Electronic Theses and Dissertations, 2020-

2022

Examining the Relationship between Six Sigma Failures and the Utilization of Cost Engineering Approaches

Dennis Tribby
University of Central Florida

EXAMINING THE RELATIONSHIP BETWEEN SIX SIGMA FAILURES AND THE UTILIZATION OF COST ENGINEERING APPROACHES

By

DENNIS JAMES TRIBBY
B.S. University of Cincinnati, 1989
M.B.A. University of Cincinnati, 1993
M.Eng. University of Cincinnati, 2019

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Fall Term
2022

Major Advisor: Ahmad Elshennawy

ABSTRACT

The purpose of the quantitative non-experimental research study is to analyze the relationship between the impact of using cost engineering approaches and the success rate of Six Sigma projects in the manufacturing industry. This study focuses on the relationship between Six Sigma project failures and whether skilled cost engineering professionals, methods or a cost management system was used to ensure that accurate cost data was utilized during the design project's lifecycle. Many companies using Six Sigma and related methodologies for product design have implemented with great success yet there are studies indicating that only 13% of firms reported achieving their annual profit objectives (Cooper, 2019; Guarraia, 2008). Researchers have found numerous critical failure factors associated with Six Sigma project failures but there is little research as to whether the underlying causes were related to the accuracy of cost estimate inputs required for manufacturing a product (Antony, Lizarelli, & Machado Fernandes, 2020). There is also an abundance of research studies that discuss critical success factors that support the increased likelihood of product design success so it is reasonable to assume that product design projects that failed may have neglected to implement these factors. Using a two-phase explanatory mixed-methods design that began with a nominal quantitative survey that included 177 Six Sigma practitioners responding to 26 questions. This phase was conducted to verify and validate the proposed research questions. Based on the analysis of the survey results a set of explanatory questions was developed for a qualitative semi-structured interview study that included nine subject matter experts recruited from the field of cost engineering (Creswell, 2015). Using thematic analysis, the responses from the interviews were then coded and categorized. After multiple iterations of analysis themes emerged allowing the

researcher to develop a conclusion about the research question (V. Braun & V. Clarke, 2021). The results of this study indicate that the four themes, if implemented properly, can improve the failure rates for Six Sigma projects caused by cost related issues.

ACKNOWLEDGMENTS

I want to express my profound appreciation for my committee chair, Professor Ahmad Elshennawy. His patience, wisdom, support, encouragement, and guidance through this research process were invaluable.

My gratitude goes to the dissertation committee, Dr. Luis Rabelo, Dr. Adan Vela, and Dr. Nabeel Yousef, as well as all the faculty and staff in the Department of Industrial Engineering and Management Systems at the University of Central Florida for providing me with such a rich intellectual education and research experience.

I would also like to thank my friend and colleague Dr. Irving Brown for his advice and support during the final leg of this journey.

I want to thank my daughters, Stacey, Sarah, and Amber, for always believing in me and providing me with numerous encouraging notes on my whiteboard.

Most importantly, this dream would not have been possible without the love, support, and understanding of my wife, Raquel Tribby. She always believed in me and endured many unsolicited discussions about my research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

ABC	activity-based costing
ASDI	analysis, specification, design and implementation
CFF	critical failure factors
CMS	cost management system
CSF	critical success factors
DfA	design for assembly
DfC	design for cost
DfM	design for manufacturing
DfQ	design for quality
DfX	design for excellence
DFSS	design for six sigma
DMADOV	define, measure, analyze, design, optimize, validate
DMADV	define, measure, analyze, design, validate
DMAIC	define, measure, analyze, improve, control
DMEDI	define, measure,
IDOV	identify, design, optimize, validate
PCM	product cost management
TPS	Toyota production system
VE	value engineering

CHAPTER 1: INTRODUCTION

"Every system is perfectly designed to get the result that it does," this is a quote from W. Edwards Deming, and it describes the premise that intended and unintended consequences are both designed into our systems. With this concept in mind and understanding that as engineering principles have advanced, so too has the demand for higher quality products that can be produced at lower costs and still be at a desirable customer price point. One method for companies to meet the demand for delivering quality products at competitive prices is to begin with the end in mind. Companies need to understand where they want to position themselves in their market with regards to quality, variety, functionality and certainly price. They can adopt the stance of quick, low-cost, poor-quality products that can be sold cheaply in volume with little concern for their reputation and potential for loss of market share. Or they may choose to only produce products that are superior in quality but at a very high cost. This too could pose negative consequences as their market base may be too small to sustain an on-going business venture (S. A. Albliwi, Antony, & Lim, 2015; Antony, 2011; Imam, 2012). As such, it may be in the best interest of companies to understand cost engineering practices as it applies to the many aspects of the lifecycle of a product.

Six Sigma has been a proven approach for process improvement since the late 1980's. But process improvement applies to existing products and processes. The need for a design-based improvement methodology ushered in the Six Sigma variant design for Six Sigma among other approaches that focused on designing in characteristics such as cost, manufacturability, assembly, reliability, sustainment and others (Schenkelberg, 2016). These methods have also proven to be highly effective when successfully deployed, but research indicates alarmingly high failure rates. This is somewhat of a paradox that Six Sigma methodologies are very successful in some situations but have staggeringly high failure rates most of the time. Research is replete with studies as to critical success and failure factors for Six Sigma projects, but in product design where design of six sigma (DFSS) is the primary tool, there is not much research indicating the root causes behind project failures. Interestingly, cost engineering is a field that is covered extensively by researchers and has shown that the successful utilization of cost engineering methods and the use of skilled practitioners can result in increased cost savings, customer satisfaction as well as process efficiency (Domanski, 2020; Shermon, 2017). Again, there is little in the way of research discussing cost engineering approaches when designing new products using DFSS or similar Six Sigma methodologies.

This study will focus on this research gap between the impact of using a cost engineering approach in conjunction with the success of design projects using Six Sigma or related methodologies.

This chapter begins by giving a background of the research problem followed by a statement of the research problem, as well as descriptions of the purpose and significance of the study. Next this chapter describes the research question and hypotheses followed by relevant definition of terms used within the study. Last, this chapter will describe the proposed research design, assumptions, and limitations associated with this study. This chapter concludes with a description of the organization of the remainder of the study.

Background of the Problem

Starting with lean principles and its origins that date back many centuries but was popularized by Ford's moving assembly line process. Progressing to the Toyota Production System (TPS) and Japan's market changing success after WWII. The concept of lean principles caught the attention of the U.S. to use to regain lost market share (Womack, 2021). But companies successful implementing lean principles quickly realized that that lean would only be successful if it were supported by senior management who understood that this would be a long-term commitment involving everyone in the organization. The mid-1980's ushered in the start of Six Sigma. Rather than concern for focusing on the various types of waste that lean was proven to be effective, Six Sigma focused on process improvements that removed defects from the final product. But, like lean, Six Sigma was only effective with senior management support as well as numerous other success factors. Often coupled with Six Sigma, lean Six Sigma was popularized in the early 2000's as two complimentary methods that both could be implemented together but with different goals. Bhaskar (2020) pointed out that Lean management in isolation cannot remove variation from a process while Six Sigma by itself cannot remove many of waste from a process.

Even with Six Sigma producing massive bottom-line impact in manufacturing, design, finance, healthcare and many other areas and was clearly a methodology that was here to stay, but there were some things missing that would enable it to have even greater impact (Antony, Snee, & Hoerl, 2017). DMAIC was the approach behind six sigma and is a proven method for improving existing products and services to significant levels, but the overall performance of the product or service is often limited by its initial design. Honeywell, in the early 2000's, had successfully applied Six Sigma to design new projects but there was not an existing process to use as a guide. At the same time GE was seeing the same limitations and began building on the foundation of six sigma creating the Define-Measure-Analyze-Design-Verify (DMADV) approach which is still the primary approach used today. This new six Sigma variant would be called Design for Six Sigma (DFSS) (Antony et al., 2017). Design for Six Sigma (DFSS) quickly became the natural choice of an approach for a company to use for the design or redesign of new products. An often-quoted rule of thumb in the world of design is that 20% of costs can be affected by improving the efficiency of a design process but 80% of costs are locked in during the design process itself (Mandelbaum, Hermes, Parker, & Williams, 2012).

Design for Six Sigma (DFSS) and Design for Excellence (DfX) are both sub-topics under Six Sigma but focus on product and process design and redesign rather than the improvement of existing products and processes. DfX considers many aspects of part design and manufacturing including concepts around parts modularity and re-use (variant reduction), alternate manufacturing processes, weight optimization, manufacturability (DfM), assembly (DfA), quality (DfQ), materials selection and substitution and supplier parts management. The most important aspect of designing with cost in mind is quality. All three concepts work together to create a balance of quality products and a cost that delivers value to a customer. Quality as well as cost must be part of every discussion to maintain the desired expected value.

For the family of Six Sigma methods, critical success and failure factors are important topics to understand and mitigate to avoid project failure. The top success and failure factors vary slightly on most researchers lists. A particularly relevant finding from of Antony’s study on critical success factors shows significant failure rates for LSS projects with the highest termination rates in the measure and analyze phases using DMAIC or DMADV (Antony et al., 2020). Both measure and analyze requires commitments from many departmental areas from within a company requiring personnel with specialized skills to carry out critical data analysis to properly calculate the baseline and projected costs of the process or product improvement (Cooper, 2019). Guarraia notes that some organizations will add additional black and green belts to projects in lieu of having resources with the proper skillsets. Managers who are unsure how to recruit skilled subject matter experts too often utilize black belts to remedy all problems (Guarraia, 2008). Complementary skills among project teams as well as having adequately skilled team members are two similar but slightly different critical failure factors. Selecting team members is a critical step in aligning personnel skills for the project to ensure that the project will successfully meet stakeholder expectations (Antony & Gupta, 2019).

Product cost estimation is clearly not the responsibility of one department. Antony, et.al., notes that purchasing will sometimes chase only supplier costs and not communicate with engineering early in the design phase while engineering departments often fail to fully understand costing structures that apply to the product's full lifecycle. Similarly purchasing departments typically are not trained to recognize cost reduction ideas that will not degrade the design. Collaboration and utilization of proper skillset is a critical factor for success (Antony & Banuelas, 2002; Sreedharan V, Sunder M, & R, 2018). Complementary skills among project teams as well as having adequately skilled team members are two similar but slightly different critical failure factors. Selecting team members is a critical step in aligning personnel skills for the project to ensure that the project will successfully meet stakeholder expectations (Gupta et al., 2019).

Senior management's lack of commitment and support is an obvious reason for most performance initiatives to fail. However, the question of why senior management would not commit or support a Six Sigma initiative has not been fully resolved in literature, yet it routinely listed as one of the top critical failure factors (Antony & Gupta, 2019).

Cost engineering as defined by the Association for the Advancement of Cost Engineering (AACE) is “the application of scientific principles and techniques to problems of estimation; cost control; business planning and management science; profitability analysis; project management; and planning and scheduling.” Dating back to the 1940’s, shortages becoming am when labor, materials and parts for military equipment were in short supply engineers realized that equal or better-quality parts were available at lower costs ushering in the principle of Value Engineering.

Since that time, many cost estimating tools have been developed and utilized to address various cost estimating concerns. Domanski notes in his book on cost engineering is really an umbrella of various cost estimating methods that comprise some the tools. His list includes target costing, cost estimating, should costing, cost modeling, marginal costing, activity-based costing, value analysis, value engineering, standard costing and TRIZ (Domanski, 2020).

Given the training, experience and certifications appropriate to be a cost practitioner, it is easy to imagine that a Six Sigma or DFSS team will have difficulty recruiting someone that can fulfil the cost estimating requirements to participate in a DMAIC, DMADV or other design methodologies. Should projects continually fail to meet their planned objectives, management will lose faith with Six Sigma other methodologies such as DFSS or DfX. Antony et al. (2019) noted that one of the critical factors for project failure is adequately skilled team members and knowledge to support projects. This is a glaring omission from the literature given the description of a cost engineer as: “someone whose judgement and experience is used in the application of scientific principles and techniques to the areas of business planning and management science, profitability analysis, estimating, decision and risk management, cost control, planning, scheduling, and dispute resolution, etc. to support asset, project, program, and portfolio management" (AACE, 2022).

Product Cost Management (PCM) systems are typically data sources that pull cost data into and integrated environment usually from PLM/PDM and ERP systems as well as materials, labor rate and manufacturing process libraries. Not a method itself, a PCM is a database of costs that are sourced from various locations that contain the most accurate date available. The use of a PCM system allows cost engineers the ability to respond quickly to the costs involved in ever-changing product designs (Ostroukh, Gusenitsa, Golubkova, & Yurchik, 2014).

Problem Statement

The literature indicates that Six Sigma design related methodologies like Six Sigma, Design for Six Sigma (DFSS) and Design for Excellence (DfX) have been implemented with great success yet there are studies indicating only 13% of firms report that their total new product efforts achieve their annual profit objectives (Cooper, 2019; Guarraia, 2008).

Studies show a wide variance around these and other performance statistics, however, some companies tend to do much better than others. The Cooper (2019) study found that about 40% of new products are estimated to fail at launch while as well as out of 7 to 10 new product concepts, only one may see commercial success (Cooper, 2017b; Cooper, Edgett, & Kleinschmidt, 2004).

There is an abundance of research studies that discuss critical success factors that support the increased likelihood of product design success so it is reasonable to assume that product design projects that failed may have failed to implement these factors. But the answer is likely to far more complex and therefore worthy of study.

The objective of this research is to determine if the use of one or more cost engineering approaches can improve the success rate of Six Sigma related design projects minimizing some of the cost related failures that may have been avoided. The approaches in focus for this research is the strategic use of engineering methods, engineering practitioners and cost management systems.

Purpose of the Study

The purpose of the mixed-methods, non-experimental research study is to examine the relationship between the impact of using cost engineering approaches and the success of Six Sigma projects in the manufacturing industry. This study focuses on the relationship between Six Sigma project failures and whether skilled cost engineering professionals and practices were utilized to ensure that accurate cost data was used during the design project. Researchers have found numerous critical failure factors, Table 1, associated with Six Sigma project failures but there is little research whether the underlying cause was related to the accuracy of cost estimates for the numerous inputs required for manufacturing a product (Roy, 2003).

Table 1: Failure Factors. Source: (Antony et al., 2020).

Failure factors
Resistance to change (partial cooperation by employees)
Lack of commitment and support from top management
Incompetent team
Inappropriate rewards and recognition system/culture
Inconsistent monitoring and control (lack of expert supervision)
Inadequate training and learning
Sub-optimal team size and composition
Poor communication practices
Faulty selection of process improvement methodology and its associated tools/techniques
Scope creep

Estimated costs during the design of a product is essential for the understanding the cost of manufactured product. It is the pre-project estimate of the product cost that influences management to make a go or no-go approval decision for funding a Six Sigma or related design project. Should projects continually fail to meet their planned objectives, management will lose faith with Six Sigma projects returning to producing products that are not optimally designed their customer or company's objectives. (F. Clark, Lorenzoni, & Jimenez, 1996; Creese, 2018; Domanski, 2020; Humphreys & Müller, 1995).

Significance of the Study

The main contribution of this research is to analyze whether incorporating cost engineering approaches into Six Sigma methodologies would positively impact the outcome of designed-based projects. DFSS and DfX product design projects are very cost-oriented with costs emanating from many sources. Cost estimating methods are well document and utilized in many industries and have clear value with improving estimates. Additionally, the use of a cost practitioner who is trained, skilled and certified in cost engineering can add often lacking skills needed for developing cost models for quickly evolving designs. The last approach researched for this study is whether the utilization of a Cost Management System (CMS) system.

Research Question

A good research question does not have to be complicated to be worthy of study, but it should be specific and focused, with its answer being discoverable through proper data collection and analysis methods. If the study is conducted methodically, using proven methods, then with a degree of rigor the findings and analysis will allow the researcher to develop a cogent argument that leads to a conclusion (Doody & Bailey, 2016; Hulley, 2007; Mayo, Asano, & Pamela Barbic, 2013).

The primary research question that this study focused on relates to the relationship between cost engineering approaches and Six Sigma project success in the manufacturing and construction industry in the United States.

The research question and its associated sub-questions are demonstrated below:

Research Question:

> To what extent does incorporating a cost engineering approach relate to Six Sigma project success in the manufacturing industry as measured by the following approaches?

Approach 1: the use of cost engineering methods

Approach 2: the utilization of a skilled/trained/certified cost engineering practitioner or

Approach 3: the use of a product cost management system

The following sub-questions serve to sharpen the focus of the study:

Research Question 1:

> What perceived failure factors and cost-related causes lead to Six Sigma projects failures according to Six Sigma practitioners and cost engineering experts?

Research Question 2:

> What are the perceived relationships between the utilization of cost engineering approaches and the success of Six Sigma projects in manufacturing in the United States according to cost engineering experts?

Definition of Terms

Provided below is a list of key terms that will be referred to in the research:

Activity Based Costing (ABC) refers to a specific method of estimating or modeling costs. ABC is a formal and focused process for assigning costs that arise from the activities of an organization that are associated with a product (Zhran, 2021).

Analogous Costing is an estimation technique is also referred to as top-down estimating. It involves leveraging the estimators' experience or historical data from previous projects by adopting observed cost, duration or resource needs to a current project or portions of a project. Analogous estimating does not require data manipulation or statistical adjustments (PMI, 2022).

Bottoms-Up Costing involves estimating smaller components of something and then using the sum total of the estimates to determine the overall estimates. For projects, this approach is used for estimating things like budgets and schedules and is done as project work is being broken down or decomposed and estimated (AACE, 2022).

Cost denotes how much money a company spends on the production or creation of goods or services. It does not include profit or markup. Costs is viewed differently by different groups within a company. Manufacturing costs are sensitive to changes in production volume. Total manufacturing expenses increase as production increases. Manufacturing costs fall into three broad categories of expenses: materials, labor, and overhead. All are direct costs. Accountants may view costs as absorption or full costing which is a costing system that is used in valuing inventory. It not only includes the cost of materials and labor, but also both variable and fixed manufacturing overhead costs (Corporate Finance Institute, 2022).

Cost Estimators collect and analyze data for estimating the time, materials, and labor required to manufacture a product, construct a building, or provide a service (Latshaw & Cortese-Danile, 2002).

Cost Engineers are practitioners whose judgement and experience is used in the application of scientific principles and techniques to the areas of business planning and management science, profitability analysis, estimating, decision and risk management, cost control, planning, scheduling, and dispute resolution, etc. to support asset, project, program, and portfolio management (AACE, 2022).

Cost Engineering is the application of scientific principles and techniques to problems of estimation; cost control; business planning and management science; profitability analysis; project management; and planning and scheduling (AACE, 2022)

Cost and Value Management are broad-based terms referring to cost and value improvement activities using any cost engineering method. These terms are also used from an accounting perspective to refer to the activity of tracking costs for budget management concerns (Moisello Anna, 2012).

Cost Management System or sometimes referred to as ***Product Cost Management*** is a technology that predicts and captures estimates of the costs of products, systems or solutions over their life cycles. Software functionality predicts costs and enables users to capture estimated costs and track actual costs versus predicted costs. It includes analytical tools to identify the major sources of costs and to leverage historical predicted/estimated costs and actual costs for comparison, with future predicted/estimated product, service and solution costs for profitable trade-offs (Gartner, 2022).

Cost Modeling is often used interchangeably with cost estimating but is a more in-depth analysis of the company's costs associated with a product. Another differentiator if cost modeling is that it is used to predict the impact of design changes to the cost structure (Shermon, 2017).

Design to Cost (DtC) is an organizational methodology for integrating cost management with decision making at the design stage.

Design for Six Sigma (DFSS) is a business process management methodology variant to the of the traditional Six Sigma methodology. Where traditional Six Sigma focuses on improving or optimizing an existing product or process, DFSS aims to create a new product or process driven by the needs and wants of the customer (Francisco, Osiris Canciglieri, & Ângelo Márcio Oliveira, 2020).

Design for X (DfX). Design for X is a method of concurrent engineering activities typically performed in parallel with the aim to increase productivity for manufacturing, assembly, reliability, cost as well as product quality (Schenkelberg, 2016).

Parametric Costing describes estimating algorithms or cost estimating relationships that are highly probabilistic in nature (i.e., the parameters or quantification inputs to the algorithm tend to be abstractions of the scope). Typical parametric algorithms include, but are not limited to, factoring techniques, gross unit costs, and cost models (i.e., algorithms intended to replicate the cost performance of a process of system). Parametric estimates can be as accurate as definitive estimates. (AACE, 2022)

Product Cost Management (PCM) supports the cost and value engineering approach at an early stage of the development process by providing cost transparency for products and tools. This approach enables a quantifiable decision base for cost optimized products (Hiller, 2019)

Should Costing is a projection of the total cost of a given component if efficient manufacturing and distribution practices are followed in an optimized manner. A should-cost estimate will need to account for numerous factors including labor, materials, overhead, and profit margin. The "should" part of the name implies that the estimate will be the actual cost (aPriori, 2020; Domanski, 2020).

Six Sigma is a method that was developed to provide organizations with tools for improving the capability of their business processes. A project-oriented approach for removing defects from products, processes, and transactions (Hongbo, 2008).

Standard Costing defines the budgeted costs for every product, product component and manufacturing step on an hourly basis. After a product is produced, standard costing is then used to compare the actual cost with the budgeted or standard cost. Standard costing is used by accounts for future budget setting and only used by cost engineers for points of reference. (Domanski, 2020)

Target Costing refers to the practice of cost control by setting cost targets for every component of a product during the product development phase (Domanski, 2020).

TRIZ is a problem-solving methodology used to brainstorm cost optimized design or manufacturing solutions. Developed by Russian inventor Genrich Alshuller who analyzed historical methods of problem solving and realized that there were 40 different principles that could be applied to a problem until it was solved (Domanski, 2020)

Value Engineering deals the improvement of the value of a product as it changes during the design process. Viewed as a product cost optimization methodology for improving the value of the product to the customer with value defined as a function of the cost to produce (Mandelbaum et al., 2012).

Research Design

A research methodology or strategy should be determined by the nature of the research question and the subject being investigated. As such, the research format used in an investigation should be seen as a tool to answer the research question.

This study follows a non-experimental explanatory mix-methods design. The methods used in this study includes a quantitative phase followed by a qualitative phase.

A non-experimental design was chosen as the focus of the study to identify and observe the relationship between the use of cost engineering methods and approaches and project success (Vogt, 2011). Additionally, a non-experimental design was an appropriate option given that the study did not require the utilization of a control variable as would typically be necessary for an experimental design (Patten, 2017; Vogt, 2011). Lastly, a non-experimental design was also a more applicable option than an experimental design in this study as there was no manipulation of an independent variable (Patten, 2017; Vogt, 2011).

A quantitative methodology was chosen for the study as the research sample needed to be representative of the larger population of Six Sigma practitioners and the results must be able to validate that the identified research problem and questions are valid (Bergin, 2018; Kothari, 2019; Patten, 2017; Vogt, 2011). The analysis of the quantitative responses provided sufficient findings to create a set of questions for qualitative interviews with cost engineering experts that could be analyzed and interpreted to explain the original research questions (Bergin, 2018; Patten, 2017). A thorough description of this design is in chapter 3 of this study.

Assumptions, Limitations and Delimitations

The following sections of this chapter detail the assumptions and limitations of the relationship between the use of cost engineering approaches and Six Sigma project success in the manufacturing industry.

Assumptions

Assumptions are the key factors in a study that are accurate by the researcher and are established prior to carrying out a critical assessment (Patten & Newhart, 2017).

The first assumption made to this study is that participants fully understood the types of questions that they would be presented with on the survey before agreeing to participate. The second assumption is that participants fully understood that they were under no obligation to complete the survey and could end their participation at any time and for any reason. The last assumption in this study is that the participants responded to each question with complete honesty.

Limitations

Limitations are the key factors that the researcher has no control over but considers to be possible weaknesses in a study and are thoroughly detailed prior to critical assessment (Patten & Newhart, 2017).

Limitations are the flaws present in the specific research methods used (Patten & Newhart, 2017). A design limitation with this study is that the survey instrument was distributed virtually. This method of distribution has a great is advantage in terms of efficiency and reach, but disadvantages exist. The concern with virtual distribution is the limited ability of the researcher to respond to questions from participants related to a specific question on the survey. This limitation may lead to the potential for specification errors (Patten & Newhart, 2017).

Delimitations

Delimitations are the intentionally set boundaries applied to research that decreases the overall scope of the study (Patten & Newhart, 2017). The primary delimitation of this study is that the population has been limited to individuals from the US who are fluent in the English language, this simplifies oral and textual responses by avoiding the need for interpretation or possible misinterpretation. This will limit the results of the study making it non-generalizable to all Six Sigma practitioners in manufacturing organizations outside of the US.

