control (SPC)
26	(Kumar, & Sosnoski, 2009)	*Define*	Pareto Chart, Project Charter
		Measure	Basic Statistics, Histogram, Process Capability Analysis, Control Chart
		Analyze	Cause-and-Effect Diagram, Value Stream Mapping
		Improve	Brainstorm, Histogram
		Control	Statistical Process Control (SPC)

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
27	(Kumaravadivel & Natarajan, 2011)	*Measure*	Brainstorming, Flowchart, Cause-and-Effect Matrix, Process Capability Analysis
		Analyze	Pareto Chart
		Improve	Survey
		Control	Process Capability Analysis
28	(Lee & Wei, 2010)	*Define*	Project Charter, Critical to Quality (CTQ)
		Measure	Process Mapping, Cause-and-Effect Matrix
		Analyze	ANOVA Test, Correlation Analysis
		Improve	Failure Mode and Effect Analysis (FMEA), 5S, Total Productive Maintenance (TPM)
		Control	Control Plan
29	(Lee, Wei, & Lee, 2009)	*Define*	Brainstorming, Critical to Quality (CTQ), Project Charter
		Measure	Process Mapping, Cause-and-Effect Matrix, Failure Mode and Effect Analysis (FMEA)
		Analyze	Design of Experiments (DOE), Hypothesis testing
		Control	Control Plan
30	(Ladani, Das, Cartwright, & Yenkner, 2006; case 1)	*Measure*	Cause-and-Effect Diagram
		Analyze	Hypothesis Testing, Regression Analysis
31	(Ladani, Das, Cartwright, & Yenkner, 2006; case 2)	*Analyze*	Hypothesis Testing
32	(Kumar, Antony, Singh, Tiwari, & Perry, 2006)	*Define*	Critical to Quality (CTQ), Voice of Customer (VOC), Value stream mapping (VSM)
		Measure	Gauge R&R
		Analyze	Pareto Chart, Brainstorming, Cause-and-Effect Diagram
		Improve	Design of Experiments (DOE), 5S, Total Productive Maintenance (TPM)
		Control	Control Chart, Standardization, Mistake Proofing, Failure Mode and Effect Analysis (FMEA)

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
33	(Kumar, Antony, Antony, & Madu, 2007)	*Define*	Brainstorming, Multi-voting
		Measure	Process Mapping, Brainstorm, Cause-and-Effect Diagram, Gauge R&R, Process Capability Analysis
		Analyze	Regression Analysis
		Improve	Design of Experiments (DOE), Normal Probability Plot
		Control	Control chart, Run Chart
34	(Chen & Lyu, 2009)	*Define*	Voice of Customer (VOC), SIPOC Diagram, Critical to Quality (CTQ), Cause-and-Effect Diagram
		Measure	Cause-and-Effect Matrix, Gauge R&R
		Analyze	ANOVA Test
		Improve	Design of Experiments (DOE), Regression Analysis, Process Capability Analysis, Pareto Chart
		Control	Statistical Process Control (SPC), Control Plan
35	(Mukhopadhyay & Ray, 2006)	*Define*	Pareto Chart
		Measure	Sigma Calculation (DPMO)
		Analyze	Regression Analysis, Control Chart, Gauge R&R
36	(Zhuravskaya, Tarba, & Mach, 2012)	*Define*	SIPOC Diagram, Critical to Quality (CTQ), Voice of Customer (VOC)
		Measure	Tact Time, Overall Equipment Efficiency (OEE)
		Analyze	Causes-and-Effects Diagram, Brainstorming
37	(Pranckevicius, Diaz, & Gitlow, 2008)	*Define*	Project Charter, Gantt Chart, SIPOC Diagram, Voice of Customer (VOC), Flowchart
		Measure	Control Charts
		Analyze	Flowchart, Failure Mode and Effect Analysis (FMEA), Gauge R&R, Process Capability Analysis
		Improve	5S, Flowchart, Pilot Testing, Control Chart, Process Capability Analysis
		Control	Poka Yoke, Control Plan

