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Comparing Functions, Costs and Rewards of Quality Engineers and Six Sigma Black Belts

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COMPARING FUNCTIONS, COSTS AND REWARDS OF QUALITY ENGINEERS AND SIX SIGMA BLACK BELTS

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ABSTRACT

The respective Bodies of Knowledge (BoKs) as described by the American Society for Quality (ASQ) for Certified Quality Engineers (ASQ, 2015a) and Certified Six Sigma Black Belts (ASQ, 2015b) are quite similar, yet anecdotally, six sigma black belts are recognized and consequently rewarded more highly than are quality engineers. While Quality Engineering work is typically regarded as preventive in nature, work performed by six sigma black belts is in the realm of improvement, hence is reactive in nature. Consequently, a dichotomy exists in that preventive actions, which are less costly by their nature, are not rewarded as well as costlier reactive actions. This results in loss to the owning organization.

The intent of this research is to determine the validity of the anecdotal evidence, and subsequently determine the root cause therefor. The research method was to perform a survey of managers knowledgeable in the duties of both quality engineers and six sigma black belts combined with a Delphi Study of the ASQ certification board, which develops the respective bodies of knowledge, and a comparison in salaries of the two positions, based on the ASQ salary survey for several years. The results reflect the validity of the anecdotal evidence and indicate the need for further research.

PREFACE

This dissertation is submitted for the degree of Doctor of Philosophy at Indiana State University. The research described herein was conducted under the supervision of Dr. M. Affan Badar, Ph.D. at the College of Technology, Indiana State University, between 22 January 2019 and 19 September 2019.

This work is to the best of my knowledge original, except where cited and references are made to previous work. Neither this, nor any similar dissertation has been or is being submitted for any other degree, diploma, or other qualification at any other university.

ACKNOWLEDGEMENTS

No project of any kind is performed in a vacuum, consequently, this work is the collaboration of many unseen and unnamed individuals. However, I would like to specifically acknowledge and note my appreciation as follows:

To my wife, Patricia, who has exhibited patience that eclipses that of Job throughout this process and has demonstrated foundational support rivaling that of the pyramids.

To Tom Slagle, Director of Quality (retired), Medtronic Spine and Biologics, who noted: "Every seemingly stupid or utterly incomprehensible corporate directive, policy or procedure can be traced directly to someone's executive compensation package." This quote (which I have since labeled: "Slagle's First Law") provided the initiative to begin this process.

To Dr. Karen Hulting, Ph. D., Statistics, Medtronic Plc. Distinguished Statistician, who, when informed that I had begun this journey told me, "Grant, what you need to understand is that you don't have to be overly smart to get a Ph. D. You just have to ***NOT QUIT***." This quote provides me with the insight and impetus to conduct and conclude this course of study.

To Dr. Carrie Strief, Ph. D., Statistics, Medtronic Plc. Senior Principal Statistician; Her bravery in the face of adversity has been a shining example of courage and persistence to me.

Finally, and perhaps most importantly, to Drs. Badar, Kluse and Schafer, for their assistance, patience and support ***throughout*** this dissertation project, without all of which no individual portion of this project would have been possible.

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CHAPTER 1

INTRODUCTION

The era of modern Quality Assurance began with Dr. Walter Shewhart's publication of "***Economic Control of Quality of Manufactured Product***" in 1931. Most notable, for the purposes of this document, are Shewhart's three postulates for the "Scientific Basis for Control":

- **Postulate 1**: Chance systems of cause are not all alike in the sense that they enable us to predict the future in terms of the past,
- **Postulate 2**: Control systems of chance causes do exist in nature, and;
- **Postulate 3**: Assignable causes of variation may be found and eliminated.

In these three postulates rest the concepts, demonstrated by history, of the ability to differentiate and separate common cause variation ("chance systems of cause") from special ("assignable") cause variation, and eliminate the special cause variation, resulting in predictable processes (Shewhart, 1931).

Based on Shewhart's work, Dr. Joseph Juran, one of Shewhart's proteges at Western Electric, delved deeper into quality assurance philosophy and developed and published what has become known as the Juran Trilogy for Quality Management: Quality Planning, Quality Control and Quality Improvement (Gryna, Chua & DeFeo, p. 20, note: it is important to understand that while the Trilogy is detailed in the reference noted, this reference is the fifth (5^{th}) edition of Juran's work; the Juran Trilogy was expounded in the first edition, published in

1970 (personal communication, Tina Frigeri, 4 October 2017)).

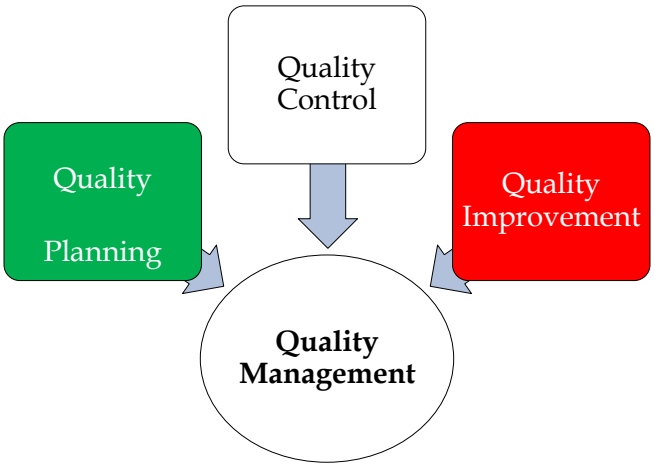

Figure 1: The Juran Trilogy (Gryna, Chua & DeFeo, 2007)

Further, in this work, Juran notes that Quality Engineering is part of Quality Planning and is thus categorized as preventive (noted in green in Figure 1, above), and that part of Quality Control which actions are categorized as preventive, and Quality Improvement is reactive (noted in red, in Figure 1, above).

Juran also noted that, when failures occurred, Quality Engineering was, in the past, responsible for Quality Improvement; thus, as defined under the Juran Trilogy, quality engineers had both preventive and reactive duties. However, the advent and implementation of Six Sigma programs have spawned structures separate from but parallel to that of the quality assurance departments, dedicated to improvement, including but not limited to quality improvement (Juran & Godfrey, 1999). Since Six Sigma programs are used for improvement not confided to quality assurance, six sigma black belts come from many functions, including but not limited to, Quality Assurance. Consequently, despite the similarities of their requisite job skills (as defined by the ASQ BoKs), six sigma black belts do not always possess the depth of quality assurance-oriented training or experience as do pure quality engineers.

Six sigma black belts, by nature of involvement with improvement projects are engaged in corrective actions. Quality engineers, having ostensibly been relieved of responsibility for improvement, engage in purely preventive actions.

This situation has resulted in a dichotomy of effect: Preventive actions are by their nature more economical than corrective actions and, additionally, can be expected to reduce the number of required futured corrections (Zivalijevic, Bevanda, & Trifunovic, 2017), yet anecdotal evidence indicates that organizations reward improvement projects, and those responsible for them, more highly than those who affect preventive measures. In effect, organizations reward "fire-fighting," thus encouraging "arson," rather than rewarding the building of fire-proof structures. This is significantly costlier in long term.

Statement of the Problem

The problem identified in this study: Companies are losing significant money focusing on corrective actions vs preventive actions, therefore there is a need to determine the potential for significant cost savings.

Statement of Purpose

The preliminary purpose of this study is to determine if companies reward and recognize corrective actions more than preventive actions, encouraging associates to prioritize corrective actions, even though the opposite manner of operation may provide for greater cost savings and thereby enable greater efficiency.

Research questions to be answered include:

- Which of these two types of actions (preventive and corrective actions) does organizational quality management purport to value more highly?

- Which of these two types of actions (preventive and corrective actions) does organizational quality management demonstrate to value more highly?
- Should a statistically significant disparity between management's purported values and demonstrated values regarding preventive and corrective actions be determined, to determine correction for that disparity, what root-cause factors contribute?
- Do any well-known quality models describe or explain these results?

Statement of Need

Cost savings are their own reward. As operations become leaner, prosperity necessitates efficiency, expressed in both tangible and intangible means; especially for operations in regions with higher standards of living faced with competition from operations with lower labor and operational costs. For organizations which produce commodity products, where there are both:

- little or no perception of quality or capability difference by brand, and;
- very low margins of profit,

efficiencies through these cost-savings can spell the difference between survival and extinction.

Statement of Assumptions

1. The requisite job skills and consequent duties for quality engineers and six sigma black belts are best described by American Society for Quality (ASQ) in their respective Bodies of Knowledge for those certifications.

2. The individuals involved in this study survey are assumed to be managers familiar with the job descriptions and requirements of both quality engineers and six sigma black belts but not directly performing either of these duties.
3. The individuals involved in this study survey provided responses that were indicative of their true beliefs, abilities and experiences.
4. The level of the Salary Survey from ASQ bias-by-response results are normally distributed with a mean of zero (i.e., the level of inflation in reporting from six sigma black belts in the survey is not significantly different than the level of inflation in reporting from quality engineers).

Statement of Limitations

The study shall be bound by the following limitations:

1. The difficulty with the study of preventive actions is that successfully implemented actions are toilsome at best and impossible at worst to value-quantify, as they present no issue(s) to measure costing.
2. The sources of the data gathered are all ASQ-oriented. While ASQ is the largest and leading authoritative and thus most representative society for Quality Professionals, including many without the United States, the data gathered therefrom should be seen as limited to that source, and somewhat partial to American business models.
3. Analyses of the Salary Survey results from ASQ are biased by response, as it only includes respondents' information, and that information is self-reported data.
4. The individuals selected for participation in the study shall be members of and attendees of national meetings of the ASQ Quality Management Division.

5. The study is confined to the job duties, expectations and performance of quality engineers and six sigma black belts.

Statement of Method

The data for this study shall be obtained through a mixed method model: A survey of quality managers shall be conducted to determine the expectations and performance of quality engineers and six sigma black belts. To reduce the bias effect of self-reported data or anecdotal data, the individuals responding to the survey shall be managers that supervise either quality engineers or six sigma black belts and are familiar with the duties of both.

As the convenience sample size for the survey is anticipated to be greater than 100, the responses shall be stratified and analyzed by industry, and the results compared for both within and between industry variability. All survey respondents shall be briefed *a priori* as to the used definitions of both ***Preventive*** and ***Corrective*** Actions.

In addition, an analysis of the results of the ASQ Salary Survey results shall be performed, comparing the salaries of quality engineers and six sigma black belts, stratified by industry. As noted in the **Statement of Limitations** above, this data is biased as it includes only respondents' self-reported data. However, as the data is pre-existing, based on a number of respondents significantly greater than one-hundred [100]); as noted in the **Statement of Assumptions** above, the level of inflation is assumed to be normal with a mean of zero, and equivalent between six sigma black belts and quality engineers. Since the metric to be measured is a ratio, the assumption of equivalence of the inflation level of self-reported data between the individual terms of the ratio mitigate, if not eliminate, any effects of individual inflation bias.

As noted above in the **Statement of Limitations**, the ability to quantify cost savings of successful preventive actions are imperfect. Consequently, the responding managers shall be required to estimate their value by basis of comparison with unsuccessful systems.

Definitions of Terms and Descriptions of Acronyms

The following terms have been defined and acronyms used herein have been provided to afford clarity:

- **ASQ**: The American Society for Quality.
- **Assignable Cause Variation**: That variation found in a process that is not inherent to that process, also known as "special cause" variation. Shewhart's Postulate 3 (shown above) notes that identification and elimination of assignable cause variation is possible.
- **Black Belt/Six Sigma Black Belt**: A six sigma black belt by job title or description.
- **BoK**: Body of Knowledge; the collection of required skills and knowledge, a specific certain level of which one must possess to receive certification in any of the applicable disciplines tested and certified by ASQ.
- **Common Cause Variation**: That variation inherent to a specific process. Shewhart noted that this variation occurs randomly over time and termed it "chance cause" variation.
- **Corrective actions**: Those actions taken to improve or correct a situation where a failure has occurred, or systemic deficiencies (gaps) are discovered which could result in failures in practice.

- **Certified Quality Engineer**: An individual with an active certification as a Quality Engineer from the ASQ.
- **Certified Six Sigma Black Belt**: An individual with an active certification as a Six Sigma Black Belt from ASQ.
- **Preventive (preventive) actions**: Those actions which, when properly implemented, result is a complete lack of failures (i.e., when a system is preventive, it operates without failure, and is expected to continue do so, with maintenance actions to address specification requirement changes over time).
- **Quality Engineer**: A quality engineer by job title or description.

CHAPTER 2

REVIEW OF LITERATURE

"An ounce of prevention is worth a pound of cure." Benjamin Franklin.

"It seems obvious that an ounce of preventive action costs much less than a pound of corrective action" (West, 2011).

Introduction

The Juran trilogy notes that managing quality consists of three (3) categories: quality planning, quality control and quality improvement. Juran provides high level guidelines as to the subcomponent elements of each of these interrelated categories. Upon review of the trilogy, the categories and each of the categorical elements, it becomes apparent that the requirements of each, while interrelated, are different:

- Planning, and the elements thereof are almost exclusively proactive processes: e.g., discovering customer needs, developing products and processes, developing process controls to transfer to operations,
- Some of the elements of Control are also proactive, e.g., choosing the correct control subjects, and establishing measurement methods and standards of acceptance, whereas;
- The remainder of the elements of Control and all the elements of Improvement are largely reactive processes, e.g.:
    - Applicable Control processes include measurement of actual performance, comparison of measurements to standards, and dispositioning based on the differences, and;

- Improvement actions include proving the need, diagnosing causes, providing remedies and demonstrating the effectiveness thereof, dealing with resistance to change, and steps to hold the gains delivered by the improvements. (Gryna, Chua, & DeFeo, 2007)

Thus, Planning is almost exclusively proactive; Control is a mixture of proactive and reactive; Improvement is almost exclusively reactive. Consequently, each of these elements of management of quality requires a different set of approaches. In addition, it is important to note that the common element to all the reactive elements is that a failure of some sort (including failure to deliver optimum performance) occurs. If there were no such failures, there would be no reason for the reactive elements of Control or Improvement. However, the proactive elements of planning and control are always necessary, regardless of whether failures occur.

Prevention vs. Correction

In the current literature regarding business and quality assurance processes, it is surprising how little scholarly work is devoted to Quality Assurance business environment. Odigie notes that there is significantly little quality-related research as compared with other disciplines, such as chemistry and physics (Odigie, 2015). While preventive actions are extolled in academic literature for other circumstances, such as noting the desirability of actions to prevent cardiac events (Mosca et al., 2006), review of the extant literature reveals that very little of that small amount is dedicated to prevention in business circumstances; in most cases evident, when "preventive" actions are described, there is great incestuous clustering combining them with "corrective" actions; in almost all cases, the two are noted together, frequently with the notation regarding preventive actions being those actions taken to prevent the recurrence of a

failure, rather than prevention of the occurrence of a failure. Salsbury notes organizations frequently concentrate on only actions to prevent recurrence, and explains that, while this is seen as preventive, they are actually corrective actions (Salsbury, 2015). West and Cianfrani note that some businesses, just to satisfy auditors, search corrective actions to discover issues to characterize as preventive (West & Cianfrani, 2015).

Many quality professionals do not differentiate between preventive actions that are follow-up to failures (in fact truly reactive corrective actions) and preventive actions that are put in place to prevent occurrence (in fact truly proactive preventive actions), either in the context of the determination, or the use of the correct tools to perform the actions:

Jacobson, in her description of using the principles of ISO9000 for the management and improvement of healthcare systems notes corrective and preventive actions as one entity, always with "preventive" following "corrective" (Jacobsen, 2008). Durivage, in his discussion of the Voice of Effectiveness (VoE), regarding the effectiveness of corrective actions, uses comparisons of pre- and post- problem occurrence levels, thereby not distinguishing prevention of occurrence from recurrence (Durivage, 2017). While Baranzelli, in his conference paper discussing the use of the precepts of ISO9000 in highway construction, notes the difference between preventive actions for occurrence and preventive actions for recurrence, he does not differentiate between the tools used specific to either, thereby effectively grouping these as one type of action (Baranzelli, 2010). Barata & Cunha group corrective and preventive actions as one when considering use with automated support systems (Barata & Cunha, 2017).

These examples, published in the American Society for Quality's lead peer-reviewed instrument of information dissemination (***Quality Progress*** magazine, which is provided to every ASQ member) or for other proceedings of the ASQ, illustrate that there exists within the

quality community a significant lack of understanding of the nature of planned and proactive problem prevention, and the tools useful for this purpose; as differentiated from actions taken to prevent recurrence, and the tools appropriate therefor.

Early Training in Quality Assurance

From the beginning of a quality assurance professional's career, (s)he is indoctrinated with the proper procedure for affecting effective corrective actions for non-conformances. Improvement is a key factor of quality cost reduction, and corrective action is a key factor of improvement (Benbow, Berger, Elshennawy, & Walker, 2002).

They are many descriptions in the literature of an effective corrective action program, notably specified in section 10 of ISO 9001 and section 8 of ISO13485, but most contain some variant inclusive of the following four (4) steps:

1. Determine the nature and range of the non-conformance; identify and isolate the non-conforming items.
2. Determine what happened in the process that allowed the non-conformance to occur.
3. Disposition, with additional work as required, the non-conforming items, and;
4. Affect corrective actions to prevent or reduce the likelihood of recurrence of the non-conformance. (International Standards Organization, 2015, 2016; *Juran's Quality Handbook, 5th ed.*, 1999).

It is important to note that the above description contains three (3) specific interrelated but differing elements (Arter, 2015):

1. The first element is non-conformance control. This is the determination of a non-conformance and then the actions necessary to ensure that the non-conforming material

doesn't contaminate the conforming material, and a decision regarding the disposition of the non-conforming material is affected.

2. The second element is determination of the root cause of the failure and institution of corrective actions designed to reduce or eliminate the probability of recurrence.
3. The last element is determination and implementation of actions necessary to ensure corrective actions affected remain in place.

Each of these different elements must be performed, in order, for there to be effective corrective action (Durivage, 2017).

There are several requirements inherent in this process, including the requirements that for all non-conformances, the results of investigations to determine root causes and corrective action effectivity thereof shall be evaluated and documented, and that documentation shall be maintained (International Standards Organization, 2015). There are many references available for the purpose of fulfilling the requirements of step "2." (***Determine what happened in the process that allowed the non-conformance to occur.***), above:

Some of the commonly used tools, each with a convenient mnemonic title, are "5-Whys" (asking why at least five times) (ASQ, 2018b) or 8-D (eight disciplines) (ASQ, 2018a). An example of a major work dedicated to the subject is ***Root Cause Analysis: A Tool for Total Quality Management*** by Wilson, Dell and Anderson. In this work, the authors provide a plethora of reactive problem-solving techniques, including:

- Intuition
- PERT
- Process Control Charts
- Nominal Group techniques
- Networking
- Flowcharts
- Trend Analyses
- Brainstorming
- Experience
- Process Charts
- Pareto Diagrams
- Fault Tree Analyses

In short, a list of well-known quality assurance techniques neatly organized into chapters (Wilson, Dell, & Anderson, 1993).