Organization of the Remainder of the Study

This chapter provided an overview of the current understanding of Six Sigma and related methodologies, critical project success and failure factors, cost engineering as well as product cost management systems. This was fulfilled by describing the background of the problem of concern, as well as descriptions of the research problem statement, purpose of study, significance of the study, research question and sub-questions, definition of terms, research design, assumptions, and limitations. The second chapter of this study provides a literature review about what is currently known as well the origins and current state of Six Sigma and related methodologies, why Six Sigma projects fail and cost engineering approaches and finally insights as to gaps in literature that may point to gaps in research. The third chapter of this study provides clear details regarding the proposed methodology and the elements required to carry out a valid study. The fourth chapter will present the results of both phases of this sequential mixed-methods study. The fifth and final chapter of this study will focus on how well this study addressed the research problem based on the discussion and interpretation of the results. Additionally, this concluding chapter will discuss the limitations and implications for practice and lastly insights as to recommendations for potential future studies.

CHAPTER 2: LITERATURE REVIEW

The purpose of this study was to expand upon the research associated with relationship between the use of cost engineering methods and practitioners, and Six Sigma project success when designing or redesigning products in the manufacturing industry. The objectives of this literature review are three-fold. First, is to analyze contextual peer-reviewed literature pertaining to the impact of using cost engineering methods and practitioners in Six Sigma projects that are focused on new or redesigned products. Second, to identify the causes and factors for Six Sigma and related methodologies failures that are focused on product design and redesign. Third, to identify the issues and opportunities with incorporating a cost engineering methods and practitioners as well as an integrated cost management system into Six Sigma and Design for Six Sigma projects that focus primarily on the design and redesign of products. As a result of this literature review the research aims to provide a comprehensive look at discovering research gaps that could be reasonably addressed using an appropriate research methodology with applicable questions.

Methods of Searching

Quality research requires a system that defines the process for finding scientific literature in very specific areas to summarize information in a thorough and unbiased manner. This is necessary to help identify research questions as well as justifying the need for research in that area. The process can be very complex given the number of factors involved in performing a search for peer reviewed papers in a specific area. Lack of knowledge and the ability to identify journals that contain the research pertinent to the desired area of study is one of the biggest challenges that a new research faces. Researchers also need to have a skills in finding the correct keywords to search for relevant peer-reviewed papers. Assuming the researcher has some existing knowledge in the proposed research area they likely have a set of keywords that will be used for the initial search. It is often the case that some of these keywords searched independent of any other keyword modifiers may not produce sufficient results. Knowing which databases contain the most relevant information is crucial and can return significantly different results (Kitcheham, et.at., 2010). Lastly, knowing how to filter the findings to exclude papers that are not appropriate for the research subject is time consuming, but necessary, as papers whose title and keywords sound relevant but address the topic in a way that is not germane to the researcher's interest.

There are numerous methodologies that go into detail how to perform a systematic literature review. For the research community it is important to understand what entails a non-biased systematic literature review versus a biased search which involves collecting a list of papers using a simple keywork using the main topic name with possibly some filtering using dates or other discriminators (Torres-Carrion, 2018). The bias in this type of search is the lack of using multiple keywords that are relevant to the study as well as the inclusion and exclusion criteria that focuses the results. For systematic literature reviews, one of the primary prerequisites is a firm grasp of the proposed researcher's purpose statement. Having the purpose statement in mind during then planning of the literature review allows the researcher to focus on keyword searches as well as other inclusion and exclusion criteria that are directly or indirectly related to the search.

This literature review aims to provide a comprehensive background to discover research gaps that could be feasibly addressed by the proposed methodology by (Bacca, 2014; McLean et.al., 2013) and adapted to this literature review which follows the following flow:

Planning:

- Database selection
- Keyword selection
- Keywork modifiers
- Definition of inclusion and exclusion criteria of studies
- Definition categories for the analysis

Conduct the review:

- Study selection
- Data extraction (Content analysis method was applied)
- Data synthesis
- Data coding

Reporting the review:

- Analysis of results
- Discussion of findings
- Trends
- Conclusions of the review

Keeping an awareness of the purpose statement as the foundation the planning phase, the following choices were made with regards to database selection, keyword selection and date range for searches. Given that this study focuses on DFSS and Six Sigma failures that are attributed to poor or lack of Cost Engineering practices it was a reasonable assumption to choose a database that had a focus on Industrial Engineering topics. Conferring with the university librarian, the choice was made to use Compendex (EI Engineering Village), ABI/INFORM (Proquest) and emerald Insight as the starting point for keyword searches. The next step was to select the set of keywords to apply to the database search. The individual keywords were also modified to search for specific topics as well.

The following was the list of keywords selected.

- Six Sigma (and similar names)
- Cost Engineering
    - Cost (2012 – present)
    - Cost Engineering Methods (and similar names), (2012 – present)
    - Cost Engineering Practitioners (and similar names)
    - Cost Management Systems (and similar names)
- Six Sigma Project Failure (and similar names), (2012 – present)

The Venn diagram shown in Figure 1. represents the intersection of the areas of interest for this research.

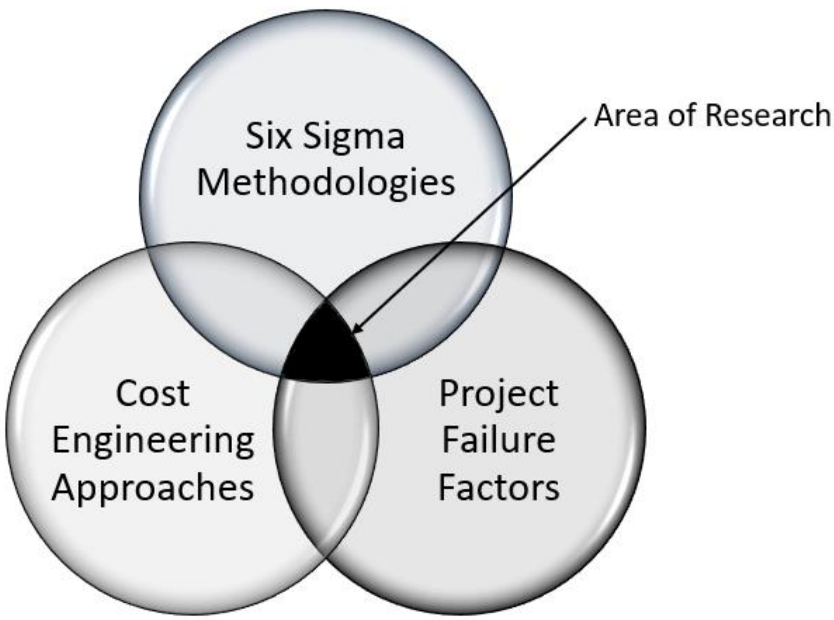


Figure 1: Venn Diagram of Search Words

The last decision to make prior to performing key word searches was to determine the date range for each keyword. Rather than arbitrarily setting a date range the researchers felt that some early background literature would be valuable in the following areas: Lean, Six Sigma, Lean Six Sigma, Design for Six Sigma, Design to Cost and Cost Engineering. As such, no starting date range was entered allowing the researcher to review materials from the beginnings of these topics to better understand the history and rationale. The starting date for Six Sigma Project Failure and Cost Management Systems were set to 2012 to provide more recent studies as part of this research. Lastly, this search only included articles that have been peer reviewed and available in English. All metadata from the search results were stored in the software package EndNote 20; a software package for storing, organizing and citing references. The systematic literature review process with document count is shown in Figure 2.

Reference Selection Diagram

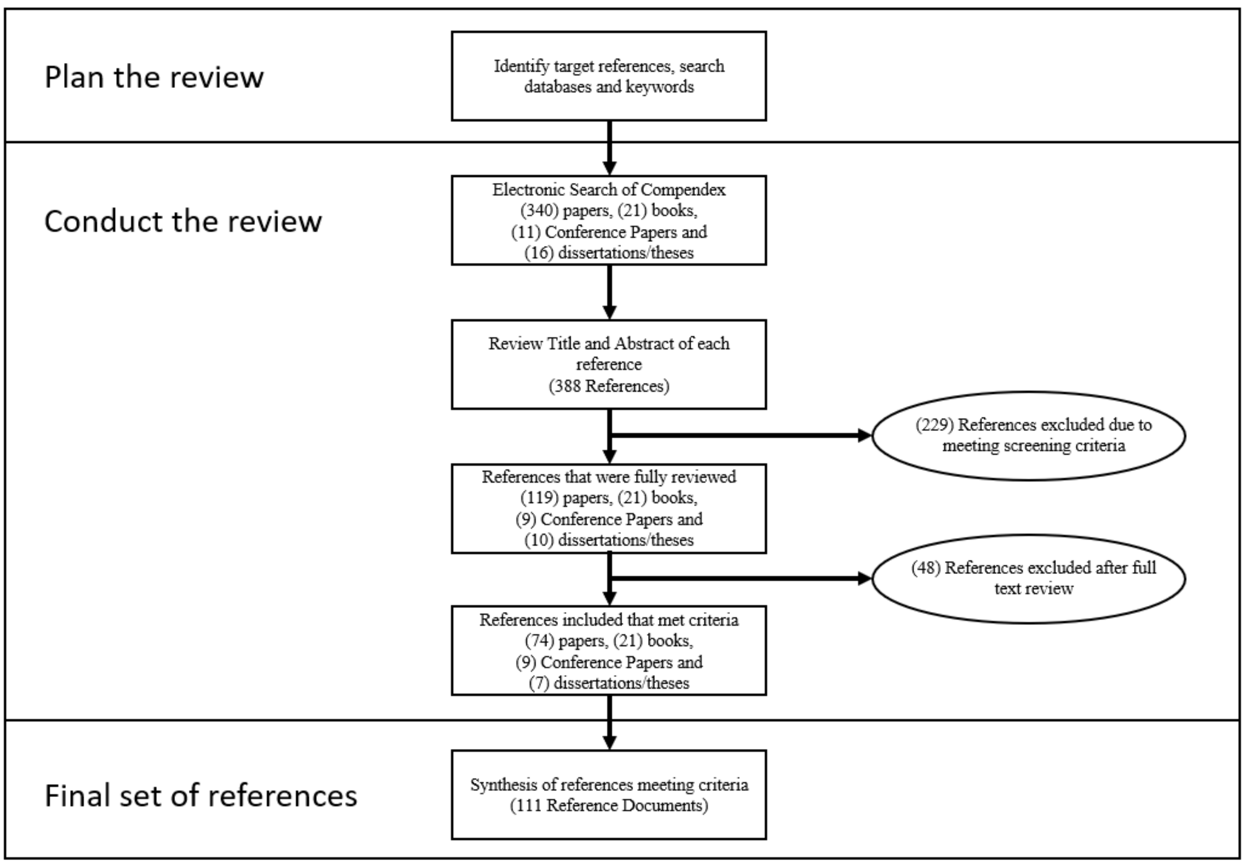


Figure 2: Literature Review Process with Document Count

The initial keyword searches yielded a total of 388 documents which were then sorted into electronic folders based on keyword name. Once the search for literature was complete the review process began. The initial review step was to read the title and abstract for each document to exclude items that were not product design oriented or were focused in different areas of interest. This review excluded a total of 229 documents across all types bring the total number of candidate documents to 159.

The final review for excluding documents was a review of the full text for each item. There were 48 excluded documents that either had no full text available, did not contain adequate content based on the title and abstract or was a duplicate of another document. The complete breakdown is shown in Table 2.

Table 2: Document Count by Keyword

	Peer Review Journals	Books	Dissertations	Conference Proceedings	Grey	Total
Six Sigma Related						
Six Sigma	15	4		1	1	**21**
Design for Six Sigma (DFSS_	10	2	2	1		**15**
Design for Excellence (DfX)	5	2	2	2		**11**
Cost Engineering						
Cost Engineering Methods	10	2	2	2	2	**18**
Value Engineering	3	3		1	1	**8**
Cost Management	8	2	2	2	1	**15**
Cost Practitioners	3	3		1	1	**8**
Cost Engineering Systems		1			3	
Why Do Projects Fail	13		1	1		**15**
	67	**19**	**9**	**11**	**9**	**111**

Review of the Literature

This section of this paper is a discussion of the literature extracted from peer reviewed journals based on the criteria discussed above. As noted in the introduction the objective of this paper is to research whether Six Sigma related design and re-design projects can be more successful using cost engineering practices. Given this objective it will first be necessary to review the seminal papers associated with Lean, Six Sigma, Lean Six Sigma, Design for Six Sigma, and Design for Excellence. These frameworks all have methods, processes and steps that pertain to either new product design or redesign of an existing product. The review of these frameworks provide research to gain insight as to how the applicable processes within these methodologies find or determine the associated costs for the various steps in designing products. The purpose of this literature review is additionally fulfilled through a thorough review of the recent, major, and interrelated studies associated with the cost estimation causes of project failures for Six Sigma, DFSS and Design to Cost projects involving the design of products.

Six Sigma and Related Methodologies

Lean

Lean thinking dates back many hundreds of years, but Henry Ford is the person credited for instantiating lean practices into manufacturing (Stern, 2019). Ford used process-based assembly sequences to minimize part movement. His process was based on a go/no-go system that advanced the assembly to the next station for further assembly or fabrication. Ford’s system was excellent at producing a high volume of vehicles, but he was not able to provide much in the way of variety. Engineers at Toyota were aware of Fords success and started studying ways to immolate the assembly line concept but with more variety. Starting in the 1930’s and then more aggressively after World War II, the Toyota team, including Kiichiro Toyoda and Taiichi Ohno, developed the Toyota Production System (TPS). TPS shifted the focus to product flow though the shop by right sizing the machines to the process, introducing self-monitoring machines for quality control and developing quick setup techniques to improve product variety. Extended from the Toyota Production System (TPS) philosophy that is now known as lean thinking (Jones & Womack, 1996). The foundation for Lean vision is to focus on the product and its value stream with the goal of producing products at the lowest cost and as fast as possible by eliminating wastes, or muda, within the system. The seven forms of waste include: over-production, unnecessary inventory, inappropriate processing, excessive transportation, waiting and unnecessary motion. Identifying value-added and non-value-added activities in a product's value-stream creates the possibility of shortening lead times by removing some of these wastes and allowing for higher quality results from the value-added processes. When implemented successfully lean can help enable a learning culture engaged in continually improving all aspects of the organization including faster throughput and ultimately more savings to increase profit. Lean not only allows for cost reductions while improving quality, but it can also position a company to achieve tremendous growth (Pepper & Spedding, 2010). For these reasons, it has become a key business strategy that many companies have attempted to implement in order to replicate the successes of Toyota as well as other companies (Bhaskar, 2020).

There are numerous tools used in the lean, but the overall thought process, see Figure 3. below, as describe by Womack & Jones (1996) begins with first identifying the problem, challenging the value stream by removing waste, create product flow for the remaining steps, establish pull between steps and then continuously improve the process (Jones & Womack, 1996).

Figure 3: The Five Lean Principles. Source: Jones and Womack (1996).

When the news of the Toyota's success with the lean philosophy, automotive manufacturers in the United States started to take notice. The rationale was clear as Toyota was quickly taking market share from U.S. manufacturers by bringing a broader selection of vehicles to market faster. Adopting lean, U.S. automakers were able to increase productivity between 1968 and 1978 by 23.6% as compared to 89.1% by Toyota (Pepper & Spedding, 2010). Delphi, an automotive supplier, took lean and applied it to supplier development, cost management, strategic sourcing as well as quality. They realized that lean would only be successful of it were led by senior management who understood that this would be a long-term commitment in order to realize success (Nelson, 2004).

The rush to adopting lean as a philosophy to reduce non-value-add activities and change a company's profitability has often been unsuccessful. Whether it is from poor understanding of the long-term commitment, lack of senior management leadership, employee resistance or a general lack of communication, lean programs do not always work. Research by Irani, (2020), Research suggests that lean works best in high volume and low variability shops like automotive manufacturers, but not as well in job-shop environments with low volume and high variability (Irani, 2020). This makes sense from the standpoint that shops with many products means that each job is handled differently so that production approaches cannot be standardized.

Lean thinking still enjoys continued success with demand spreading beyond manufacturing into areas such as logistics, retail, healthcare, government and energy (Womack, 2021).

Six Sigma

In the late 1980's in response to relentless competition, primarily from Japan, Motorola reliability engineer Bill Smith and others developed began tackling several improvement projects. Their approach was similar in nature to previously run Total Quality Management (TQM) projects using a variety of methods including statistical process control, design of experiments, quality function deployment, experimental design as well as attempting to get everyone in the organization on board with quality improvements (Antony, 2011; Bhaskar, 2020). One of the limitations with TQM was the lack of a methodology that could be used on different projects. TQM had plenty of tools but there was no overall strategy for approaching problems or any strict adherence to metrics and measurements to determine project success. Several years after Motorola's improvement initiatives began, Mikal Harry joined with Smith to formalize the initiative basing the foundation on reducing process variations to the degree that specification limits for key processes metrics would be six standard deviations from the mean – this new initiative was call Six Sigma (Antony et al., 2017).

By definition Six Sigma is statistical measurement representing 99.99966% or 3.4 defects per million opportunities (DPMO). As the name implies Six Sigma is an analysis-based initiative based on fact-based decision making at all levels of the organization. Six Sigma operates as a top-down approach utilizing a rigorous closed-loop methodology that eliminates non-value add steps while focusing on key metrics, often new to the process, as well as adding steps for continuous improvement after the project has been completed (Hongbo, 2008).

DMAIC is the methodology supporting Six Sigma and is broken down into five discrete phases that breakdown into many steps with associated tools for solving problems that are encountered during the project. Table 3 below lists the DMAIC phases and the key steps that must be conducted with each phase.

Table 3: Key Steps of the DMAIC Process. Source: Hongbo, 2008.

Steps	Key processes
Define	Define the requirements and expectations of the customer Define the project boundaries Define the process by mapping the business flow
Measure	Measure the process to satisfy customer's needs Develop a data collection plan Collect and compare data to determine issues and shortfalls
Analyze	Analyze the causes of defects and sources of variation Determine the variations in the process Prioritize opportunities for future improvement
Improve	Improve the process to eliminate variations Develop creative alternatives and implement enhanced plan
Control	Control process variations to meet customer requirements Develop a strategy to monitor and control the improved process Implement the improvements of systems and structures

A methodology this complex requires highly trained resources able to think critically about how to approach each phase before the prior phase is correctly completed. The role of the Six Sigma project leader is so critical for project success that several organizations have developed training and certification programs where successful graduates are given the title of Black Belt. An iSixSigma editorial noted that '*All businesses – regardless of sector, size, or project – link their success to one factor. In Six Sigma parlance, it is the Black Belt*" (iSixSigma, 2020). The role of the Six Sigma Black Belt (SSBB) is that of a change agent. Considered a leadership role responsible for implementing process improvement projects using the DMAIC methodology. SSBB are very knowledgeable and highly skilled with the tools and approaches needed to carry out a successful project. Aside from the critical role of the SSBB there are many other factors that play into the success of deploying a successful six sigma project. A research study by Anthony & Banuelas (2002) surveyed 300 companies with 45 respondents about what the key factors were for a successful six sigma implementation. The survey consisted of 34 statements (variables) culled from recent literature pertaining to factors that make six sigma projects successful. After the 34 statements were formulated, they were grouped into 11 factor groups each with roughly three statements. The results of this often cited survey revealed the rankings as shown in Table 4 below (Antony & Banuelas, 2002).

Table 4: Ranking Analysis of Key Ingredients for Six Sigma. Source: Antony & Banuelas (2015)

Ranking Analysis of Key Ingredients for Six Sigma

Ranking Analysis of Key Ingredients for Six Sigma
1. Management commitment and involvement
2. Understanding of Six Sigma methodolgy, tools and techniques
3. Linking Six Sigma to business strategy
4. Linking Six Sigma to customers
5. Project selection, reviews and tracking
6. Organizational infrastructure
7. Cultural change
8. Project management skills
9. Linking Six Sigma and suppliers
10. Training
11. Linking Six Sigma to employees

Studies from 2002-2020 show effectively the same findings with some ranking differences largely attributed to survey demographics (Anbari, 2014; Antony & Banuelas, 2002; Sreedharan V et al., 2018; Yadav & Desai, 2016).

Lean Six Sigma

The term 'Lean Six Sigma' was first used to discuss the integration of the Lean and Six Sigma philosophies in a paper published in 2000 by J.H. Sheridan (Sheridan, 2000). The integration of Lean and Six Sigma creates both a business strategy as well as a process improvement methodology. When implemented successfully LSS maximizes shareholder value by improving quality, customer satisfaction, faster throughput and overall cost reductions. LSS achieves this by merging tools and principles from both Lean and Six Sigma (Antony et al., 2017; Laureani & Antony, 2019; Munteanu, 2017; Pepper & Spedding, 2010; Stern, 2019). Lean is all about removing wastes of various types in an effort to increase speed and efficiency. Both philosophies have similar goals but come from disparate roots which have been successfully on their own. Lean is focused on removing non-value-added steps to simplify the process flow utilizing many tools that are used and understood by all levels of workers. Six Sigma is concerned with precision and accuracy employing statistical methods in order to reduce variations that contribute to defective products. Figure 4 below illustrates the key differences between Lean and Six Sigma (Munteanu, 2017).

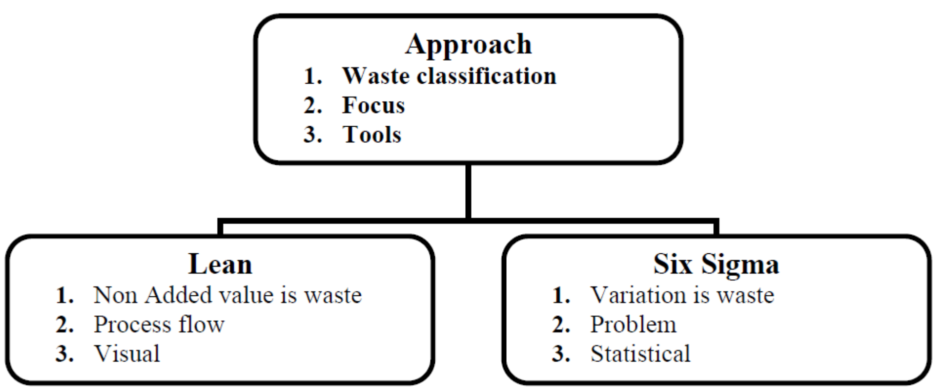


Figure 4: Key Differences Between Lean and Six Sigma. Source (Munteanu, 2017).

Imam (2020) the authors notes that an organization should capitalize on the best of both Lean and Six Sigma in order to realize the full value of both philosophies. To do so, an organization should include the following three primary tenets of lean management (Imam, 2012):

1) Build an organizational culture that seeks to maximize the value-added processes

2) Evaluate all incentive systems in place to ensure that they result in global rather than local optimizations

3) Incorporate management decision processes that bases every decision on how the customer is impacted by proposed changes

Similarly, an organization should include the following three primary tenets of Six Sigma:

1) base decisions on data-driven statistics rather than ad hoc studies.

2) promote methodologies that strive to minimize variation of quality characteristics.

3) design and implement a company-wide education and training program

As stated by Albliwi, et al. (2014) lean and six sigma complement each creating an obvious relationship that works very well when managed properly as shown in Figure 5.

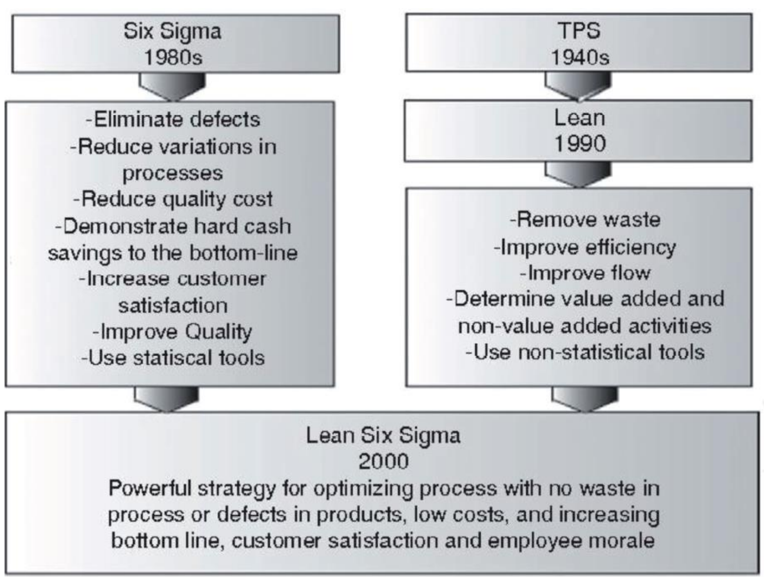


Figure 5: Lean and Six Sigma Relationship Synergies.Source: (S. A. Albliwi et al., 2015).