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
38	(Ray & Das, 2011)	*Define*	Process Mapping, Critical to Quality (CTQ), Project Charter
		Measure	Brainstorming, Gauge R&R, ANOVA Test, Process Capability Analysis, Control Chart
		Analyze	Brainstorming, Tree Diagram, ANOVA Test
		Improve	Design of Experiments (DOE), ANOVA Test, Process Capability Analysis
		Control	Control Plan
39	(Reddy & Reddy, 2010)	*Define*	SIPOC Diagram
		Measure	Sigma Calculation (DPMO), Gauge R&R
		Analyze	Pareto Chart, Cause-and-Effect Diagram
		Control	Control Chart
40	(Sahoo, Tiwari, & Mileham, 2008)	*Measure*	Brainstorming, Control Chart, Cause-and-Effect Diagram
		Analyze	Taguchi Methods, ANOVA Test
41	(Saravanan, Mahadevan, Suratkar, & Gijo, 2012)	*Define*	Project Charter, Brainstorming, Critical to Quality (CTQ)
		Measure	Gauge R&R, Process Capability Analysis, Normal Probability Plot
		Analyze	Brainstorming, Cause-and-Effect Diagram
		Improve	Design of Experiments (DOE), Taguchi Methods, Process Capability Analysis
		Control	Standardization, Control Chart
42	(Sekhar & Mahanti, 2006)	*Analyze*	Failure Mode and Effect Analysis (FMEA), Cause-and-Effect Diagram
		Improve	Simulation, Flowchart
		Control	Control Chart, Run Chart, Pareto Chart, Benchmark

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
43	(Singh & Bakshi, 2012)	*Define*	Critical to Quality (CTQ), Voice of Customer (VOC), Project Charter, SIPOC Diagram, Cost of Poor Quality (COPQ)
		Measure	Sigma Calculator (DPMO), Process Capability Analysis, Pareto Chart, Failure Mode and Effect Analysis (FMEA), Cause-and-Effect Matrix, Gauge R&R
		Analyze	Chi-Square Test, Hypothesis Testing, ANOVA Test, Regression Analysis, Cause-and-Effect Diagram, Why-Why Analysis
		Improve	Design of Experiments (DOE), Poka-Yoke, Kaizen
		Control	Control Plan, Control Chart
44	(Soković, Pavletić, & Krulčić, 2006)	*Measure*	Pareto Chart, Process Mapping, Cause-and-Effect Matrix
		Analyze	Failure Mode and Effect Analysis (FMEA), ANOVA Test, Box Plot, Multi-vary Analysis
		Improve	Brainstorming, Process Capability Analysis, Gage R&R
		Control	Control Plan
45	(Kumar, Satsangi, & Prajapati, 2011)	*Define*	Brainstorming
		Measure	Critical to Quality (CTQ)
		Analyze	Taguchi Methods, ANOVA Test
46	(Lo, Tsai, & Hsieh, 2009)	*Measure*	Process Capability Analysis, Critical to Quality (CTQ)
		Analyze	Cause-and-Effect Diagram, Taguchi Methods, Flowchart, ANOVA Test, Regression Analysis
		Improve	Process Capability Analysis

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
47	(Vinodh, Kumar, & Vimal, 2014)	*Define*	Project Charter
		Measure	Value Stream Mapping, Seven wastes, Value-Added Analysis
		Analyze	Cause-and-Effect Diagram
		Improve	Design of Experiments (DOE), 5S, Kanban, Total Productive Maintenance (TPM), Value Stream Mapping (VSM)
		Control	Control Chart
48	(Zaman, Pattanayak, & Paul, 2013)	*Define*	SIPOC Diagram
		Measure	Normal Probability Plot, Process Capability Analysis
		Analyze	Pareto Chart, Cause-and-Effect Analysis, Regression Analysis, ANOVA Test
		Improve	Brainstorming, Process Capability Analysis, Dot Plot, Pareto Chart
		Control	Control Charts, Pareto Chart
49	(Aggogeri & Mazzola, 2008)	*Define*	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)
		Measure	Brainstorming, Gage R&R, Process Capability Analysis, Time Value Map diagram, Value-Added Analysis
		Analyze	Cause-and-Effect Diagram, Run Chart, Box Plot, Control Chart, Histogram, ANOVA Test
		Improve	Process Capability Analysis, Single Minute Exchange of Die (SMED)
		Control	Control Plan
50	(Aksoy & Orbak, 2009)	*Measure*	Gage R&R, Process Mapping, Cause-and-Effect Diagram, Brainstorming
		Analyze	Process Capability Analysis
		Improve	Hypothesis testing, Taguchi Methods, Process Capability Analysis