The training and indoctrination of the tools relative to proactive preventive actions is far less extensive, and typically occur later in the quality professional's career. West noted that there are three (3) general methods to develop truly preventive actions:

1. Reduce complexity,
2. Manage Risks, and;
3. Manage Uncertainty.

The three primary preventive tools to accomplish those methods are Statistical Process Control (SPC), Failure Mode and Effects Analyses (FMEAs) and error proofing (also known "Poka Yoke").

As noted in Chapter 1, SPC was invented by Shewhart, when he noted that it was possible to separate "chance systems of cause" from "assignable" cause variation, and that in the elimination of assignable cause variation, the resulting process was stable and predictable over time (Shewhart, 1931). Deming, referencing Shewhart, noted that in the period after assignable cause variation is eliminated, the process can be monitored, using the same SPC tools employed to find and eliminate the assignable causes. This monitoring ensures processes remained stable, and that should evidence exist that a process was beginning to become unstable, actions could be taken before non-conformances occurred (Deming, 1986). Using SPC manages risks and uncertainty, by allowing the organization to understand processes and monitor stability.

FMEA is a systematic methodology to address potential failures (AIAG, 2008). It was initially developed by the United States Army as a forward-looking analysis technique,

assuming that in complex systems, the ability to detect problems in all cases was negligible. Consequently, there is no capability to affect the proper mitigations for those undetected problems (U. S. Army, 1980). While there are two typical uses:

- Design (dFMEA): A listing of potential failures to customer or functional requirements based on product design, and the effects thereof, and;
- Process (pFMEA): A listing of potential failures to customer or functional requirements based on the process of product manufacture, and the effects thereof,

both prioritized by the combined effects of severity and probability of occurrence; the format can be used to proactively assess risk in any format. However, while the tool is intended to be a living document, updated whenever additional risks are determined; history has demonstrated this aspect of FMEAs to be the least supported (AIAG, 2008). Consequently, FMEAs are frequently most useful as a proactive tool, less useful as a reactive tool.

The use of FMEAs manages risks by listing them and providing mitigation when required and reduces complexity by allowing the organization to see how multiple systems work together, thereby allowing for mitigations to span multiple problem causes.

FMEAs are not without flaws: Three (3) aspects of risk: Severity, Probability of occurrence and Probability of detection, are each listed as integer values between one (1) and ten (10) inclusive. The resultant overall risk (called the Risk Priority Number [RPN]) is the product of the three individual aspect ratings. As such, the consequence of finding that mathematical result is that each of the aspects is of equal importance. Further, the assignment of values is frequently subjective. Flaws notwithstanding, however, FMEAs are a commonly used preventive tool. (Guinot, Sinn, Badar, & Ulmer, 2017).

Error-proofing is a procedure used to define methodology such that the probability of making an error is very low, and it will be obvious when one occurs. Frequently, this is a reactive measure, one precipitated by an earlier failure, but in the presence of determined and clear planning it can be proactive. Frequently, in use, it is referred to by the Japanese term Poka-Yoke (Tague, 2005). While the method is usually used in production processes, Kaiser notes that the concept may be used for prevention of errors during software development (Kaiser, 2014).

The use of error-proofing manages uncertainty by making the probability of problem occurrence much lower, and the detection of probability occurrence much higher.

Examination of these methods reveals that they are largely based for use in operational processes, and only marginally apply to systemic policies. Consequently, they prevent problems on the operational level, but there is little in the toolbox other than experience and insight to prevent issues on the systemic level.

Juran on Quality Improvement = DMAIC

In the currently literature, as well as current practice, the model most used for implementation of improvement and corrective action is the Six Sigma process using the acronym DMAIC (Gryna et al., 2007; *Juran's Quality Handbook, 5th ed.*, 1999). This acronym lays out for the practitioner an opportune mnemonic for the sequence of actions for a Six Sigma improvement project: Define, Measure, Analyze, Improve and Control (Breyfogle, 2003).

Six Sigma has been reported to have its origins at the Motorola Corporation in the early 1970s: Bill Smith, a senior technical employee, determined the need for an organization, independent from but familiar with both the operations and quality assurance organizations,

to provide ongoing and, more importantly, profitable improvement projects (Breyfogle, 2003). The basis for the name "Six Sigma" originated from the concept that processes and tolerances were examined in order to make the former sufficiently efficient and latter sufficiently reasonable that all products could be manufactured such that there were at least six standard deviations of the processing mean between the nominal value and the nearest product specification; even when the processing mean was allowed to drift ± 1.5 standard deviations from that nominal value, as a result of anticipated special cause factors such as tool wear (Breyfogle, 2003). The investigatory, analytical and communication tools used are common to both the CSSBB and the CQE BoKs, arranged in the order specified by the acronym DMAIC (ASQ, 2015a).

Deeper investigation of quality improvement methods, however, reveals that while Six Sigma purported to be a new method, it is in fact a repackaging of the methods for quality improvement first developed by Dr. Joseph Juran in the 1950s and first published in 1964; both in text books, the most recent edition of which is (Gryna et al., 2007); and in work books (Juran, 1982).

In the most recent edition of ***Juran's Quality Planning and Analysis for Enterprise Quality***, the authors specifically list Juran's quality improvement steps, and, perhaps as a bow to the inevitability of the across-the-board adoption of Six Sigma programs, conveniently provide a translation for each step into the language of Six Sigma. They are:

Table 1: Translation from Juran on Quality Improvement to Six Sigma

Step	Juran on Quality Improvement Step Name	Six Sigma Step Name
1	Verify the Project Need and Mission	**D**efine
2	Diagnose the Causes	**M**easure & **A**nalyze
3	Provide a Remedy and Prove its Effectiveness	**I**mprove
4	Deal with Resistance to Change	**I**mprove
5	Institute Controls to Hold the Gains	**C**ontrol

While the Juran step names do not provide such a convenient acronymic mnemonic that Six Sigma step names afford: (DMAIC (pronounced duh-máy-ick)); casual review of Table 1 reveals that they accomplish the same objectives, in the same order. The true telling is that Juran's methods were established and published far earlier (Gryna et al., 2007). However, it is perhaps indicative of the widespread success of Six Sigma that that the primary citation published by the Juran institute specifically notes the nearly complete correlation between the methods, whereas the primary six sigma text (Breyfogle, 2003) merely mentions the Juran improvement methods as a way to resolve special cause variation.

Comparison of the ASQ CQE and CSSBB BoKs

As job descriptions and the consequent inherent responsibilities vary significantly between business organizations, some modicum of standardization is necessary when comparing the duties and responsibilities of quality engineers and six sigma black belts. The respective American Society for Quality Bodies of Knowledge provide such standardization.

To determine current states of responsibilities and knowledge levels for each of the requisite skills of the position's titles tested by ASQ's Certification Exams, to keep the exams current and widely applicable, the society performs periodic Job Analysis Surveys for each

certification. The description of the job analysis survey, provided by Carmen O'Neill, the ASQ psychometrician, is as follows:

> **"Job analysis:** A widely recognized and legally defensible strategy for establishing the content validity of a CQI credentialing examination, the job analysis process identifies and validates the tasks performed on the job and the knowledge needed to perform the job. The content outline of an examination is then linked to this empirical description of practice, creating a framework for an examination that is job related and content valid."

The most recent Job Analysis survey for the ASQ CQE was conducted in 2015; the most recent Job Analysis survey for the ASQ CSSBB was conducted in 2014. (Carmen O'Neill, personal communication, 14 August 2018). The respective BoKs where developed therefrom.

Attached at Appendix A and B, respectively, are the current CQE (ASQ, 2015a) and CSSBB (ASQ, 2015b) BoKs. The comparison was performed as follows:

- Since the two BoKs do not fall in the same order, it was necessary to choose one as the standard, to which the other was compared. For this comparison, the CQE BoK was used as the standard, to which the CSSBB BoK was compared.
- Each individual entry from the CQE BoK was listed, in order, and sections with applicable comparative information from the CSSBB BoK were listed in association.
- Since the entries were frequently not exactly alike, and the subject material was not divided identically, frequently one entry from one of the BoKs corresponded to more than one entry from the other.
- In the event that a subject heading (which had no requirements descriptions) was present but the information was redundant to that in the sub-heading, the subject heading was deleted.
- Similarities and gaps between the two BoKs were determined and are listed below.

Review of the comparison reveals a great deal, but the major conclusions therefrom are based on both the similarities and gaps found, as follows:

- The two BoKs are relatively identical regarding many skills such as project management, leadership principals and techniques, lean tools, and classical technical techniques are represented relatively equally and in largely equivalent levels of taxonomy:
    1. Statistical Techniques such as Statistical Process Control (SPC),
    2. Design of Experiments (DoE),
    3. Probability,
    4. Test of Hypotheses,
    5. Capability,
    6. Regression, and,
    7. Measurement Systems Analyses (MSA).
- However, there are significant gaps in the CSSBB BoK with regards to the conduct of day-to-day business for an operational organization: There are no requirements in the CSSBB BoK for expertise regarding:
    1. Quality Information Systems,
    2. Supplier Management,
    3. Basic Elements of the Quality System,
    4. Product Design, Inputs & Reviews
    5. Quality Documentation,
    6. Quality Audits,
    7. Product/Process Validation/Verification
    8. Product Reliability,
    9. Material Control,
    10. By-Lot Acceptance Sampling,
    11. Total Quality Management,
    12. The Shewhart/Deming Cycle
    13. Pre-Control *&* Short Run SPC,
    14. Risk Management *&* Mitigation planning, and, perhaps most tellingly,
    15. Understanding of the ASQ Code of Ethics.

    all of which exist in the CQE BoK.

- The applicable skills extant in the CSSBB BoK missing from the CQE BoK are:
    1. Detailed taxonomy of how project teams work (e.g., team types and constraints; roles and responsibilities; selection criteria; success factors, et al.), and;
    2. Non-parametric tests of hypotheses (e.g., Kruskal-Wallis and Mann-Whitney tests).

Based on this comparison of the two BoKs, which are, as noted above, representative of how a large portion of businesses work, it is apparent that quality engineers are largely responsible for two (2) of the three aspects of the Juran Trilogy at the user level: Planning and Control. Six sigma black belts are largely responsible for Improvement. In addition, it is apparent that the clear majority of the CSSBB BoK is present in the CQE BoK, but the converse is not true.

Separation of Quality Engineering and Black Belt Roles

With the initiation of Six Sigma at Motorola, as referenced above, and its adoption by other large organizations (most notably General Electric and Allied Signal), the program became a relatively well accepted and regarded part of total quality management programs. One glaring difference between Six Sigma and previously initiated Total Quality Management (TQM) programs was the establishment of a full-time staff parallel to that of the quality organization. In the formation of Six Sigma departments facilitators are chosen, from both within and without the Quality Assurance organization, and given training in improvement methods (*Juran's Quality Handbook, 5th ed.*, 1999). Off-the-shelf software, including statistical software, provide assistance with the requisite analytical skills for those not coming to the job with those skills (*Juran's Quality Handbook*, 2010). Consequently, Six Sigma Black Belt facilitators have the potential to be from all departments, both those for which possession of technical skills are a requirement and those for which such possession are not. A

representative four-week training period including instruction on how to use statistical software substitutes for the technical skills and experience required by many organizations for quality engineers.

As noted above, quality engineers are, as a result of the implementation of a Six Sigma program in their organization, relegated to two portions of the Juran Trilogy: the realms Quality Planning and Quality Control. Six sigma black belts are assigned the remaining realm of the trilogy: Quality Improvement. It is in the planning and control responsibilities that the Quality Engineer frequently disappears.

In his work "Standards Outlook: Defining your role" in ***Quality Progress*** magazine, Russell notes that the reason that quality professionals frequently seem to be invisible is that they cannot describe what it is they do in the approximately twenty seconds it takes for an elevator to ascend from the reception lobby to the mahogany-clad hallways of the "C" suite. Russell provides several suggestions for defining the roles of quality professionals, many of which must be tailored to meet the specifics of the quality professional using them. His final suggestion for the beginning of the elevator speech is:

"Quality for the customer is getting what you are expecting; quality for the supplier is getting it right the first time" (Russell, 2014).

The problem, Russell suggests, is that while people understand the value and can estimate the financial gain related to fixing problems, they do not as well understand the value, and cannot easily estimate the financial gain of preventing them. Indeed, frequently,

those in the financial departments will disavow preventive cost savings, since the problems for which they are intended never occurred (Russell, 2014).

Six sigma black belts have no such issues. To say, in effect, "I facilitate improvement projects which save the company, at a minimum, $100,000 per project. I can, at your convenience, give you a list of the projects completed so far and the cost savings thereof," is accurate, timely possibly most importantly, spoken in the language of management: money (Juran, 1982).

The Root of Misunderstanding

As noted above, organizations, and the more importantly, the management thereof, frequently do not inherently distinguish between actions taken to prevent occurrence of an issue and actions taken to prevent recurrence of an issue.

During the periods of darkness described above, some voices of reason stood out: West writing in ***Quality Progress,*** warned that preventive actions don't look at problems that have already occurred, they look ahead. In addition, he noted that most organizations do not implement preventive actions when they have the potential for maximum effectiveness, at the time of establishment of the quality management system; they wait until later when the use of preventive actions are not as effective (West, 2012).

However, the root cause of the misunderstanding may be found in the changes to standards which provide clarity: Westcott notes that the current version of ISO9000 ((International Standards Organization, 2015)), specifies the differences: "section 8.5.2 says corrective action eliminates the *cause* of nonconformities to *prevent recurrence*, and section 8.5.3 says preventive action determines and eliminates the *causes* of potential nonconformities … to

prevent occurrence," and then explains that previous versions of the standard did not do so (Westcott, 2005); Hoffman notes that the primary difference between a CAPA and a purely preventive action is whether or not a failure has occurred (Hoffman, 2007). The difference between prevention recurrence and occurrence is affirmed by Arter, noting that the failure to differentiate between actions to prevent recurrence and actions to prevent occurrence existed also in the previous versions of ISO13485 (Arter, 2015). Consequently, in the past in part, quality professionals were driven by standard to this misunderstanding.

Perhaps some of the remainder of the cause for this confusion can be explained by the real and vital importance of good corrective actions. The training and initiation of the past which emphasized corrective actions was and remains important; effective corrective actions are required to fix problems. While noting the differences between Correction (which eliminates a nonconformity without considering root cause) and Corrective Action (which eliminates or reduces the probability of recurrence and is system based, requiring the investigation, determination and correction of the root cause), Boswell also reminds the reader that both actions are necessary and important parts of driving out problems (Boswell, 2013).

Finally, there is some cause to say that prevention of occurrence and prevention of recurrence do indeed overlap in practice: In my research, I could not find any definition as to how much time must have passed after a failure has occurred such that actions put into place at a some later date can be said to be preventive of occurrence; nor could I find where anyone has determined whether a problem (and the subsequent solution) encountered by a quality professional in a previous position which drives actions put into place in the current position to prevent occurrence are truly defined as such. From review of the quality assurance community that publish in and for ASQ, most combine and confuse these actions.

In addition, Taylor notes that preventive actions require systematic reviews of data records for issue prevention, some of which (e.g., monitoring rates of material consumption and monitoring delivery times of materials to ensure materials are always available, reviews of capability analyses, and monitoring of equipment characteristics) are plainly proactive; while others, such as monitoring of non-conforming materials reports (NCMRs), reviewing for unacceptable trends, and monitoring corrective action effectivity are plainly reactive (Taylor, 1998). Consequently, separation of the two concepts is frequently more than a matter of being conscious of the difference, it is a subjective matter of opinion based on experience.

Summary

There is a difference between actions taken to prevent problem occurrence and actions taken to prevent problem recurrence. The former is the result of proactive measures, the latter is a result of reactive measures.

It is difficult to financially quantify (put the value in the language of upper management: money (Juran, 1982)) the value of actions taken to prevent occurrence, since management never sees the failures.

It is easy to quantify the financial value of actions taken to prevent recurrence; all of Six Sigma has been established to provide that calculation (Breyfogle, 2003).

As a result of the division of the elements of the Juran Trilogy, quality engineers are largely responsible for the proactive actions; six sigma black belts are largely responsible for the reactive elements.

It is widely accepted that true prevention is more cost effective than correction (Franklin; West, 2011). However, due to its ease of financial determination, correction is

anecdotally more widely accepted and rewarded. The aim of this research is to affirm or contradict the anecdotal information.

CHAPTER 3

METHODOLOGY

The intent of this study is to determine if, contrary to the established dogma that proactive actions to prevent occurrence of problems are far more economical, actions taken to correct and prevent recurrence of issues are recognized more readily and rewarded more highly. To complete this study, two separate quantitative analyses were performed; the intent of this method is to use the divergent analyses of each to mitigate biases and/or weakness of the other.

The intent of the separate but parallel approach is that collecting data from multiple sources provides a deeper understanding of the problem. Following this approach, the data was collected as follows:

- First, a survey was performed to determine methodologies and input from individuals familiar with the work and duties of both quality engineers (QEs) and six sigma black belts (SSBBs). This was performed on site at the ASQ World Conference in Fort Worth, Texas in May 2019, using members of the Quality Management Division, ASQ's largest division;
- Second, a Delphi Study was conducted to provide theoretical responses to the duties and expectations of QEs and SSBBs, as well as provide a cross-reliability and validity check with the survey, during the annual meeting of the ASQ Certification Board at ASQ World Conference, using the members of the Certification Board as the oracles.

- Finally, a comparison of salary data as gathered and published by the American Society for Quality (ASQ) in the annual ASQ Salary Survey, for equivalent levels of those two job titles, using the mean and standard deviation data presented for the past four (4) years.

Restatement of the Problem

The problem of this study is to determine if corrective actions are recognized and rewarded more than preventive actions, even though the opposites manner of operation would provide greater costs savings and thereby enable greater efficiency.

Restatement of the Research Questions

- Which of these two actions (preventive and corrective actions) does organizational quality management purport to value more highly?
- Which of these two actions does organizational quality management demonstrate to value more highly?
- Should a statistically significantly significant disparity between management's purported values and demonstrated values regarding preventive and corrective actions be determined, to determine correction for that disparity, what root-cause factors contribute??
- Do any well-known quality models describe or explain these results?

Review of the literature suggests Quality Management is aware, at least at an intellectual level, that preventive actions are preferable to corrective actions. However, it also suggests that that there is significant confusion within the Quality Assurance community regarding the true nature of preventive actions.

By definition, Management is responsible for subordinate organizational policies. Therefore, Quality Management is responsible for Quality organizational policies.

Delphi Study

A Delphi Study is a method of utilizing experts as advisors in decision making. It possesses three (3) specific characteristics:

- Anonymous response,
- Iteration and controlled feedback, and;
- Statistical group response.

The concept was introduced by The Rand Corporation for the U. S. Air Force (Dalkey, 1969).