Bhaskar (2020) points out that Lean management in isolation cannot remove variation from a process while Six Sigma by itself cannot remove many of waste from a process (Bhaskar, 2020).

With regards to tools utilized in LSS it is reasonable to find that there would be some overlap in commonality of tools yet lean still relies on tools that focus on wastes whereas six sigma uses statistic tools to find process variation (Munteanu, 2017). A representative list of LSS tools is shown in Figure 6 below.

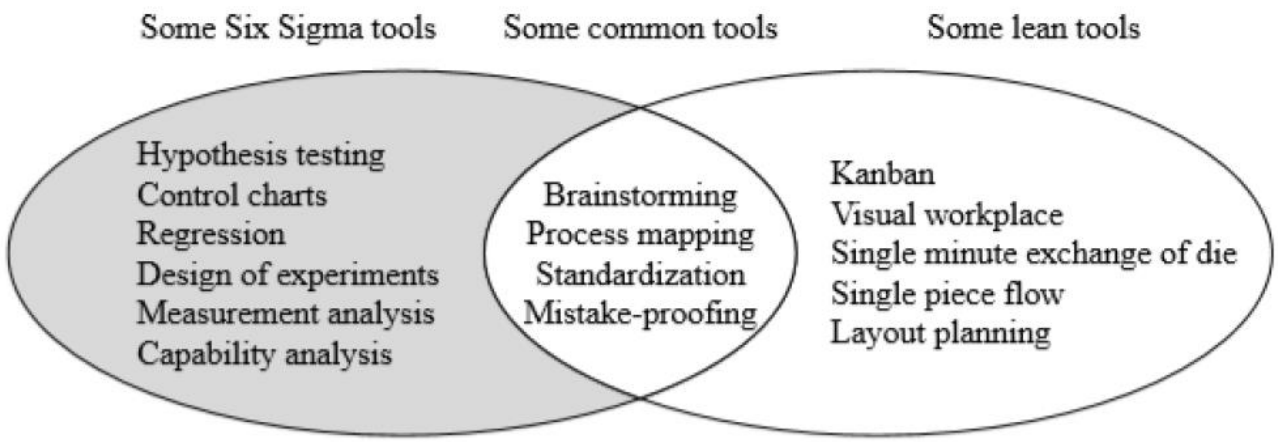


Figure 6: Six Sigma and Lean Tools. Source. (Munteanu, 2017).

Design for Six Sigma

A major challenge for many companies is their ability to design new products in the shortest possible time while bringing it to market at a competitive cost with the quality and customer services expected by customers (Chang, 2016; Eggers, 2014; Franke, 2013). Six sigma organizations determined that they sometimes could only improve products and processes by as little as three or four sigma without performing a redesign of the product or process. This implies that six sigma levels of performance, 3.4 defects per million, must be designed into the product or process. Given that the objective of six sigma's DMAIC approach is process improvement of existing products and processes it stands to reason that a product design-oriented approach would be needed for new and re-designed products and processes. Figure 7 below illustrates the often-tenuous relationship between DFSS and DMAIC.

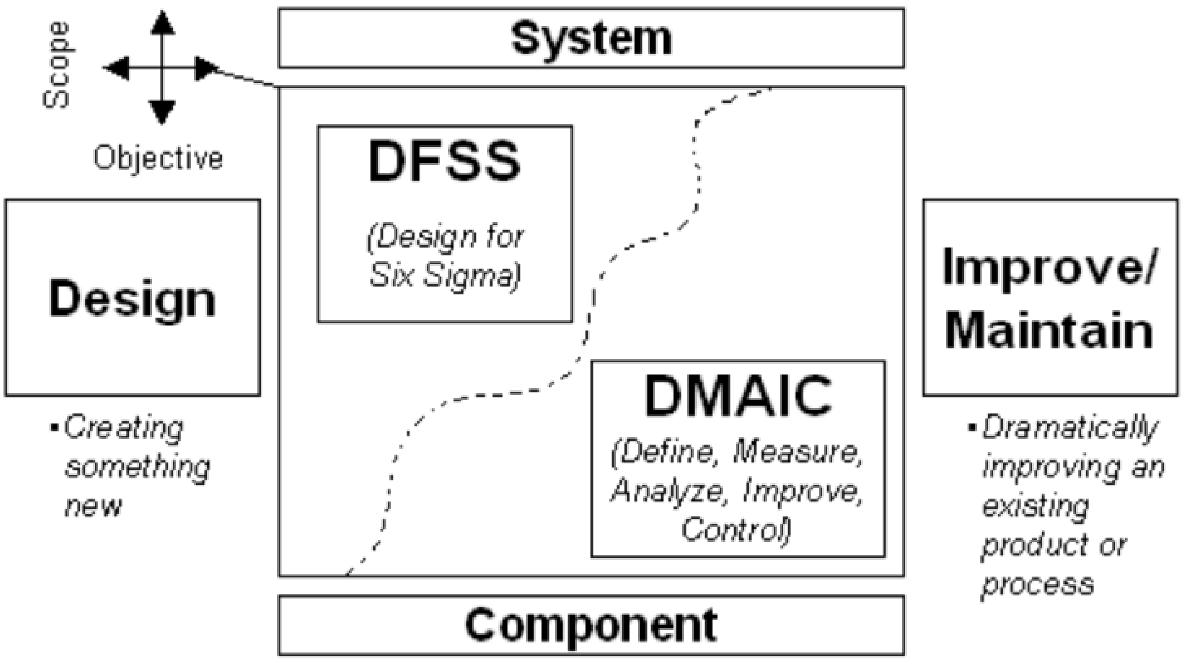


Figure 7: Relationship between DFSS and DMAIC. Source: ISIXSIGMA.

It is important to note that Six Sigma was producing massive bottom-line impact in manufacturing, design, finance, healthcare and many other areas and was clearly a methodology that was here to stay, but there were some things missing that would enable it to have even greater impact (Antony et al., 2017). DMAIC which is the acronym for Define-Measure-Improve-Control is the approach behind six sigma and is a proven method for improving existing products and services to significant levels, but the overall performance of the product or service is often limited by its initial design. DFSS was developed for the design of new products or the re-design of existing products. (Mandelbaum et al., 2012) noted the often-quoted rule of thumb that 20% of costs can be affected by improving the efficiency of a design process but 80% of costs are locked in during the design process itself.

Honeywell, in the early 2000's, had successfully applied Six Sigma to design new projects but there was not an existing process to use as a guide. At the same time GE was seeing the same limitations and began building on the foundation of six sigma creating the Define-Measure-Analyze-Design-Verify (DMADV) approach which is still the primary approach used today. This new six Sigma variant would be called Design for Six Sigma (DFSS) (Antony et al., 2017). Design for Six Sigma (DFSS) quickly became the natural choice of an approach for a company to use for the design or redesign of new products. It is important to realize that how difficult it can be to choose between Six Sigma and DFSS. What seems to be a typical Six Sigma DMAIC improvement project might be more appropriately changed to a DFSS redesign project. Ahmad Elshennawy and Abhishek Vootukuru proposed a solution for a hybrid approach that combines both Six Sigma DMAIC and the DFSS DMADV into an integrated approach they call DMARC which stands for Define, Measure, Analyze, Redesign, and Control. The redesign phase consists of the four DMADV sub-phases: Measure, Analyze, Design, and Verify. The use of this hybrid model may take care of any need for a full redesign during an improvement initiative (Elshennawy & Vootukuru, 2009).

There are numerous papers that discuss DFSS and DMADV approaches, but researchers have found at least 15 methods. Patil, as noted in Table 5 shows a list of the 10 most queried methods that support DFSS Google queries do not necessarily translate to frequency of use on DFSS projects, but it does imply interest.

Table 5: DFSS Methods. Source: (Patil, 2013).

DFSS-Cycle	Hits of Google*	Phases					
DMADV	59.000	Define	Measure	Analyse	Design		Verify
IDOV	13.400		Identify		Design	Optimize	Verify
DMADOV	3.060	Define	Measure	Analyse	Design	Optimize	Verify
DMEDI	2.680	Define	Measure	Explore	Develop	*Implement*	
CDOV	1.730			Concept	Design	Optimize	Verify
DCCDI	1.350	Define	Customer	Concept	Design	*Implement*	
DCOV	1.350	Define		Characterize		Optimize	Verify
DIDOV	473	Define	Identify		Design	Optimize	Verify
DMADIC	76	Define	Measure	Analyse	Design	*Implement*	Control
DMCDOV	38	Define	Measure	Characterize	Design	Optimize	Verify

Recent literature shows that along with DMADV, the IDOV method uses an optimization phase typically used in the aerospace and heavy manufacturing industries are the most prevalent methods. But all these methods utilize the same statistical and quality tools including QFD, benchmarking, Design or Experiments, simulations, statistical optimizations, FMEA and others (Alghamdi, Elshennawy, & Rabelo, 2016; Alvarez, 2015; Alwerfalli, 2012; Patil, 2013).

Given that DFSS is a Six Sigma method focused on new designs or re-designs of a product or process focusing on reducing product variability using many analytical models as well as knowledge of manufacturing processes. DFSS' focus on design requires, as noted earlier in this paper, a different methodology than Six Sigma. Namely, the DMAIC becomes DMADV where the final two steps for DFSS are Design and Verify. It is in the design step that many very desirable outcomes, as shown in Table 6, can be achieved that likely could not be improved after production commences (Itani, Ahmad, & Al-Hussein, 2019; Yang & El-Haik, 2003).

Table 6: Desired outcomes of a DFSS project. Source (Yang & El-Haik, 2003).

Desired Outcomes for a DFSS Project

Desired Outcomes for a DFSS Project
Customer driven and focused
Measures of the effectiveness of the design process
Measures to compare performance versus requirements
Achieve key business objectives
Effective use of human resources and knowledge
Adherence to teamwork
Upfront development of robustness and testing for verification
Foster learning organization
Forces a paradigm shift from find-fix-test to prevention
Handles changes without affecting customer
Insensitive to development processes noises
Concurrent methods, consistent training—everyone knows how
Uses integrated approach to design from concept to validation
Allows useful decision to be taken with absence of data (e.g., in the conceptual phase)
Capable of checking the feasibility of having the Six Sigma capability *analytically* in the design entity
Pinpoints where it is easier to implement changes when needed
Increases the potential for high reliability and robustness
Provides ample room to establish Six Sigma capability by conceptual means upfront
Uses optimization to set tolerances

Design for X (DfX) – Concurrent Engineering

"If I ever started with a Six Sigma initiative again, I would focus on design rather than on production." This is a quote from Bob Galvin, CEO of Motorola during the creation of the Six Sigma philosophy. Galvin stated that process improvement is required because of an ineffective design process but that it is much better and cheaper to prevent problems during the design process rather than solve after production begins. The objective of DfX and DFSS is to bring innovation much earlier into a controlled situation and to minimize problems with the market introduction (Favi, Germani, & Mandolini, 2016; Lee & Kulvatunyou, 2019; McDermaid, 2019).

Given that DFSS is a Six Sigma method focused on new designs or re-designs of a product or process focusing on reducing product variability using many analytical models as well as knowledge of manufacturing processes. DFSS' focus on design requires, as noted earlier in this paper, a different methodology than Six Sigma. Namely, the DMAIC becomes DMADV where the final two steps for DFSS are Design and Verify. It is in the design step that many very desirable outcomes can be achieved that likely could not be improved after production commences (Itani et al., 2019; Yang & El-Haik, 2003).

The ”X” in DfX stands for any range from any product life phase such as cost, manufacturing, assembly, reliability through obsolescence. Often cited in research as “Design for eXcellence” the term does not have a clear origin, but the term ‘Design for Production” first appeared in a 1953 report by the British Productivity Council titled “Design for Production: Report of a Visit to the U.S.A” (Schenkelberg, 2016). Given all the potential targets that DfX has to offer it is reasonable to see how designers can focus on one or more targets simultaneously. Designers can reach design goals, investigate constraints, overcome difficulties, and consider the impact of their decisions earlier in the product lifecycle using DfX techniques (Ahmad, Lahonde, & Omhover, 2014). Figure 8 below illustrates how various Design for X (DfX) approaches impact costs during product design (Itani et al., 2019).

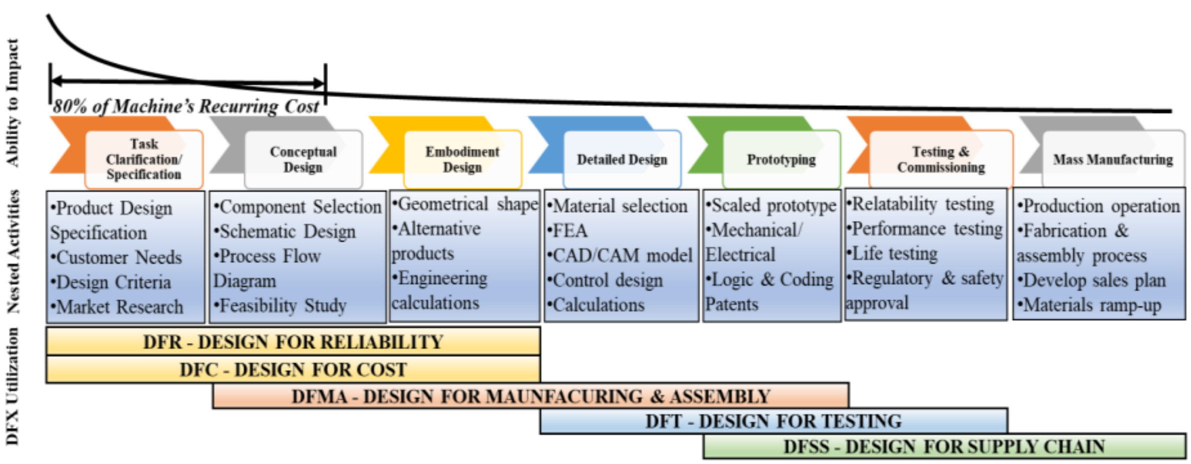


Figure 8: Cost Impact during Design Phases. Source: (Itani et al., 2019).

Starting with Design-for-Assembly (DfA) and Conceptual DfA criteria designers can develop designs that create cost-effective assembly sequences for complex products. Using a

Design-for-Manufacturing (DfM) approach the designer can focus on costs and issues related to materials and manufacturing processes selection. If the effort is to minimize costs using a Design-for-Cost (DfC) approach, there may be many constraints that must be held while targeting a cost minimized design (Favi et al., 2016).

Favi et al., (2017) developed a multi-objective framework model that begins at a product’s conceptual design and carries through to production. This approach uses a design concept that is centered around Design for Assembly (DfA) as well as Design for Manufacturing (DfM) and Design for Cost (DfC). They propose reviewing multiple conceptual designs to evaluate various manufacturing processes to produce parts as well as evaluating assembly to minimize build time. Cost is a consideration throughout the process by evaluation materials costs and time costs in manufacturing and assembly.

Below is an illustration from Itani that shows the link between the process and various design elements (Itani et al., 2019).

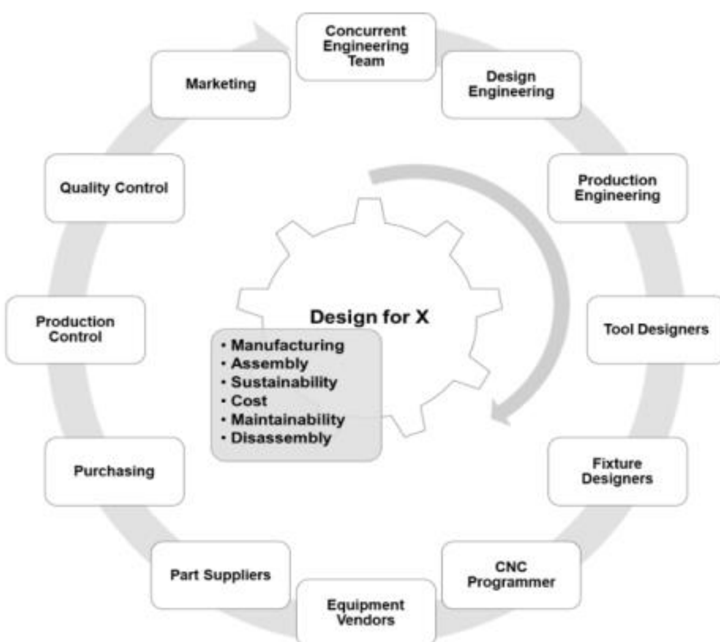


Figure 9: Design for X Model. Source: (Itani et al., 2019).

Six Sigma and Related Methodologies Summary

The research for six Sigma and related methodologies provided a review the seminal papers associated with Lean, Six Sigma, Lean Six Sigma, Design for Six Sigma, and Design for Excellence. These frameworks all have methods, processes and steps that pertain to either new product design or redesign of an existing product. The review of these frameworks provides insight as to how the applicable processes within these methodologies find or determine the associated costs for the various steps in designing products. Below is a table of authors with the year the cited paper was published and the applicable area of interest.

Table 7: Literature review summary for Six Sigma and related methodologies

Literature Review Summary for Six Sigma and related Methodologies

Literature Review Summary for Six Sigma and related Methodologies

Paper Year	*Year*	*Lean*	*Six Sigma*	*Lean Six Sigma*	*Design for Six Sigma*	*Design for Excellence*
Womack, J.	2021	✓	✓	✓		
Bhaskar, H.	2020	✓	✓	✓		
Imam, S. T., Ashok; Sarkar, Sudipto.	2020	✓	✓	✓		
Irani, S. A.	2020	✓				
Favi, C., Germani, M., & Mandolini, M.	2019				✓	✓
Itani, A., Ahmad, R., & Al-Hussein, M.	2019				✓	✓
Laureani, A., & Antony, J.	2019		✓	✓		
McDermaid, D.	2019				✓	✓
Stern, T. V.	2019	✓	✓	✓		
Sreedharan V, R., Sunder M, V., & R, R.	2018	✓	✓	✓		
Antony, J., Snee, R., & Hoerl, R.	2017		✓	✓		
Munteanu, A. M. C.	2017	✓	✓			
Alghamdi, M. A., Elshennawy, A. K., & Rabelo, L.	2016		✓	✓	✓	
Chang, W. T., S.A.	2016				✓	✓
Schenkelberg, F.	2016					✓
Yadav, G., & Desai, T. N.	2016	✓	✓	✓		
Alvarez, J. C.	2015	✓	✓	✓	✓	
Albliwi, S. A., Antony, J., & Lim, S. A. h.	2015	✓	✓	✓		
Ahmad, R., Lahonde, N., & Omhover, J.-F.	2014					✓
Anbari, F. T. K., Young Hoon.	2014		✓			
Patil, A., Paul.	2013				✓	
Mandelbaum, J., Williams, H. W., & Hermes, A. C.	2012	✓	✓	✓	✓	✓
Alwerfalli, D., ;Lash, Trevor.	2012				✓	
Antony, J.	2011	✓	✓	✓		
Yoon, H.-K., & Byun, J.-H.	2011		✓		✓	
Pepper, M. P. J., & Spedding, T. A.	2010	✓	✓			
Hongbo, W.	2008		✓			
Nelson, R. D.	2004	✓				
Yang, K., & El-Haik, B.	2003				✓	
Antony, J., & Banuelas, R.	2002		✓	✓		
Sheridan, J. H.	2000	✓	✓	✓		
Jones, D., T., & Womack, J., P.	1996	✓				

Why Projects Fail

Six sigma and related methodologies are part of many businesses strategy to increase process performance and new product development resulting in enhanced customer satisfaction and improved results. Seeking to improve the bottom-line results of organizations in cost savings as well as to create value for customers. Six Sigma differs from other quality management approaches in its structure and methodology as it tends to be more of a data-driven approach with many tools and techniques to solve problems (Antony et al., 2020).

The literature indicates that Six Sigma design related methodologies like Six Sigma, Design for Six Sigma (DFSS) and Design for Excellence (DfX) have been implemented with great success yet there are studies indicating only 13% of firms report that their total new product efforts achieve their annual profit objectives (Cooper, 2019; Guarraia, 2008). An older Bain & Company's survey found that 80 percent of 184 companies responding claimed that "Lean Six Sigma efforts are failing to drive the anticipated value" and 74 percent said, "they are not gaining the expected competitive edge because they haven't achieved their savings targets" (Guarraia, 2008). Additionally, research is rich with papers listing the top reasons for LSS and DFSS project failures. This list could have easily been named critical failure factors for implementing a continuous improvement project as the top reasons for succeeding are the same reasons that projects fail.

While these are many lists available from researchers showing the factors causing failure or success, there are few papers that explain the underlying reasons for failure or early termination of a Six Sigma or related project. A 2020 systematic literature review conducted by Antony included 21 papers to determine the main reasons for Lean, Six Sigma and Lean Six Sigma failures. The results from the research found the top ten failure factors can be found in table 8 (Antony et al., 2020).

Table 8: Top ten failure factors

Top Ten Failure Factors (Antony et.al., 2020)

Top Ten Failure Factors
Lack of commitment and support from top management
Poor communication practices
Incompetent teams
Inadequent training and learning
Faulty selection of a process improvement methodology and associated tools/techniques
Failure to deliver on promised value
Scope creep
Sub-optimal team size and composition
Inconsistent monitoring and control (lack of expert supervision)
Resistance to change (partial cooperation by employees)

As expected, some variations of these causes are cited by researchers, but the Antony list above is a good representation of the most common factors from a meaningfully recent study. Breaking down a few of the identified factors into their root causes will be helpful in this research study. All factors are significant and deserve research and understanding, but two that pertain directly to this research are senior management's lack of commitment and incompetent team makeup.

Senior management's lack of commitment and support is an obvious reason for most performance initiatives to fail. However, the question of why would senior management not commit or support a six sigma initiative has not been fully resolved in literature. It is somewhat surprising that a project would be approved without management's approval and involvement. The results from the research found the top effects and can be found in table 9 (Antony et al., 2020).

Table 9: Effects of senior management lack of support

Effects of Senior Management Lack of Support (Antony et.al., 2019)

Effects of Senior Management's Lack of Support
Involvement in goal setting
Project planning and resource allocation
Project monitoring and contol
Aligning project objectives with corporate strategy
Systematic methodology for project selection, prioritization and tracking
Incompetent teams are factors that appear on most researchers list of failure factors.
Selecting team members is a critical step in aligning personnel skills for the project.

Antony's research also discusses the following as root causes for poor team member performance The results from the research found the top causes can be found in table 10 (Antony et al., 2020).

Table 10: Top causes behind team member's poor performance

Top Causes Behind Team Member's Poor Performance (Antony et. al., 2019)

Top Causes Behind Team Member's Poor Performance
Common goal, and interdependence among team members
Adequately skilled team members
Problem solving expertise/knowledge by team members
Mmotivation on behalf of the team members
Establishing and optimizing the project team based on
Detailed task descriptions and allocation analysis
Ccomplementing skill among project members
Learning new skills to respond to changes in the business environment
Project leadership skills necessary to lead the team

A particularly relevant finding from of Antony's study shows significant failure rates for Six Sigma related projects had higher termination rates in the measure and analyze phases using DMAIC or DMADV (Antony et al., 2020). Both measure and analyze requires commitments from different areas within the company. Often personnel with specialized skills are needed to carry out critical data analysis as part of the measure and analysis phases. A critical success factor requires having the proper skillsets for the task and adding additional black and green belts can slow performance improvement efforts. Managers who are unsure how to deploy subject matter experts too often utilize black belts to remedy all problems (Guarraia, 2008).

Project Failure Factors Summary

The research for why projects fail ties back into the critical success and failure factors associated with Lean, Six Sigma, Lean Six Sigma, Design for Six Sigma, and Design for Excellence. These critical factors and underlying causes are key in beginning to understand why projects fail. Below is a table of authors with the year the cited paper was published and the primary focus of the paper.

Table 11: Why projects fail

Literature Review Summary for Why Project Fail

Literature Review Summary for why projects fail

Paper Year	*Year*	*Focus of Paper*
Antony, J., Lizarelli, F. L., & Machado Fernandes, M.	2020	A global study into the reasons for Six Sigma project failures
Antony, J., & Gupta, S.	2019	Top ten reasons for Six Sigma project failures
Antony, J., Lizarelli, F. L., Fernandes, M., et. al.	2019	Reasons for process improvement failures
Cooper, R. G.	2019	The drivers for success in new product development
Sreedharan V, R., Sunder M, V., & R, R.	2018	Critical success factors for Six Sigma
Guarraia, P. C., Gib; Corbett, Allisair; Neuhaus, Klaus	2008	Six Sigma project succeess and failures
Antony, J., & Banuelas, R.	2002	Key factors for effective Six Sigma project implementations

Cost Engineering Approaches

As product development and go-to market timelines shrink, manufacturers are leveraging enhanced cost estimation processes and models to deploy design to cost and other cost reduction strategies to stay competitive with companies in the global marketplace .