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
51	(Artharn & Rojanarowan, 2013)	*Measure*	Pareto Chart, key Process Input Variable (KPIVs), Cause-and-Effect Diagram, Failure Mode and Effect Analysis (FMEA)
		Analyze	Chi-Square Test, Regression Analysis
		Control	Control Plan, Control Chart
52	(Belokar & Singh, 2013)	*Define*	Flowchart
		Measure	Sigma Calculation (DPMO)
		Analyze	Pareto Diagram, Cause-and-Effect Diagram
		Improve	Sigma Calculation (DPMO)
53	(Chowdhury, Deb, & Das, 2014)	*Define*	Checklist
		Measure	Critical to Quality (CTQ), Cause-Effect-Diagram, key Process Input Variable (KPIVs), Key Process Output Variables (KPOVs), Cause-and-Effect Matrix, Pareto Chart
		Analyze	Failure Mode and Effect Analysis (FMEA), Hypotheses Testing
54	(Desai & Shrivastava, 2008)	*Define*	Pareto Chart, Project Charter, SIPOC Diagram, Critical to Quality (CTQ), Voice of Customer (VOC)
		Measure	Process Mapping, Sigma Calculation (DPMO)
		Analyze	Pareto Chart, Failure Mode and Effect Analysis (FMEA), Cause-and-Effect Diagram, Why-Why Analysis
		Improve	Matrix Diagram
		Control	Control Plan
55	(Enache, Simion, Chiscop, & Adrian, 2014)	*Define*	Project Charter, Voice of Customer (VOC), Critical to Quality (CTQ), Flowchart, SIPOC Diagram, Cause-and-Effect Diagram
		Measure	Gage R&R, Control Chart, Process Capability Analysis
		Analyze	ANOVA Test, Process Capability Analysis, Cause-and-Effect Diagram

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
56	(Farahmand, Marquez Grajales, & Hamidi, 2010)	*Define*	Failure Mode and Effect Analysis (FMEA)
		Measure	Process Capability Analysis
		Analyze	Cause-and-Effect Diagram
		Improve	Design of Experiments (DOE), Pareto Chart, Normal Probability Plot
57	(Hayajneh, Bataineh, & Al-tawil, 2013)	*Define*	Project Charter, Prioritization Matrix
		Measure	Flowchart, Pareto Chart, Cause-and-Effect Diagram
		Analyze	Pareto Chart
		Improve	5S
		Control	Control Plan, Flowchart
58	(Ruthaiputpong & Rojanarowan, 2013)	*Define*	Project Charter
		Measure	Gage R&R, Process Capability Analysis, Brainstorming, Cause-and-Effect Matrix
		Analyze	Design of Experiments (DOE), ANOVA Test, Normal Probability Plot
		Improve	Regression Analysis, ANOVA Test
		Control	Hypothesis testing, Control Plan, Check Sheets, Process Capability Analysis
59	(Sambhe, 2012)	*Define*	Project Charter, Critical to Quality (CTQ), SIPOC Diagram, Process Mapping
		Measure	Pareto Chart, Failure Mode and Effect Analysis (FMEA)
		Analyze	Cause-and-Effect Diagram, Brainstorming, Descriptive Statistics, Box Plot, Process Mapping, Six Thinking Hat
		Improve	Design of Experiments (DOE), Pareto Chart
		Control	Control Chart

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
60	(Chung, Yen, Hsu, Tsai, & Chen, 2008)	*Define*	Process Mapping
		Measure	Pareto Chart
		Analyze	Simulation
61	(Tong, Tsung, & Yen, 2004)	*Define*	Critical to Quality (CTQ)
		Measure	Gage R&R, Statistical Process Control (SPC)
		Analyze	Process Capability Analysis
		Improve	Design of Experiments (DOE)
62	(Abbas, Ming-Hsien, Al-Tahat, & Fouad, 2011)	*Define*	Process Mapping, Control Chart
		Measure	Process Capability Analysis
		Analyze	Cause-and-Effect Diagram
		Improve	Taguchi Methods, ANOVA Test
63	(Al-Refaie, Li, Jalham, Bata, & Al-Hmaideen, 2013)	*Define*	Process Mapping
		Measure	Control Chart, Process Capability Analysis
		Analyze	Taguchi Methods
		Improve	Taguchi Methods
		Control	Control Chart
64	(Nair, 2011)	*Measure*	Quality Function Deployment (QFD)
		Analyze	Cause-and-Effect Diagram
65	(Dambhare, Aphale, Kakade, Thote, & Jawalkar, 2013)	*Measure*	Gage R&R
		Analyze	Fault Tree Analysis, Tree Diagram, Key Input Variables (KIVs), Multi-vari Analysis
		Improve	Action Plan
		Control	Control Plan