For this study the experts used were those responsible for the development and implementation of the BoKs of the ASQ Global Certifications Examinations: the ASQ Certification Board (hereafter, "The Oracles"). The five items to be resolved were:

- What are the preferred tools for determination and implementation of corrective actions (actions to prevent recurrence of problems)?
- What are the preferred tools for determination and implementation of preventive actions (actions to prevent occurrence of problems)?
- How does an organization best assess the financial value of actions to prevent recurrence of problems?
- How does an organization best assess the financial value of actions to prevent occurrence of problems?
- What are the best Quality Assurance models currently in use that may describe the various common Quality Assurance job descriptions?

The purpose of the Delphi study was to use expert opinion to: establish the definitional bases for, and provide validity and reliability to, the survey results.

Survey

A survey was administered to the attendees at the national meeting of the ASQ Quality Management Division (QMD) at the ASQ World Conference in Fort Worth, Texas in May 2019. While a minimum number of one hundred (100) respondents was expected, inclement weather in the area at the time of the meeting (the meeting was conducted in a building across the street from the conference hotel) limited the number of respondents to eighty (80).

This data was gathered at this meeting, to mitigate low survey response rate levels seen for surveys administered remotely:

- The survey was administered manually and in person,
- During a period specifically designated for completing the survey.
- In accordance with the requirements of Indiana State Institutional Review Board, the survey was administered at the end of the meeting, after a short break, to allow those that did not wish to respond to leave,
- In accordance with the Indiana State Institutional Review Board, none of those assisting in the distribution and collection of the surveys were members of the Quality Management Division Executive committee.
- Finally, while the survey sponsor (this author) is the former chair of the QMD's signature certification exam (the ASQ Certified Manager of Quality and Organizational Excellence [CMQ/OE]), the credentials reported to the respondents was that the survey sponsor was a graduate student performing research, as required by the Indiana State Institutional Review Board.

The survey flow was as follows:

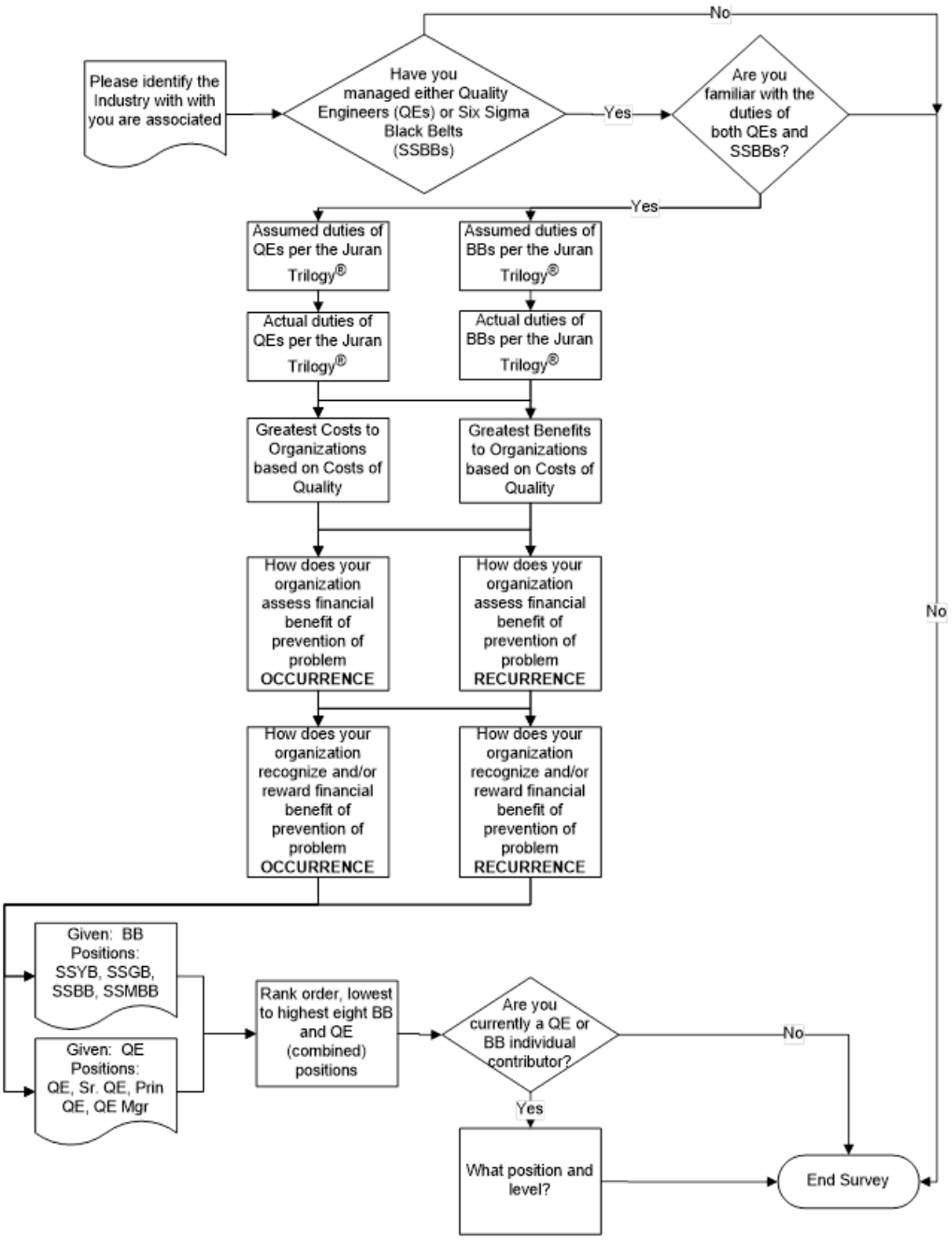

Figure 2: Survey Flow Chart

The questions were designed in parallel to reduce inter-item bias:

- For each item requesting information regarding quality engineers, there is a parallel item, using identical wording, requesting the same information regarding six sigma black belts.

- For the item requesting information regarding financial costs related to costs of quality, there is a parallel item requesting information regarding financial benefits related to costs of quality.
- For items requesting information about the financial gains from actions taken to prevent problem occurrence ("cost avoidance"), there is a parallel item, using identical wording (with the exception of the respectively appropriate terms: "cost avoidance" vs. "cost savings"), requesting information about the financial gains from actions taken to prevent recurrence ("cost savings").
- All other wording is identically parallel.

The penultimate question requests the respondent to rank order, from lowest to highest, the combined four common Six Sigma job descriptions, and the four common Quality Engineering job descriptions, each with three ascending levels of individual contributors, and one first level manager.

The final set of questions asks the respondent if (s)he is currently in the position as an individual contributor, and if so, the job description that best describes them. This information may be used as a delimiter.

As the accessible population is relatively small when compared to the overall population (i.e., the quality managers, representing multiple countries, attending the ASQ World Conference compared to the unknown number of quality managers in the world), and there is no evidence that the accessible population is representative of the theoretical population, every participant of the accessible population was asked to participate. This is, in accordance with Gliner, Morgan & Leech, a **convenience sample**. (Gliner, Morgan, & Leech, 2009)

The manual application of the survey presented several unforeseen events:

- While the intent of the survey flow chart (noted above) was to disqualify those respondents that either had not managed QEs or SSBBs, or were not familiar with their duties, there was no functionality, as exists in a computer-administered survey, to prevent them from responding to all the survey questions anyway. Consequently, for those that were not so qualified, but answered the survey anyway, the necessary items' disqualifications occurred during the post hoc analysis of the respondent data (see Chapter 4).
- For the manually administered survey, there was also a lack functionality to limit the number responses for an item where only one response was requested. For the items in which only one response was requested and multiple were received, those responses were disqualified during analysis. This created slight discrepancies in the total numbers of responses to some items.
- The survey item which rank ordered four (4) position ascending titles of a Quality Engineering organization:
    - Quality Engineer,
    - Principal Quality Engineer,
    - Quality Engineering Manager, and;
    - Senior Quality Engineering Manager

  and four ascending position titles of a Six Sigma organization:
    - Six Sigma Yellow Belt,
    - Six Sigma Green Belt,
    - Six Sigma Black Belt, and;
    - Six Sigma Master Black Belt,

was intended to allow for level comparisons between the two organizational entities. However, in several cases, the respondents seemed to provide the ranking in reverse order. To determine if this were the case for each respondent, comparisons of job titles within each of the two organizations were performed. Four criteria were used, as follows:

- Did the respondent rank a **Quality Engineer** (the nominally lower ranking position) ***higher*** than a **Principal Quality Engineer** (the nominally higher-ranking position)?
- Did the respondent rank a **Quality Engineering Manager** (the nominally lower-ranking position) ***higher*** than a **Senior Quality Engineering Manager** (the nominally higher-ranking position)?
- Did the respondent rank a **Six Sigma Green Belt** (the nominally lower-ranking position) ***higher*** than a **Six Sigma Black Belt** (the nominally higher-ranking position)?
- Did the respondent rank a **Six Sigma Black Belt** (the nominally lower-ranking position) ***higher*** than a **Six Sigma Master Black Belt** (the nominally higher-ranking position)?

If the answer to two (2) or more of these four questions was yes, the respondent was judged to have rank-ordered the positions in reverse order; the rankings for each applicable respondent were reversed, allowing for overall comparisons of all respondents to be made consistently.

ASQ Salary Survey

The ASQ Salary Survey is taken once every year, with significant data analyzed, summarized and presented in Quality Progress Magazine. The salary data comparing the equivalent level of six sigma black belts and quality engineers was analyzed for statistically significant differences.

Reflexivity

Although the analyses listed above are nominally quantitative, there exists the possibility of the influence of researcher bias, based on the author's long experience in the Quality Assurance field. To minimize that effect, the Delphi study was administered. The results of the Delphi study serve, as noted above, to provide validity and reliability to the survey results. (Creswell, 2014)

Addressing the Research Questions

Research questions were addressed as follows:

Research Question 1: "Which of these two actions [prevention v. correction] does organizational quality management prescribe to value more highly?"

Survey items 4 and 5 asked the respondents to theoretically classify the duties of both quality engineers and six sigma black belts using the three processes of the Juran trilogy, items 6 and 7 asks the respondent to classify the duties of the two positions from an actual standpoint.

Survey items 8 and 9 asked the respondent to identify how which actions related to costs of quality incur the greatest costs and benefits respectively to organizations. Items 10 and 11 asked the respondents to identify how organizations assess the financial benefits of preventive vs corrective actions, and items 12 and 13 asked the respondent to identify how organizations recognize and reward those actions.

Using these results together, the actions of prevention and correction can be associated with the appropriate positions in both theory (in the responses to items 4 and 5) and in practice (the responses to items 6 and 7), and with which types of actions are

perceived to provide the greatest benefit and incur the greatest costs (from the responses to items 8 and 9).

Research Question 2: "Which of these two actions [prevention v. correction] does organizational quality management demonstrate to value more highly?"

As above, once the responses to items 4 – 7 have associated actions of prevention correction with specific positions, responses to items 12 and 13 provide information as to how organizations actually recognize and reward such actions.

In addition, the results of the ASQ Salary Survey for the past four years were compared, using applicable hypothesis testing to determine which of parallel levels between quality engineering and six sigma positions are more highly paid.

Research Question 3: "Should a disparity exist between prescription and demonstration; what factors contribute to that disparity?"

Once research questions one and two are answered, a simple comparison of those results using applicable hypothesis testing will demonstrate whether they are inconsistent. If so, the responses to survey items 10 and 11 shall be used to determine the ability to assess the benefits of preventive v. corrective actions to address the possible reasons. In addition, the responses to Delphi items 1 – 4 which address the correct tools to use to assess the financial benefits of preventive and corrective actions, as well as organizations theoretical ability to use those tools shall provide best case information regarding the disparity.

If no disparity is found, this research question is null.

Research Question 4: "Do any well-known quality models describe or explain these results?"

This question was to be answered by Delphi item number 5: The Oracles are the best source of current quality models and their use throughout industry. Consequently, their knowledge was to be utilized. Unlike Research Question 3, this question was not to be nullified should no disparity exist between Research Questions 1 and 2.

CHAPTER 4

FINDINGS AND ANALYSIS

Overview

This chapter describes the results of the data collected from the three (3) data sources:

- The Survey of the ASQ Quality Management Division,
- The Delphi Study of the ASQ Certification Board, and;
- The results of the ASQ Salary Survey for the past four (4) years, for the position titles Quality Engineer (QE) and Six Sigma Black Belt (SSBB),

and how the analyzed data integrates.

The Survey

The survey asked the members of the Quality Management Division questions regarding the theoretical and actual duties of the two positions, from a point of view of individuals that were not performing those functions, but were either familiar with both functions and had, at some time, possibly managed those functions. In this manner, self-reporting bias was minimized.

The first three questions were to provide administrative identification of the respondent for data sorting. They were:

- Identification of the current industry of the respondent,
- Identification as to whether the respondent had managed either QEs or SSBBs, and;
- Identification as to whether the respondent was familiar with the duties of both QEs and SSBBs.

The results for the following items shall be presented in two formats, as follows: Personnel that are familiar with the two positions, separated by industry, and personnel that have managed QEs or SSBBs, separated by industry.

The first two non-administrative items dealt with the theoretical categorization of duties of QEs and SSBBs in terms of the Juran trilogy: Planning, Control or Improvement. Tables 2 - 5 show the results of these item for Managers and for those familiar with the duties of SSBBs and QEs.

Table 2: Managers' view of Theoretical Duties of QEs, by Industry

		Juran Trilogy Category		
Industry	**Respondents**	**Plan**	**Control**	**Improve**
Aerospace	5	4	0	1
Commercial	5	3	2	0
Defense	1	0	1	0
Education	2	1	1	0
FDA Reg Health Care	5	1	3	1
Non-FDA Reg Health Care	3	1	2	0
Other	20	6	8	6
Total	41	16	17	8
Percentages		39.02%	41.46%	19.51%

Table 3: Views of those Familiar with Theoretical Duties of QEs, by Industry

		Juran Trilogy Category		
Industry	**Respondents**	**Plan**	**Control**	**Improve**
Aerospace	7	4	1	2
Commercial	6	4	2	0
Defense	1	1	0	0
Education	3	2	1	0
FDA Reg Health Care	10	3	4	3
Non-FDA Reg Health Care	3	0	3	0
Other	28	12	10	6
Total	58	26	21	11
Percentages		44.83%	36.21%	18.97%

Of the 41 respondents that had managed either of the two positions, the view of QEs theoretical duties held that 80.48% of those duties concerned either planning or control; for those that listed themselves as familiar with the theoretical duties, a very similar 81.03 % held those duties to be either planning or control.

Table 4: Managers' view of Theoretical Duties of SSBBs, by Industry

		Juran Trilogy Category		
Industry	**Respondents**	**Plan**	**Control**	**Improve**
Aerospace	4	0	1	3
Commercial	5	1	0	4
Defense	1	0	0	1
Education	2	0	0	2
FDA Reg Health Care	6	0	0	6
Non-FDA Reg Health Care	3	1	0	2
Other	21	4	1	16
Total	42	6	2	34
Percentages		14.29%	4.76%	80.95%

Table 5: Views of those Familiar with Theoretical Duties of SSBBs, by Industry

		Juran Trilogy Category		
Industry	**Respondents**	**Plan**	**Control**	**Improve**
Aerospace	6	1	2	3
Commercial	6	1	0	5
Defense	1	0	0	1
Education	3	0	0	3
FDA Reg Health Care	12	0	0	12
Non-FDA Reg Health Care	3	0	0	3
Other	29	4	1	24
Total	60	6	3	51
Percentages		10.00%	5.00%	85.00%

Of the 42 respondents that had managed either of the two positions, the view of SSBBs theoretical duties held that 80.95% of those duties concerned improvement; for the 60

respondents that listed themselves as familiar with the theoretical duties, a somewhat greater percentage of 85.00 % held those duties to be improvement.

The next two survey items dealt with the actual categorization of duties of QEs and SSBBs in terms of the Juran trilogy. Tables 6 - 9 shows the results of this item for those familiar with the duties of SSBBs and QEs.

Table 6: Managers' view of Actual Duties of QEs, by Industry

		Juran Trilogy Category		
Industry	**Respondents**	**Plan**	**Control**	**Improve**
Aerospace	5	1	3	1
Commercial	5	2	2	1
Defense	1	1	0	0
Education	2	1	1	0
FDA Reg Health Care	5	0	5	0
Non-FDA Reg Health Care	3	0	1	2
Other	19	6	6	7
Total	40	11	18	11
Percentages		27.50%	45.00%	27.50%

Table 7: Views of those Familiar with Actual Duties of QEs, by Industry

		Juran Trilogy Category		
Industry	**Respondents**	**Plan**	**Control**	**Improve**
Aerospace	7	1	4	2
Commercial	6	2	3	1
Defense	1	1	0	0
Education	3	2	1	0
FDA Reg Health Care	10	0	8	2
Non-FDA Reg Health Care	3	0	1	2
Other	27	8	11	8
Total	57	14	28	15
Percentages		24.56%	49.12%	26.32%

Of the 40 manager respondents that answered this item, 72.50% held that QEs actual duties concerned either planning or control. For the 57 (Table 7 shows 57) respondents that

listed themselves as familiar with the actual duties of a QE, a similar 73.68% held that QEs actual duties concerned either planning or control.

Table 8: Managers' view of Actual Duties of SSBBs, by Industry

		Juran Trilogy Category		
Industry	**Respondents**	**Plan**	**Control**	**Improve**
Aerospace	4	1	0	3
Commercial	5	1	0	4
Defense	1	0	0	1
Education	2	1	0	1
FDA Reg Health Care	6	0	0	6
Non-FDA Reg Health Care	3	0	0	3
Other	21	4	1	16
Total	42	7	1	34
Percentages		16.67%	2.38%	80.95%

Table 9: Views of those Familiar with Actual Duties of SSBBs, by Industry

		Juran Trilogy Category		
Industry	**Respondents**	**Prevent**	**Control**	**Improve**
Aerospace	6	1	1	4
Commercial	6	1	1	4
Defense	1	0	0	1
Education	3	1	0	2
FDA Reg Health Care	12	1	1	10
Non-FDA Reg Health Care	3	1	0	2
Other	29	5	2	22
Total	60	10	5	45
Percentages		16.67%	8.33%	75.00%

Of the 42 manager respondents that answered this item, 80.95% held that SSBBs actual duties concerned improvement. For the 60 respondents that listed themselves as familiar with the actual duties of a SSBB, a slightly fewer (75.00%) held that SSBBs actual duties concerned improvement.

The next two survey items asked which of the four quality costs:

- Prevention,

- Assessment,
- Internal Failure, and;
- External Failure,

afforded the greatest financial costs and greatest financial benefits to an organization. As these items did not require assessment of the duties of QEs and SSBBs, the views of all respondents were considered. Tables 10 and 11 provide the results.

Table 10: Quality Cost Actions that Afford the Greatest Financial Costs to Organizations, by Industry.