Estimating costs and then subsequently controlling costs, within the limits of the estimate, during the design of a product is essential for the successful of the project. It is the pre-project estimate of the product cost that influences management to make a go or no-go approval decision for funding a design for Six Sigma or design for excellence project. Should projects continually fail to meet their planned objectives, management will lose faith with DFSS or DfX projects and continue producing products that are not optimally designed for their customers (F. Clark et al., 1996; Creese, 2018; Domanski, 2020; Humphreys & Müller, 1995).

As defined by the Association for the Advancement of Cost Engineering (AACE) the definition of cost engineering is "the application of scientific principles and techniques to the areas of business planning and management science, profitability analysis, estimating, decision and risk management, cost control, planning, scheduling, and dispute resolution, etc. to support asset, project, program, and portfolio management."

As noted previously, often-quoted rule of thumb that 20% of costs can be affected by improving the efficiency of a design process yet 80% of costs are locked in during the design process itself. Consequently, improving the design early in the life cycle, when the design flexibility is highest, has far greater leverage (Mandelbaum et al., 2012). The figure below, illustrates this notion of the positive impact of managing costs during the design phase rather than attempting to improve the situation after production begins (Yang & El-Haik, 2003).

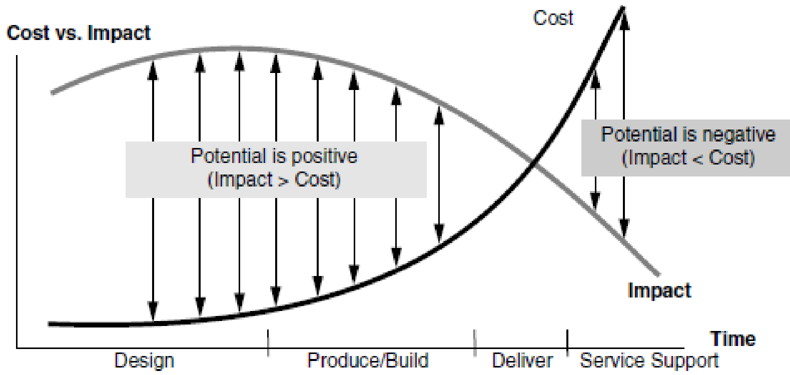


Figure 10: Impact of Cost during Design Product Life cycle.
Source:(Yang & El-Haik, 2003).

Some of the basic costs that need to be determined as part of a new or redesign manufactured parts includes the following from Domanski's book (Domanski, 2020). Below is a table of authors with the year the cited paper was published and the primary focus of the paper.

Table 12: Basic costs for new or redesigned products

Basic Costs for New or Redesigned Products (Domanski, 2020)

Basic Costs for New or Redesigned Products
Manufacturing labor rates
Raw materials
Purchased components
Floor space cost
Machine costs
Reference process times
Machine setup
Tooling and fixtures

Cost Engineering Methods

The basic concept behind cost engineering is the ability to accurately estimate the cost of the product that is made up of both vendor purchased parts and parts produced in-house. But, as Domanski, 2020 notes, it is important to understand what goes into each part's cost that makes the final product. It is important to factor in all the costs as noted in table 12, but also the additional costs that might be incurred during assembly and sustainment (Domanski, 2020).

Cost estimating uses predictive processes to determine costs of the resources that are required to fulfil the scope of the products final design and production. The ultimate goal of cost estimating is to minimize the uncertainty of the estimate while providing an expected cost that fails inside a derived probabilistic distribution (Creese, 2018). The figure below lists the processes that fall under the category of cost engineering methods that are allow cost engineers to model costs for estimating, cost control, cost forecasting, investment appraisal and risk analysis.

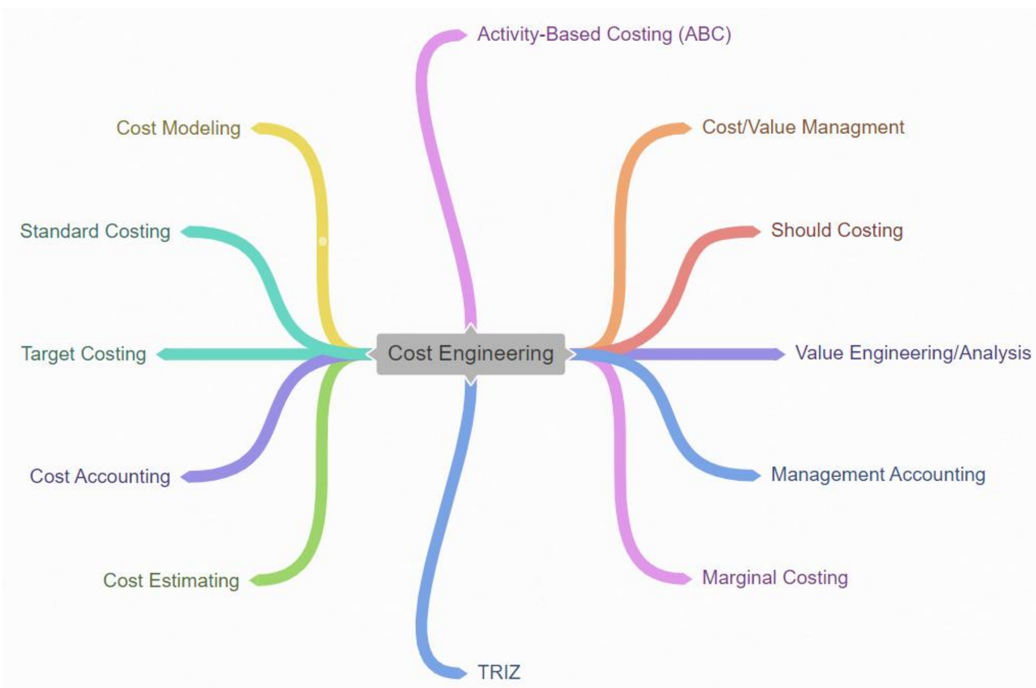


Figure 11: Cost Engineering Methods.

The estimated cost of a new design is very difficult to determine, but necessary to ensure that it can be sold at profit. The simplest method is use target costing. Someone from sales or marketing may look at the prevailing market prices of a product to determine what the maximum product costs should be considered for profit mark-up, design, production, and other product related costs. If the product cost exceeds the expected market price, then the decision to develop and produce will not be approved. If the product is considered important enough, then either the cost can be reduced through redesign, profit margin can be reduced or the target price can be increase or some combination (Creese, 2000). The steps in the target cost process are illustrated in following figure.

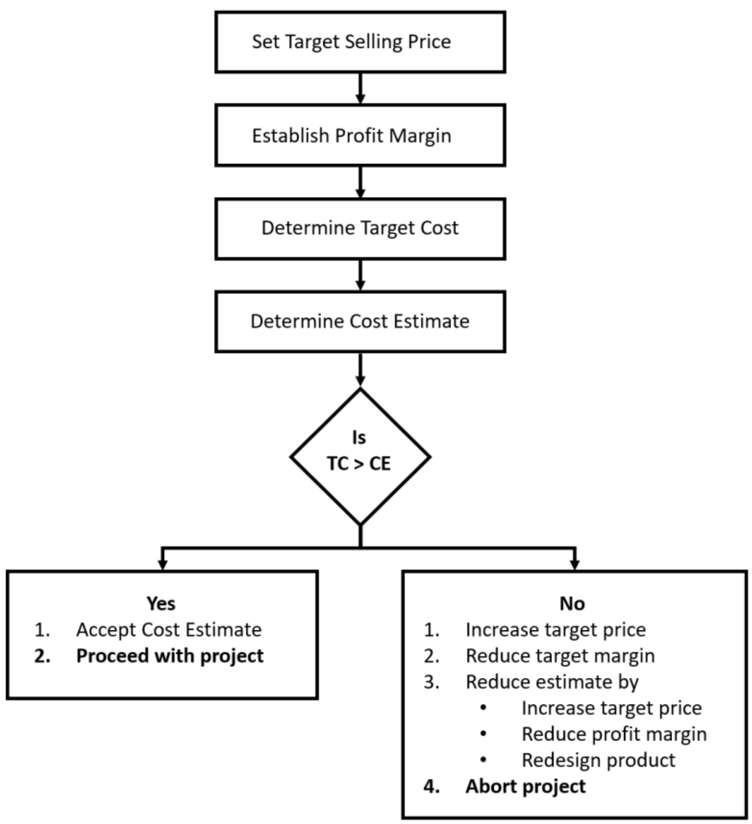


Figure 12: Steps in a Basic Target Costing Process. Source: (Creese, 2000).

Activity-based-costing (ABC) is a complex cost engineering method that involves modelling the activities around how costs are assigned by a company to the causal inputs for producing a product. ABC costing is useful for developing cost models that can accurately predict the costs of a product which, in turn, can help with profitability analysis (Hicks, 2004).

Analogous cost estimating uses the cost of a similar system with adjustments for differences. This method is based on historical data which may be out of date and or based in a single data point. Typically used early in the design phase to get a rough order of magnitude cost (NASA, 2008).

Parametric cost estimating is more complex than analogous in that it involves statistical relationships between historical costs and other product characteristics that may include physical or performance changes. Parametric estimating is sometimes used when only a 3-D model is available with limited historical data (NASA, 2008).

Bottoms-up or engineering build-up estimating produces a detailed cost estimate that evaluates every activity involved in the production of that part. This is a time intensive, detailed methodology that produces the most accurate and defensible estimate of a product (NASA, 2008)

Cost Engineering Practitioners

Using AACE's description of a cost engineer as: "someone whose judgement and experience is used in the application of scientific principles and techniques to the areas of business planning and management science, profitability analysis, estimating, decision and risk management, cost control, planning, scheduling, and dispute resolution, etc. to support asset, project, program, and portfolio management" (AACE, 2022). Given this skill set it is easy to imagine that a Six Sigma or design for Six Sigma team will need to recruit someone with these skills to fulfil the cost estimating requirements during the DMAIC, DMADV or other methodologies with product design steps.

Cost engineering practitioners is an umbrella term for anyone who uses costing methods to estimate the cost of a product. Typically, cost practitioners are employed in most industries involving large investment products such as construction, automotive and manufacturing. Cost engineering practitioners can earn credentials by gaining certification as a cost engineering practitioner of various types.

Cost Management Systems

Many companies have and still rely on spreadsheets for historical data information from previous development efforts which may be satisfactory for small operations that develop simple designs and have a handle on the input costs. However, companies that perform design, manufacturing and sourcing on a global scale must be able to work at a scale that exceeds anything simple estimation techniques could possibly satisfy. Regardless of the cost estimation used, there are many costs and factors that must be considered during the design of a new product. A tool that can be used to predict and estimate the cost with acceptable accuracy requires different types of input as depicted in Figure 13.

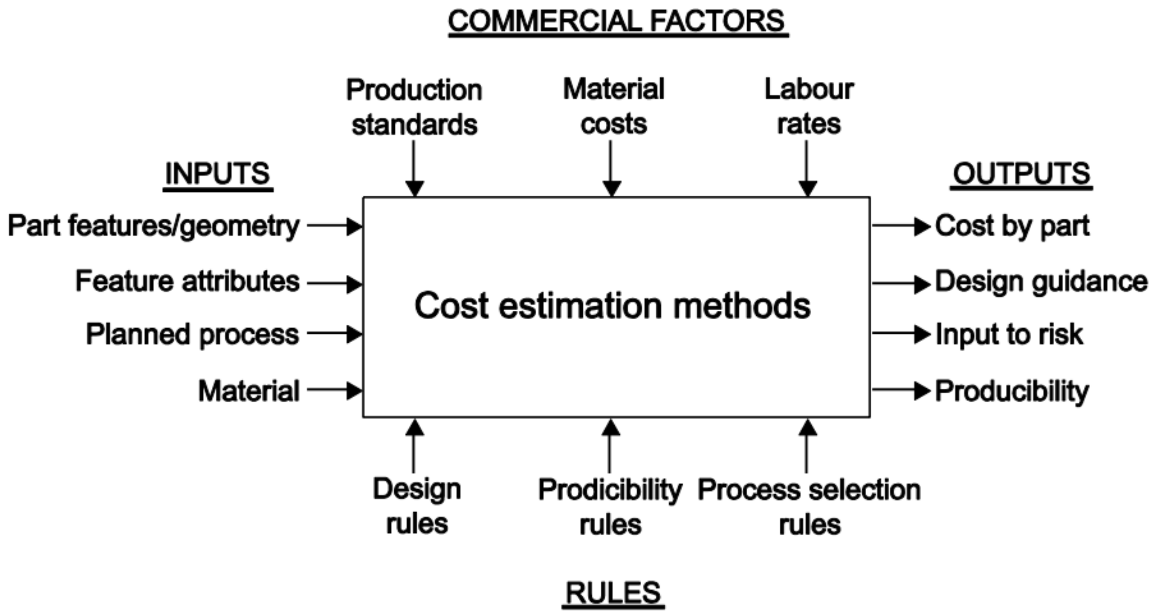


Figure 13: Information Required for Accurate Cost Estimations. Source: (Roy, 2003).

The first commercial tools specializing in manufacturing cost estimating appeared in the early 1980's. These tools were had crude interfaces and required significant hours of training and expertise to use properly. As software technology advanced, so too did cost estimating software. The inclusion of a database to store part cost data allowed for somewhat easier retrieval began to appear in the marketplace allowing designers to understand the cost of their design was under over the target. As the 2000's progressed so did the technology and demand from various groups from within companies. Sourcing managers were asking for detailed should cost estimates as a tool for negotiating with suppliers and build to order shops and cost engineers were in desperate need of a system that was able to provide cost comparisons for many CAD models to understand the cost range of a particular design (Hiller, 2019).

As cost estimating requirements grew commercial software started to add libraries of material costs and machine processing costs as well as integrating PDM/PLM and ERP systems emerged creating what is called Product Cost Management (PCM) and is illustrated in Figure 14 (Ostroukh et al., 2014).

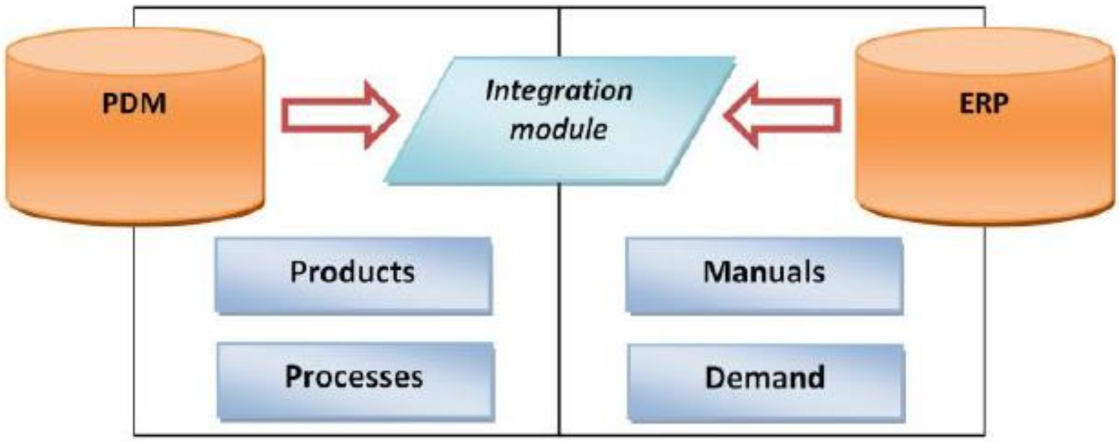


Figure 14: Integration Framework, PDM and ERP. Source: (Ostroukh et al., 2014).

A Product Cost Management System is not an accounting system; it is an integrated infrastructure that allows experts in various areas of design, engineering, manufacturing and sourcing to share cost data for the purpose of creating proposals ROI estimates as well as having a source that contains various manufacturing processes and their associated costs involved in designing and producing a product. A PCM system can provide very detailed analyses of costs for evaluating the total cost of production before the first part makes it to production. (aPriori, 2020).

Cost Engineering Approaches Summary

The research for cost engineering approaches includes cost engineering methods, cost engineering practitioners and cost management systems which is also referred to as product cost management systems. Of these three approaches, there exists many resources on cost engineering methods with books and papers dating back many decades covering many topics. Research on the topic of cost engineering professions is basically non-existent in peer-reviewed journals but there does exist information on commercial sites such as the Association for the Advancement of Cost Engineering (AACE) or The Society of Product Cost Engineering Analytics. Both of these organizations offer certifications and education opportunities for new or experienced professionals. Below is a table of authors with the year the cited paper was published and the primary focus of the paper.

Table 13: Literature review summary of engineering approaches

Literature Review Summary for s Engineering Approaches

Literature Review Summary for cost engineering approaches

Paper Year	***Year***	***Focus of Paper***
AACE	2022	Commercial site targeted towards cost engineering professionals
Domanski, C.	2020	Cost engineering principles for manufacturing
Hiller, E.	2019	The evolution of product cost management systems
Creese, R. C.	2018	Fundamentals of cost engineering methods and techniques
Ostroukh, A. V., Gusenitsa, D. O., et. al.	2014	Integration of ERP and PDM for product cost management
Mandelbaum, J., Hermes, A., Parker, D., & Williams, H.	2012	Value engineering and Six Sigma
Roy, R.	2003	Cost engineering principles
Yang, K., & El-Haik, B	2003	How cost impacts Six Sigma development
Creese, R. C.	2000	Inegrated cost management techniques and topics
Clark, F., Lorenzoni, A. B., & Jimenez, M.	1996	An early book on cost engineering principles
Humphreys, K. K., & Müller, M.	1995	An early paper on cost engineering

Literature Review Summary and Research Gap

This intent of this chapter was to explore the existing research areas associated with the relationship between the use of cost engineering methods and practitioners, and Six Sigma project success when designing or redesigning products in the manufacturing industry.

The first search for papers focused on the history and relationship between Six Sigma related methodologies. Starting with lean principles and its origins that date back many centuries but was popularized by Ford's moving assembly line process. Progressing to TPS and Japan's market changing success after WWII. The concept of lean principles caught the attention of the U.S. to use to regain lost market share. But companies successful implementing lean principles quickly realized that that lean would only be successful if it were supported by senior management who understood that this would be a long-term commitment involving everyone in the organization. The mid-1980's ushered in the start of Six Sigma. Rather than concern for focusing on the various types of waste that lean was proven to be effective, Six Sigma focused on process improvements that removed defects from the final product. But, like lean, Six Sigma was only effective with senior management support as well as numerous other success factors. Often coupled with Six Sigma, lean Six Sigma was popularized in the early 2000's as two complimentary methods that both could be implemented together but with different goals. Bhaskar (2020) pointed out that Lean management in isolation cannot remove variation from a process while Six Sigma by itself cannot remove many of waste from a process. Given this study was focused on product design and redesign the search for papers shifted to include Design for Six Sigma and a Design for X. Both methods are sub-topics under Six Sigma but focus on product and process design and redesign rather than the improvement of existing products processes. The findings from these papers are like Six Sigma and lean Six Sigma with regards to the need for strict adherence to the methodology as well as understanding and abiding by the critical success factors for a successful deployment.

The second search for papers focused on critical success and failure factors which are plentiful in the expected population of literature. The success factors as well as failure factors are very similar across the body of literature reviewed with the top factors only varying slightly based on the perspective of the targeted group. Revisiting the quote from Bain & Company which conducted a survey finding that 80 percent of 184 companies responding claimed that "Lean Six Sigma efforts are failing to drive the anticipated value" and 74 percent said, "they are not gaining the expected competitive edge because they haven't achieved their savings targets" (Guarraia, 2008). Additional studies found similarly high failure rates usually with a list of failure factors with little mention of the underlying cause. For this research study the concern is largely focused on failure factors for design based Six Sigma methods. The failure factors discuss in DFSS and DfX papers were, again, high level factors that were general to Six Sigma projects.

The third search was for papers on cost engineering methods, approaches, practitioners and cost database/product database systems. To frame this summary, it may be useful to repeat the Association for the Advancement of Cost Engineering's definition of cost engineering which was, "the application of scientific principles and techniques to problems of estimation; cost control; business planning and management science; profitability analysis; project management; and planning and scheduling." As expected, search databases were rich with cost engineering papers and the findings that were relevant to this research in that the researcher have studied the evolution of cost engineering principles from WWII with the advent of Value Engineering until today. Researchers discussed the need for cost estimation methods and tools for estimating costs and then subsequently controlling all the costs associated with the design and associated manufacturing of a product. Researchers note that is the pre-project estimate of the product cost that influences management to make go or no-go approval decisions for funding of a DFSS or DfX project. Should projects continually fail to meet their planned objectives, management will lose faith with Six Sigma other methodologies such as DFSS or DfX. Not represented in the literature was any discussion of the use of a skilled, trained, certified Cost Engineer to augment the Six Sigma resource team. Antony et al. (2019) noted that one of the root causes for project failure is adequately skilled team members with specific skills and knowledge to support projects. This is a glaring omission from the literature given the description of a cost engineer as: "someone whose judgement and experience is used in the application of scientific principles and techniques to the areas of business planning and management science, profitability analysis, estimating, decision and risk management, cost control, planning, scheduling, and dispute resolution, etc. to support asset, project, program, and portfolio management" (AACE, 2022).

The last set of key word searches was targeted at finding research on cost data, cost database and product cost management systems. Literature is very thin in this area with a few papers describing the concept of an integrated system using PLM/PDM and ERP systems which is the logical place for cost data to reside given that product BOM's are contained in these systems. This study was able to find software and consulting services white papers and general information about Cost Management Systems (CMS) or Product Cost Management (PCM) systems.

CHAPTER 3: METHODOLOGY

The methodology utilized in a research study is critical as it helps to establish the validity and reliability of the study (Patten, 2017). Researchers use two primary methodologies which can be qualitative or quantitative which can be used independently or combined into a mixed-method design. Each method has unique strengths and weaknesses that are different in several ways as discussed below (Kothari, 2019). This chapter presents the methodology process used for this research study including a description of the specific procedures used to identify, collect, measure, and analyze data for this research topic.

Starting with the purpose of this study and preliminary research question as the root of this study, the research will be followed-up with an in-depth literature review that identified several research gaps. Based on those research gaps the research question will be refined and written. The next step of the study will be to determine a proper design of experiments with an applicable data collection method and analysis protocol. Once the data has been thoroughly analyzed and interpreted the researcher will write the conclusion, significance of the research as well as areas for future research. This chapter explores various research design methods based on the research question identified for this study.

Quantitative Research

Quantitative research emphasizes objective measurements and the use of structured systematic methodologies that employ statistical, mathematical and numerical analysis of data collected from surveys which can be used to provide significant evidence of specific patterns in data from large populations (Vogt, 2011). The quantitative methodology is considered appropriate when conducting research in where the goal is to draw conclusions from data-driven analyses. One of the strengths of quantitative methodologies is that it provides more reliable numerical results from statistical analysis due to limited bias from subjectivity (Vogt, 2011). Quantitative methodology is usually less expensive, less intrusive and more likely to be repeatable than a qualitative methodology (Kothari, 2019). The weakness of the quantitative methodology is that it often requires large samples creating greater potential for confirmation bias. Additionally, quantitative methodologies require minimal if any personal interaction with the respondents which can be problematic in instances where a participant is unsure of how to answer a question (Vogt, 2011).

Phase 1 of this study was quantitative in nature and utilized a survey instrument designed using a nominal questionnaire format to better understand the "what" questions related to the research problem. The survey data analysis was then used to determine the "why" questions posed in the qualitative research phase of this study (Creswell, 2015).

Qualitative Research

Qualitative research involves the use of an unstructured systematic methodology such as content or thematic analysis which may be verbal or behavioral research and narrative analysis allowing a researcher to explore concepts and experiences (K. R. Clark & Vealé, 2018). Qualitative research, if used as the only design method, is considered appropriate when the goal is strictly exploratory, like for exploring root causes or specific non-numeric characteristics. It can also be used as an explanatory design to explain the responses from a quantitative survey to validate the initial research questions (Creswell, 2015). The value of performing a qualitative research study is that it requires fewer respondents and can be analyzed by summarization or interpretation (Clark & Vealé, 2018) or by thematic analysis (V. Braun & V. Clarke, 2021). Qualitative methods often allows researchers to gain in-depth hands-on experience providing easier identification of outliers and contradictions in data that can't be directly experienced using quantitative methodologies (Kothari, 2019). The primary concern with qualitative methodologies is the decreased validity and reliability attributed to subjectivity (K. R. Clark & Vealé, 2018).