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
66	(Dambhare, Aphale, Kakade, Thote, & Borade, 2013)	*Measure*	Control Chart
		Analyze	Fault Tree Analysis, Multi-Vari Analysis, Hypothesis Testing, Regression Analysis, Gage R&R, Normal Probability plot, Histogram
		Improve	Box Plot, Control Chart
67	(Hahn, Piller, & Lessner, 2006)	*Define*	Quality Function Deployment (QFD)
		Measure	Gage R&R, Simulation, Normal Probability Plot
		Analyze	Hypothesis Testing, Process Mapping
		Improve	Design of Experiments (DOE), Normal Probability Plot, Control Chart, Process Capability Analysis, Hypothesis Testing
		Control	Control Charts
68	(Puvanasvaran, Ling, Zain, & Al-Hayali, 2012)	*Analyze*	Hypothesis Testing, Box Plot
69	(Al-Mishari & Suliman 2008)	*Define*	Process Capability Analysis
		Measure	Gage R&R, Process Mapping, Cause-and-Effect Diagram, Weibull Analysis, Survey
		Analyze	Regression Analysis
		Improve	Hypothesis Testing
		Control	Control Chart
70	(Kumar, Jawalkar, & Vaishya, 2014)	*Define*	SIPOC Diagram
		Measure	Process Capability Analysis, Sigma Calculation (DPMO)
		Analyze	Cause-and-Effect Diagram, Pareto Chart
		Control	Process Capability Analysis, Sigma Calculation (DPMO)

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
71	(Sajeev & M, 2013)	*Define*	Critical to Quality (CTQ), Project Charter
		Measure	Sigma Calculation (DPMO), Pareto Chart
		Analyze	Cause-and-Effect Diagram, Brainstorming, GEMBA
72	(Jie, Kamaruddin, & Azid, 2014)	*Define*	Value Stream Mapping (VSM), Flowchart
		Measure	Pareto Chart, Process Mapping
		Analyze	Cause-and-Effect Diagram, 5 Why Analysis
		Control	5S, Standard Operating Procedure (SOP)

APPENDIX B

DMAIC TOOLS AND TECHNIQUES IN SERVICE

Table B1

DMAIC Tools and Techniques for the 68 Cases in Service

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
1	(Barone & Franco, 2012; p.269)	*Define*	Project Charter, 5 whys Analysis, Gantt Chart, SIPOC Diagram, Process Mapping
		Measure	Interview, Observation, Histogram
		Analyze	ANOVA Test, Cause-and-Effects Diagram, Pareto Chart
2	(Barone & Franco, 2012; p.283)	*Define*	Project Charter, Gantt Chart, P-diagram, SIPOC Diagram, Process Mapping, Critical to Quality (CTQ), Tollgate Checklist
		Measure	Interview, Observation
		Analyze	Histogram, Time series plots, Box Plot, Interval plot, Kawakita Jiro (KJ) Method, Cause-and-Effect Diagram, ANOM, Pareto Chart, Process Capability Analysis, Correlation Analysis
3	(Barone & Franco, 2012; p.314)	*Define*	Project Charter, Gantt Chart, Y and y definitions, P-diagram, SIPOC Diagram, Process Mapping
		Measure	Interview, Observation, Kawakita Jiro (KJ) Method, Cause-and-Effect Analysis, Voting, Pareto Chart, VMEA
4	(Al-Bashir & Al-Tawarah, 2012)	*Measure*	Flowchart, Brainstorming, Cause-and-Effect Diagram
		Analyze	Pareto Chart, Sigma Calculation (DPMO)
		Improve	Action Plan

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
5	(Allen, Tseng, Swanson, & McClay, 2009)	*Define*	Key Output Variables (KOVs)
		Measure	Process Mapping, Standard Operating Procedure (SOP), Control Chart, Benchmark
		Analyze	Key Input Variables (KIVs), Pareto Chart, Cause-and-Effect Matrix, Brainstorming, Process Mapping
		Control	Nonparametric Test
6	(Antony, Bhuller, Kumar, Mendibil, & Montgomery, 2012)	*Define*	SIPOC Diagram, Voice of Customer (VOC), Affinity Diagram, Brainstorming, Project Charter
		Measure	Critical to Quality (CTQ), Key Output Variable (KPOV), Gage R&R, Pareto Chart
		Analyze	Cause-and-Effect Diagram, Multi-voting, Survey, Process Mapping, Flowchart
7	(Cash, 2013)	*Define*	Project Charter, Critical to Quality (CTQ), Customer-needs Mapping
		Improve	Control Charts
		Control	Quality Function Deployment
8	(Drenckpohl, Bowers, & Cooper, 2007)	*Define*	Process Mapping, Cause-and-Effect Diagram
		Analyze	Root Cause Analysis
9	(Eldridge et al., 2006)	*Define*	Project Charter
		Measure	Process Map, Cause-and-Effect Matrix, Observation, Survey
		Analyze	Failure Modes and Effects Analysis (FMEA), Multi-vari Analysis
		Control	Control Plan, Checklist
10	(Feng & Antony, 2009)	*Define*	Cause-and-Effect Diagram
		Analyze	Basic Statistics