		Quality Cost Action Category			
Industry	**Respondents**	**Prevent**	**Assess**	**Int Fail**	**Ext Fail**
Aerospace	8	0	0	3	5
Commercial	6	0	0	1	5
Defense	2	0	0	0	2
Education	4	1	0	1	2
FDA Reg Health Care	14	1	0	4	9
Non-FDA Reg Health Care	5	1	0	2	2
Other	32	6	5	3	18
Total	71	9	5	14	43
Percentages		12.68%	7.04%	19.72%	60.56%

Table 11: Quality Cost Actions that Afford the Greatest Financial Benefits to Organizations, by Industry

		Quality Cost Action Category			
Industry	**Respondents**	**Prevent**	**Assess**	**Int Fail**	**Ext Fail**
Aerospace	8	7	1	0	0
Commercial	6	6	0	0	0
Defense	2	2	0	0	0
Education	4	4	0	0	0
FDA Reg Health Care	14	12	2	0	0
Non-FDA Reg Health Care	4	3	0	0	1
Other	32	29	1	2	0
Total	70	63	4	2	1
Percentages		90.00%	5.71%	2.86%	1.43%

Table 10 shows that 80.28% (19.72 + 60.56) of the respondents held that of the quality costs categories, actions related to failures (internal and external) constituted the greatest

financial costs to an organization, while 90% of the respondents held that actions related to prevention constituted the greatest financial benefits to an organization.

The next two survey items dealt with how organizations assessed the financial benefits of actions dealing with prevention of problem occurrence (truly preventive actions) and actions dealing with prevention of recurrence (truly corrective actions). For these two items, respondents were asked to list multiple applicable methods, consequently the values are responses, not respondents. Tables 12 and 13 detail those results.

Table 12: Organizational Methods Used to Assess the Financial Benefits of Preventive Actions, by Industry

Industry	Responses	Risk Based Calcs, e.g. FMEA	Comparing w/External Results	Comparing W/Internal Results	Models e.g. PDCA, DMAIC	Internal Finance Model	Do not Assess	Other
Aerospace	10	3	0	3	1	1	2	0
Commercial	7	1	1	0	1	0	3	1
Defense	3	1	0	0	1	0	1	0
Education	7	1	0	1	2	1	2	0
FDA Reg Health Care	17	5	1	4	2	2	2	1
Non-FDA Reg Health Care	7	1	2	2	0	1	1	0
Other	53	15	6	14	7	4	5	2
Total	104	27	10	24	14	9	16	4
Percentages		25.96%	9.62%	23.08%	13.46%	8.65%	15.38%	3.85%

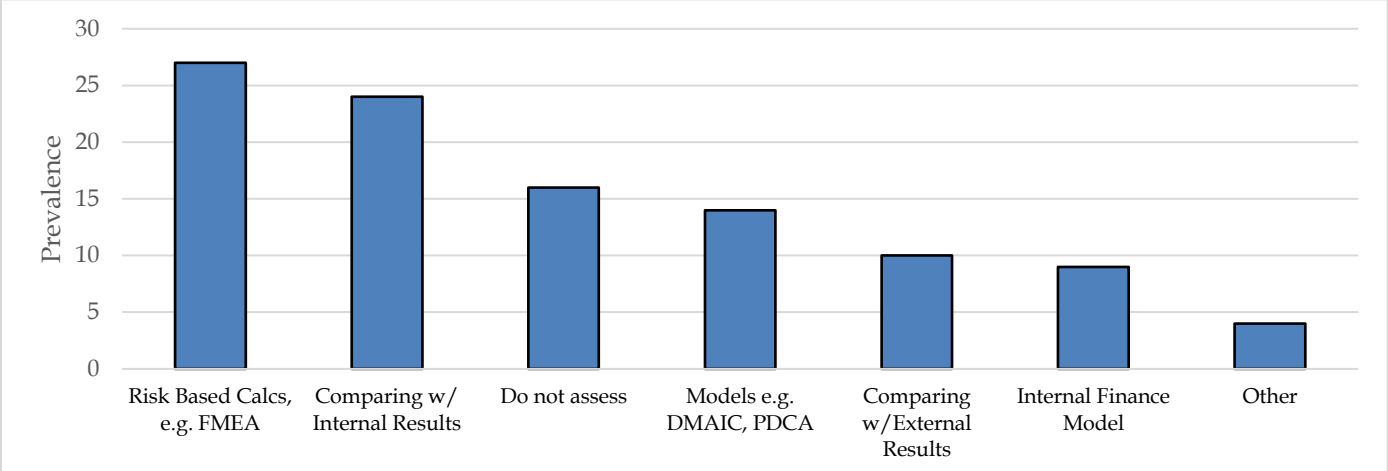

Figure 3: Pareto Chart of Financial Assessment Method of Preventive Actions

Table 13: Organizational Methods Used to Assess the Financial Benefits of Corrective Actions, by Industry

Industry	Responses	Risk Based Calcs, e.g. FMEA	Comparing w/External Results	Comparing W/Internal Results	Models e.g. PDCA, DMAIC	Internal Finance Model	Do not Assess	Other
Aerospace	10	0	1	4	2	1	2	0
Commercial	5	1	0	2	1	0	0	1
Defense	5	2	0	0	1	1	0	1
Education	5	1	0	2	0	1	1	0
FDA Reg Health Care	15	1	1	4	5	1	3	0
Non-FDA Reg Health Care	8	1	2	1	2	1	1	0
Other	47	9	5	18	3	4	6	2
Total	95	15	9	31	14	9	13	4
Percentages		15.79%	9.47%	32.63%	14.74%	9.47%	13.68%	4.21%

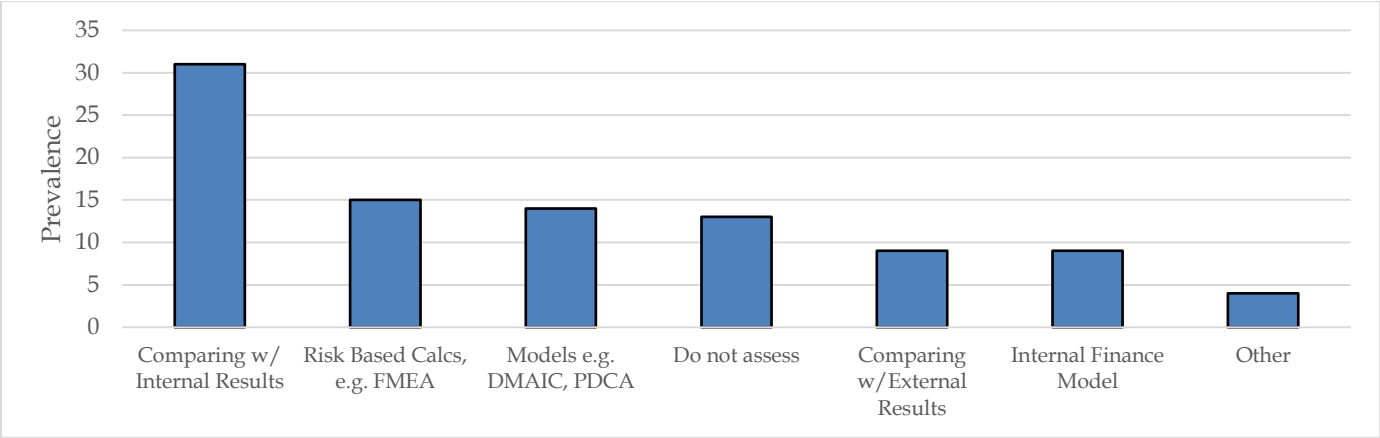

Figure 4: Pareto Chart of Financial Assessment Method of Corrective Actions

It is important to note that the most prevalent actions used to assess the financial impact of both preventive and corrective actions are using Risk-Based Calculations such as in a failure mode and effects analysis and comparison with internal results, with the risk-based calculation method the most prevalent method for prevention, and second most prevalent for correction. In addition, for preventive actions, the third most frequent response was that the financial value was not assessed.

The next two survey items dealt with how organizations recognized and/or rewarded the financial benefits of actions dealing with prevention of problem occurrence (truly preventive actions) and actions dealing with prevention of recurrence (truly corrective actions). For these two items, respondents were asked to list multiple applicable methods, consequently the values are responses, not respondents. Tables 14 and 15 detail those results.

Table 14: Organizational Methods Used to Recognize and Reward Preventive Actions, by Industry

Industry	Responses	Monetary Award	Monetary Award + Public Recognition	Hawthorne Model	Job Assessment: Exceeds Expectations	None: Prevention is a Job Description	Other
Aerospace	10	0	1	3	3	2	1
Commercial	6	0	0	0	1	4	1
Defense	2	0	0	0	0	2	0
Education	5	1	0	2	0	2	0
FDA Reg Health Care	17	2	4	2	2	6	1
Non-FDA Reg Health Care	5	0	0	1	1	3	0
Other	40	1	1	12	6	16	4
Total	85	4	6	20	13	35	7
Percentages		4.71%	7.06%	23.53%	15.29%	41.18%	8.24%

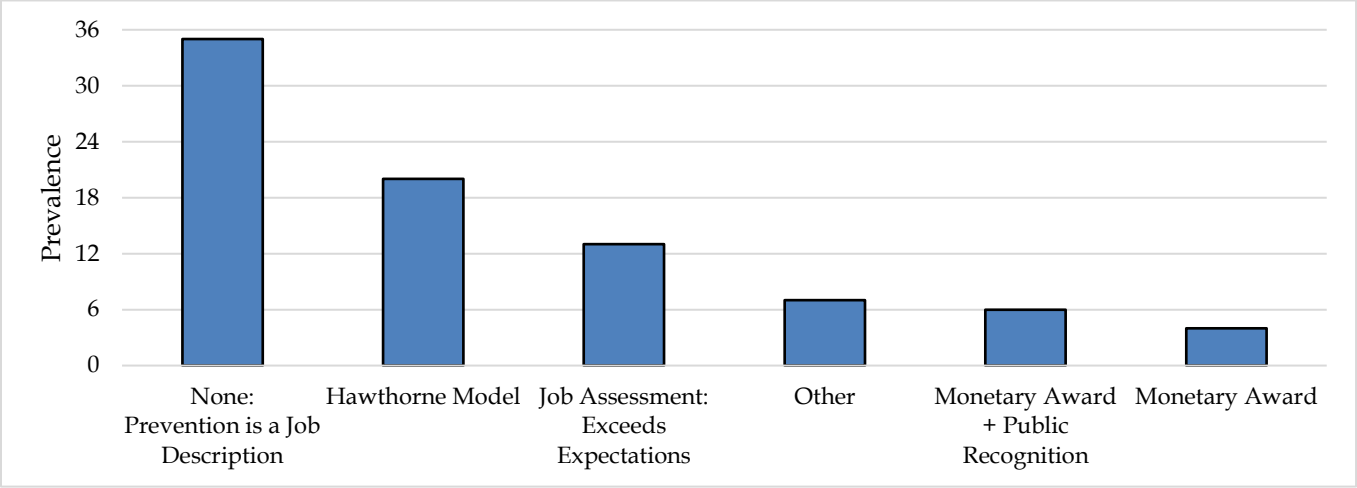

Figure 5: Pareto Chart of Recognition/Reward Methods of Preventive Actions

Table 15: Organizational Methods Used to Recognize and Reward Corrective Actions, by Industry

Industry	**Responses**	Monetary Award	Monetary Award + Public Recognition	Hawthorne Model	Job Assessment: Exceeds Expectations	None: Correction is a Job Description	Other
Aerospace	10	0	0	3	3	3	1
Commercial	6	0	1	0	3	2	0
Defense	2	0	0	0	0	2	0
Education	4	1	1	0	0	2	0
FDA Reg Health Care	14	1	2	3	0	7	1
Non-FDA Reg Health Care	5	0	0	0	1	4	0
Other	24	1	1	11	8	0	3
Total	65	3	5	17	15	20	5
Percentages		4.62%	7.69%	26.15%	23.08%	30.77%	7.69%

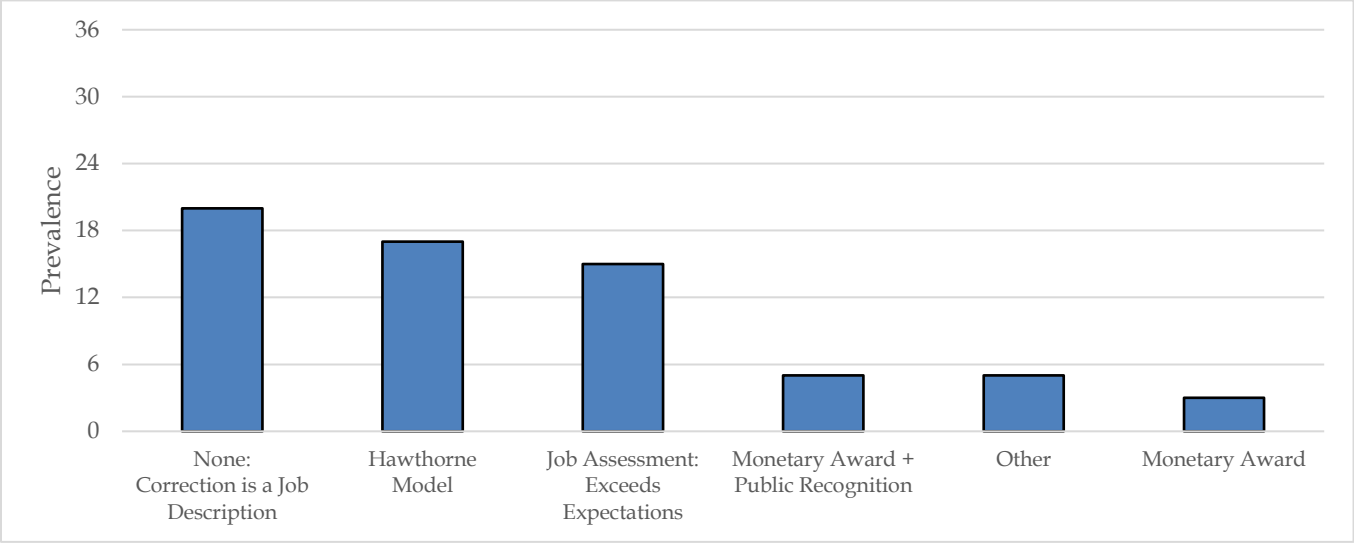

Figure 6: Pareto Chart of Recognition/Reward Methods of Corrective Actions

The final non-administrative survey item asked the respondents to provide their perceived rank order, from lowest to highest relative ranking, of four (4) relatively common positions in a quality assurance organizational structure: Quality Engineer, Principal Quality Engineer, Quality Engineering Manager and Senior Quality Engineering Manager; and four relatively common positions in a Six Sigma organizational structure: Six Sigma Yellow Belt, Six Sigma Green Belt, Six Sigma Black Belt, and Six Sigma Master Black Belt. While eight total

position titles were compared for this item, the item's true purpose was to compare the relative perception of ranking between quality engineers and six sigma black belts; the additional position titles included were used as camouflage for the true purpose. In addition, it was fortuitous that the additional position titles enabled necessary sorting information to determine if the rankings were reversed (as noted and described in Chapter Three, an analysis to determine whether the respondent ranked the positions in reverse order was performed. This allowed the rankings that were listed in reverse order, to be corrected), using an equal number of representative positions for both types of organizations listed. Seventy-two (72) respondents made the comparison between QEs and SSBBs.

While this item used ordinal data, the concept of relative ranking, the large sample size (n=72) and the effects of the central limit theorem (that the means of all distributions approach normality as the sample sizes increase) affords its use as interval data. Consequently, the responses were arranged as whole integers from one (lowest) to eight (highest) with the perceived data calculated as average values.

The relative rankings, as interval data are as follows:

Table 16: Relative Perceived Rankings of four QE positions and four Six Sigma positions

Position	Integer Rank (1 – 8)	Relative Ranking
Senior QE Manager (SR QE MGR)	8	6.514
Six Sigma Master Black Belt (SSMBB)	7	6.375
QE Manager (QE MGR)	6	5.639
Principal QE (Prin QE)	5	5.250
Six Sigma Black Belt (SSBB)	4	4.667
Quality Engineer (QE)	3	3.028
Six Sigma Green Belt (SSGB)	2	2.500
Six Sigma Yellow Belt (SSYB)	1	1.625

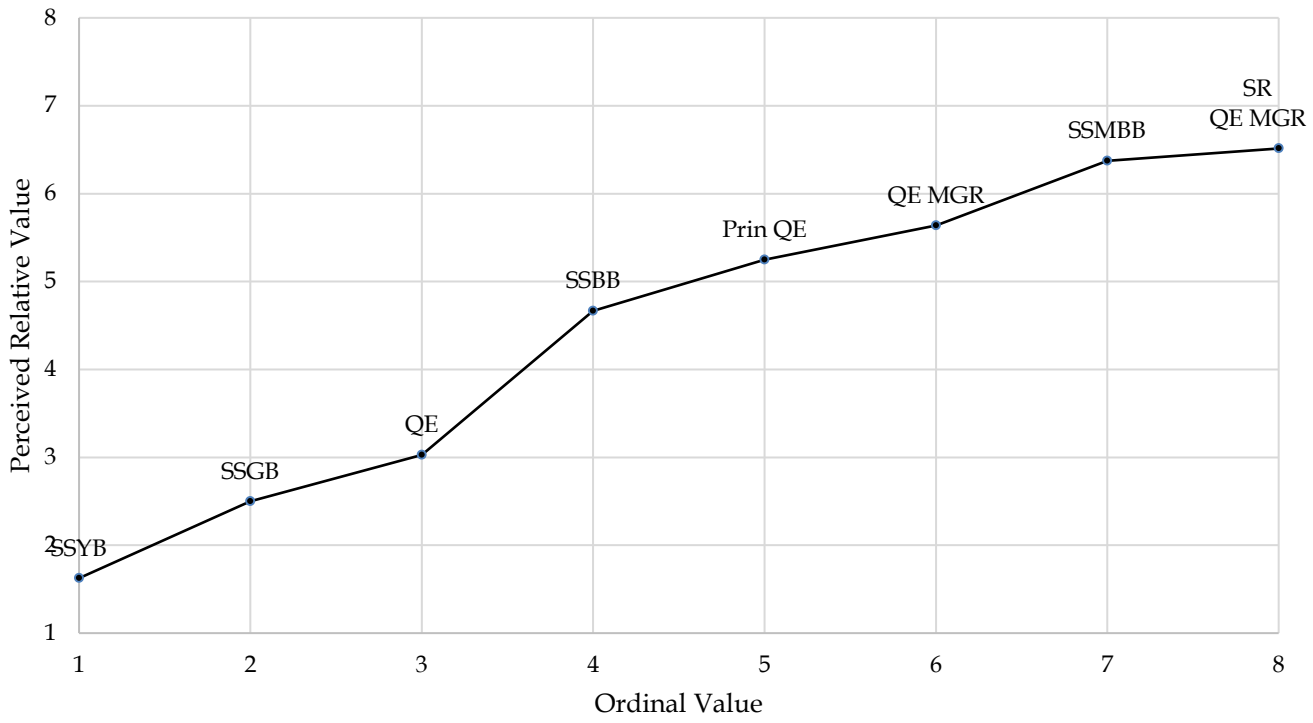

Figure 7: Relative Perceived Rankings of Positions

It is important to note that the largest step between positions is that between Quality Engineer (3.028 perceived ranking) and Six Sigma Black Belt (4.437 perceived ranking), the comparison of interest for this work.