The qualitative data analysis chosen for this study was thematic analysis. Thematic analysis is used as the qualitative data analysis method developed for analyzing interview questions. Researchers use this systematic technique to find patterns and relationships between the entirety of the interviewee's transcribed data sets. Thematic analysis helps focus on realizing the noticeable meanings of the data as it has the flexibility and accessibility to find themes (V. Braun & V. Clarke, 2021; A. Fugard, Potts, H., Atkinson, P., Delamont, S., Cernat, A., Sakshaug, J., & & Williams, 2020; Nowell, Norris, White, & Moules, 2017).

Thematic analysis is a good approach for this research given that we need expert opinions to explain the research questions that were validated from the responses to the phase 1 survey.

Rather than trying to summarize the interview responses or attempting to fit responses around the research questions, thematic analysis allows the researcher to iteratively review the transcripts to identify common themes that can then be interpreted to draw conclusions regarding the research questions. As part of the analysis, the researcher needs to be aware of the approaches that should be considered for finding themes:

- a deductive approach involves the researcher analyzing the data with a pre-conceived notion of the themes prior to the start of the study based on existing knowledge
- an inductive approach involves allowing the data to determine the themes

The research method typically used by researchers for conducting a thematic analysis study is based on Braun and Clark's 6-step framework. Although the framework is listed numerically, each step can be visited and revisited as often as necessary to define the study's themes. It is important to not make and inferences during this 6-step process (Virginia Braun & Victoria Clarke, 2021).

Below, in table 8, is a description of each step.

Table 8: Age Demographic

Braun & Clarke's Six Stem Mthod for Thematic Analysis

Braun & Clarke's Six Stem Mthod for Thematic Analysis	
Step 1:	Become familiar with the data by reading each transcript several times and taking notes about related and interesting observations.
Step 2:	Generate initial codes from the transcripts into meaningful chunks. It is important to bear the research questions in mind during coding, but do not be afraid to include comments that are interesting as they may be related later in the analysis.
Step 3:	Search for themes that emerge from the patterns that the codes reveal. Again, these themes must relate to the research questions for this study.
Step 4:	Review themes for modification, if necessary. This is the time to gather all the relevant transcript data into groups representing each theme. This allows the researcher to read all the theme-related content to ensure that the data supports the theme.
Step 5:	Define the themes by ensuring that they are pertinent to the research question, has sufficient data to support it and does not overlap with other themes.
Step 6:	Write-up the analysis for each theme using the data to support the validity of the theme's claim. This is most effective of there are several meaningful quotes to substantiate the analysis.

Phase 2 of this study is qualitative in nature and utilizes a semi-structured interview format for data collection to better understand the "why" responses developed from the survey analysis. The interview response data will be analyzed using thematic analysis for identifying themes (Virginia Braun & Victoria Clarke, 2021; Creswell, 2015).

Explanatory Mix-Methods Design

The research question is what leads the researcher to determine the appropriate research design method. Ideally, a mono-method design using either a quantitative or qualitative design may sufficient unless the research question cannot be completely explained using just one of these methods (Creswell, 2015). Mixed methods designs have been challenged as being better than the mono-method design unless there is some value in justifying the mixed methods model. A few of the justifications for using a mixed methods design includes: Triangulation (convergence), Expansion and Exploration (Greene, Caracelli, & Graham, 1989).

A convergent design should determine to what extend the quantitative and qualitative results converge. This parallel design model allows the researcher to compare the merged results of the quantitative and qualitative data which are performed in parallel to answer an over-arching research question. The rationale for a convergent design is that a quantitative and qualitative design, by itself, may not be able to provide sufficient results (Creswell, 2015). Figure 15 show shows the data from the parallel methods coming together for analysis and interpretation.

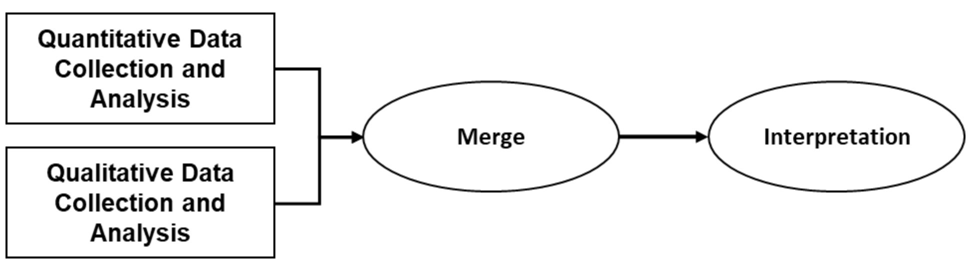


Figure 15: Convergent - to what extent does the quantitative and qualitative results converge

An exploratory design should determine in what ways do the qualitative data explain the quantitative results. This sequential design model is described as using a qualitative method as the primary phase that can be used to identify and develop variables and hypotheses that do not exist (Creswell, 2015). The general model is shown in figure 16.

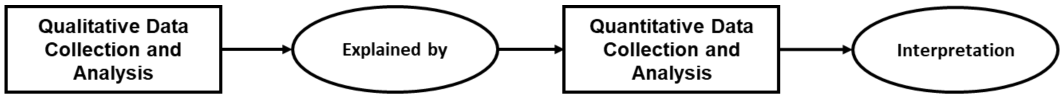


Figure 16: Exploratory – qualitative data explained by quantitative results

An explanatory design should determine in what ways do the qualitative results generalize the quantitative findings. This sequential design model may be designed using a larger quantitative phase which is then analyzed and explained by a qualitative phase. This is a powerful design in which the quantitative phase guides the development of the qualitative phase (Creswell, 2015). The general model is shown in figure 17.

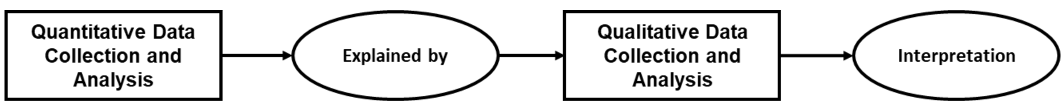


Figure 17: Explanatory - quantitative results generalized by quantitative findings

As with most mix method models there are advantages and disadvantages. The advantage of the convergent model is that both studies run concurrently keeping the study timeline shorter than the exploratory and explanatory models which are sequential in nature. In all three models the researcher needs to be mindful of the justification for using a mix methods approach (Creswell, 2015; Doyle, Brady, & Byrne, 2016).

Purpose of the Study

The purpose of the mixed-methods non-experimental research study is to analyze the relationship between the impact of using cost engineering approaches and failures in Six Sigma projects in the manufacturing industry. Researchers have found numerous critical failure factors associated with Six Sigma project failures but there is little research whether the underlying cause was related to the accuracy of cost estimates for the numerous inputs required for manufacturing a product.

Estimated costs during the design of a product are essential for the understanding the cost of manufactured product. It is the pre-project estimate of the product cost that influences management to make a go or no-go approval decision for funding a Six Sigma project. Should projects continually fail to meet their planned objectives, management will lose faith in Six Sigma projects ability to produce products that are not optimally designed or meet their customer or company's objectives. (F. Clark et al., 1996; Creese, 2018; Domanski, 2020; Humphreys & Müller, 1995).

When projects fail value is not recognized from the cost and effort expended. Today, many companies' success hangs in the balance based upon the success of key products being competitively price in the market. The general problem is that corporate managers fail to understand what cost really means in their own business. As a result, projects are undertaken that are doomed to fail from the start due to poor cost estimates. The specific problem is that poor cost engineering approaches can have a negative on the success of Six Sigma projects. Therefore, the purpose of this study is to analyze the perceived impact of using cost engineering approaches as related to the success or failure of Six Sigma projects in the manufacturing industry.

Research Problem

The primary research question that this study focused on relates to the relationship between cost engineering approaches and Six Sigma project success in the manufacturing and construction industry in the United States.

The research question and its associated sub-questions are demonstrated below:

Research Question:

> To what extent does incorporating a cost engineering approach relate to Six Sigma project success in the manufacturing industry as measured by the following approaches?
>
> Approach 1: the use of cost engineering methods
>
> Approach 2: the utilization of a skilled/trained/certified cost engineering practitioner or
>
> Approach 3: the use of a product cost management system

The following sub-questions serve to sharpen the focus of the study:

Research Question 1:

> What perceived failure factors and cost-related causes lead to Six Sigma projects failures according to Six Sigma practitioners and cost engineering experts?

Research Question 2:

> What are the perceived relationships between the utilizing of cost engineering approaches and the success of Six Sigma projects in manufacturing in the United States according to cost engineering experts?

Research Design

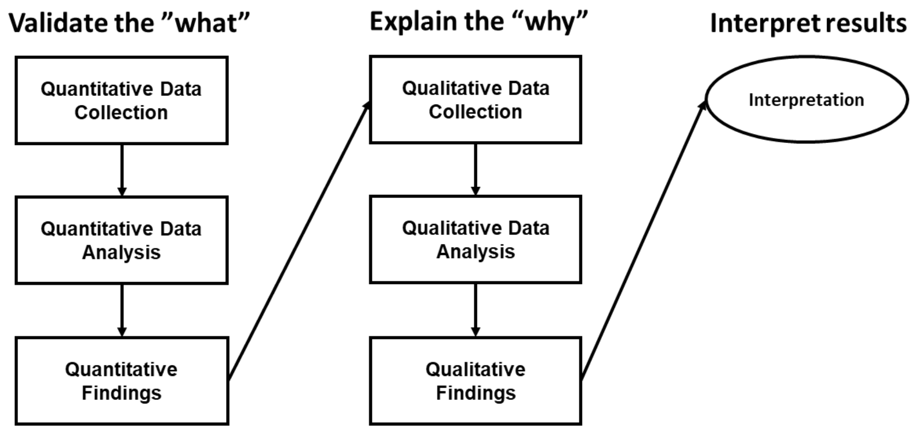
A research methodology or strategy should be determined by the nature of the research question and the subject being investigated. As such, the research format used in an investigation should be seen as a tool to answer the research question.

This study follows a non-experimental explanatory mix-methods design. The methods used in this study includes a quantitative phase followed by a qualitative phase.

An experimental design was chosen as the focus of the study to identify and observe the relationship between the use of cost engineering methods and approaches and project success (Vogt, 2011). Additionally, a non-experimental design was an appropriate option given that the study did not require the utilization of a control variable as would typically be necessary for an experimental design (Patten, 2017; Vogt, 2011). Lastly, a non-experimental design was also a more applicable option than an experimental design in this study as there was no manipulation of an independent variable (Patten, 2017; Vogt, 2011).

A quantitative methodology was chosen for the study as the research sample needed to be representative of the larger population of Six Sigma practitioners and the results must be able to validate that the identified research problem and questions are valid (Bergin, 2018; Kothari, 2019; Patten, 2017; Vogt, 2011). The analysis of the quantitative responses provided sufficient findings to create a set of questions for qualitative interviews with cost engineering experts that could be analyzed and interpreted to explain the original research questions (Bergin, 2018; Patten, 2017).

Figure 18 is a graphical representation of the steps for this explanatory mixed methods research design for this study.



Survey results may validate the research questions from the literature review	Interview results explain the results of the survey which validate the research questions	Mixed-method's design results can then be analyzed and interpreted to draw conclusions about the research question

Figure 18: Mixed-Method Research Methodology Flowchart

The following presents the philosophical underpinnings of each of these forms of research.

Phase 1 of this study utilizes a nominal quantitative survey questionnaire targeted towards Six Sigma practitioners. The quantitative survey will first be conducted to validate and confirm the research questions from the literature review. Based on the analysis of the survey results a set of explanatory questions will be developed for the subsequent qualitative phase.

Figure 19 is a graphical representation of the flowchart of the quantitative phase of the mixed methods design for this study.

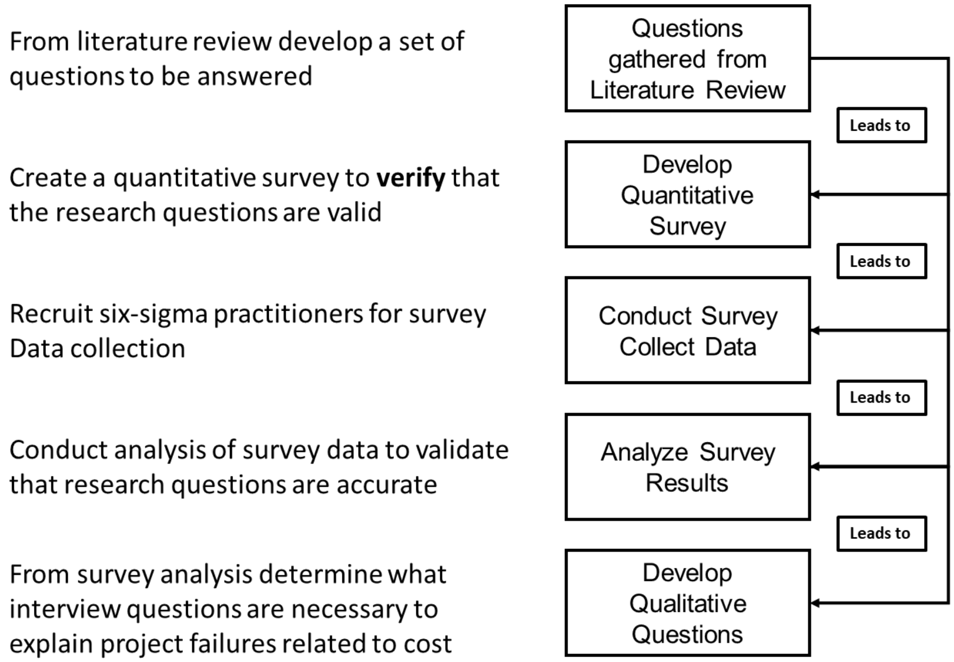


Figure 19: Phase 1 Quantitative Flowchart

Phase 2 of this study utilizes a semi-structured qualitative interview method targeted towards cost engineering experts to explain the results of the nominal survey responses. Once the interview transcripts have been analyzed, the findings will then be interpreted to draw conclusions about the research question.

Figure 20 is a graphical representation of the flowchart of the qualitative phase of the mixed methods design for this study.

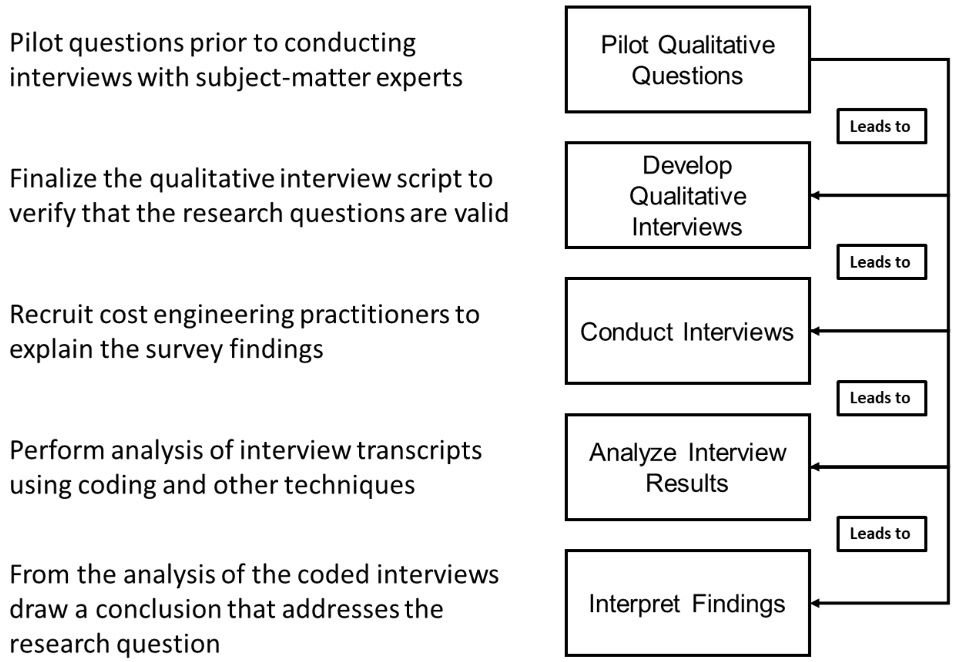


Figure 20: Mixed-Method Research Methodology Flowchart

Now that the philosophical background of the above has been presented, the following will describe the participants of this study followed by the general steps of data collection and analysis associated with this studies research design.

Participants

For this mixed-methods design participants will need to be separately identified and recruited for both the quantitative and qualitative research studies. Beginning with the quantitative study the following outlines the steps for identifying the population, determining the sample size and participant selection.

Phase 1 - Quantitative

In quantitative research, the data gathered from a statistically relevant sample of data should represent the entire target population. Population refers to the comprehensive pool of individuals, events, or other measures aggregated by a common factor that the researcher is focused on studying (Vogt, 2011). Additionally, a sample refers to a statistically calculated subset of data that can generate results that applies to the larger population (Vogt, 2011). The remainder of this section will provide the details pertaining to population, sample-size participant selection used in this study.

Population

Given that the main objective of this study is to investigate the relationship between failure in utilizing cost engineering approaches and Six Sigma project success, the population for this study shall consist of Six Sigma practitioners. The targeted participants will have participated in at least one Six Sigma project that was a design or re-design of a product; it is this type of project where cost engineering principles could be of value. The target group of practitioners should represent a wide range of industrial businesses. Organizations generally willingly announcing when and why Six Sigma projects fail but the literature is replete with studies that list both critical success and failure factors (S. Albliwi, Antony, Lim, & Wiele, 2014; Anbari, 2014; Antony & Gupta, 2019; Antony et al., 2020). The Six Sigma practitioners most appropriate for this study include Executives, Managers, Champions, Master Black Belts, Black Belts and Green Belts.

Sampling

Kothari's definition of sampling as the selection of some part of an aggregate on which a judgement or inference about that aggregate can be made (Kothari, 2019). The choice of participants for this study included Six Sigma practitioners comprised of Executives, Managers, Champions, Master Black Belts, Black Belts and Green Belts all of whom have participated in a six-signa, design for Six Sigma, design for cost or other related design project delivered in the United States. In effort to reach the broadest pool of participants with experience across many industries, the survey was posted on multiple LinkedIn Six Sigma groups.

Statistically, the probability of accurate results in a survey depends on the sampling strategy used in the research (Kothari, 2019; Vogt, 2011). The sampling strategy must accurately reflect the aggregated population to produce results that can be representative of the population. To reduce bias, this study will employ a random sample method which should generalize the results of the survey. Similar research studies use a confidence level of 95% and a probability of the err of 5%. Inclusion and exclusion criteria for participants reflect a study sample of Six Sigma practitioners who have participated in implementing Six Sigma and like design projects in their respective organizations. Based on the inclusion and exclusion criteria the aggregate population of potential practitioners is expected to be approximately 500. Using a 95% confidence level with 5% margin of error the ideal sample size should 218 participants (Faul, 2007).

A power analysis was conducted using the G*Power program to determine the minimum sample size for the study (Faul, 2007). A statistical f-test was conducted using an effect size of

.15 with a confidence of 95%. The effect size chosen for the study was based on the magnitude of the relationship between the variables as being large (Kothari, 2019). Calculated using a linear multiple regression: fixed model, *R2* deviation from zero statistical test, a medium effect size of .15, a probability value of .05, and one predictor resulted in a statistical minimum sample output of 89 valid responses required.

Participant Selection

The study participants will be recruited for the study based on their participation in at least one Six Sigma product design or redesign project. The recruitment process will take place through LinkedIn. Through this media, Six Sigma practitioners will be recruited to participate in the survey. The participants must fulfill at least one of the following technical criteria below:

- participant must be a certified Six Sigma Master Black Belt. Black Belt or Green Belt who has participated on a product design or redesign project, or
- participant must have sponsored a Six Sigma product design or redesign project, or
- participant must have been a manager of an organization that implemented a Six Sigma program involving the design or redesign of a product

Phase 2 – Qualitative

Qualitative research participants need to be knowledgeable, reputable and possess a broad background in the field to add meaningful input to their interview responses. Given that there will only be a small fraction of participants as compared to the number of participants in a quantitative survey, the selection process is key (Vogt, 2011). The cost engineering practitioners most appropriate for this study include cost engineering consults, cost engineering authors and cost engineer practitioners with a broad background of costing knowledge.

Population

Given that the main objective of this study is to investigate the relationship between failure in utilizing cost engineering approaches and Six Sigma project success. The population for this study shall consist of cost engineering practitioners (Vogt, 2011).

Sampling

Qualitative researchers tend to agree that there is no straightforward answer to the question of how many participants are required for a qualitative semi-structured interview as there are many factors. Literature on this topic recommends that a qualitative sample size must be large enough to allow for new information to be revealed from the interview participants. But the sample size of the participant pool should be small enough to not allow the research question to stray too far from the intended purpose of the study (Creswell, 2015; Vasileiou, Barnett, Thorpe, & Young, 2018) . A respectable sample size occurs at the point where no new information is being attained, this is often defined as the saturation point (Bergin, 2018; K. R. Clark & Vealé, 2018).

Given the nature of the study and the need to have very knowledgeable participants explain the responses from the Six Sigma survey the interview candidates would need to be carefully selected (Creswell, 2015). The initial pool of participants was planned to be between 8-10. Due to the nature of the questions and the expertise of the participants, saturation for many of the responses was occurring with the 7^{th} participant. The total number of participants for the study was 9.

Participant Selection

The study participants for this semi-structured interview study were recruited by communicating, via e-mail, to known experts in the field of cost engineering, to request their participation. In addition, some of the participants made subsequent recommendations of highly knowledgeable expects that were be willing to participate.

Data Collection

Phase 1 – Quantitative

The instrument used for this quantitative study was a survey questionnaire comprised of nominal questions developed to validate the research problem. The survey was administered using a secure link from Qualtrics and published on several Six Sigma related groups on LinkedIn.

The survey began with an overview of the study and the qualifications for participating. The opening question to participants was their agreement to consent with the study. Upon confirming their consent they were forwarded to the survey (Snow, 2012). The participants were then asked to answer all 26 questions of the survey questionnaire .

After the participants have answered all the questions in the survey questionnaire, they will be asked to submit their responses to Qualtrics. Once all the participant responses have been submitted to Qualtrics, the data will reviewed and downloaded using Qualtrics survey software

(Denzer, 2021; Snow, 2012). After all the data was downloaded to a password protected drive. The results will then be analyzed using Microsoft Excel and Qualtrics.

Prior to analysis, the data will first need to be organized, processed, and prepared. The first step of the process will be to organize the raw data once all the participant responses have been submitted to Qualtrics. The results will be downloaded from Qualtrics into a Microsoft Excel with each question separated into individual worksheets (Snow, 2012). Each of the worksheets will begin with the participant ID in the first column. Prior to beginning analysis, the data from Qualtrics will be validated against the data copied over to Excel. The results of the demographic data question will then be then reviewed and analyzed (Kothari, 2019).

Phase 2 - Qualitative

The instrument used for this qualitative study was a semi-structured interview comprised of questions resulting from the quantitative survey analysis from 177 respondents. The interviews were conducted using Microsoft Teams and all recordings were transcribed to create a “verbatim transcript” for word coding for analysis. The interviews were recorded making it easier for the researcher to focus on the interview content and the verbal prompts rather than attempting to create unreliable handwritten notes (Vogt, 2011).

The survey began with an overview of the study and the desired qualifications for participating. The opening question to each of the 9 participants was their agreement to consent with the study as well as consenting to both audio and transcription enabled. Upon confirming their consent each participant was asked 7 demographic questions followed by 7 open-ended questions related to the Six Sigma practitioner survey analysis (Kothari, 2019). The demographic responses were entered directly into a Microsoft Excel file. The interview responses were recorded by both audio and natural language transcription which was a feature provided by

Microsoft Teams software. After each interview both the audio file and transcript were saved to a password protected drive for use during the analysis phase.

Prior to analysis, the response data will first need to be organized, processed, and prepared. The first step of the process will be to organize the raw data once all the participant responses have downloaded and save from Microsoft Teams. The results of the demographic responses were recorded into a Microsoft Excel file allowing the survey results to be analyzed more efficiently and with greater ease during the analysis phase for final data preparation and analysis before being saved in a secure file system for secure storage (Bergin, 2018; K. R. Clark & Vealé, 2018).

Data Analysis

Given the sequential flow of this mixed methods study the data analysis is performed independent of each other with phase 1 analysis providing guidance for the development of phase 2 part of the study (Creswell, 2015; Doyle et al., 2016).

Phase 1 – Quantitative

Two different datasets were analyzed in phase 1 of this explanatory mixed methods study.

The first dataset was made up of demographic data comprised of 13 items as shown in Appendix A and broken down into the following areas:

- personal demographic questions
- organizational related questions

This data set was analyzed using descriptive statistics to describe the sample population of the 177 participants.