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
11	(Furterer & Elshennawy, 2005)	*Measure*	Flowchart, Waste elimination, 5S, Housekeeping, Brainstorming, Cause-and-Effect Diagram
		Analyze	Pareto Chart, Statistical Process Control (SPC), Kanban, Waste elimination, One Piece Flow, Cost\benefit Analysis
12	(Goodman, Kasper, & Leek, 2007)	*Define*	Critical to Quality (CTQ), Voice of Customer (VOC), Process Mapping
		Measure	Gage R&R, Sigma Calculation (DPMO), Control Chart, Cause-and-Effect Diagram
		Analyze	Chi-square Test, Pareto Chart
		Improve	Brainstorming, ANOVA Test
13	(Heuvel, Does, & Vermaat, 2004, case 1)	*Define*	Critical to Quality (CTQ)
		Analyze	Process Capability Analysis, Cause-and-Effect Diagram, Failure Modes and Effects Analysis (FMEA)
14	(Heuvel, Does, & Vermaat, 2004, case 2)	*Define*	Critical to Quality (CTQ)
		Measure	Gauge R&R
		Analyze	Brainstorming
15	(Heuvel, Does, & Vermaat, 2004, case 3)	*Define*	Critical to Quality (CTQ)
		Analyze	Brainstorming
16	(Chen, Shyu, & Kuo, 2010)	*Measure*	Radar Diagram
		Analyze	Cause-and-Effect Diagram
		Improve	Matrix Diagram
17	(Kapoor, Bhaskar, & Vo, 2012)	*Define*	Critical to Quality (CTQ), Voice of Customer (VOC)
		Analyze	Cause-and-Effect Diagram
		Improve	Brainstorm
		Control	Control Plan

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
18	(Kaushik, Shokeen, Kaushik, & Khanduja, 2007)	*Define*	Project Charter, Critical to Quality (CTQ), Key Performance Indicators (KPIs)
		Measure	Auditing, Interview
		Analyze	Process Mapping, Cause-and-Effect Diagram
19	(Kukreja, Ricks, & Meyer, 2009)	*Measure*	Process Mapping, Cause-and-Effect Matrix
		Analyze	Failure Mode and Effects Analysis (FMEA)
		Control	Responsible Accountable Consulted and Informed (RACI) Matrix
20	(Murphy, 2009)	*Define*	Project Charter, SIPOC Diagram
		Measure	Process Capability Analysis, Sigma Calculation (DPMO)
		Analyze	Pareto Chart
21	(Nabhani & Shokri, 2009)	*Define*	Balanced Score Card, Project Charter, SIPOC Diagram, Interview, Data Collection, Pareto Chart, Affinity Diagram
		Measure	Data Collection, Brainstorming, Histogram, Process Mapping, Sigma Calculation (DPMO)
		Analyze	X-Y Cause & Effect Analysis, Failure Modes and Effects Analysis (FMEA), Scatter Plot, Pareto Chart, Brainstorming
		Improve	Brainstorming, Affinity Diagram, Analytic Hierarchy Process (AHP), Process Mapping, Action Plan
		Control	Monitoring Chart, Sigma Calculation (DPMO), Data Collection
22	(Kumar, Wolfe, & Wolfe, 2008)	*Measure*	Flowchart
		Analyze	Histogram, Cause-and-Effect Diagram, ANOVA Test
		Improve	Poka-yoke

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
23	(Kumar, Choe, & Venkataramani, 2012)	*Define*	Voice of Customer (VOC)
		Measure	Regression Analysis, Pareto Chart, Scatter Diagram, Process Capability Analysis, Interview, Process Mapping
		Analyze	Brainstorming, Kanban
		Improve	Kaizen, 5S, Operator Balance Chart, Cell Design, Material Replenishment, Standard Work, QCPC/Turnbacks, Visual Management, Takt Time Analysis
		Control	Process Capability Analysis
24	(Kumar, Strandlund, & Thomas, 2008)	*Define*	Critical to Quality (CTQ)
		Analyze	Cause-and-Effect Diagram
		Improve	Poka-yoke
		Control	Survey
25	(Kumi & Morrow, 2006)	*Define*	Project Charter
		Measure	Process Mapping, Cause-and-Effects Matrix
		Analyze	Failure Modes and Effects Analysis (FMEA), ANOVA Test
		Control	Control Plan
26	(Laureani & Antony, 2010)	*Define*	Voice of Customer (VOC), Survey, Project Charter, Process Mapping, Value Stream Mapping (VSM)
		Measure	Sigma Calculation (DPMO)
		Analyze	Paynter Chart
		Improve	Kaizen
		Control	Control Chart