The Delphi Study

The Delphi Study asked five (5) questions: They were:

- What are the preferred tools for determination and implementation of corrective actions (actions to prevent recurrence of problems)?
- What are the preferred tools for determination and implementation of preventive actions (actions to prevent occurrence of problems)?
- How does an organization best assess the financial value of actions to prevent recurrence of problems?
- How does an organization best assess the financial value of actions to prevent occurrence of problems?
- What are the best Quality Assurance models currently in use that may describe the various common Quality Assurance job descriptions?

The study concluded the annual meeting of the ASQ Certification Board (18 May 2019), using the chairs of the ASQ Certification Examinations (the people that control the Bodies of Knowledge [BoKs] for all ASQ Certifications, as the oracles.

As per accepted practice, the study was performed by asking each one of the questions, publishing the responses without attribution to the oracles for their consideration, asking that question again, again publishing the responses without attribution to the oracles for their consideration, and asking the question a third time (if required). The response in the final round were recorded as the consensus response, and a vote was taken of the members to verify consensus.

The final results of the five Delphi Study items were as follows (Please see Appendix D for the results from each round):

- **Question 1**: What are the preferred tools for determination and implementation of corrective actions (actions to prevent recurrence of problems)?

  Consensus Response:

  - Root cause tools (e.g., 5-Why analyses, Fish-bone Diagrams, Brainstorming),
  - Implementation Plan (e.g., RACI, Tasks, schedule, Effectiveness [Validation &Verification] check, Business Cases and Budgets, VOC),
  - Record of the plan being implemented, Plan vs. Actual, with management reporting.

- **Question 2**: What are the preferred tools for determination and implementation of preventive actions (actions to prevent occurrence of problems)?

  Consensus Response:

  - Control Charts,
  - FMEAs,

  - Horizontal Lessons Learned,
  - Control plans,
  - Go & See,
  - Reliability Engineering,
  - Measurement Systems Analyses,
  - Risk Registers
  - Implementation Plans (e.g., RACI, Tasks, schedule, Effectiveness [Verification &Validation] checks, business case and budget, VOC),
  - Record of the plan being implemented,
  - Plan vs. Actual comparisons, with administrative reporting,
  - Prioritization Matrices,
  - Preventive Maintenance

- **Question 3**: How does an organization best assess the financial value of actions to prevent recurrence of problems?

  Consensus Response:

  - Failure Costs,
  - Cost Benefit Analyses.

- **Question 4**: How does an organization best assess the financial value of actions to prevent occurrence of problems?

  Consensus Response: Determine how much we'll spend to predict the prevention, but do not know the value of the problems prevented, with the exception of a comparison with a like event.

- **Question 5**: What are the best Quality Assurance models currently in use that may describe the various common Quality Assurance job descriptions?

  Consensus Response: None known.

The Salary Survey

ASQ performs an annual salary survey for its membership, based on several criteria. The comparison used for this work is that between the position titles of Quality Engineer and Six Sigma Black Belt. The pertinent data from the last four (4) years of surveys is as follows:

Table 17: ASQ Salary Survey Data ($US) for the United States for the Years 2015 – 2018 (Hansen, 2015), (Hansen, 2016), (Hansen, 2017), (Hansen, 2018)

	Year											
	2018			2017			2016			2015		
Position	n	Average	Std Dev	n	Average	Std Dev	n	Average	Std Dev	n	Average	Std Dev
QE	732	$84,944	$22,696	764	$85,974	$25,519	914	$83,991	$25,523	990	$82,124	$23,532
BB	77	$102,593	$24,536	96	$101,785	$33,357	109	$98,445	$24,120	140	$97,042	$22,813

CHAPTER 5

SUMMARY AND CONCLUSIONS

Restatement of the Problem

The problem identified in this study: Companies are losing significant money focusing on corrective actions vs preventive actions, therefore there is a need to determine the potential for significant cost savings. A quantitative method was used to determine if companies reward and recognize corrective actions more than preventive actions, encouraging associates to prioritize corrective actions, even though the opposite manner of operation may provide for greater cost savings and thereby enable greater efficiency. This method employed three (3) separate studies:

- A survey of the ASQ Quality Management Division members to determine and contrast their observations as to the theoretical and actual duties of quality engineers and six sigma black belts, the costs and benefits of actions taken to address the known Costs of Quality, and the rewards and recognition bestowed for affecting effective preventive and correction actions,
- A Delphi Study of the ASQ Certification Board to provide authoritative information regarding the tools and methods for affecting preventive and corrective actions, and;
- A review of published data to compare the salaries of quality engineers and six sigma black belts.

Summary of Data Analytical Methods

For comparison purposes, standard hypotheses testing of means was employed to determine level of statistical significance. The level of confidence employed was 95% (i.e., Type I risk = 0.05). The tests of hypotheses tests were two-tailed.

As the as the sample sizes in the survey broken down by industry are in many cases too small to allow for effective comparisons, the combined data was used for comparisons.

Restatement of the Research Questions

- Which of the two types of actions (preventive and corrective actions) does organizational quality management purport to value more highly?
- Which of these two types of actions (preventive and corrective actions) does organizational quality management demonstrate to value more highly?
- Should a statistically significant disparity between management's purported values and demonstrated values regarding preventive and corrective actions be determined, to determine correction for that disparity, what root-cause factors contribute?
- Do any well-known quality models describe or explain these results?

Summary of the Data Analysis

Research Question 1: "Which of the two actions [prevention v. correction] does organizational quality management prescribe more highly?"

Survey Items 4 and 5 asked respondents to theoretically classify the duties of both quality engineers and six sigma black belts using the three processes of the Juran Trilogy. The results of these items are found in Tables 2 – 5. Table 2 noted that 33 of the 41 management respondents classified the theoretical duties of QEs with either planning or control (those actions in the Juran Trilogy which identify with prevention); Table 4 noted that 6 of the 42

management respondents classified the theoretical duties of a black belt with either planning or control. A two sample proportions test notes:

Test and CI for Two Proportions

Method

p_1: proportion where Sample 1 = Six Sigma Black Belts

p_2: proportion where Sample 2 = Quality Engineers

Difference: $p_1 - p_2$

Descriptive Statistics

Sample	N	Event	Sample p
Six Sigma Black Belts	42	6	0.142857
Quality Engineers	41	33	0.804878

Test

Null hypothesis	$H_0: p_1 - p_2 = 0$
Alternative hypothesis	$H_1: p_1 - p_2 \neq 0$

Method	Z-Value	P-Value
Normal approximation	-8.06	0.000
Fisher's exact		0.000

Tables 3 and 5 noted similar results of the larger set of those familiar with duties of quality engineers and six sigma black belts; however, a comparative analysis was not performed, as this the research question queried managers.

Table 6 noted that 29 of the 40 management respondents classified the actual duties of QEs with either planning or control (those actions in the Juran Trilogy which identify with prevention); Table 8 noted that 8 of the 42 management respondents classified the theoretical duties of a black belt with either planning or control. A two sample proportions test notes:

Test and CI for Two Proportions

Method

p_1: proportion where Sample 1 = Six Sigma Black Belts

p_2: proportion where Sample 2 = Quality Engineers

Difference: $p_1 - p_2$

Descriptive Statistics

Sample	N	Event	Sample p
Six Sigma Black Belts	42	8	0.190476
Quality Engineers	40	29	0.725000

Test

Null hypothesis	$H_0: p_1 - p_2 = 0$
Alternative hypothesis	$H_1: p_1 - p_2 \neq 0$

Method	Z-Value	P-Value
Normal approximation	-5.75	0.000
Fisher's exact		0.000

Tables 7 and 9 noted similar proportions.

Survey Items 8 and 9 asked respondents to identify which actions related to costs of quality incur the greatest costs and benefits respectively to organizations. Table 10 notes that for cost to organizations, of 71 total respondents, 9 identified prevention, 5 identified assessment, and 57 identified failure (either external or internal). A chi-squared goodness of fit test demonstrates that failures are statistically significantly higher than the other two costs:

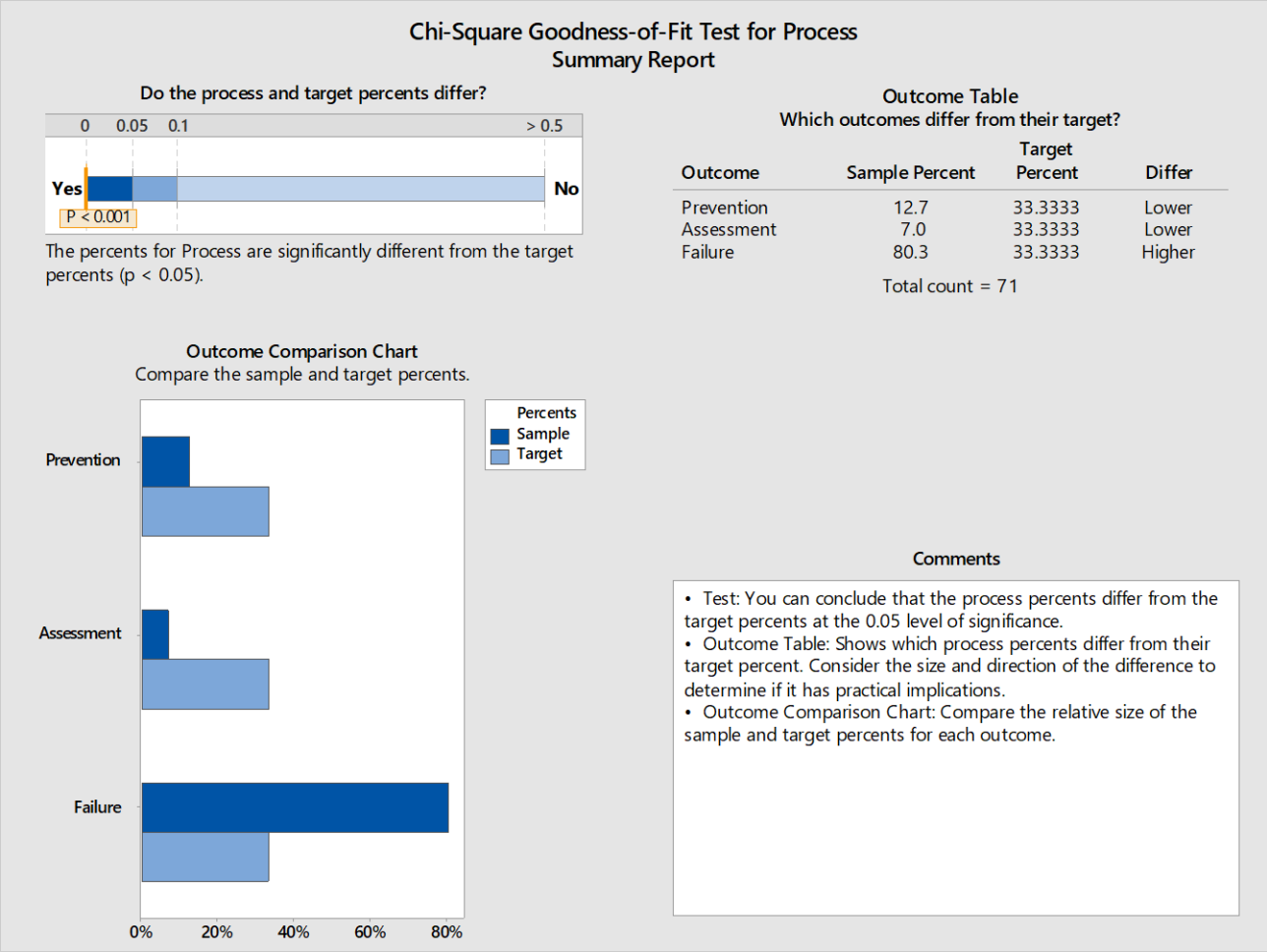

Figure 8: Chi-Squared Goodness of Fit Test Results for Highest Costs of Costs of Quality

Table 11 notes that for benefits to organizations, of 70 total respondents, 63 identified prevention, 4 identified assessment and 4 identified failure. A chi-squared goodness of fit test demonstrates that Prevention is statistically significantly lower than the other two costs:

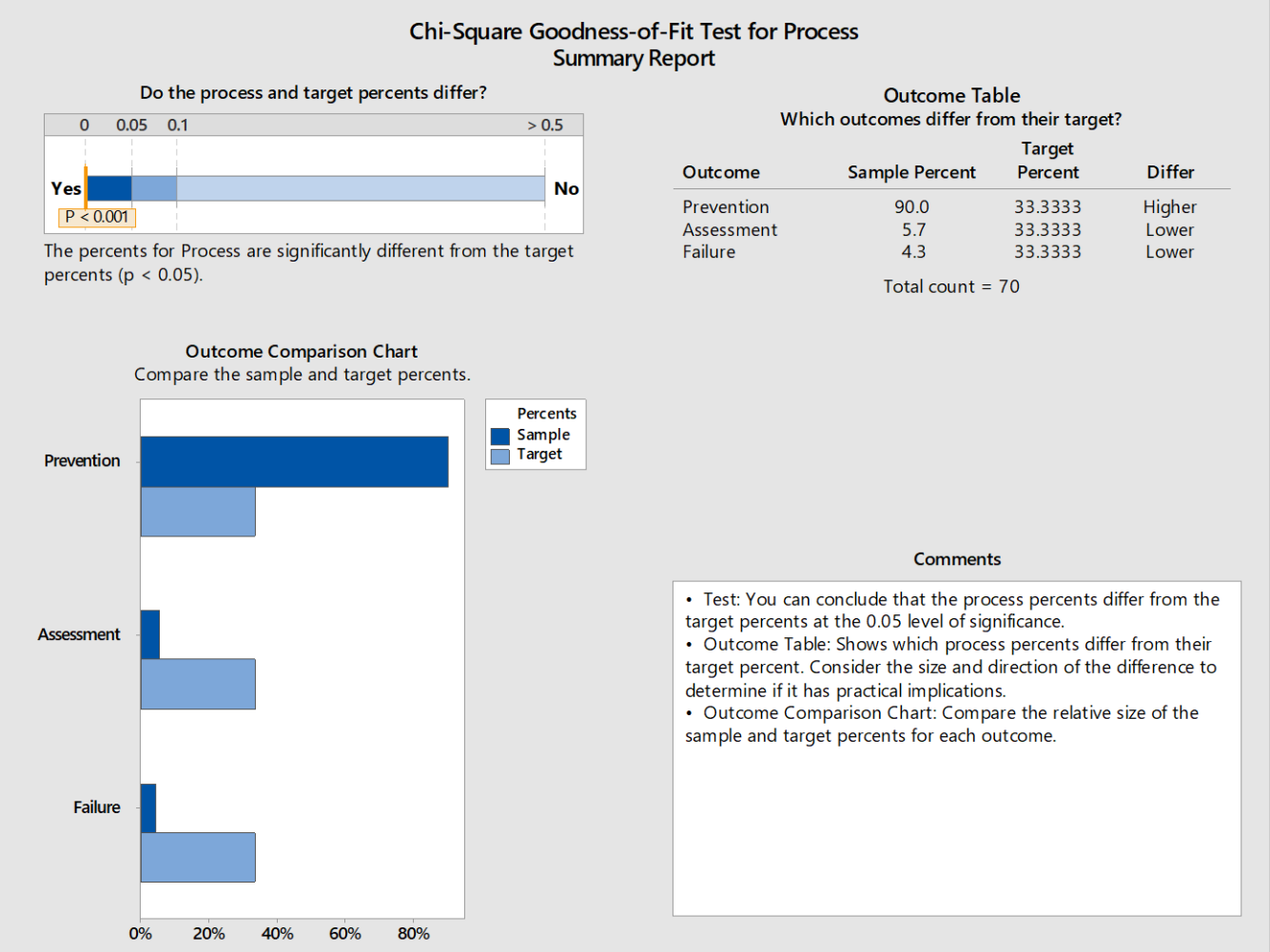

Figure 9: Chi-Squared Goodness of Fit Test Results for Greatest Benefit of Costs of Quality

Items 8 and 9 of the survey asked all respondents to identify which types of actions are used to assess the costs and benefits of preventive and corrective actions. The results of these items are found in Tables 12 and 13. There are no statistically significant differences between items within each table or between like causes comparing between costs and benefits between these tables.

Discussion of Research Question 1**:**

The results of the survey clearly differentiate (with statistically significant differences) the duties of a quality engineer, both theoretical and actual as those duties categorized with prevention, from those of a six sigma black belt, both theoretical and actual, as those duties that categorized as correction. Further, the survey results differentiate sources of greatest costs (failures) and greatest benefit (prevention).

The survey did not detect any statistically significant differentiation between the parallel methods used to assess, recognize and reward preventive actions and corrective actions.

Conclusion of Research Question 1**:**

Quality managers inherently understand the advantages of prevention over correction, and that prevention is largely the purview of quality engineers, whereas correction is largely the purview of six sigma back belts. However, they could not describe any differentiation in their actions in assessing the relative financial values of the two job functions or recognizing or rewarding them.

Research Question 2: "Which of these two types of actions (preventive and corrective actions) does organizational quality management demonstrate to value more highly?"

While, as noted above, the survey did not detect statistically significant differences between the individual methods within items, or the cost v. benefit values of like methods between items, the ASQ Salary Survey data, noted in Table 17, for the past four years reveals statistically significant differences. Comparisons by year are as follows:

For 2015, testing first for equal variances:

Test and CI for Two Variances, Year 2015

Method

σ_1: standard deviation of Quality Engineers

σ_2: standard deviation of Six Sigma Black Belts

Ratio: σ_1/σ_2

F method was used. This method is accurate for normal data only.

Descriptive Statistics

Sample	N	StDev	Variance	95% CI for σ
Sample 1	990	233532.000	5.45372E+10	(223679.208, 244299.532)
Sample 2	140	22813.000	5.20433E+08	(20417.478, 25850.392)

Test

Null hypothesis	$H_0: \sigma_1 / \sigma_2 = 1$
Alternative hypothesis	$H_1: \sigma_1 / \sigma_2 \neq 1$
Significance level	$\alpha = 0.05$

Method	Test Statistic	DF1	DF2	P-Value
F	1.06	989	139	0.654

As there is not sufficient cause to say the variances are not different, assume they are equal for the test of means.

For 2015, testing for difference in means:

Two-Sample T-Test and CI, Year 2015

Method

μ_1: mean of Quality Engineers

μ_2: mean of Six Sigma Black Belts

Difference: $\mu_1 - \mu_2$

Equal variances are assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Quality Engineers	990	82124	23532	748
Six Sigma Black Belts	140	97042	22813	1928

Test

Null hypothesis	$H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis	$H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-7.05	1128	0.000

Consequently, there is a statistically significant difference between the mean salary of a six sigma black belt and a quality engineer in 2015, and six sigma black belts were paid more.