The second dataset was also comprised of 13 questions as shown in Appendix B. These questions were related to the research questions posed for this study. These questions fell into three areas:

- project failure factors, failure causes and project phase where the failure occurred
- costing methods used and who made the estimates during the various phases of the project
- perceived value and expected usage of cost engineering practitioners, methods and cost management systems on current and future projects

This data set was analyzed also using descriptive statistics to confirm that the research questions posed was valid and to then generate a semi-structured set of questions for phase 2 of this study (Creswell, 2015; Doyle et al., 2016). Both datasets were organized and processed using Qualtrics and Microsoft Excel for preparation and analysis.

Phase 2 - Qualitative

Two different datasets were analyzed in phase 2 of this explanatory mixed methods study. The first dataset was made up of demographic data comprised of 10 items as shown in Appendix C and broken down into the following areas:

- personal demographic questions
- organizational related questions

This data set was analyzed using descriptive statistics to describe the sample population of the 9 interview participants.

The second dataset was also comprised of 8 items as shown in Appendix B and was made up of data from questions related to the research question posed for this study. These questions fell into four areas:

- explanation of the project failure factors failure causes and project phase where the failure occurred
- explanation of the costing methods used and who made the estimates during the various phases of the project
- explanation of the survey responses regarding the perceived value and expected usage of cost engineering practitioners, methods and cost management systems on current and future projects
- recommendations for reducing cost related causes for project failures

This data set was analyzed using the iterative thematic analysis method for coding, categorizing and then the development of themes to be discussed and interpreted in the discussion and conclusion chapters of this study. Both datasets were organized and processed using Qualtrics, Microsoft Excel and NVIVO for preparation and analysis.

Ethical Considerations

The privacy of participants is of great importance and only required information in the study related to the participants company role, demographic, Six Sigma or cost engineering certifications, and product design project experience will be discussed in the results chapter of this study. All private information will be immediately removed following receiving the data needed for this research study (Kissel, 2012; McCallister, 2010). Additionally, all data collected in the study shall be stored on a password protected encrypted storage device. Data, prior to final storage, will be protected with limited access given only to the researcher the researcher's dissertation committee (Kissel, 2012). Lastly, all relevant data will be destroyed within seven years following the publication of the study to avoid security issues (Kissel, 2012).

Summary

The purpose of this study was to research the relationship between Six Sigma project failures and the use of cost engineering methods, practitioners and cost management systems. This chapter was developed to detail the specific methods and data handling used to answer the research questions proposed in this study so that the applied procedures may be replicated for future research.

Using an explanatory design beginning with a nominal quantitative survey that included 177 six sigma practitioners responding to 26 questions was conducted to verify and validate the proposed research questions. Based on the analysis of the survey results a set of explanatory questions were developed for a qualitative semi-structured interview that included nine subject matter experts recruited from the field of cost engineering. The responses from the interviews were then coded, categorized. After multiple iterations of analysis several themes emerged which allowed the researcher to develop a conclusion about the research question. Figure 21 describes the high-level flow of the explanatory mixed methods process.

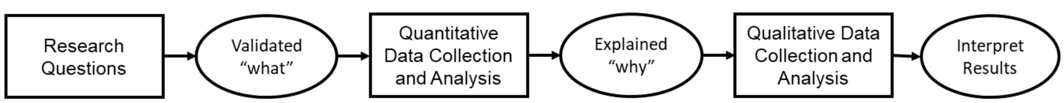


Figure 21: Explanatory Mixed-Methods Design

As a result of this study there will be new knowledge regarding whether the use of cost engineering approaches can create a reduction of Six Sigma failures.

Chapter 4 of this research study will provide analysis and details pertaining to the data collected bringing this study to the final chapter which will include a discussion and conclusions of this study.

CHAPTER 4: FINDINGS

The purpose of the quantitative non-experimental research study is to analyze the relationship between the impact of using cost engineering approaches and success in Six Sigma projects in the manufacturing industry. This study focuses on the relationship between Six Sigma project failures and whether skilled cost engineering professionals and methods were used to ensure that accurate cost data was used during the design project.

This chapter will describe the results of the quantitative and qualitative results utilized to answer the research questions introduced in the literature review: to what extent does incorporating a cost engineering approach relate to Six Sigma project success in the manufacturing industry as measured by the following approaches?

Approach 1: the use of cost engineering methods
Approach 2: the utilization of a skilled/trained/certified cost engineering practitioner or
Approach 3: the use of a product cost management system

The following sub-questions serve to sharpen the focus of the study:

Research Question 1:

What perceived failure factors and cost-related causes lead to Six Sigma projects failures according to Six Sigma practitioners and cost engineering experts?

Research Question 2:

What are the perceived relationships between the utilizing of cost engineering approaches and the success of Six Sigma projects in manufacturing in the United States according to cost engineering experts?

This research will proceed by first sharing insights into the description of the sample, demographic sample, followed by the analysis of each phase's respective data. Research findings are listed by importance as related to addressing the research question posed for this study.

Research Design

This study followed an explanatory mix-methods design that sequentially included a quantitative nominal survey for phase one followed by a qualitative semi-structured interview for phase two. The following is an overview of each phase.

Phase 1 of this study utilizes a nominal quantitative survey questionnaire targeted toward Six Sigma practitioners. The quantitative survey was conducted to validate and confirm the research questions from the literature review. Based on the analysis of the survey results a set of explanatory questions was developed, see Appendix D, to explain why the survey responses for the subsequent qualitative phase. Phase 2 of this study utilized a semi-structured qualitative interview method target towards cost engineering experts to explain the results of the nominal survey responses. Once the interview transcripts have been analyzed, the findings will then be interpreted to draw conclusions about the research question. Figure 22 is a graphical description of the research design process used for this study.

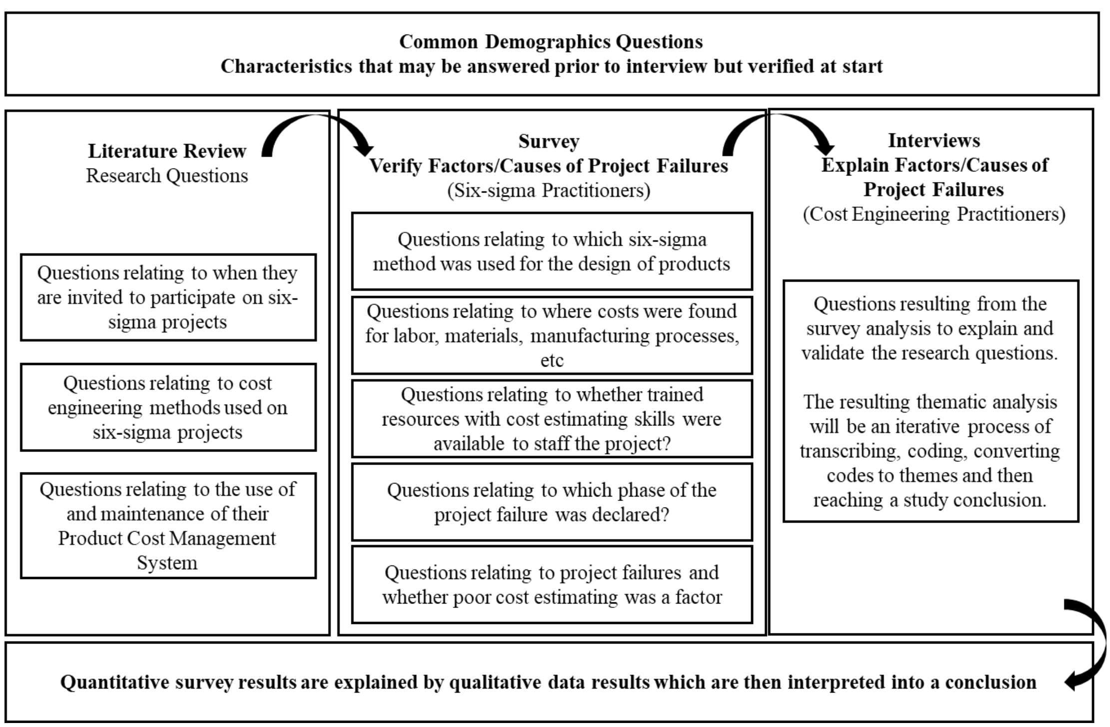


Figure 22: Mixed-Methods Design Summary

Presentation of Data

An important part of displaying the results and findings of research in that it should organize the data in a clear and concise manner as to make the results more easily understandable where each table or chart should be self-explanatory without the need to refer to the text for more information. Similarly, the text description should be sufficiently detailed enough to not rely on any tables or charts for further explanation (Duquia, Bastos, Bonamigo, González-Chica, & Martínez-Mesa, 2014). This study incorporated categorical variables, mostly ordinal with some nominal, for all the demographic questions from both the survey and the interviews. For the demographics results of this study the researcher has chosen to use text descriptions supplemented with a frequency table. For the survey focus questions the results are all nominal responses have been sorted from high to low and described textual and displayed graphically using either a horizontal or stacked bar chart. The responses from the interviews will be text based with a few tables to show frequencies of common findings.

Quantitative Findings

Description of the Sample

Based on the inclusion and exclusion criteria the aggregate population of potential practitioners is expected to be approximately 500. Using a 95% confidence level with 5% margin of error the ideal sample size should 218 participants (Faul, 2007).

A power analysis was conducted using the G*Power program to determine the minimum sample size for the study (Faul, 2007). A statistical f-test was conducted using an effect size of .15 with a confidence of 95%. The effect size chosen for the study was based on the magnitude of the relationship between the variables as being large (Kothari, 2019). Calculated using a linear multiple regression: fixed model, *R2* deviation from zero statistical test, a medium effect size of

.15, a probability value of .05, and one predictor resulted in a statistical minimum sample output of 89 valid responses required.

The survey was posted to a Six Sigma and Design for Six Sigma LinkedIn group with an active member population of approximately 500. From that group there were 211 total responses. From that total, 34 surveys were started but not complete enough to have any usable data. These surveys appear to have been started and then abandoned based on the starting and ending timestamps. These surveys were removed from the analysis as they provided no research value. The remaining 177 completed surveys yielded a response rate of approximately 7.3% from the total published group size and 44.3% from the anticipated participant pool. Response rates can vary based on the type of survey and the targeted sample. A survey response rate of 10% to 25% is typical when conducting employee surveys (A. Fugard & Potts, 2015; Kothari, 2019). Therefore, the response rate for this research study was found to be within the expected range of 89 – 218 for the sample size.

Demographic Sample

The target population of this analysis was Six Sigma practitioners working in companies in the United States. Demographic data from the sample of participants (N = 177) was collected for analysis in this study was comprised of 10 items: years practicing, participant age, Six Sigma certifications, Six Sigma project experience, Six Sigma design project experience, company sector and company size. Having a demographic profile of the survey participants provides insight as to the depth and breadth of experiences included in the responses as well as providing validity that the target audience was properly selected (Kothari, 2019; Vogt, 2011).

Participants predominantly noted their age between 35 and 44 (61.0%) with two groups noting their age between 25 and 34 (24.9%) and 45 – 54 (13.6%). The remaining participant reported their age as 65+ (0.6%). The frequency and percentage of participant age response results are demonstrated in Table 9.

Table 9: Age Demographic

Age Demographic (N = 177)

Age	Frequency	Percent
< 24	0	0.0%
25-34	44	24.9%
35-44	108	61.0%
45-54	24	13.6%
55-64	0	0.0%
65 +	1	0.6%
	177	100.0%

Participants noted the number of years practicing Six Sigma ranged from 3 to 20 years. 32 participants had between 3 to 5 years (18.1%), 76 participants had between 5 to 10 years (42.9%), 60 participants had between 10 and 15 years (33.9%) while 9 participants had 15 to 20 years (5.1%). There were no participants with less than 3 years or more than 20 years of experience responding to this survey. The frequency and percentage of participant years practicing Six Sigma response results have been demonstrated in Table 10.

Table 10: Years Practicing Six Sigma

Years Practicing Six Sigma Demographics (N = 177)

Years Practicing Six Sigma Demographics	Frequency	Percent
< 1 year	0	0.0%
1 < 3 years	0	0.0%
3 < 5 years	32	18.1%
5 < 10 years	76	42.9%
10 < 15 years	60	33.9%
15 < 20 years	9	5.1%
> 20 years	0	0.0%
	177	100.0%

Participants Six Sigma certifications yielded 96 responses of master lean and Six Sigma black belt representing 28.7% of all responses. The two black belt selections include a total of 161 responses for 48.1%. The two green belt selections total 78 responses for 23.3% of total certifications. This was a multi-select selection question allowing participants to select all certifications earned. The frequency and percentage of participant Six Sigma certifications response results have been demonstrated in Table 11.

Table 11: Six Sigma Certification

Six Sigma Certifications Demographic (N = 177)

Which Six Sigma Certifications do you Hold	**Frequency**	**Percent**
Master Lean Six Sigma Black Belt	30	9.0%
Master Six Sigma Black Belt	66	19.7%
Lean Six Sigma Black Belt	90	26.9%
Six Sigma Black Belt	71	21.2%
Lean Six Sigma Green Belt	45	13.4%
Six Sigma Green Belt	33	9.9%
	335	100.0%

Six Sigma project participation responses showed that 7 respondents participated in less than 5 projects. The remaining three groups were relatively even with 52 responses (29.4%) participating in 6-10 projects, 67 responses (37.9%) participating in 11-15 projects and 51 responses (28.8%) indicated participation in more than 16 projects. The frequency and percentage of participant years practicing Six Sigma response results have been demonstrated in Table 12.

Table 12: Number of Six Sigma Projects

Six-Sigma Project Participation Demographic (n = 177)

Six-Sigma Project Participation	**Frequency**	**Percent**
< 5	7	4.0%
6-10	52	29.4%
11-15	67	37.9%
16 +	51	28.8%
	177	100.0%

Six Sigma projects focusing on product designs responses showed that 70 respondents participated in less than 5 projects (39.5%). The largest population of participants, 98 responses (55.4%), indicated participation in 6-10 projects, 8 responses (4.5%) showed participation in 11-15 projects and 1 response (0.6%) indicated participation in more than 16 projects. The frequency and percentage of participant years practicing Six Sigma response results have been demonstrated in Table 13.

Table 13: Number of Six Sigma Design Projects

Six-Sigma Design/Re-Design Project Participation Demographic (n = 177)

How many Design or Re-Design Six-Sigma Projects	Frequency	Percent
< 5	70	39.5%
6-10	98	55.4%
11-15	8	4.5%
16 +	1	0.6%
	177	100.0%

Six Sigma methodologies responses showed that 125 practitioners use DMAIC (25.8%). DMADOV and IDOV were selected 111 (22.9%) and 104 (21.5%) times, respectively. DAMDV and DMEDI were selected 83 (17.1%) and 56 (11.6%) times, respectively. The remaining methodologies showed negligible use with a combined 1% response rate. This was a multi-select selection question allowing participants to select all methodologies used. The frequency and percentage of methodologies Six Sigma response results have been demonstrated in Table 14.

Table 14: Six Sigma Methodology

Six Sigma Methodology Demographic (N = 177)

What Methodologies do you Use	Frequency	Percent
DMAIC (Six Sigma)	125	25.8%
DMADOV	111	22.9%
IDOV	104	21.5%
DAMDV	83	17.1%
DMEDI	56	11.6%
CDOV	4	0.8%
other	1	0.2%
	484	100.0%

Participant industry responses for aerospace/defense and telecommunications shows approximately 11% each. The construct7ion and medical sectors were both roughly 19% each with 52 participants (15.3%) indicating automotive as their industry. Electronics/semiconductor was the largest represented industry with 83 responses for 24.4% of the total. This was a multi-select selection question allowing participants to select all industries that they work across. The frequency and percentage of participant industries worked response results have been demonstrated in Table 15.

Table 15: Primary Industry

Industry Demographic (N = 177)

What is your Primary Industry	Frequency	Percent
Aerospace and Defense	37	10.9%
Automotive	52	15.3%
Construction	64	18.8%
Electronics/Semiconductor	83	24.4%
Medical/Biomedical	65	19.1%
Telecommunications	38	11.2%
Heavy Equipment	1	0.3%
	340	100.0%

Company size, as measured by number of employees, revealed that 6 participants or 3.4% worked for companies with between 100 and 500 employees. More than have of the respondents 92 (52.0%), work for companies with between 501-1000 employees. Companies employing between 1000 and 2000 represented 50 participants for 28.3% of the total. The remaining 29 participants work at companies with more than 2000 employees, of that total 2 participants work for companies with 5000-10000 employees and 1 participant works for a company with more than 10,000 employees. The frequency and percentage of company size response results have been demonstrated in Table 16.

Table 16: Company Size

Company Size Demographic (N = 177)

How many Employees does your Company Employee	Frequency	Percent
< 100	0	0.0%
101-500	6	3.4%
501-1000	92	52.0%
1001-1500	32	18.1%
1501-2000	18	10.2%
2001-2500	10	5.6%
2501-5000	16	9.0%
5001-10000	2	1.1%
> 10000	1	0.6%
	177	100.0%

Participants noted that 93.2% of their company's revenue was between $10 million and $500 million. Only one company had revenue less than $10 million while only one company had revenue greater than $10 billion. The remaining 10 companies had revenues between $500 million and $5 billion. The frequency and percentage of company revenue response results have been demonstrated in Table 17.

Table 17: Company Revenue

Company Revenue Demographic (N = 177)

Approximately what is your Companies Annual Revenue	Frequency	Percent
< $10 Million (M)	1	0.6%
$10 M - $50 M	13	7.3%
$51 M - $100 M	71	40.1%
$101 M - $250 M	43	24.3%
$251 M - $500 M	38	21.5%
$501 M - $1 Billion (B)	9	5.1%
$1 B - $5 B	1	0.6%
$5 B - $10 B	0	0.0%
> $10 B	1	0.6%
	177	100.0%

Findings Relating to the Research Question

This section describes the findings for the quantitative survey responses from the Six Sigma participants pertaining to the research question posed for this study and listed in order of importance. This is the first phase of the mixed methods study whose intent was to confirm the initial research question was valid. Each finding section begins with the survey question presented to the Six Sigma participants followed by the analysis of the responses. For the finding that required further explanation, a question was created for the phase 2 part of this study where cost engineering experts responded with their opinion and explanation.

The use of tables, horizontal and stack bar charts was used to display the findings for this portion of the quantitative study as some findings are more easily conveyed graphically rather than in table format. The focus of the questions for this portion of the study was, "*what perceived factors and cost-related causes would you attribute to Six Sigma projects failures?"*

Finding 1: 70% of all projects fail in the first two phases

The following question was a multi-select question illustrating the participants experience with failures during Six Sigma projects. *"For projects that failed, in which phase was the failure determined?"* Table 28 lists the number and frequency of failures beginning with 14% of failures occurring during pre-project approval. There was a reported 170 or (30.5%) failures during the initial phase of the project. The second phase of the project indicated that 145 or (26%) of projects failed. Failures decreased as the project continued with a cumulative 100 failures or ((18%). Participants noted that 64 or (11.5%) of projects were declared failed after it was closed. The responses from the failure rates by phase question needed further explanation and was therefore added to the list of questions for the semi-structured cost engineering interview. The qualitative question was: "*How would you explain the failure rates at the various phases in the* *project?* The follow up question to this was, *"during which phase did the project fail?"* The frequency and percentage of which phase the failure occurred from the Six Sigma response results are demonstrated in Table 18.

Table 18: Project Failure Phase

Phase in which Project Failed (N=177)

Phase where Failure Occurred	**Frequency**	**Percent**
Pre-Approval	78	14.0%
Define	170	30.5%
Measure	145	26.0%
Analyze	30	5.4%
Implement	15	2.7%
Control	55	9.9%
Post Project	64	11.5%
	557	100.0%

Finding 2: 48% of failures are costing related

This question was a multi-select question with answer choices selected from the literatures review's top from illustrating the participants experience with failures during Six Sigma projects. *"For failed projects, please cite the most likely critical failure factor."* Table 19 lists the number and frequency of failures sorted from highest to lowest responses. Participants responded that inadequate training was 21.9% closely followed by failure to deliver on promised value 18.3%. The next three failure factor categories, incompetent teams, lack of commitment from management and faulty selection of tools, were relatively close in frequency with roughly 14.5% - 16.9%. The second to last failure factor, sub-optimal team size and composition, was reported at 32 instances or (5.7%).

The frequency and percentage of the critical failure factor from the Six Sigma response results are demonstrated in Table 19.

Table 19: Critical Failure Factors

Critical Failure Factors (N=177)

Critical Failure Factor	Frequency	Percent
Inadequate training and learning	113	21.9%
Failure to deliver on promised value	102	18.3%
Incompetent teams (lack of skills)	94	16.9%
Lack of commitment and support from management	91	16.3%
Faulty selection of a process or method	81	14.5%
Sub-optimal team size and composition	32	5.7%
Inconsistent monitoring and control	3	0.5%
	516	100.0%

Related to the previous question was identifying the primary cause of the project failure. Failures can be attributed to many factors. This question was a single entry, fill-in-the-blank question allowing for only one response per participant. The question was, *"were any of the failures associated with poor or lack of or cost estimation techniques (i.e., using old costing data, poor costing estimation techniques, etc.)?"* The findings revealed that 84 or (41.8%) of the responses were costing related factors. The second highest cause was failure to deliver value with 27 response and 15.3% of that total. The next five responses were relatively close in infrequecy with between 6.2% and 9.0% for training, monitoring and control, lack of management support, team member selection, incorrect choice of strategy. The lowest responses were for lack of team commitment and poor project selection with a total of 12 responses and 6.8% of the total. The responses from the critical failure factor and cause behind failure factor questions needed further explanation and was therefore added to the list of questions for the semi-structured cost engineering interview. The qualitative question was: "*How would you explain these failure factors and underlying causes associated with poor or lack of cost* *estimation methods and techniques?*" The frequency and percentage of causes of the failure Six Sigma response results are demonstrated in Table 20.

Table 20: Causes Behind the Failure Factors

Causes Behind the Factors (N=177)

Cause Behind the Failure Factor	Frequency	Percent
Costing Related Failures	84	47.5%
Lack of Management Support	16	9.0%
Training / Learning	16	9.0%
Incorrect Strategy	15	8.5%
Monitoring and Control	13	7.3%
Team Member Selection	12	6.8%
Incorrect Project	11	6.2%
Lack of Team Commitment	8	4.5%
Failed to Delivery Value	2	1.1%
	177	100.0%

Finding 3: Six Sigma projects use a variety of cost estimate methods

"Which cost estimating method was used throughout the design process to determine manufacturing, assembly and sustainment costs?" The follow-up question was, "*where do you get cost data?* This question was a multi-select question with answer choices selected from the literatures review's top costing methods used in industry today.

Participant's top choice was a bottoms-up approach used 17.3% of the time. Analogous, ABC and parametric costing closely followed with 15.2%, 14.8% and 13.5% utilization. Lesser utilized methods included the use of cost accounting reports (12.0%), Target cost modeling (10.2%) and should-costing 6.6%). Only 1.6% of respondents said that they do not consider costing during the design process. The responses from the costing method utilized for estimations question needed further explanation and was therefore added to the list of questions for the semi-structured cost engineering interview. The qualitative question was: "*From the survey the following question was asked about which costing methods used during Six Sigma* *related projects.*" The frequency and percentage of costing methods used from the Six Sigma response results are demonstrated in Table 21.

Table 21: Costing Methods Utilized

Costing Methods Used for Estimations (N = 177)

Costing Methods Used for Estimations	Frequency	Percent
Bottoms-up - Estimate individual parts	105	17.3%
Analogous Estimating from prior projects	92	15.2%
Activity Based Costing (ABC)	90	14.8%
Parametric Estimating from prior projects	82	13.5%
Cost accounting report s	73	12.0%
Target Costing model	62	10.2%
Should Costing model	53	8.7%
Value Engineering Analysis	40	6.6%
We don't consider costing during the design process	10	1.6%
	607	100.0%

Finding 4: Many different roles contribute to cost estimating by lifecycle phase

"Who was tasked with estimating the costs associated with the design, manufacturing, assembly and sustainment of that product?" This question was regarding products (not processes) that were designed or re-designed. This was effectively a four-part question with multi-selection. This question was intended to challenge the Six Sigma practitioner to think about the product lifecycle with regards to all the roles that contribute to costing estimates. Manufacturing and cost engineering roles were relatively close with approximately 22-23% each of the total for all phases of estimates. The remaining roles were close at roughly 11% each for all phases of the product lifecycle. Some notable responses include somewhat gradual increase form manufacturing, including planning, estimates across the lifecycle. Also worth noting is the noticeable decrease of cost practitioners input as the lifecycle matures. The use of sales/marketing, procurement and finance are relatively evenly distributed across the lifecycle. Product design and engineering appear to increase as the lifecycle matures apart from product design which has a slightly higher contribution during the design phase. The responses from the

who estimates costs by product lifecycle phase question needed further explanation and was therefore added to the list of questions for the semi-structured cost engineering interview. The qualitative question was: *"Who typically provides the cost estimate for each of the four primary product lifecycle phases."* The frequency and percentage of participant years practicing Six Sigma response results are demonstrated in the table below.