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
27	(Martinez & Gitlow, 2011)	*Define*	SIPOC Diagram, Critical to Quality (CTQ), Voice of Customer (VOC)
		Measure	I-MR Chart, Anderson-Darling Normality Test
		Analyze	Process Mapping
		Improve	Regression Analysis, Flowchart, Cause-and-Effects Matrix
		Control	ISO 9000, Control Plan, Plan-Do-Study-Act (PDSA)
28	(Martinez, Chavez-Valdez, Holt, Grogan, Khalifeh, Slater, Winner, Moyer, & Lehmann, 2011)	*Define*	Project charter, Auditing
		Measure	Cause-and-Effect Diagram, Force Field Analysis, Survey, Process Mapping
		Analyze	Kruskal-Wallis Test, Chi-square Test
29	(Franchetti & Bedal, 2009)	*Measure*	Process Mapping, SIPOC Diagram, Brainstorming, Cause-and-Effect Diagram, Sigma Calculation (DPMO)
		Analyze	Process Capability Analysis, Pareto Chart, 5 whys Analysis, Regression Analysis, Failure Mode and Effects Analysis (FMEA), Value Stream Mapping (VSM), Sampling
		Improve	Process Capability Analysis, Hypothesis Testing, Histogram, Survey
30	(O'Neill & Duvall, 2005)	*Define*	Project Charter, Key Performance Indicators (KPIs)
		Measure	Survey
		Analyze	Statistical Process Control (SPC)
		Improve	Control Chart
		Control	Survey

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
31	(Pan, Ryu, & Baik, 2007)	*Define*	Flowchart, Critical to Quality (CTQ), Project Charter
		Measure	Survey, Sigma Calculation (DPMO)
		Analyze	Cause-and-Effect Diagram
		Control	Survey
32	(Pandey, 2007)	*Define*	Survey, Pareto Diagram, Benchmarking, Prioritization Matrix
		Analyze	Hypothesis testing, Pareto Chart, Voice of Customer, Chi-square Test, ANOVA Test, Cause-and-Effect Diagram
		Improve	Process Capability Analysis
33	(Prasad, Subbaiah, & Padmavathi, 2012)	*Define*	Critical to Quality (CTQ), SIPOC Diagram
		Measure	Process Capability Analysis
		Analyze	Cause-and-Effect Diagram, Pareto Chart
		Improve	Failure Mode and Effect Analysis (FMEA)
		Control	Control Chart
34	(Redzic & Baik, 2006)	*Define*	Project Charter, SIPOC Diagram, Voice of Customer, Process Mapping, Gantt Chart, Kano Analysis
		Measure	Process Capability Analysis, Sigma Calculation (DPMO)
		Analyze	Pareto Chart
		Improve	Cause-and-Effect Diagram, Cause-and-Effect Matrix, Process Capability Analysis, Pilot Plan

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
35	(Rivera & Marovich, 2001)	*Define*	Project Charter, Critical to Quality (CTQ), SIPOC Diagram, Voice of Customer (VOC)
		Measure	Survey, Process Mapping, Pareto Chart, Histogram, Tally Check Sheet
		Analyze	Simulation, Pareto Chart
		Improve	Prioritization Matrix, Cost/Benefit Analysis, Pilot Plan
36	(Salzarulo, Krehbiel, Mahar, & Emerson, 2012)	*Define*	Project Charter
		Measure	Survey
		Analyze	Scatter Diagram, Frequency Table, Basic Statistics
37	(Furterer, 2011)	*Define*	Project Charter, Voice of Customer (VOC), SIPOC Diagram
		Measure	Process Mapping
		Analyze	Brainstorming, Why-Why Diagram
		Improve	Cost/Benefit Analysis
		Control	Control Plan
38	(Ray, Das, & Bhattachrya, 2011)	*Define*	SIPOC Diagram, Critical to Quality (CTQ), Process Mapping
		Measure	Run Chart, Sigma Calculation (DPMO), Process Capability Analysis
		Analyze	Brainstorming, Tree Diagram, ANOVA Test, Regression Analysis
39	(Li, Wu, Yen, & Lee, 2011)	*Define*	Cause-and-Effect Matrix
		Measure	Frequency Table, Process Capability Analysis, Flowchart, SIPOC Diagram
		Analyze	Process Capability Analysis
		Improve	Cause-and-Effect Diagram, Flowchart
		Control	Sigma Calculation (DPMO)