For 2016, testing first for equal variances:

Test and CI for Two Variances, Year 2016

Method

σ_1: standard deviation of Quality Engineers

σ_2: standard deviation of Six Sigma Black Belts

Ratio: σ_1/σ_2

F method was used. This method is accurate for normal data only.

Descriptive Statistics

Sample	N	StDev	Variance	95% CI for σ
Sample 1	914	25523.000	6.51424E+08	(24404.206, 26750.103)
Sample 2	109	24120.000	5.81774E+08	(21287.678, 27828.553)

Test

Null hypothesis	$H_0: \sigma_1 / \sigma_2 = 1$
Alternative hypothesis	$H_1: \sigma_1 / \sigma_2 \neq 1$
Significance level	$\alpha = 0.05$

Method	Test Statistic	DF1	DF2	P-Value
F	1.12	913	108	0.462

As there is not sufficient cause to say the variances are not different, assume they are equal for the test of means.

For 2016, testing for difference in means:

Two-Sample T-Test and CI, Year 2016

Method

μ_1: mean of Quality Engineers

μ_2: mean of Six Sigma Black Belts

Difference: $\mu_1 - \mu_2$

Equal variances are assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Quality Engineers	914	83991	25523	844
Six Sigma Black Belts	109	98445	24120	2310

Test

Null hypothesis	$H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis	$H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-5.62	1021	0.000

Consequently, there is a statistically significant difference between the mean salary of a six sigma black belt and a quality engineer in 2016, and six sigma black belts were paid more.

For 2017, testing first for equal variances:

Test and CI for Two Variances, Year 2017

Method

σ_1: standard deviation of Quality Engineers

σ_2: standard deviation of Six Sigma Black Belts

Ratio: σ_1/σ_2

F method was used. This method is accurate for normal data only.

Descriptive Statistics

Sample	N	StDev	Variance	95% CI for σ
Quality Engineers	764	25519.000	6.51219E+08	(24300.445, 26867.180)
Six Sigma Black Belts	96	33357.000	1.11269E+09	(29213.717, 38880.600)

Test

Null hypothesis	$H_0: \sigma_1 / \sigma_2 = 1$
Alternative hypothesis	$H_1: \sigma_1 / \sigma_2 \neq 1$
Significance level	$\alpha = 0.05$

Method	Test Statistic	DF1	DF2	P-Value
F	0.59	763	95	0.000

As there is sufficient cause to say the variances are not different, assume they are not equal for the test of means.

For 2017, testing for difference in means:

Two-Sample T-Test and CI, Year 2017

Method

μ_1: mean of Quality Engineers

μ_2: mean of Six Sigma Black Belts

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Quality Engineers	764	85974	25515	923
Six Sigma Black Belts	96	101785	33357	3404

Test

Null hypothesis	$H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis	$H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-4.48	109	0.000

Consequently, there is a statistically significant difference between the mean salary of a six sigma black belt and a quality engineer in 2017, and six sigma black belts were paid more.

For 2018, testing first for equal variances:

Test and CI for Two Variances, Year 2018

Method

σ_1: standard deviation of Quality Engineers

σ_2: standard deviation of Six Sigma Black Belts

Ratio: σ_1/σ_2

F method was used. This method is accurate for normal data only.

Descriptive Statistics

Sample	N	StDev	Variance	95% CI for σ
Quality Engineers	732	22696.000	5.15108E+08	(21589.939, 23922.403)
Six Sigma Black Belts	77	24536.000	6.02015E+08	(21179.323, 29166.988)

Test

Null hypothesis	H_0: $\sigma_1 / \sigma_2 = 1$
Alternative hypothesis	H_1: $\sigma_1 / \sigma_2 \neq 1$
Significance level	$\alpha = 0.05$

Method	Test Statistic	DF1	DF2	P-Value
F	0.86	731	76	0.327

As there is not sufficient cause to say the variances are not different, assume they are equal for the test of means.

For 2018, testing for difference in means:

Two-Sample T-Test and CI, Year 2018

Method

μ_1: mean of Quality Engineers

μ_2: mean of Six Sigma Black Belts

Difference: $\mu_1 - \mu_2$

Equal variances are assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Quality Engineers	732	84944	22696	839
Six Sigma Black Belts	77	102593	24536	2796

Test

Null hypothesis	$H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis	$H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-6.44	807	0.000

Consequently, there is a statistically significant difference between the mean salary of a six sigma black belt and a quality engineer in 2018, and six sigma black belts were paid more.

Finally, survey Item 14 rank ordered the relative perceived ranking of quality engineers and six sigma black belts, along with three other position titles in each of the quality engineering and six sigma organizations. Those relative rankings are listed at Table 16 and Figure 7. Comparing the relative rankings of quality engineers and six sigma black belts:

Two-Sample T-Test and CI: Perceived Ranking: Quality Engineers, Six Sigma Black Belts

Method

μ_1: mean of Quality Engineers

μ_2: mean of Six Sigma Black Belts

Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Quality Engineers	72	3.03	1.33	0.16
Six Sigma Black Belts	72	4.67	1.45	0.17

Test

Null hypothesis	$H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis	$H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
-7.05	140	0.000

Consequently, there is a statistically significant difference between the perceived relative ranking of quality engineers and six sigma black belts, and six sigma black belts are perceived to have higher relative ranking.

Conclusion of Research Question 2:

While the survey respondents did not identify any statistically significant differences between the methods used to assess financial impacts or rewards either between preventive and corrective actions, or within either category, the comparative salaries of six sigma black belts and quality engineers indicate with statistical significance that six sigma black belts are paid more, consistently over a four-year period, and the relative ranking item on the survey indicates that six sigma black belts are perceived to have a statistically significantly higher relative ranking. However, it is important to mention Limitation 2 noted in Chapter One regarding the level of representation of the groups and sources from whom the data is gathered.

Research Question 3: "Should a statistically significant disparity between management's purported values and demonstrated values regarding preventive and corrective actions be determined, to determine correction for that disparity, what root-cause factors contribute?"

As noted above, survey items 10 and 11, the results for which are found in Tables 15 and 16 and figures 6 and 7, did not provide statistically significant differences either between like methods for preventive and corrective actions, or between different methods within each of the categories. However, the Delphi Study provides pertinent information.

The response to Delphi Study Item 1 listed the preferred tool for determination and implementation of corrective actions. That list is brief and well established; As noted in Chapter 2, the tools for corrective actions are well known to quality professionals.

The response to Delphi Study Item 2 listed the preferred tools for determination and implementation of preventive actions. That list is significant in both length and lack of

familiarity to quality professionals. During the discussion it was noted that many of the tools listed largely theoretical but sporadically used.

The response to Delphi Study Item 3 listed the preferred ways to assess the financial value of corrective actions. The list is significant in its brevity, and that the tools listed are reaction based, and consequently are quantitative, based on known costs.

Finally, the response to Delphi Study Item 4 was indicative of the problems inherent to assessing the financial values of preventive actions. The consensus response that, lacking a comparative event of known cost, there is no way to assess the financial value of preventive actions.

Conclusion of Research Question 3**:**

The Delphi Study and Survey provide interdependent validity and reliability, as their responses provide mutual support. Both instruments note that assessing the costs and value of preventive actions is difficult and that assessing the costs and value of corrective actions is rather straight forward. Ultimately, as quoted in Chapter 2, Juran's admonition that the language of management is money (Juran, 1982), and preventive actions cannot be easily financially quantified, even though quality managers understand them to be more cost effective. Consequently, managers concentrate on what they can quantify, and reward it accordingly.

Research Question 4: "Do any well-known quality models describe or explain these results?"

Unfortunately, the oracles could not find any well-known quality models to describe these results.

Conclusion of Research Question 4**:**

The primary conclusion of this research question is that a model to describe or explain these results wasn't known or considered. This required the author to respond.

The simplified Kano model noted below consists of three kinds of design requirements (delighters, satisfiers and dissatisfiers) plotted a cartesian grid with the horizontal being increasing levels of provision of the requirement, and the vertical axis being customer satisfaction.

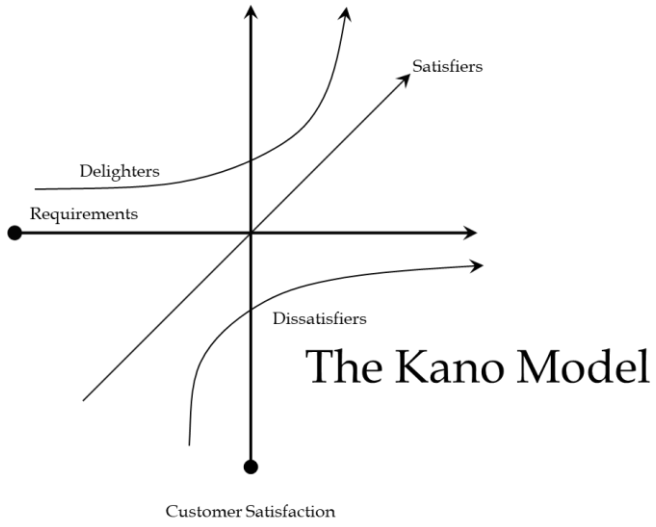

Figure 10: The Kano Model (Tague, 2005)

Delighters are features that the customer doesn't expect and doesn't specify, but provide significant satisfaction when provided, increasing at a greater than linear rate. Satisfiers are features the customer specifies over the level of basic expectations, and the customer satisfaction with their provision is linear. Dissatisfiers are those basic features the customer expects without specification, and only impact satisfaction (negatively) if they are missing (Tague, 2005).

The results of the survey, the Delphi Study and the Salary Survey analysis point to the conclusion that while prevention is understood to be more cost effective, it is difficult to

quantify and thus difficult to recognize and reward, rendering successful prevention by definition a basic expectation; a dissatisfier. On the other hand, correction is relatively easy to quantify financially especially when improvement projects quantify the cost savings. Consequently, by definition, they become either satisfiers: something positive the customer (management) specified, or delighters: something positive the customer (management) didn't specify but got anyway.

Prevention is difficult to quantify financially; is a basic expectation and is thus a dissatisfier by definition.

Correction is easy to quantify financially; a response to a specification or a pleasant surprise and is thus either a satisfier or delighter by definition.

Consequently, the Kano Model explains the results.

Overall Summary

The results noted above demonstrate that despite a nearly identical expectation of skill sets, as found the ASQ Bodies of Knowledge for quality engineers and six sigma black belts, current expectations of duties have quality engineer performing largely preventive actions and six sigma black belts largely corrective actions.

In addition, these results demonstrate that while managers understand the relative value of preventive actions over corrective actions, they recognize and reward corrective actions more highly. The overall practical consequence is that this disparity results in largely unquantifiable loss to organizations, which presents several practical implications to business organizations:

- Business organizations must understand these results, and that losses are occurring.

- Business organizations should investigate and determine, if not a precise measurement, the consequent order of magnitude of the losses that occur. Since it has been both anecdotally exhibited that organizations reward correction over prevention, savvy practitioners have emphasized corrective actions over preventive action, knowing the higher probability for recognition and reward. Understanding of the magnitude of this disparity will allow organizations to implement correction to that system.
- Business organizations must implement systems for understanding and recognizing preventive actions. While, as demonstrated above, this change will not be easily implemented, due to the relative difficulty in calculating preventive value in the "language of management" (money), it is necessary for the reduction or elimination of the largely unquantified losses incurred due to the current emphasis of recognition and reward of correction over prevention.
- Finance departments within business organizations must be prepared and qualified to apportion the recognition of prevention over correction. Prevention, in finance terms, is labeled as "Cost Avoidance," which finance organizations are loath to recognize, whereas correction is labeled as "Cost Savings," which finance organizations are quick to recognize. For these unquantified losses to end, both "Cost Avoidance" and "Cost Savings" must be calculated and recognized with equal diligence.

Finally, the results of this study indicate that the underlying model that usefully demonstrates this concept is the Kano model.

Recommendations for Future Study

As noted above, there is a dearth of academic and only slightly more trade study material regarding the use and benefits of preventive actions in business, and very little differentiation between the actions to prevent occurrence and recurrence of problems. Consequently, it is recommended that further study be devoted to the:

- Determination of comprehensive methods for determination of implementation of preventive actions,
- Determination of comprehensive method for determination of financial benefits of preventive actions,
- Clear separation of actions to prevent occurrence and recurrence of problems.
- Development and implementation of methods and subsequent computer applications to assist in the determination of the financial value of prevention.

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APPENDIX A

Survey Questions

1. Please indicate which type of industry with which you are associated:

   A. Aerospace
   B. Commercial
   C. Defense
   D. Education
   E. FDA Regulated Health Care
   F. Non-FDA Regulated Health Care
   G. Other (please specify)

2. Do you now, or have you in the past, managed either Six Sigma Black Belts or Quality Engineers?

   Yes
   No

3. Are you familiar with the duties of both Quality Engineers and Six Sigma Black Belts?

   Yes
   No

4. Using the Juran Trilogy® process for Quality Management, to which of the following are the duties of a Quality Engineer intended to primarily belong?

   A. Quality Planning
   B. Quality Control
   C. Quality Improvement

5. Using the Juran Trilogy® process for Quality Management, to which of the following are the duties of a Six Sigma Black Belt intended to primarily belong?

   A. Quality Planning
   B. Quality Control
   C. Quality Improvement

6. Using the Juran Trilogy® process for Quality Management, to which of the following do the duties of a Quality Engineer actually belong?

   A. Quality Planning
   B. Quality Control
   C. Quality Improvement

7. Using the Juran Trilogy® process for Quality Management, to which of the following do the duties of a Six Sigma Black Belt actually belong?

   A. Quality Planning
   B. Quality Control

C. Quality Improvement

8. Which of the following afford the greatest financial ***COSTS*** to an organization?

A. Actions related to Prevention
B. Actions related to Assessment
C. Actions related to Internal Failure
D. Actions related to External Failure

9. Which of the following afford the greatest financial ***BENEFITS*** to an organization?

A. Actions related to Prevention
B. Actions related to Assessment
C. Actions related to Internal Failure
D. Actions related to External Failure

10. How does your organization assess the financial benefit of actions which prevent problem ***OCCURRENCE***? (please mark all that apply)

A. Risk-based calculations, using FMEA severity and occurrence ratings as a guideline
B. Comparative results based on perceived costs of failures occurring outside our organization
C. Comparative results based on previous internal failures
D. Using established models, such as DMAIC and PDCA
E. Using an internal model provided by the organization's finance department
F. We do not assess the financial benefit of cost-avoidance
G. Other (please specify)

11. How does your organization assess the financial benefit of actions which prevent problem ***RECURRENCE***? (please mark all that apply)

A. Risk-based calculations, using FMEA severity and occurrence ratings as a guideline
B. Comparative results based on perceived costs of failures occurring outside our organization
C. Comparative results based on previous internal failures
D. Using established models, such as DMAIC and PDCA
E. Using an internal model provided by the organization's finance department
F. We do not assess the financial benefit of cost-savings.
G. Other (please specify)

12. How does your organization recognize and/or reward the implementation of actions taken to prevent problem ***OCCURRENCE***? (please mark all that apply)

A. Monetary award proportional to calculated cost avoidance
B. Monetary award proportional to calculated cost avoidance combined with public recognition
C. Hawthorne model: Non-monetary award combined with public recognition
D. Job assessment for exceeding expectations
E. None: problem occurrence prevention is a basic job description
F. Other (please specify)

13. How does your organization recognize and/or reward the implementation of actions taken to prevent problem ***RECURRENCE***? (please mark all that apply)

    A. Monetary award proportional to calculated cost savings.
    B. Monetary award proportional to calculated cost savings combined with public recognition
    C. Hawthorne model: Non-monetary award combined with public recognition
    D. Job assessment for exceeding expectations
    E. None: problem recurrence prevention is a basic job description
    F. Other (please specify)

14. Please rank order from lowest (1) to highest (8) the relative level of the following position titles (currently randomized to prevent positional bias):

	SSBB		PrinQE		SSMBB		QE		SSBB		SSBB		QEMgr		QEMgr
	SSYB		SrQE		SSYB		SSMBB		SSGB		PrinQE		SSGB		SSMBB
	PrinQE		QEMgr		PrinQE		SSYB		SSYB		QEMgr		SrQE		QE
	QEMgr		SSMBB		QEMgr		SrQE		QE		SSGB		SSYB		SSYB
	SSMBB		SSBB		SrQE		QEMgr		QEMgr		SrQE		PrinQE		PrinQE
	QE		SSGB		SSGB		SSGB		SSMBB		SSMBB		SSBB		SrQE
	SSGB		QE		SSBB		PrinQE		SrQE		QE		SSMBB		SSBB
	SrQE		SSYB		QE		SSBB		PrinQE		SSYB		QE		SSGB

Note: *For the purpose of review only: I have noted eight (8) different randomizations of the job titles. I included only one (1) on each survey, but eight different surveys were provided during data gathering, to reduce bias. The titles associated with the abbreviations above are as follows*

SSYB:	*Six Sigma Yellow Belt*	*SSGB:*	*Six Sigma Green Belt*
SSBB:	*Six Sigma Black Belt*	*SSMBB:*	*Six Sigma Master Black Belt*
QE:	*Quality Engineer*	*SrQE:*	*Senior Quality Engineer*
PrinQE:	*Principal Quality Engineer*	*QEMgr:*	*Quality Engineering Manager*

15. Are now in a Quality Engineering or a Six Sigma ***individual contributor*** position?

    Yes
    No

16. If you answered "yes" to Number 15, which type position are you in and at which level? (Please circle only one)

Quality Engineering	Six Sigma
Quality Engineer	Six Sigma Yellow Belt
Senior Quality Engineer	Six Sigma Green Belt
Principal Quality Engineer	Six Sigma Black Belt

☐ I do not wish to participate.

Thank you for your time!

APPENDIX B

Delphi Study Items

1. What are the preferred tools for determination and implementation of corrective actions (actions to prevent recurrence of problems)?

2. What are the preferred tools for determination and implementation of preventive actions (actions to prevent occurrence of problems)?