Table 22: Who Estimated each Phase of Product Lifecycle

Costing Estimates by Product Lifecycle Phase (N = 177)

Who Estimated	**Design**		**Manuf.**		**Assembly**		**Support**		**Totals**	
	Frequency	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Manufacturing	81	20.2%	164	22.4%	140	21.7%	94	29.1%	**480**	**22.8%**
Cost Practitioner	116	28.9%	173	23.7%	121	18.8%	47	14.6%	**458**	**21.8%**
Procurement	43	10.7%	80	10.9%	84	13.0%	31	9.6%	**238**	**11.3%**
Finance	33	8.2%	86	11.8%	83	12.9%	30	9.3%	**232**	**11.1%**
Product Designer	48	12.0%	68	9.3%	70	10.9%	44	13.6%	**230**	**11.0%**
Sales/Marketing	44	11.0%	81	11.1%	70	10.9%	35	10.8%	**230**	**11.0%**
Engineering	36	9.0%	74	10.1%	74	11.5%	42	13.0%	**226**	**10.8%**
other/not sure	0	0.0%	5	0.7%	2	0.3%	0	0.0%	**7**	**0.3%**
	401	100.0%	731	100.0%	644	100.0%	323	100.0%	**2102**	**100.0%**

Finding 5: 53% of the time a cost practitioner was not used on projects

The next question relates to when the cost practitioner was engaged in the project, "When (what phase) in the project was a cost engineering practitioner brought onto the project?" This question yielded some surprising results with 53.1% of respondents saying that a cost engineering practitioner was not utilized during the project. Starting with pre-project approval, cost engineering was engaged at a steadily decreasing rate from define through implement phases (or equivalent depending on the methodology) with utilization rates starting at 11.9% then drifting downwards to 0.0%. The control phase typically considered the go-live phase saw an increase of cost engineering participation at 6.2%. The post go-live phase then decreased to 3.4% participation. The responses from the question, was a cost engineering practitioner used on the project needed further explanation and was therefore added to the list of questions for the semi-structured cost engineering interview. The qualitative question was: "*if utilized, when was a cost* *practitioner brought on the project?"* The frequency and percentage of participant years practicing Six Sigma response results are demonstrated in Table 23.

Table 23: When did Cost Practitioner Join the Project

When did a Cost Practitoner Join the Project (N=177)

When, if at all, did a Cost Practitioner join the Project	Frequency	Percent
Prior to Project Approval	25	14.1%
Define (or equivalent)	21	11.9%
Measure (or equivalent)	15	8.5%
Analyze (or equivalent)	5	2.8%
Implement (or equivalent)	0	0.0%
Control (or equivalent)	11	6.2%
Post Project	6	3.4%
Not Utilized at all	94	53.1%
	177	100.0%

Finding 6: Nearly 64% Six Sigma leaders consider cost practitioners part the team

This survey question posed to the Six Sigma practitioner group was if a cost practitioner were brought onto the project, would they be considered part of the Six Sigma team or as an external resource. This question was an either/or based question with 113 responses indicating that they would consider a cost practitioner to part of the Six Sigma team. The remaining 64 responses were to keep the costing role external to the team.

The responses from the question, "*should a cost engineering practitioner be considered part of the Six Sigma team?"* needed further explanation and was therefore added to the list of questions for the semi-structured cost engineering interview. The qualitative question was: "*should be consider as a part of the Six Sigma team pr external?"* The frequency and percentage of participant years practicing Six Sigma response results are demonstrated in Figure 22.

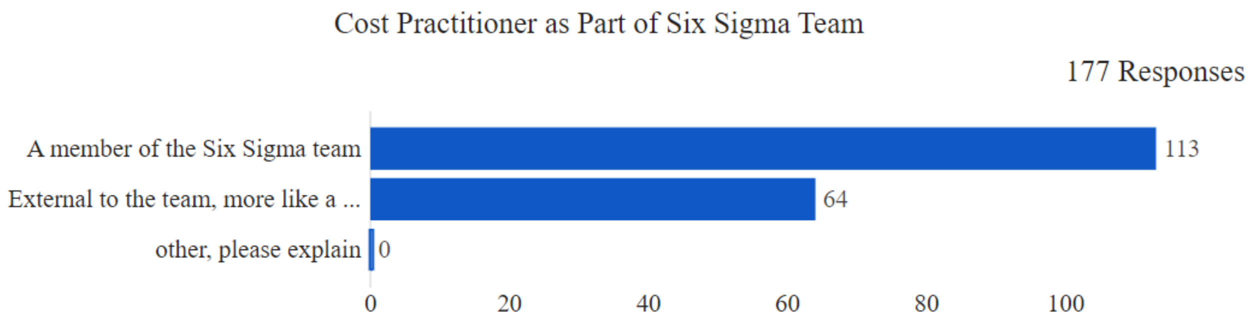


Figure 22: Cost Practitioners as part of the Six Sigma Team

Finding 7: Six Sigma leaders noted mixed results regarding various cost approaches

The next question asks the Six Sigma practitioners, *"Do you think that a cost practitioner may be able to improve the accuracy of costing data improving the likelihood of a successful project*?" 100% of respondents agreed that having a cost engineering practitioner would allow for more accurate cost information and increase the likelihood of a successful project.

The next question asked was, "*Would a Cost Management System (CMS) allow you to obtain more accurate cost information*?" Again, there was close to a unanimous agreement with 176 out of 177 participants or 99.4% of respondents agreeing that having a CMS would allow for more accurate cost information.

The final question of the Six Sigma survey asked respondents was, *"Would you, as a Six Sigma leader, be open to using cost engineering approaches on future projects*?"

For cost practitioner, the response was 122 definitely and 55 maybe using on future projects. The use of costing methods was 146 definitely, 30 maybe with one response say not needed on future projects. For cost management systems the responses were 55 definitely, 118 maybe with 4 responses saying not needed. The responses from each of these questions needed further explanation and was therefore added to the list of questions for the semi-structured cost engineering interview. The qualitative question was: "*How would you interpret the responses* *from Six Sigma practitioners regarding the use and value of cost engineering approaches?*" The follow-up question was "*Should Six Sigma practitioners plan to use cost engineering approaches on future projects?*" The frequency and percentage of participant years practicing Six Sigma response results are demonstrated in Figure 23.

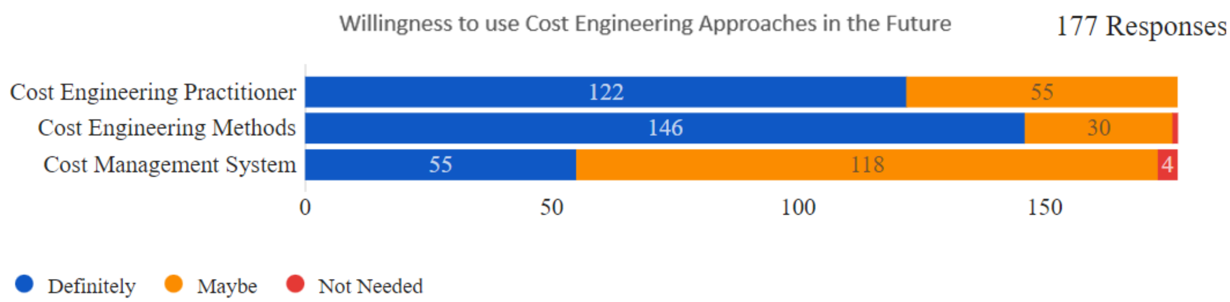


Figure 23: Willingness to Use Cost Engineering Approaches

Summary of the Quantitative Findings

The demographic profile of the six sigma participants was broad given that there were 177 total participants. All participants were from the United States with 61% of the participants in the 35-44 age range with 25% between 25-34 , and 13.6% between 45-54 with one person over 65. Their Six Sigma years of experience ranged between three and 20 years with 77% of respondents having between 5 and 15. The 177 participants had a total of 335 Six Sigma certifications with 78 of those at the green belt level while the remaining 257 certifications at some black belt level. Of the 177 participants 70 have worked on 5 or fewer Six Sigma design projects, 98 have worked on between 6 and 10, eight have worked on between 11 and 15 while one participant has worked on 16 or more. The participants work relatively evenly across most of the listed industries with only one working in heavy equipment. The company size demographics varied broadly with employee size between 101 and > 10,000 employees. Similarly, the company revenue size ranged from $10 M to $1 B with one response of < $10 M and two responses of >

$10 B. The complete list of demographic and focus questions for the Six Sigma practitioners survey is in Appendix A and B of this study.

The findings from the focus questions from the survey confirmed that research question and aims for this study were valid. The analysis produced a total of seven findings which were related to the research questions and aims for this study are shown in table 24 below.

Table 24: Findings from the Quantitative Analysis

Findings from Quantitive Analysis

Finding from Quantitative Study
Finding 1: 70% of all projects fail in the first two phases
Finding 2: 48% of failures are costing related
Finding 3: Six Sigma projects use a variety of cost estimate methods
Finding 4: Many different roles contribute to cost estimating by lifecycle phase
Finding 5: More than 50% of the time a cost practitioner was not used on projects
Finding 6: 64% Six Sigma leaders would consider cost practitioners to be part the team
Finding 7: Six Sigma leaders noted mixed results regarding various cost approaches

As a result of the findings from this analysis a list of questions was created for the cost engineering practitioner interviews. The full list of semi-structured interview questions for cost engineering experts can be found in Appendix D of this study.

Qualitative Findings

Description of the Sample

Qualitative researchers tend to agree that there is no straightforward answer to the question of how many participants are required for a qualitative semi-structured interview as there are many factors. Literature on this topic recommends that a qualitative sample size must be large enough to allow for new information to be revealed from the interview participants. But the sample size of the participant pool should be small enough to not allow the research question to stray too far from the intended purpose of the study (Creswell, 2015; Vasileiou et al., 2018) . A respectable sample size occurs at the point where no new information is being attained, this is often defined as the saturation point (Bergin, 2018; K. R. Clark & Vealé, 2018). The initial pool of participants was planned to be between 8-10. Due to the nature of the questions and the expertise of the participants, saturation for many of the responses was occurring with the 7th participant. The total number of participants for the study was 9.

Demographic Sample

The target population of this analysis was cost engineering professionals that were highly skilled and knowledgeable in cost engineering practices. The study participants for this semi-structured interview study were recruited by communicating, via e-mail, to known experts in the field of cost engineering, to request their participation. In addition, some of the participants made subsequent recommendations of highly knowledgeable expects that were be willing to participate. Demographic data from the sample of participants (*N* = 9) was collected for analysis in this study was comprised of 7 items: age, years practicing, cost engineering role, where and what cost engineering certifications do you hold, Six Sigma project experience, Six Sigma design project experience, non-Six Sigma design project experience. Having a demographic profile of the survey participants provides insight as to the depth and breadth of experiences included in the responses as well as providing validity that the target audience was properly selected (Kothari, 2019; Vogt, 2011).

Participants predominantly noted their ages in every age-range other that the < 24 group. The youngest age group reported was 1 respondent in the 25-34 group as well as 1 respondent in the 65+ group. Approximately 78% of the respondents fell int the 35-64 range. The frequency and percentage of participant age response results are demonstrated in Table 24.

Table 24: Age Demographic

Age Demographic (N = 9)

Age	Frequency	Percent
< 24	0	0.0%
25-34	1	11.1%
35-44	2	22.2%
45-54	2	22.2%
55-64	3	33.3%
65 +	1	11.1%
	9	100.0%

When asked what their primary role in cost engineering the responses varied from 33.3% as cost engineers or consultant with 1 respondent indication that they were an engineering consultant and author. There were two respondents that noted their role as management consultant and author. The frequency and percentage of participant role response results are demonstrated in Table 25.

Table 25: Cost Practitioner Role

Cost Practitioner Role Demographic (N = 9)

Primary Cost Practitioner Role	Frequency	Percent
Cost Engineering	3	33.3%
Cost Engineering Consultant	3	33.3%
Cost Engineering Consultant and Author	1	11.1%
Management Consultant and author (Cost Focused)	2	22.2%
	9	100.0%

Participants noted the number of years practicing cost engineering ranged from 5 to greater than20 years. 1 participant had between 5 to 10 years (11.1%), 2 participants had between 51 to 20 years (22.92%), Whereas the remaining 6 participants had more than 20 years of cost engineering experience (66.7%). There were no participants with less than 5 years' experience responding to this survey. The frequency and percentage of participant years practicing cost engineering response results are demonstrated in Table 26.

Table 26: Years as a Cost Practitioner

Years Practicing Cost Engineering Demographic (N = 9)

Years Practicing Cost Engineering	**Frequency**	**Percent**
< 5 years	0	0.0%
5 < 10 years	1	11.1%
10 < 15 years	0	0.0%
15 < 20 years	2	22.2%
> 20 years	6	66.7%
	9	100.0%

This was a multiselect question for each participant's industry in which they work. Automotive industry was selected by all nine respondents. Two participants selected electronics/semiconductor (13.5%). Aerospace & defense, telecommunications, medical and construction sectors were all reported at 5 responses totaling (54%). Heavy equipment was the largest represented industry with 6 responses for 16.% of the total. This was a multi-select selection question allowing participants to select all industries that they work across. The frequency and percentage of participant industry response results are demonstrated in Table 27.

Table 27: Primary Industry(s)

Industry Demographic (n = 9)

What is your Primary Industry	Frequency	Percent
Aerospace and Defense	5	13.5%
Automotive	9	24.3%
Construction	5	13.5%
Electronics/Semiconductor	2	5.4%
Medical/Biomedical	5	13.5%
Telecommunications	5	13.5%
Heavy Equipment	6	16.2%
	37	100.0%

Six Sigma project participation responses showed that only one respondent participated in 11-15 projects (11.1%). The balance of the respondents indicated participation in more than 16 projects (88.9%). The frequency and percentage of participant years practicing Six Sigma response results are demonstrated in Table 28.

Table 28: Number of Six Sigma Design Projects

Six-Sigma Design/Re-Design Project Participation Demographic (n = 9)

How many Design or Re-Design Six-Sigma Projects	Frequency	Percent
< 5	0	0.0%
6-10	0	0.0%
11-15	1	11.1%
16 +	8	88.9%
	9	100.0%

Qualitative Findings based on the Research Question

This section describes the findings for the qualitative semi-structured interview responses from the Cost Engineering participants. The questions asked during the interviews were developed from the analysis of the Six Sigma survey responses which were intended to confirm that the research questions were valid. As such, the questions for the interviews were written in such a way as to get expert explanations, observations, opinions and interpretations of the survey responses. The findings from the interview responses were arrived at using thematic analysis and have been presented in a text-based format and listed in their order of importance.

The analysis for this chapter was based on Braun and Clarke's, (2016) six step method for thematic analysis. This process began with transcribing and reading the transcripts multiple times to find related and interesting observations. Then each transcript was reviewed with initial codes generated that related to the research question and aims. After codes were generated, they were reviewed and merged to create categories that focused on a central finding or theme. When codes and categories start answering the research question and aims for the study, they become themes. To support the claim for each theme the researcher explained what it included did not include based on the input from the interviewee transcripts. The claim was then supported with relevant quotes and data extracts from the transcripts. The key findings for the theme will then be summarized to lay the foundation for discussion in the next chapter. The themes from the interview responses have been presented in a text-based format and listed in their order of importance.

The primary theme from this study is *Educating the Organization about Cost Engineering Approaches and Practices*. This theme emerged inductively from the analysis of the cost engineering interviews and was present throughout the findings and analysis.

Theme 1: Benefits of Educating the Organization

Educating the organization about the value of cost engineering approaches and practices was one of the participant's top comments throughout the interviews. This theme includes many areas of cost engineering that are directly related to the research question and aim of this study. Below are the analysis and results of the four sub-themes to the primary theme for this study.

Sub-theme 1: Educating the organization on the value of cost engineering practices

> *"Basically, a lot of companies would like to manage costs, but they don't know where to begin"* (ID 4).

The first sub-theme was centered on management's need for education about the value of cost engineering approaches for competing as a business. A participant told the following story of how embracing cost management brought their company back to being competitive.

> *"Several years ago, the German auto industry, like in the US, was in a financial crisis. This was when they started to understand the importance of managing costs early before they made the decisions. The managing of costs in the early phases was heavily influential in getting cost under control an becoming competitive again"* (ID 4).

Each of the cost engineering interviewees expressed similar opinions that many cost related failures come from people not understanding the cause and effect of cost on the plant floor. The focus of many projects seems to be about meeting the technical requirements rather than producing a profitable product. Several responses indicated that it is common for everyone to be happy to win a project with hope and optimism that things will work out just fine. The sentiment for the participants was that companies need to understand be aware of costing practices to not only correctly estimate the cost products throughout its lifecycle, but also to make sure that the market pricing provides the expect returns. From the question of who should perform cost estimates the sentiment from the interviewees was that it was dangerous to let salespeople estimate the cost of a product. One participant was blunt with the following statement:

"But the salespeople are worrying about selling at a low price, not low cost. So, it is dangerous to get too much input from sales and marketing" (ID 4).

The general fear was that sales and marketing may be short-sighted with selling products at a low price rather than ensuring that the sell is profitable to the company. As noted by several interviewees, if a project is off on its profit assumptions because of poor costing there is not much that can do but accept that the design will result in higher than expect costs to produce making the endeavor a failure. When probed further on this topic a response from one participant noted that even when costing practices were followed, they may not yield results that everyone agrees are correct.

"Costing related failures could be due to the fact that nobody likes the results" (ID 8).

Therefore, with regards to educating the organization about effective costing approaches, the overall sentiment among the costing experts was that companies need to educate themselves on the value of using cost engineering approaches to compete in the marketplace. For those companies that have embraced cost engineering principles they understand that every decision made is based on a cost. As one respondent noted,

Sub-theme 2: Educating the organization about the various definitions of cost

"What we find is that the definition of cost is different depending on how it is ultimately used" (ID 5)

The next sub-theme for educating the organization is the definition of cost. Easily one of the most important and frequently discussed topics was the perception that cost was viewed differently by different groups within the organization. The costing experts interviewed noted that in the various consultations that they have participated in there has routinely been confusion over the definition of cost. According to the participant responses, when sales, marketing or finance is involved in cost estimating they use historical data from accounting reports then try to factor the new design cost up or down. The sentiment is that the definition of cost is different depending on how it is ultimately used. So, manufacturing guys tend to get it. But when you are talking to finance and accounting, they think about things like depreciation, and it throws everything off.

> *"In the realm of cost and accounting they must be kept separate. The reason is that accounting will write off a machine over a 10-year period, or whatever. But, in the cost world that machine is going to last decades, assuming it has been maintained properly, even though it was depreciated over that 10-year period. Instead of using accounting costs you should be using the replacement value for that machine. This will make a big difference in how machine costs are calculated in the manufacturing process"* (ID 5).

Given that cost is the fundamental concept for cost estimation, the interviewees were quick to reiterate the importance of everyone participating on Six Sigma projects understand and use the same definition which may require some form of education for Six Sigma stakeholders. Cost is not always a language that can be spoken between people within an organization and instantly understood as being the same. As note by one cost engineering expert,

> *"It is a lack of understanding between cost and price that can cause projects to fail" (ID 4)*.

Therefore, with regards to educating the organization about the meaning of cost to different groups withing the organization, the overall sentiment among the costing experts was that companies need to establish what cost mean for different functions.

Sub-theme 3: Educating Six Sigma practitioners about the value of cost practitioners

> *"Most people within an organization aren't aware that they have a costing person to consult with on projects. If they are not used properly or given the right visibility, then their input won't be recognized. So, often costing related failures are not because of wrong data, but maybe it's because they don't ask the right people"* (ID 7).

The next sub-theme for educating the organization was the role of the cost engineering practitioner. The costing experts interviewed noted that in the various consultations that they have participated in there has routinely been confusion about the role of the cost engineer. Most people within an organization are not aware that they have a costing person to consult with on projects. If they are not used properly or given the right visibility, then their input will not be recognized. So, often costing related failures are not because of wrong data, but maybe it's because they don't ask the right people. As one interviewee noted,

> *"What does cost mean to different people? You could have a cost engineer that specializes in ABC cost modeling and that gives you one perspective on cost. You could also have a different person who is highly skilled in design to cost. Then you might have a lean cost guy, or you might have a someone from accounting or finance that has totally different view of cost. All these roles can estimate costs, but they may have a slightly different perspective on what cost really is and this can create some misleading costs over the lifecycle of the product. That is why it makes sense to have a skilled cost engineer who is knowledgeable about the industry and product line manage the cost estimating"* (ID5).

Additionally, it was noted that the high rate of Six Sigma project failures due to cost related issues could be reduced if a cost practitioner were brought into the project during the project approval process to prevent potential downstream cost issues.

> *"If you need cost engineering, they should be brought in early and then retained for the duration of the project in order to manage and report on costs" (ID 8).*

Therefore, as for educating the Six Sigma practitioners about the value of using cost engineering practitioners they need to be made aware that it is critical for a company to have a trained cost engineer if they can afford to have one on staff. This means that they will have someone who is skilled in costing methods and can build models that apply to that company for their industry but be someone who can work with the other functional areas to begin building costing into the company's product development culture.

Sub-theme 4: Educating Six Sigma leaders on the value of cost engineering methods

> "So, I think its definitions that are important here and it points out that Six Sigma teams need to know what costing tools and methods are available and what they can do" (ID9).

The costing experts noted repeatedly that projects often start out with the wrong cost estimation method only to find out several phases later find that is not the correct one. But by the time the mistake has been caught there is not enough time to change because you have already made some big financial commitments. Many respondents also noted that when sales or marketing is making the early estimates, they tend to past product costs that are likely out of date and don't account for new manufacturing or other downstream costs. Six Sigma leads are generally not aware of that cost practitioners exist much less what cost estimate techniques should be used and when. Several participants commented that it is a good practice to various roles contribute to cost estimating. One of the recommendations from a respondent was the following,

> *"The biggest recommendation is that the cost models should be developed with the input of everybody along the way. Which basically gets everyone's approval about what costs need to be included and where should the come from in addition to other factors. When you're done, the key players from design, engineering, manufacturing, etc. have already agreed in principle to how it works. So, when a cost engineer sends out a cost estimate it makes it harder for someone to say that it doesn't make any sense"* (ID 4).

As noted by several respondents, cost methods are often not understood suggesting that most companies use historical cost data to build up a quote by estimating some of the parts individually and call it a bottoms-up estimate. This ends up being problematic and often leads to a poor estimate of cost during the approval process. The issue, as observed by the interviewees, was that regardless of who does the cost estimating they need to understand when and how to use the correct method for the product.

Suggestions from the cost engineering experts about how to educate Six Sigma practitioners about the value of cost engineering methods should be carried out by one of the company cost engineers. The purpose of the class would be to educate the Six Sigma participants on the various costing methods and when to use them.

Summary of Theme 1

Theme 1 found four sub-themes pertaining to how educating the organization may improve the success rate of Six Sigma projects in the manufacturing industry. Educating the organization is a theme that permeates the remaining themes. The benefits of cost engineering approaches can only be realized if everyone associated with Six Sigma design projects are educated and knowledgeable about those approaches.

The following will present another theme discovered through the data analysis.

Theme 2: Benefits of using a cost practitioner/engineer

> *"It's critical for a company to have a trained cost engineer if they can afford to have one on staff. This means that they will have someone who is skilled in costing methods and can build models that apply to that company for the industry they are in"* (ID 1).

According to the cost engineering experts the most accurate data comes from a person whose performance is measured against cost accuracy. Sales and even Six Sigma project managers may play with the costs to achieve different ends. The cost engineer is the responsible for giving the financial estimates for the project. They find and validate the cost data from various departments and from past projects or from a cost management system. Cost engineers may take a little more time assembling a cost report, but it should be more accurate than simply pulling number together from historical reports.

> *"Cost engineers are looking at different things, but it's a holistic view and you should have one team with a common goal in mind. So, it would make sense that they should be part of the team because they are going to have the best view into the cost side of the product over its lifecycle"* (ID 4).