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
40	(Silich, Wetz, Riebling, Coleman, Khoueiry, Bagon, & Szerszen, 2012)	*Define*	Project Charter, Process Mapping
		Measure	Process Capability Analysis, Sigma Calculation (DPMO)
		Analyze	Cause-and-Effect Analysis, Failure Mode and Effect Analysis (FMEA), Hypothesis Testing
		Control	Process Capability
41	(Southard, Chandra, & Kumar, 2012)	*Define*	Critical to Quality (CTQ)
		Measure	Value Stream Map (VSM)
		Analyze	Process Mapping, Simulation, Poka-yoke, Flowchart
		Improve	Cost/Benefit Analysis
42	(Taner, Sezen, & Atwat, 2012)	*Define*	SIPOC Diagram, Critical to Quality (CTQ)
		Measure	Cause-and-Effect Diagram
		Analyze	Failure Mode and Effect Analysis (FMEA), Cause-and-Effect Diagram, Pareto Chart, Tree Analysis Diagram. Survey, Process Capability
		Improve	Sigma Calculation (DPMO)
		Control	Balanced Scorecards
43	(Taner & Sezen, 2009)	*Define*	SIPOC Diagram, Process Mapping, Critical to Quality (CTQ)
		Measure	Survey, Process Capability Analysis, Histogram, Control Chart
		Analyze	Sigma Calculation (DPMO), Gage R&R, Histogram, Cause-and-Effect Diagram, Pareto Chart, Regression Analysis, ANOVA Test
		Improve	Process Mapping
		Control	Sigma Calculation (DPMO), Control Plan

(table contines)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
44	(Wei, Sheen, Tai, & Lee, 2010)	*Define*	Project Charter, Voice of Customer (VOC), Critical to Quality (CTQ)
		Measure	Process Mapping, Cause-and-Effect Diagram, Cause-and-Effect Matrix, Failure Mode and Effect Analysis (FMEA)
		Analyze	ANOVA Test
		Control	Control Plan
45	(McAdam, Davies, Keogh, & Finnegan, 2009)	*Define*	Focus Group
		Measure	Frequency Table
		Analyze	Frequency Table
		Improve	Process Mapping
		Control	Run Chart
46	(Cheng & Chang, 2012)	*Define*	Voice of Customer (VOC), SIPOC Diagram
		Analyze	Cause-and-Effect Diagram, Brainstorming, 5 Whys Analysis
		Control	Flowchart, Standardization
47	(Chiarini, 2012)	*Define*	Voice of Customer (VOC), Critical to Quality CTQ
		Measure	Value Stream Mapping (VSM), Process Mapping, Failure Mode and Effect Analysis (FMEA), Pareto Chart
		Analyze	Brainstorming, Cause-and-Effect Diagram, 5 Whys Analysis
		Control	Failure Mode and Effect Analysis (FMEA)
48	(Das & Hughes, 2006)	*Measure*	Process Mapping
		Control	Control Chart

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
49	(Desai, 2006)	*Define*	Project Charter, Process Mapping, Critical to Quality (CTQ)
		Measure	Sigma Calculation (DPMO)
		Analyze	Action Plan, Process Mapping, Cause-and-Effect Diagram, Multi-voting, Pareto Chart, 5 Whys Analysis
		Improve	Process Mapping
50	(Ng, Tsung, So, & Li, 2005)	*Define*	Interview
		Measure	Tree Diagram, Survey, Correlation Analysis
		Analyze	Cause-and-Effect Diagram, Relations Diagram
		Control	Control Plan
51	(Kapadia, Hemanth, & Sharda, 2003)	*Measure*	Process Mapping, Dashboards
		Analyze	Pareto Chart, Brainstorming
		Improve	Control Chart
		Control	Flowchart, Control Plan
52	(Nanda, 2010)	*Define*	Project Charter
		Analyze	Process Mapping, Failure Mode and Effect Analysis (FMEA), Brainstorming, Histogram
		Improve	Brainstorming
53	(Kumar, Jensen, & Menge, 2008)	*Define*	Project Charter
		Measure	Process Mapping, Cause-and-Effect Diagram
		Analyze	Poka-yoke, Brainstorming
		Improve	Process Mapping