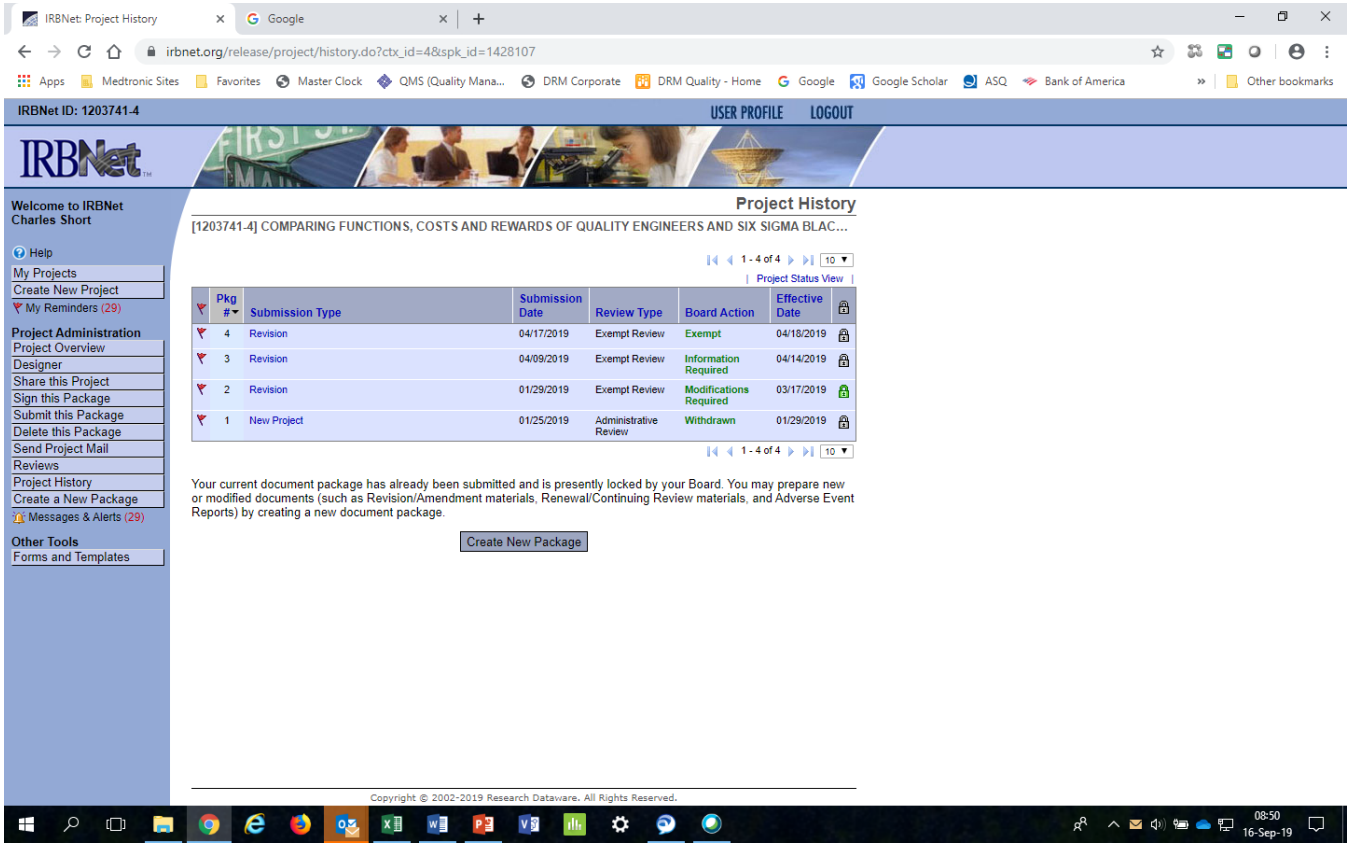
3. How does an organization best assess the financial value of actions to prevent recurrence of problems?

4. How does an organization best assess the financial value of actions to prevent occurrence of problems?

5. What are the best Quality Assurance models currently in use that may describe the various common Quality Assurance job descriptions?

APPENDIX C

IRB Approval



APPENDIX D

CERTIFIED QUALITY ENGINEER (CQE)
BODY OF KNOWLEDGE

The topics in this Body of Knowledge include subtext explanations and the cognitive level at which the questions will be written. This information will provide useful guidance for both the Exam Development Committee and the candidate preparing to take the exam. The subtext is not intended to limit the subject matter or be all-inclusive of that material that will be covered in the exam. It is meant to clarify the type of content that will be included on the exam. The descriptor in parentheses at the end of each entry refers to the maximum cognitive level at which the topic will be tested. A complete description of cognitive levels is provided at the end of this document.

I. Management and Leadership (18 Questions)

A. Quality Philosophies and Foundations

Describe continuous improvement tools, including lean, six sigma, theory of constraints, statistical process control (SPC), and total quality management, and understand how modern quality has evolved from quality control through statistical process control (SPC) to total quality management and leadership principles (including Deming's 14 points). (Understand)

B. The Quality Management System (QMS)

1. **Strategic planning**
   Identify and define top management's responsibility for the QMS, including establishing policies and objectives, setting organization-wide goals, and supporting quality initiatives. (Apply)

2. **Deployment techniques**
   Define, describe, and use various deployment tools in support of the QMS such as:

   a. Benchmarking

      Define the concept of benchmarking and why it may be used. (Remember)

   b. Stakeholder

      Define, describe and use stakeholder identification and analysis. (Apply)

   c. Performance

      Define, describe and use performance measurement tools. (Apply)

   d. Project management

      Define, describe and use project management tools, including PERT charts, Gantt charts, critical path method (CPM), and resource allocation. (Apply)

3. **Quality information system (QIS)**
   Identify and describe the basic elements of a QIS, including who will contribute data, the kind of data to be managed, who will have access to the data, the level of flexibility for future information needs, and data analysis. (Understand)

C. ASQ Code of Ethics for Professional Conduct

Determine appropriate behavior in situations requiring ethical decisions. (Evaluate)

D. **Leadership Principles and Techniques**

Analyze various principles and techniques for developing and organizing teams and leading quality initiatives. (Analyze)

E. **Facilitation Principles and Techniques**

1. **Roles and responsibilities**

Describe the facilitator's roles and responsibilities on a team. (Understand)

2. **Facilitation tools**

Apply various tools used with teams, including brainstorming, nominal group technique, conflict resolution, and force-field analysis. (Apply)

F. **Communication Skills**

Identify specific communication methods that are used for delivering information and messages in a variety of situations across all levels of the organization. (Analyze)

G. **Customer Relations**

Define, apply, and analyze the results of customer relation tools such as quality function deployment (QFD) and customer satisfaction surveys. (Analyze)

H. **Supplier Management**

1. **Techniques**

Apply various supplier management techniques, including supplier qualification, certification, and evaluation. (Apply)

2. **Improvement**

Analyze supplier ratings and performance improvement results. (Analyze)

3. **Risk**

Understand business continuity, resiliency, and contingency planning. (Understand)

I. **Barriers to Quality Improvement**

Identify barriers to quality improvement, analyze their causes and impact, and implement methods for improvement. (Analyze)

II. The Quality System (16 Questions)

A. **Elements of the Quality System**

1. **Basic elements**

Interpret the basic elements of a quality system, including planning, control, and improvement, from product and process design through quality cost systems and audit programs. (Evaluate)

2. **Design**

Analyze the design and alignment of interrelated processes to the strategic plan and core processes. (Analyze)

B. **Documentation of the Quality System**

1. **Document components**

Identify and describe quality system documentation components, including quality policies and procedures to support the system. (Understand)

2. **Document control**

Evaluate configuration management, maintenance, and document control to manage work instructions and quality records. (Evaluate)

C. **Quality Standards and Other Guidelines**

Apply national and international standards and other requirements and guidelines, including the Malcolm Baldrige National Quality Award (MBNQA), and describe key points of the ISO 9000 series of standards. [Note: Industry-specific standards will not be tested.] (Apply)

D. **Quality Audits**

1. **Types of audits**
   Describe and distinguish between various types of quality audits such as product, process, management (system), registration (certification), compliance (regulatory), first, second, and third party. (Apply)

2. **Roles and responsibilities in audits**
   Identify and define roles and responsibilities for audit participants such as audit team (leader and members), client, and auditee. (Understand)

3. **Audit planning and implementation**
   Describe and apply the stages of a quality audit, from audit planning through conducting the audit. (Apply)

4. **Audit reporting and follow-up**
   Apply the steps of audit reporting and follow up, including the need to verify corrective action. (Apply)

E. **Cost of Quality (COQ)**

Identify and apply COQ concepts, including cost categorization, data collection, reporting, and interpreting results. (Analyze)

F. **Quality Training**

Identify and apply key elements of a training program, including conducting a needs analysis, developing curricula and materials, and determining the program's effectiveness. (Apply)

III. Product, Process, and Service Design (23 Questions)

A. **Classification of Quality Characteristics**
Define, interpret, and classify quality characteristics for new and existing products, processes, and services. [Note: The classification of defects is covered in IV.B.3.] (Evaluate)

B. **Design Inputs and Review**

1. **Inputs**

   Translate design inputs such as customer needs, regulatory requirements, and risk assessment into robust design using techniques such as failure mode and effects analysis (FMEA), quality function deployment (QFD), Design for X (DFX), and Design for Six Sigma (DFSS). (Analyze)

2. **Review**

   Identify and apply common elements of the design review process, including roles and responsibilities of participants. (Apply)

C. **Technical Drawings and Specifications**
Interpret specification requirements in relation to product and process characteristics and technical drawings, including characteristics such as views, title blocks, dimensioning and tolerancing, and GD&T symbols. (Evaluate)

D. **Verification and Validation**
Interpret the results of evaluations and tests used to verify and validate the design of products, processes and services, such as installation qualification (IQ), operational qualification (OQ), and process qualification (PQ). (Evaluate)

E. **Reliability and Maintainability**

1. **Predictive and preventive maintenance tools**
   Describe and apply the tools and techniques used to maintain and improve process and product reliability. (Apply)

2. **Reliability and maintainability indices**
   Review and analyze indices such as MTTF, MTBF, MTTR, availability, and failure rate. (Analyze)

3. **Reliability models**
   Identify, define, and distinguish between the basic elements of reliability models such as exponential, Weibull, and bathtub curve. (Apply)

4. **Reliability / Safety / Hazard Assessment Tools**
   Define, construct, and interpret the results of failure mode and effects analysis (FMEA), failure mode, effects, and criticality analysis (FMECA), and fault tree analysis (FTA). (Evaluate)

IV. Product and Process Control (25 Questions)

A. Methods

Implement product and process control methods such as control plan development, critical control point identification, and work instruction development and validation. (Analyze)

B. Material Control

1. **Material identification, status, and traceability**
   Define and distinguish between these concepts, and describe methods for applying them in various situations. (Analyze)

2. **Material segregation**
   Describe material segregation and its importance, and evaluate appropriate methods for applying it in various situations. (Evaluate)

3. **Material classification**
   Classify product and process defects and non-conformities. (Evaluate)

4. **Material review board (MRB)**
   Describe the purpose and function of an MRB and evaluate nonconforming product or material to make a disposition decision in various situations. (Evaluate)

C. Acceptance Sampling

1. **Sampling concepts**
   Interpret the concepts of producer and consumer risk and related terms, including operating characteristic (OC) curves, acceptable quality limit (AQL), lot tolerance percent defective (LTPD), average outgoing quality (AOQ), and average outgoing quality limit (AOQL). (Analyze)

2. **Sampling standards and plans**
   Identify, interpret, and apply ANSI/ASQ Z1.4 and Z1.9 standards for attributes and variables sampling. Identify and distinguish between single, double, multiple, sequential, and continuous sampling methods. Identify the characteristics of Dodge-Romig sampling tables and when they should be used. (Analyze)

3. **Sample integrity**
   Identify and apply techniques for establishing and maintaining sample integrity. (Apply)

D. Measurement and Test

1. **Measurement tools**
   Select and describe appropriate uses of inspection tools such as gage blocks, calipers, micrometers, and optical comparators. (Analyze)

2. **Destructive and nondestructive tests**
   Identify when destructive and nondestructive measurement test methods should be used and apply the methods appropriately. (Apply)

E. **Metrology**
Apply metrology techniques such as calibration, traceability to calibration standards, measurement error and its sources, and control and maintenance of measurement standards and devices. (Analyze)

F. **Measurement System Analysis (MSA)**
Calculate, analyze, and interpret repeatability and reproducibility (Gage R&R) studies, measurement correlation, capability, bias, linearity, precision, stability and accuracy, as well as related MSA quantitative and graphical methods. (Evaluate)

V. Continuous Improvement (27 Questions)

A. **Quality Control Tools**
Select, construct, apply, and interpret the following quality control tools:
1. Flowcharts
2. Pareto charts
3. Cause and effect diagrams
4. Control charts
5. Check sheets
6. Scatter diagrams
7. Histograms (Analyze)

B. **Quality Management and Planning Tools**
Select, construct, apply, and interpret the following quality management and planning tools:
1. Affinity diagrams and force field analysis
2. Tree diagrams
3. Process decision program charts (PDPC)
4. Matrix diagrams
5. Interrelationship digraphs
6. Prioritization matrices
7. Activity network diagrams (Analyze)

C. **Continuous Improvement Methodologies**
Define, describe, and apply the following continuous improvement methodologies:
1. Total quality management (TQM)
2. Kaizen
3. Plan-do-check-act (PDCA)
4. Six sigma
5. Theory of constraints (TOC) (Evaluate)

D. **Lean tools**
Define, describe, and apply the following lean tools:
1. 5S
2. Value-stream mapping
3. Kanban
4. Visual control
5. Waste (Muda)
6. Standardized work
7. Takt time
8. Single minute exchange of die (SMED) (Evaluate)

E. **Corrective Action**
Identify, describe, and apply elements of the corrective action process, including problem identification,

failure analysis, root cause analysis, problem correction, recurrence control, and verification of effectiveness. (Evaluate)

F. **Preventive Action**
Identify, describe and apply various preventive action tools such as error-proofing/poka-yoke, robust design and analyze their effectiveness. (Evaluate)

VI. Quantitative Methods and Tools (36 Questions)

A. Collecting and Summarizing Data

1. **Types of data**
Define, classify, and compare discrete (attributes) and continuous (variables) data. (Apply)

2. **Measurement scales**
Define and describe nominal, ordinal, interval, and ratio scales. (Understand)

3. **Data collection methods**
Describe various methods for collecting data, including tally or check sheets, data coding, automatic gaging, and identify the strengths and weaknesses of the methods. (Apply)

4. **Data accuracy and integrity**
Apply techniques that ensure data accuracy and integrity, and identify factors that can influence data accuracy such as source/resource issues, flexibility, versatility, inconsistency, inappropriate interpretation of data values, and redundancy. . (Apply)

5. **Descriptive statistics**
Describe, calculate, and interpret measures of central tendency and dispersion (central limit theorem), and construct and interpret frequency distributions, including simple, categorical, grouped, ungrouped, and cumulative. (Evaluate)

6. **Graphical methods for depicting relationships**
Construct, apply, and interpret diagrams and charts such as stem-and-leaf plots, and box-and-whisker plots. [Note: Scatter diagrams are covered in V.A.] (Analyze)

7. **Graphical methods for depicting distributions**
Construct, apply, and interpret diagrams such as normal and non-normal probability plots. [Note: Histograms are covered in V.A.] (Analyze)

B. Quantitative Concepts

1. **Terminology**
Define and apply quantitative terms, including population, parameter, sample, statistic, random sampling, and expected value. (Analyze)

2. **Drawing statistical conclusions**
Distinguish between numeric and analytical studies. Assess the validity of statistical conclusions by analyzing the assumptions used and the robustness of the technique used. (Evaluate)

3. **Probability terms and concepts**
Describe concepts such as independence, mutually exclusive, multiplication rules, complementary probability, and joint occurrence of events. (Understand)

C. Probability Distributions

1. **Continuous distributions**
Define and distinguish between these distributions such as normal, uniform, bivariate normal, exponential, lognormal, Weibull, chi square, Student’s t and F. (Analyze)

2. **Discrete distributions**
   Define and distinguish between these distributions such as binomial, Poisson, hypergeometric, and multinomial. (Analyze)

D. **Statistical Decision-Making**

1. **Point estimates and confidence intervals**
   Define, describe, and assess the efficiency and bias of estimators. Calculate and interpret standard error, tolerance intervals, and confidence intervals. (Evaluate)

2. **Hypothesis testing**
   Define, interpret, and apply hypothesis tests for means, variances, and proportions. Apply and interpret the concepts of significance level, power, type I and type II errors. Define and distinguish between statistical and practical significance. (Evaluate)

3. **Paired-comparison tests**
   Define and use paired-comparison (parametric) hypothesis tests, and interpret the results. (Apply)

4. **Goodness-of-fit tests**
   Define chi square and other goodness-of-fit tests, and understand the results. (Understand)

5. **Analysis of variance (ANOVA)**
   Define and use ANOVAs and interpret the results. (Analyze)

6. **Contingency tables**
   Define and use contingency tables to evaluate statistical significance. (Apply)

E. **Relationships Between Variables**

1. **Linear regression**
   Calculate the regression equation for simple regressions and least squares estimates. Construct and interpret hypothesis tests for regression statistics. Use linear regression models for estimation and prediction. (Analyze)

2. **Simple linear correlation**
   Calculate the correlation coefficient and its confidence interval, and construct and interpret a hypothesis test for correlation statistics. (Analyze)

3. **Time-series analysis**
   Define, describe, and use time-series analysis, including moving average to identify trends and seasonal or cyclical variation. (Apply)

F. **Statistical Process Control (SPC)**

1. **Objectives and benefits**
   Identify and explain the objectives and benefits of SPC. (Understand)

2. **Common and special causes**
   Describe, identify, and distinguish between these types of causes. (Analyze)

3. **Selection of variable**
   Identify and select characteristics for monitoring by control chart. (Analyze)

4. **Rational subgrouping**
   Define and apply the principles of rational subgrouping. (Apply)

5. **Control charts**
   Identify, select, construct, and use various control charts, including **Error! Objects cannot be created from editing field codes.**−R, **Error! Objects cannot be created from editing field codes.**−s, individuals and moving range (ImR or XmR), moving average and moving range (MamR), p, np, c, and u. (Analyze)

6. **Control chart analysis**
   Read and interpret control charts and use rules for determining statistical control. (Evaluate)

7. **Pre-control charts**
   Define and describe these charts and how they differ from other control charts. (Understand)

8. **Short-run SPC**
   Identify and define short-run SPC rules. (Understand)

G. **Process and Performance Capability**

1. **Process capability studies**
   Define, describe, calculate, and use process capability studies, including identifying characteristics, specifications and tolerances, developing sampling plans for such studies, and establishing statistical control. (Analyze)

2. **Process performance vs. specifications**
   Distinguish between natural process limits and specification limits, and calculate percent defective, defects per million opportunities (DPMO), and parts per million (PPM). (Analyze)

3. **Process capability indices**
   Define, select, and calculate C_p, C_{pk}, C_{pm}, and C_r, and evaluate process capability. (Evaluate)

4. **Process performance indices**
   Define, select, and calculate P_p and P_{pk}, and evaluate process performance. (Evaluate)

H. **Design and Analysis of Experiments**

1. **Terminology**
   Define terms such as dependent and independent variables, factors, levels, response, treatment, error, and replication. (Understand)

2. **Planning and organizing experiments**
   Identify the basic elements of designed experiments, including determining the experiment objective, selecting factors, responses, and measurement methods, and choosing the appropriate design. (Analyze)

3. **Design principles**
   Define and apply the principles of power and sample size, balance, replication, order, efficiency, randomization, blocking, interaction, and confounding. (Apply)

4. **One-factor experiments**
   Construct one-factor experiments such as completely randomized, randomized block, and Latin square designs, and use computational and graphical methods to analyze the significance of results. (Analyze)

5. **Full-factorial experiments**
   Construct full-factorial designs and use computational and graphical methods to analyze the significance of results. (Analyze)

6. **Two-level fractional factorial experiments**
   Construct two-level fractional factorial designs and apply computational and graphical methods to analyze the significance of results. (Analyze)

VII. Risk Management (15 Questions)

A. **Risk Oversight**

1. Planning and oversight
Understand identification, planning, prioritization, and oversight of risk. (Understand)

2. Metrics
Identify and apply evaluation metrics. (Apply)

3. Mitigation planning
Apply and interpret risk mitigation plan. (Evaluate)

B. **Risk Assessment**
Apply categorization methods and evaluation tools to assess risk. (Analyze)

C. **Risk Control**

1. Identification and documentation
Identify and document risks, gaps and controls. (Analyze)

2. Auditing and Testing
Apply auditing techniques and testing of controls. (Evaluate)

APPENDIX E

AMERICAN SOCIETY FOR QUALITY
CERTIFIED SIX SIGMA BLACK BELT (CSSBB)
BODY OF KNOWLEDGE

The topics in this Body of Knowledge include additional detail in the form of subtext explanations and the cognitive level at which test questions will be written. This information will provide guidance for the candidate preparing to take the exam. The subtext is not intended to limit the subject matter or be all-inclusive of what might be covered in an exam. It is meant to clarify the type of content to be included in the exam. The descriptor in parentheses at the end of each entry refers to the maximum cognitive level at which the topic will be tested. A complete description of cognitive levels is provided at the end of this document.