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
54	(Al-Qatawneh, Abdallah, & Zalloum, 2013)	*Define*	Critical to Quality (CTQ), Voice of Customer (VOC), Survey
		Measure	Process Mapping
		Analyze	Value-added Analysis, Brainstorming, Cause-and-Effect Diagram
55	(Baddour & Saleh, 2013)	*Measure*	Flowchart
		Analyze	Brainstorming, Cause-and-Effect Diagram, Survey, Pareto Chart
		Improve	Brainstorming, Gant Chart, Pilot Testing
56	(Kumar, Phillips, & Rupp, 2009)	*Define*	Process Mapping
		Measure	Survey
		Analyze	Cause-and-Effect Diagram
		Improve	Process Mapping, Poka-yoke
57	(Hagg, El-Harit, Vanni, & Scott, 2007)	*Define*	Voice of Customer (VOC), Project Charter
		Measure	Process Mapping
		Analyze	Spaghetti Diagram
		Control	Pilot Testing, Control Chart, Action plan
58	(Kanakana, Pretorius, & van Wyk, 2012)	*Define*	Pareto Chart, Flowchart, Project Charter, Value Stream Mapping (VSM), 5S.
		Measure	Critical to Quality (CTQ), Sigma Calculation (DPMO), Gage R&R
		Analyze	Pareto Chart, Cause-and-Effect Diagram, 5 Whys Analysis, Survey, Hypothesis Testing
		Improve	Box Plot, Control Chart
		Control	Auditing

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
59	(Lokkerbol, Schotman, & Does, 2012)	*Define*	SIPOC Diagram, Critical to Quality (CTQ)
		Analyze	Brainstorming
		Improve	Frequency Table
60	(Lokkerbol, Molenaar, & Does, 2012)	*Define*	SIPOC Diagram, Process Mapping
		Measure	Critical to Quality (CTQ), Brainstorming
		Analyze	Process Mapping, Value Stream Mapping (VSM)
		Control	Value Stream Mapping (VSM)
61	(Miski, 2014)	*Define*	SIPOC Diagram, Voice of Customer (VOC), Critical to Quality (CTQ)
		Measure	Interview, Survey, Frequency Table, Benchmarking, Kano Model
		Analyze	Cause-and-Effect Diagram, Pareto Chart, 5 Whys Analysis
		Improve	Brainstorming, Affinity Diagram
		Control	Control Chart
62	(Pranoto & Nurcahyo, 2014)	*Define*	Project Charter, Voice of Customer (VOC)
		Measure	Sigma Calculation (DPMO), Process Capability Analysis, Cause-and-Effect Diagram
		Analyze	Failure Mode and Effect Analysis (FMEA)
		Control	Survey
63	(Cheng, 2013)	*Measure*	Hypothesis Testing, Survey
		Analyze	Cause-and-Effect Diagram
		Improve	Matrix Diagram

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
64	(Barone & Franco, 2012; p. 330)	*Define*	Project Charter, Gantt Chart, Y and y definitions, SIPOC Diagram, Process Mapping
		Measure	Process Mapping, Gage R&R
		Analyze	Affinity Diagram, Cause-and-Effect Diagrams, Cause-and-Effect Matrix, Pareto Chart, Histogram, Normal Probability plot, Scatter Plots, Pie chart
		Improve	Improvement Solutions Rating, Prioritizing Tool, Cost\Benefits Analysis, Matrix Diagram
		Control	Control Plan, Control Chart
65	(Elberfeld, Goodman, & Mark Van Kooy, 2004)	*Define*	Project Charter, Process Mapping
		Measure	Control Chart, Gage R&R, Sigma Calculation (DPMO), Process Mapping
		Analyze	Brainstorming
		Improve	Non-parametric Test
		Control	Flow Chart, Control Chart
66	(Wang & Chen, 2010)	*Define*	SIPOC Diagram, Value Stream Mapping (VSM)
		Measure	Process Capability Analysis
		Analyze	Cause-and-Effect Matrix, Pareto Chart, Failure Mode and Effect Analysis (FMEA)
		Improve	TRIZ, Value Stream Mapping (VSM), Process Capability Analysis
		Control	Control Plan, Control Chart

(table continues)

Case Number	Case Reference	DMAIC Phase	Tools & Techniques
67	(Kim, Kim, & Chung, 2010)	*Define*	Voice of Customer (VOC), Critical to Quality (CTQ)
		Measure	Sigma Calculation (DPMO), Survey
		Analyze	Error Modes and Effects analysis (EMEA), Window Analysis, Mann-Whitney Test, Kruskal-Wallis Test, Correlation Analysis, Hypothesis Testing
		Improve	questionnaire survey, simulation, process capability analysis
		Control	Risk Evaluation Matrix, Survey
68	(Laureani, Antony, & Douglas, 2010)	*Define*	SIPOC Diagram, Process Mapping, Seven Wastes (Muda)
		Measure	Sigma Calculation (DPMO)
		Analyze	Pareto Chart
		Improve	Brainstorming
		Control	Control Plan