I. Organization-wide Planning and Deployment (Questions 12)

A. Organization-wide considerations

1. Fundamentals of six sigma and lean methodologies

Define and describe the value, foundations, philosophy, history, and goals of these approaches, and describe the integration and complementary relationship between them. (Understand)

2. Six sigma, lean, and continuous improvement methodologies

Describe when to use six sigma instead of other problem-solving approaches, and describe the importance of aligning six sigma objectives with organizational goals. Describe screening criteria and how such criteria can be used for the selection of six sigma projects, lean initiatives, and other continuous improvement methods. (Apply)

3. Relationships among business systems and processes

Describe the interactive relationships among business systems, processes, and internal and external stakeholders, and the impact those relationships have on business systems. (Understand)

4. Strategic planning and deployment for initiatives

Define the importance of strategic planning for six sigma projects and lean initiatives. Demonstrate how hoshin kanri (X-matrix), portfolio analysis, and other tools can be used in support of strategic deployment of these projects. Use feasibility studies, SWOT analysis (strengths, weaknesses, opportunities, and threats), PEST analysis (political, economic, social, and technological) and contingency planning and business continuity planning to enhance strategic planning and deployment. (Apply)

B. Leadership

1. Roles and responsibilities

Describe the roles and responsibilities of executive leadership, champions, sponsors, process owners, master black belts, black belts, and green belts in driving six sigma and lean initiatives. Describe how each group influences project deployment in terms of providing or managing resources, enabling changes in organizational structure, and supporting communications about the purpose and deployment of the initiatives. (Understand)

2. Organizational roadblocks and change management

Describe how an organization's structure and culture can impact six sigma projects. Identify common causes of six sigma failures, including lack of management support and lack of resources. Apply change management techniques, including stakeholder analysis, readiness assessments, and communication plans to overcome barriers and drive organization-wide change. (Apply)

II. Organizational Process Management and Measures (10 Questions)

A. Impact on stakeholders

Describe the impact six sigma projects can have on customers, suppliers, and other stakeholders. (Understand)

B. Benchmarking

Define and distinguish between various types of benchmarking, e.g., best practices, competitive, collaborative, breakthrough. Select measures and performance goals for projects resulting from benchmarking activities. (Apply)

C. Business measures

1. Performance measures

Define and describe balanced scorecard, key performance indicators (KPIs), customer loyalty metrics, and leading and lagging indicators. Explain how to create a line of sight from performance measures to organizational strategies. (Analyze)

2. Financial measures

Define and use revenue growth, market share, margin, net present value (NPV), return on investment (ROI), and cost-benefit analysis (CBA). Explain the difference between hard cost measures (from profit and loss statements) and soft cost benefits of cost avoidance and reduction. (Apply)

III. Team Management (18 Questions)

A. Team formation

1. Team types and constraints

Define and describe various teams, including virtual, cross-functional, and self-directed. Determine what team type will work best for a given a set of constraints, e.g., geography, technology availability, staff schedules, time zones. (Apply)

2. Team roles and responsibilities

Define and describe various team roles and responsibilities for leader, facilitator, coach, and individual member. (Understand)

3. Team member selection criteria

Describe various factors that influence the selection of team members, including the ability to influence, openness to change, required skills sets, subject matter expertise, and availability. (Apply)

4. Team success factors

Identify and describe the elements necessary for successful teams, e.g., management support, clear goals, ground rules, timelines. (Apply)

B. Team facilitation

1. Motivational techniques

Describe and apply techniques to motivate team members. Identify factors that can demotivate team members and describe techniques to overcome them. (Apply)

2. Team stages of development

Identify and describe the classic stages of team development: forming, storming, norming, performing, and adjourning. (Apply)

3. Team communication

Describe and explain the elements of an effective communication plan, e.g., audience identification, message type, medium, frequency. (Apply)

4. Team leadership models

Describe and select appropriate leadership approaches (e.g., direct, coach, support, delegate) to ensure team success. (Apply)

C. Team dynamics

1. Group behaviors

Identify and use various conflict resolution techniques (e.g., coaching, mentoring, intervention) to overcome negative group dynamics, including dominant and reluctant participants, groupthink, rushing to finish, and digressions. (Evaluate)

2. Meeting management

Select and use various meeting management techniques, including using agendas, starting on time, requiring pre-work by attendees, and ensuring that the right people and resources are available. (Apply)

3. Team decision-making methods

Define, select, and use various tools (e.g., consensus, nominal group technique, multi-voting) for decision-making. (Apply)

D. Team training

1. Needs assessment

Identify the steps involved to implement an effective training curriculum: identify skills gaps, develop learning objectives, prepare a training plan, and develop training materials. (Understand)

2. Delivery

Describe various techniques used to deliver effective training, including adult learning theory, soft skills, and modes of learning. (Understand)

3. Evaluation

Describe various techniques to evaluate training, including evaluation planning, feedback surveys, pre-training and post-training testing. (Understand)

IV. Define (20 questions)

A. Voice of the customer

1. Customer identification

Identify and segment customers and show how a project will impact both internal and external customers. (Apply)

2. Customer data collection

Identify and select appropriate data collection methods (e.g., surveys, focus groups, interviews, observations) to gather voice of the customer data. Ensure the data collection methods used are reviewed for validity and reliability. (Analyze)

3. Customer requirements

Define, select, and apply appropriate tools to determine customer needs and requirements, including critical-to-X (CTX when 'X' can be quality, cost, safety, etc.), CTQ tree, quality function deployment (QFD), supplier, input, process, output, customer (SIPOC) and Kano model. (Analyze)

B. Business case and project charter

1. Business case

Describe business case justification used to support projects. (Understand)

2. Problem statement

Develop a project problem statement and evaluate it in relation to baseline performance and improvement goals. (Evaluate)

3. Project scope

Develop and review project boundaries to ensure that the project has value to the customer. (Analyze)

4. Goals and objectives

Identify SMART (specific, measureable, actionable, relevant and time bound) goals and objectives on the basis of the project's problem statement and scope. (Analyze)

5. Project performance measurements

Identify and evaluate performance measurements (e.g., cost, revenue, delivery, schedule, customer satisfaction) that connect critical elements of the process to key outputs. (Analyze)

6. Project charter review

Explain the importance of having periodic project charter reviews with stakeholders. (Understand)

C. Project management (PM) tools

Identify and use the following PM tools to track projects and document their progress. (Evaluate)

1. Gantt charts
2. Toll-gate reviews
3. Work breakdown structure (WBS)
4. RACI model (responsible, accountable, consulted and informed)

D. Analytical tools

Identify and use the following analytical tools throughout the DMAIC cycle. (Apply)

1. Affinity diagrams
2. Tree diagrams
3. Matrix diagrams
4. Prioritization matrices
5. Activity network diagrams

V. Measure (25 Questions)

A. Process characteristics

1. Process flow metrics

Identify and use process flow metrics (e.g., work in progress (WIP), work in queue (WIQ), touch time, takt time, cycle time, throughput) to determine constraints. Describe the impact that "hidden factories" can have on process flow metrics. (Analyze)

2. Process analysis tools

Select, use and evaluate various tools, e.g., value stream maps, process maps, work instructions, flowcharts, spaghetti diagrams, circle diagrams, gemba walk. (Evaluate)

B. Data collection

1. Types of data

Define, classify, and distinguish between qualitative and quantitative data, and continuous and discrete data. (Evaluate)

2. Measurement scales

Define and use nominal, ordinal, interval, and ratio measurement scales. (Apply)

3. Sampling

Define and describe sampling concepts, including representative selection, homogeneity, bias, accuracy, and precision. Determine the appropriate sampling method (e.g., random, stratified, systematic, subgroup, block) to obtain valid representation in various situations. (Evaluate)

4. Data collection plans and methods

Develop and implement data collection plans that include data capture and processing tools, e.g., check sheets, data coding, data cleaning (imputation techniques). Avoid data collection pitfalls by defining the metrics to be used or collected, ensuring that collectors are trained in the tools and understand how the data will be used, and checking for seasonality effects. (Analyze)

C. Measurement systems

1. Measurement system analysis (MSA)

Use gauge repeatability and reproducibility (R&R) studies and other MSA tools (e.g., bias, correlation, linearity, precision to tolerance, percent agreement) to analyze measurement system capability. (Evaluate)

2. Measurement systems across the organization

Identify how measurement systems can be applied to marketing, sales, engineering, research and development (R&D), supply chain management, and customer satisfaction data. (Understand)

3. Metrology

Define and describe elements of metrology, including calibration systems, traceability to reference standards, and the control and integrity of measurement devices and standards. (Understand)

D. Basic statistics

1. Basic statistical terms

Define and distinguish between population parameters and sample statistics, e.g., proportion, mean, standard deviation. (Apply)

2. **Central limit theorem**

   Explain the central limit theorem and its significance in the application of inferential statistics for confidence intervals, hypothesis tests, and control charts. (Understand)

3. **Descriptive statistics**

   Calculate and interpret measures of dispersion and central tendency. (Evaluate)

4. **Graphical methods**

   Construct and interpret diagrams and charts, e.g., box-and-whisker plots, scatter diagrams, histograms, normal probability plots, frequency distributions, cumulative frequency distributions. (Evaluate)

5. **Valid statistical conclusions**

   Distinguish between descriptive and inferential statistical studies. Evaluate how the results of statistical studies are used to draw valid conclusions. (Evaluate)

E. Probability

1. **Basic concepts**

   Describe and apply probability concepts, e.g., independence, mutually exclusive events, addition and multiplication rules, conditional probability, complementary probability, joint occurrence of events. (Apply)

2. **Distributions**

   Describe, interpret, and use various distributions, e.g., normal, Poisson, binomial, chi square, Student's t, F, hypergeometric, bivariate, exponential, lognormal, Weibull. (Evaluate)

F. Process capability

1. **Process capability indices**

   Define, select, and calculate C_p and C_{pk}. (Evaluate)

2. **Process performance indices**

   Define, select, and calculate P_p, P_{pk}, C_{pm}, and process sigma. (Evaluate)

3. **General process capability studies**

   Describe and apply elements of designing and conducting process capability studies relative to characteristics, specifications, sampling plans, stability and normality. (Evaluate)

4. **Process capability for attributes data**

   Calculate the process capability and process sigma level for attributes data. (Apply)

5. **Process capability for non-normal data**

   Identify non-normal data and determine when it is appropriate to use Box-Cox or other transformation techniques. (Apply)

6. **Process performance vs. specification**

   Distinguish between natural process limits and specification limits. Calculate process performance metrics, e.g., percent defective, parts per million (PPM), defects per million opportunities (DPMO), defects per unit (DPU), throughput yield, rolled throughput yield (RTY). (Evaluate)

7. **Short-term and long-term capability**

   Describe and use appropriate assumptions and conventions when only short-term data or only long-term data are available. Interpret the relationship between short-term and long-term capability. (Evaluate)

VI. Analyze (22 Questions)

A. Measuring and modeling relationships between variables

1. Correlation coefficient

Calculate and interpret the correlation coefficient and its confidence interval, and describe the difference between correlation and causation. (Evaluate)

2. Linear regression

Calculate and interpret regression analysis, and apply and interpret hypothesis tests for regression statistics. Use the regression model for estimation and prediction, analyze the uncertainty in the estimate, and perform a residuals analysis to validate the model. (Evaluate)

3. Multivariate tools

Use and interpret multivariate tools (e.g., factor analysis, discriminant analysis, multiple analysis of variance (MANOVA)) to investigate sources of variation. (Evaluate)

B. Hypothesis testing

1. Terminology

Define and interpret the significance level, power, type I, and type II errors of statistical tests. (Evaluate)

2. Statistical vs. practical significance

Define, compare, and interpret statistical and practical significance. (Evaluate)

3. Sample size

Calculate sample size for common hypothesis tests: equality of means and equality of proportions. (Apply)

4. Point and interval estimates

Define and distinguish between confidence and prediction intervals. Define and interpret the efficiency and bias of estimators. Calculate tolerance and confidence intervals. (Evaluate)

5. Tests for means, variances, and proportions

Use and interpret the results of hypothesis tests for means, variances, and proportions. (Evaluate)

6. Analysis of variance (ANOVA)

Select, calculate, and interpret the results of ANOVAs. (Evaluate)

7. Goodness-of-fit (chi square) tests

Define, select, and interpret the results of these tests. (Evaluate)

8. Contingency tables

Select, develop, and use contingency tables to determine statistical significance. (Evaluate)

9. Non-parametric tests

Understand the importance of the Kruskal-Wallis and Mann-Whitney tests and when they should be used. (Understand)

C. Failure mode and effects analysis (FMEA)

Describe the purpose and elements of FMEA, including risk priority number (RPN), and evaluate FMEA results for processes, products, and services. Distinguish between design FMEA (DFMEA) and process FMEA (PFMEA), and interpret their results. (Evaluate)

D. Additional analysis methods

1. Gap analysis

Analyze scenarios to identify performance gaps, and compare current and future states using predefined metrics. (Analyze)

2. Root cause analysis

Define and describe the purpose of root cause analysis, recognize the issues involved in identifying a root cause, and use various tools (e.g., 5 whys, Pareto charts, fault tree analysis, cause and effect diagrams) to resolve chronic problems. (Analyze)

3. Waste analysis

Identify and interpret the seven classic wastes (overproduction, inventory, defects, over-processing, waiting, motion, transportation) and resource under-utilization. (Analyze)

VII. Improve (21 Questions)

A. Design of experiments (DOE)

1. Terminology

Define basic DOE terms, e.g., independent and dependent variables, factors and levels, response, treatment, error, nested. (Understand)

2. Design principles

Define and apply DOE principles, e.g., power, sample size, balance, repetition, replication, order, efficiency, randomization, blocking, interaction, confounding, resolution. (Apply)

3. Planning experiments

Plan and evaluate DOEs by determining the objective, selecting appropriate factors, responses, and measurement methods, and choosing the appropriate design. (Evaluate)

4. One-factor experiments

Design and conduct completely randomized, randomized block, and Latin square designs, and evaluate their results. (Evaluate)

5. Two-level fractional factorial experiments

Design, analyze, and interpret these types of experiments, and describe how confounding can affect their use. (Evaluate)

6. Full factorial experiments

Design, conduct, and analyze these types of experiments. (Evaluate)

B. Lean methods

1. Waste elimination

Select and apply tools and techniques for eliminating or preventing waste, e.g., pull systems, kanban, 5S, standard work, poka-yoke. (Analyze)

2. Cycle-time reduction

Use various tools and techniques for reducing cycle time, e.g., continuous flow, single-minute exchange of die (SMED), heijunka (production leveling). (Analyze)

3. Kaizen

Define and distinguish between kaizen and kaizen blitz and describe when to use each method. (Apply)

4. Other improvement tools and techniques

Identify and describe how other process improvement methodologies are used, e.g., theory of constraints (TOC), overall equipment effectiveness (OEE). (Understand)

C. Implementation

Develop plans for implementing proposed improvements, including conducting pilot tests or simulations, and evaluate results to select the optimum solution. (Evaluate)

VIII. Control (15 Questions)

A. Statistical process control (SPC)

1. Objectives

Explain the objectives of SPC, including monitoring and controlling process performance, tracking trends, runs, and reducing variation within a process. (Understand)

2. Selection of variables

Identify and select critical process characteristics for control chart monitoring. (Apply)

3. Rational subgrouping

Define and apply the principle of rational subgrouping. (Apply)

4. Control chart selection

Select and use control charts in various situations: $\overline{X} - R$, $\overline{X} - s$, individual and moving range (ImR), p, np, c, u, short-run SPC, and moving average. (Apply)

5. Control chart analysis

Interpret control charts and distinguish between common and special causes using rules for determining statistical control. (Analyze)

B. Other controls

1. Total productive maintenance (TPM)

Define the elements of TPM and describe how it can be used to consistently control the improved process. (Understand)

2. Visual controls

Define the elements of visual controls (e.g., pictures of correct procedures, color-coded components, indicator lights), and describe how they can help control the improved process. (Understand)

C. Maintain controls

1. Measurement system reanalysis

Review and evaluate measurement system capability as process capability improves, and ensure that measurement capability is sufficient for its intended use. (Evaluate)

2. Control plan

Develop a control plan to maintain the improved process performance, enable continuous improvement, and transfer responsibility from the project team to the process owner. (Apply)

D. Sustain improvements

1. Lessons learned

Document the lessons learned from all phases of a project and identify how improvements can be replicated and applied to other processes in the organization. (Apply)

2. Documentation

Develop or modify documents including standard operating procedures (SOPs), work instructions, and control plans to ensure that the improvements are sustained over time. (Apply)

3. Training for process owners and staff

Develop and implement training plans to ensure consistent execution of revised process methods and standards to maintain process improvements. (Apply)

4. Ongoing evaluation

Identify and apply tools (e.g., control charts, control plans) for ongoing evaluation of the improved process, including monitoring leading indicators, lagging indicators, and additional opportunities for improvement. (Apply)

IX. Design For Six Sigma (DFSS) Framework and Methodologies (7 Questions)

A. Common DFSS methodologies

Identify and describe DMADV (define, measure, analyze, design, and validate) and DMADOV (define, measure, analyze, design, optimize, and validate). (Understand)

B. Design for X (DFX)

Describe design constraints, including design for cost, design for manufacturability (producibility), design for test, and design for maintainability. (Understand)

C. Robust designs

Describe the elements of robust product design, tolerance design, and statistical tolerancing. (Understand)