Observations from the interviewees noted that cost engineers have a unique role where they span many functions. They act as a communication bridge to those discrete functions in many organizations. A skilled cost engineer should be able to talk with a manufacturing engineers about a manufacturing process. Meet with procurement about supplier negotiations and make-versus-cost costing. In addition, they should be able to talk with financial planners about budgeting and forecasting. So, they act as this bridge to all these functions that wouldn't necessarily come together to do a project. Another comment receive was that a recommendation is that when hiring a cost engineer look for candidates that have a manufacturing background rather than accounting making it easier for them to understand the economics of the plant floor. A comment from one participant noted that,

> *"Good cost engineers also look at the entire life cycle of the product from a financial standpoint, whereas a Six Sigma guy might look at the life cycle from a manufacturing, assembly and serviceability point of view"* (ID 2).

Regarding the interview questions pertaining to when a cost practitioner should be involved in the project there was considerable unanimity that cost engineers look at different things related to the product cost, more of a holistic view that spans the entire product's lifecycle. So, if you just have cost engineering practitioners involved from the beginning many of the failure causes related to cost estimating can be avoided, not always, but enough of the time. That will solve most of the problems, and assuming they know how and when to do costing techniques and methods and possibly have access to a cost management system, then you're likely to far more successful projects. As one participant noted,

> *"I would recommend is that if you have a strong costing person who has developed costing models that reflect the product lifecycle and has access to an accurate cost database system, then that person must be able to convincingly get that information to the Six Sigma project managers into order to have an impact on whether to proceed. In some companies this type of information doesn't get passed along in a timely manner and can cause cost overrun problems that could have been avoided" (ID 5).*

Many of the interviewees noted that the Six Sigma black belts that they have worked with wanted a cost engineer assigned to their team for the duration of the project saying that it is nice to have somebody whose style and skills they knew. Six Sigma black belts also wanted to have a cost engineer in their workshops because they wanted to have answers on costs right away. The cost engineering experts noted that having a cost practitioner on a Six Sigma project enabled the team to begin building process for cost verification throughout the product design process. Again, every interviewee commented that there is not a special moment during the project when they are needed, they should be in the project from the beginning until the end and that the cost engineer should be a neutral role in the organization where they use develop cost estimates based on proven cost models.

Summary of Theme 2

Theme 2 explained the benefits of having a cost engineering practitioner on Six Sigma projects which was evidenced from the results of the nine cost engineering interviews. Beginning with having a resource whose expertise and purpose is to provide accurate estimates for products across the product's lifecycle should provide a Six Sigma leader with some level of assurance that cost related failure are minimized.

The following will present another theme discovered through the data analysis.

Theme 3: Benefits of using the right cost engineering methods

> *"Cost engineers stress the value of using the right costing methods on Six Sigma projects at the right time"* (ID 6).

Cost engineering experts do not completely agree on which costing method to use in every phase of a product design project, but all share the sentiment that having an accurate cost model from the beginning may have prevented some project failures. Most cost engineers like to start with a parametric model to establish a starting point in order to understand the cost at a low precision level for getting the project approved. Then as the project moves into the design phase, they start getting more detailed and switch to a bottoms-up cost model. Other cost engineering participants noted that starting with parametric costing creates a dependence on trends of past figures setting the project up for possible failure in later phases. As one participant notes,

> "*There is no perfect fit cost engineering approach that will fit all your needs. But there are some that will closely come to the results expected. Despite that, every methodology has pros and cons. There is not one that has everything pros and no con right for this"* (ID 7).

Given that all the cost engineering interviewees had some experience in the automotive industry there were many comments about the automotive industry doing a lot of pilot projects to determine if the product was marketable. The designers tended to be more involved during the pilot phase so in order to get the pilot approved they needed to convince the team that their parametric cost model was correct, but very often wasn't very accurate. The issues with starting with a bad cost estimate is echoed by the comment from an interviewee,

> *"Maybe you start with the wrong methodology and then several phases later find that isn't the correct one. But you don't have time to change because you have already made some big financial commitments"* (ID 1).

Most companies still use over generalized correlation-based ways to calculate costs. They focus on financial and financial statement costs and work it all through formulas. Generally material labor, overhead and they often have still plant wide rates for their various manufacturing processes, and they seldom include cause and effect relationships. Too often companies develop cost models for one product or process then try to reuse it on something entirely different. The problem is that when you do not have the right model you are forced to make it work and it gives you a poor cost estimate. A recommendation from one cost engineering expert was for companies to create cost models. Cost models are predictive, so the impact of a change can quickly be calculated into the updated product design. This interviewee went on to say,

> *"The model you use to create something is more important than the data in it. Because you can get a good answer processing poor data in a in a valid model. Then you can put in perfect data in an invalid model"* (ID 6).

A second recommendation noted by several interviewees was to recruit costing resources that are familiar with costing methods and how they are doing it at your company and at competitor companies to see if there are better ways. A particular comment related to this point is,

> *"So, I think it's more important to have built in into your process different cost methodologies and a knowledgeable cost engineer to keep track of cost estimates and verify the accuracy"* ID 2).

The benefits of using cost engineering methods on Six Sigma projects was also very evident from the results of the nine cost engineering interviews. Even though all cost engineers did not agree on which methods to use they do all agree that merely using cost engineering methods will increase cost estimating accuracies. Several recommendations emerged including the use of cost modeling and recruiting costing resources that know costing methods for their industry.

Summary of Theme 3

Theme 3 explained the benefits of using cost engineering methods on Six Sigma projects as evidenced from the results of the nine cost engineering interviews. Even though all cost engineers did not agree on which methods to use they do all agree that merely using cost engineering methods will increase cost estimating accuracies. Several recommendations emerged including the use of cost modeling and recruiting costing resources that know costing methods for their industry.

The following will present another theme discovered through the data analysis.

Theme 4: Benefits of using a cost management system

"You cannot do accurate costing without a cost management system" (ID 1).

The final theme from the cost engineering practitioner interviews was what are the benefits of using a cost management system as a practical approach for cost management and estimating. From the interviews the cost engineering experts recommended using a cost management system as a systematic approach to managing cost throughout the life cycle of any project. One interviewee noted that over the past few decades, the automotive industry has been under tremendous cost pressure and has slowly started to adopt a bottoms-up costing approach using product cost management system. Companies buy commercial product cost management systems because they do not really have a single source of truth. They may have incurred big losses in the past because sales were calculating something and then finance was calculating something different and they so far apart that it was hard to know what the actual cost was going to be. A cost management system provides a single source of truth with regards to costs as well as other business intelligence. Soon, the US is going to need to focus on carbon footprint for all the manufacturing and sustainment for products. A comment from one participant noted that it makes using a cost management system even more beneficial given that carbon footprint data can be stored and retrieved just as easily as cost data.

> *"You get a lot of business intelligence that you can extract to learn things about how you're running your business"* (ID 3).

Several from the group of interviewees did note that older Six Sigma practitioners are not big software supporters. They do not want trust data that is not on an accounting report or purchase order. Further it was noted that many companies believe that it is more beneficial to have a costing expert rather than to try to use some system where they cannot explain where the data comes.

> *"Six Sigma practitioners probably don't trust or understand what a cost management system is because that's kind of new technology"* (ID 8).

Given that cost management systems are relatively new, as one respondent noted, it is becoming necessary for companies to have a cost management system that is maintained and updated regularly. The need to get quick reports for designs and updates is critical to stay competitive. Also noted from a participant was that Six Sigma people seem to be really into whatever makes sense because as a Six Sigma you are you want to make things better and you want to have a full understanding of where costs come from and what methods and techniques should be used. So, having a product cost management system would give them some assurance as well. As one participant noted about the need for a cost management system,

"Cost comes into play everywhere" (ID 5).

Summary of Theme 4

Theme 4 explained the benefits of using a cost management system on Six Sigma projects as evidenced from the results of the nine cost engineering interviews. The single source of truth for data was frequently noted as the best method for performing a bottoms-up or part by part cost estimation for products. Additionally, a cost management system provides other business information that might be valuable as new caron footprint regulations begin. Also, the respondents noted that even with some older Six Sigma leaders reluctant to try new technology, some embrace it assurance of cost accuracy.

Summary of the Qualitative Findings

The demographic profile of the nine cost engineering participants showed an age range from the mid 20's to over 65 years of age. Seven of the 9 participants were cost engineers while two of the participants were management consults working in the cost engineering field. Three of the nine participants were authors in the field of engineering. Six of the nine participants had more than 20 years of costing experience, two had between 15 and 20 years, while one participant had between 5 and 10 years of costing experience. All nine of the participants work in the automotive sector and with the remaining industry sectors showing 5-6 responses. Eight of the nine participants had worked in more than 16 Six Sigma design projects with one having worked between 11-15.

The semi-structured interviews were transcribed, coded, categorized and interpreted to create themes and sub-themes using Braun and Clarke's six-step thematic analysis method. This iterative method allowed the researcher to view the interview responses by participant, grouped by question, collected and view by codes and categories then interpreted into themes (Braun & Clarke, 2016). The findings from the qualitative semi-structured interviews resulted in four themes with the first theme containing four sub-themes as shown in table 29.

Table 29: Themes and Sub-themes from the Qualitative Thematic Analysis

Themes and Sub-themes from Qualitative Thematic Analysis

Themes and Sub-themes from Qualitative Thematic Analysis
Theme 1: Educating the Organization.
Sub-theme 1: Educating the organization about the benefits of cost engineering practices.
Sub-theme 2: Educating the organization about the various definitions of cost.
Sub-theme 3: Educating Six Sigma practitioners about the value of cost practitioners.
Sub-theme 4: Educating Six Sigma practitioners about the value of cost engineering methods.
Theme 2: Benefits of using a cost practitioner/engineer.
Theme 3: Benefits of using the right cost engineering methods.
Theme 4: Benefits of using a cost management system.

Summary

The purpose of the results chapter summarizes and presents the findings of the study to put them in context with the research question in an unbiased manner without researcher interpretation. To do so, the researcher provided a detailed description of the samples utilized as well as a detailed view of the demographics for each participant group. Demographic data is a helpful tool for understanding the participants background and qualifications for this study. The findings for both the quantitative and qualitative studies contain both the demographic and research focused studies. These are in separate sections of this chapter each having a summary of findings.

The quantitative study was completed as part of phase 1 of this explanatory mixed methods research to successfully validate the research questions from the literature review with the findings analysis used to create the phase 2 semi-structured interview questions found in Appendix D.

The qualitative phase of this research was conducted to collect expert opinions and explanations to explain the survey responses which were analyzed to create findings that were interpreted to draw conclusions about the research question. The findings from this study resulted in four themes to be discussed in the next chapter. Figure 24 illustrates the high-level flow of this design.

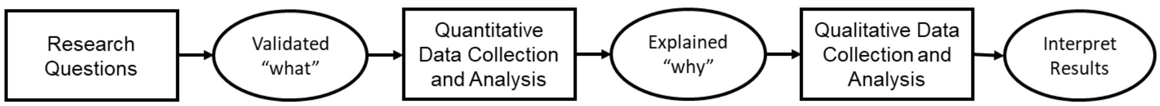


Figure 24: Explanatory Mixed-Methods Design

CHAPTER 5: DISCUSSION AND CONCLUSION

The primary objective of this chapter was to interpret and analyze the findings from the research study with the desired result of explaining how the research problem was addressed through an interpretation of the results. These results are the product of that analysis have been summarized below in order to lay the foundation for interpretation through discission, limitations of the study, conclusions based on the results and recommendations for further research (V. Braun & V. Clarke, 2021).

Summary of Key Findings

This study began in earnest when the problem statement was turned into a logical research question. Findings and themes arose when the iterative coding process began to answer the research question. A research question draws its answer or conclusion through an analysis of evidence (Doody & Bailey, 2016). The findings from the focus questions from the survey confirmed that research question and aims for this study were valid. The analysis produced a total of seven findings which were related to the research questions and aims for this study are shown in table 30.

Table 30: Findings from the Quantitative Analysis

Findings from Quantitive Analysis

Finding from Quantitative Study
Finding 1: 70% of all projects fail in the first two phases
Finding 2: 48% of failures are costing related
Finding 3: Six Sigma projects use a variety of cost estimate methods
Finding 4: Many different roles contribute to cost estimating by lifecycle phase
Finding 5: More than 50% of the time a cost practitioner was not used on projects
Finding 6: 64% Six Sigma leaders would consider cost practitioners to be part the team
Finding 7: Six Sigma leaders noted mixed results regarding various cost approaches

As a result of the findings from this analysis a list of questions was created for the cost engineering practitioner interviews. The full list of semi-structured interview questions for cost engineering experts can be found in Appendix D of this study.

The semi-structured interviews were transcribed, coded, categorized and interpreted to create themes and sub-themes using Braun and Clarke's six-step thematic analysis method. This iterative method allowed the researcher to view the interview responses by participant, grouped by question, collected and view by codes and categories then interpreted into themes (Braun & Clarke, 2016). The findings from the qualitative semi-structured interviews resulted in four themes as shown in table 31.

Table 31: Themes from the Qualitative Thematic Analylsis

Themes from Qualitative Thematic Analysis

Themes from Qualitative Thematic Analysis
Theme 1: Educating the Organization. Educating the organization about the benefits of cost engineering practices.
Theme 2: Benefits of using a cost practitioner/engineer. Establishing the value utilizing cost practitioners.
Theme 3: Benefits of using the right cost engineering methods. Establishing the value of utilizing costing methods.
Theme 4: Benefits of using a cost management system. Establishing the value of utilizing a cost management system.

Discussion of the Results

Discussion of Quantitative Results

As part of the two-phase mixed-methods study, the purpose of this survey was to confirm that the proposed study research questions were valid. Based on these findings it is evident that that the research questions are valid and should be investigated further as part of phase 2 of this study. Phase 2 involves creating a set of questions to from these findings and ask expert cost engineering professionals to explain these findings with regards to what extent does incorporating a cost engineering approach relate to Six Sigma project success in the manufacturing industry.

Finding 1: 70% of all projects fail in the first two phases

This finding addresses the high percentage of projects that fail within the first two phases. Six Sigma projects fail at relatively high rates beginning at the approval phase as well as the initial (Define) and second (Measure) phases. Understanding the factors behind these failures may provide insight as to how to mitigate the possible risk factors. A relevant finding on critical success factors shows significant failure rates for Six Sigma projects with the highest termination rates in the measure and analyze phases using DMAIC or DMADV (Antony et al., 2020). These results are important enough to be added to the list of semi-structured interview questions posed to a group of expert cost engineering professionals for further understanding as to how this finding relates, if it does, to the research question. The qualitative question was: "*How would you explain the failure rates at the various phases in the project? The follow up question to this was "during which phase did the project fail?*"

Finding 2: 48% of failures are costing related

This finding looks at the failure factors and most significant underlying cause for project failure. Given the high percentage of project failures early in the project, what critical factors would be attributed to the failure and what is the underlying cause. Survey responses indicate that cost related failures are the most significant cause of failure with a response rate of close to 48%. The literature supports this claim from a study indicating that only 13% of firms reported their total new product efforts from Six Sigma related projects achieved their annual profit objectives (Cooper, 2019; Guarraia, 2008). This study's finding is very important and will be used as a question in the interview phase the question posed was. "*How would you explain these failure factors and the underlying causes associated with poor or lack of cost estimation methods and techniques?*"

Finding 3: Six Sigma projects use a variety of cost estimate methods

Finding 3 looks at which cost estimating method was used throughout the design process to determine manufacturing, assembly and sustainment costs. From the previous findings the research can now look at some of the underlying issues with cost related causes. This finding is significant in that it begins to reveal problems with the choice of costing methods utilized. The literature supports this finding noting that costing methods need to be careful to select the right costing method and model for each product by industry (Hueber, Horejsi, & Schledjewski, 2016). This is also a critical finding that should be posed to the expert cost engineering professionals for their input. The qualitative question was: "*From the survey the following question was asked about which costing methods used during Six Sigma related projects.*"

Finding 4: Many different roles contribute to cost estimating by lifecycle phase

This finding pertains to which roles in the company are estimating the costs associated with the design, manufacturing, assembly and sustainment of that product. Asking what roles in the organization was making the estimates for each of the products design lifecycle helped to shed light on what skills and reason is behind some roles acting in a costing capacity. Costing literature agrees with this finding discussing the need to have skilled costing specialists estimating and checking cost estimates throughout the product design lifecycle (Domanski, 2020). This finding needed further explanation and was therefore added to the list of questions for the semi-structured cost engineering interview. The qualitative question was: "Who typically provides the cost estimate for each of the four primary product lifecycle phases."

Finding 5: 53% of the time cost practitioners were not used on projects

This finding relates to when a cost practitioner was brought into a Six Sigma project. The responses for this finding from the survey respondents indicated that cost engineering practitioners started on less than 12% of all projects with each phase declining until the go-live phase. The significance of this finding is that more the 50% of the time no cost practitioner was brought into the project. This is new research as there is no indications of a similar finding in cost engineering or Six Sigma literature. Based on the significance of this finding a question was formulated for the cost engineering interview. The qualitative question was: "if utilized, when was a cost practitioner brought on the project?"

Finding 6: 64% of Six Sigma leaders consider cost practitioners on the team

This finding is about if a costing professional were engaged on a project would the Six Sigma leader consider them to be part of the team or external. With 64% of the Six Sigma responses indicating that they would consider a costing resource to be part of the team, this raised the question as to why and for the 36% who said no, why not? This is new research as there is no indications of a similar finding in cost engineering or Six Sigma literature. This finding requires further explanation and was therefore added to the list of questions for the semi-structured cost engineering interview. The qualitative question was: “should be consider as a part of the Six Sigma team pr external?”

Finding 7: Six Sigma leaders noted mixed results regarding cost approaches

This finding involves how Six Sigma practitioners viewed the use and value of all three cost engineering approaches. The result from this analysis is a mixed bag of responses with respondents indicating that they would definitely use cost practitioners 69% of the time versus 31% saying maybe, they would definitely use costing methods 82% of the time versus 18% saying maybe and they would definitely use a cost management system only 32% of the time versus 68% saying maybe. There is no research providing support for this or similar findings in cost engineering or Six Sigma literature. The responses from each of these questions needed further explanation and was therefore added to the list of questions for the semi-structured cost engineering interview. The qualitative question was: “*How would you interpret the responses from Six Sigma practitioners regarding the use and value of cost engineering approaches?*” The follow-up question was “*Should Six Sigma practitioners plan to use cost engineering approaches on future projects?*”

Discussion of Qualitative Results

The primary research question regarding the relationship between the impact of using cost engineering approaches and success in Six Sigma projects in the manufacturing industry was answered by the interpretation of the qualitative interviews conducted in this mix-methods study. The results of the findings were synthesized into four themes that supports the claim that incorporating cost engineering approaches can improve the success of Six Sigma projects.

Each of the themes discussed in this chapter were discussed in the following manner: name and summarize the theme, discussed what the literature review says about the finding prior to the study, what is the relationship between the findings and the literature, why is there a difference and what should be done about it.

Thematic analysis is a good approach for this research given that we need expert opinions to explain the research questions that were validated from the responses to the phase 1 survey. Rather than trying to summarize the interview responses or attempting to fit responses around the research questions, thematic analysis allows the researcher to iteratively review the transcripts to identify common themes that can then be interpreted to draw conclusions regarding the research questions. As part of the analysis, the researcher needs to be aware of the approaches that should be considered for finding themes:

- a deductive approach involves the researcher analyzing the data with a pre-conceived notion of the themes prior to the start of the study based on existing knowledge
- an inductive approach involves allowing the data to determine the themes

Theme 1: Benefits of Educating the Organization

The primary theme from this study is *the benefits from educating the organization about cost engineering approaches and practices*. This theme emerged inductively from the analysis of the cost engineering interviews and was present throughout the findings and analysis. This theme is broken down into four sub-themes.

Sub-theme 1: Educating the organization about the benefits of cost practices

Educating the organization about the value of costing methods and practices is fundamental. As one responded noted, many *"companies want to manage costs but do not know how to begin."* These results identified four areas where companies can educate themselves to begin the journey to awareness of the benefits of cost engineering practices. The first step is to understand how they are practicing cost estimating today and why cost related issues are happening. The results confirm the literature where a particularly relevant finding from of Antony's study on critical success factors shows significant failure rates for six Sigma projects with the highest termination rates in the first two phases of the widely popular DMAIC or DMADV methodologies (Antony et al., 2020). Given that the results and research suggest that many projects are considered failed early in the product design lifecycle the next step is to understand who in the organization is making the estimates, are they qualified and which methods and tools are being used. The results also indicated that many roles from within the organization were estimating costs throughout the product's lifecycle. This finding was concerning to the cost experts due to possible anterior motives which may include sales/marketing trying to estimate the product at lower than actual cost in order to sell it at a more competitive price and designers pushing a low-cost estimate in an effort to get the product produced and hoping to reduce costs along the way. The results also indicated that 100% of Six Sigma leaders want cost practitioners on their projects from the beginning to ensure the cost estimates are accurate but less than 50% of Six Sigma projects have a cost resource on the project at all. Research agrees that not having skilled costing experts using proven costing methods and models developed for that industry could create profitability problems. With regards to who should estimate costs during the various phases of the product's lifecycle, collaboration and utilization of properly skilled roles is a critical factor for success (Antony & Banuelas, 2002; Sreedharan V et al., 2018).

Sub-theme 2: Educating the organization about the various definitions of cost

The definition of cost sub-theme was one of the most important and frequently discussed topics suggesting that cost was viewed differently by different groups within the organization and often confuse with the price of the product. This finding is supported by a study noting that cost does not determine price - the market determines price. Cost determines whether a company wants to sell at the market price (Hicks, 2004) The costing experts interviewed noted that in the various consultations there was a fundamental lack of understanding of cost from a manufacturing production perspective as that from an accounting perspective. When estimating the cost of a product the cost engineering approach tends to utilize costs associated with manufacturing, assembly and sustainment. Given that that the design may involve multiple design variants and manufacturing processes the costs need to accurately reflect current labor, materials and manufacturing costs. The justification for costing things should be to understand at the incremental cost impact on the organization. Costing part by part does not provide any costing for the processes that do not impact the part directly (Domanski, 2020). The use of historical accounting records with fully absorbed costs can grossly overestimate the true production costs erroneously killing a project during the ROI phase. Given that cost is the fundamental concept for cost estimation, the interviewees were quick to reiterate the importance that everyone participating on Six Sigma projects understand and use the same definitions which may require some form of education for Six Sigma stakeholders. This result agrees with research which states that manufacturers have moved away from ad hoc cost estimating and started using cost engineering methods (McDermaid, 2019). Paraphrasing a cost engineering expert, cost is a language that can be spoken between people within any organization that is measured off financial performance.

Sub-theme 3: Educating Six Sigma practitioners about the value of cost practitioners

The next sub-theme for educating the organization was the role of the cost engineering practitioner. The costing experts interviewed noted that in the various consultations that they have participated in there has routinely been confusion about the role of the cost engineer. The results indicated that Six Sigma leaders within an organization were not aware that they had a costing person to consult with during projects. Additionally, it was noted that the high rate of Six Sigma project failures due to cost related issues could be reduced if a cost practitioner were brought into the project during the project approval process to prevent potential downstream cost issues. If they are not used properly or given the right visibility, then their input will not be recognized. So, often costing related failures are not because of wrong data, but maybe it's because they don't ask the right people. Additionally, it was noted that the high rate of Six Sigma project failures due to cost related issues could be reduced if a cost practitioner were brought into the project during the project approval process to prevent potential downstream cost issues. These findings agree with research where the selection of team members is a critical step in aligning personnel skills for the project to ensure that the project will successfully meet stakeholder expectations (Gupta et al., 2019). Further research on critical success factors suggests that collaboration and utilization of properly skilled resources is a critical for success (Antony & Banuelas, 2002; Sreedharan V et al., 2018). As for educating the Six Sigma practitioners about the value of using cost engineering practitioners they need to be made aware that it is critical for a company to have a trained cost engineer if they can afford to have one on staff. Given the training, experience and certifications appropriate to be a cost practitioner, it is easy to imagine that a Six Sigma team will have difficulty recruiting someone that can fulfil the cost estimating requirements to participate in a Six Sigma design project.

Sub-theme 4: Educating Six Sigma practitioners about the value of cost methods

The final identified sub-theme for educating the organization is costing methods. The costing experts noted repeatedly that projects often start out with the wrong cost estimation methodology and then several phases later find that is not the correct one. We have established that many Six Sigma project managers generally are not aware that cost practitioners exist much less what cost estimate techniques should be used and when. The results found that cost methods are often not well understood suggesting that most companies use historical cost data and ad hoc methods to build estimates while estimating a few parts individually and call it a bottoms-up estimate. The literature agrees that this ends up being problematic and often leads to a poor estimate of cost during the approval process (Hueber et al., 2016). The analysis suggests that regardless of who does the cost estimating they need to understand when and how to use the correct method for the product. The literature doesn't show any research specific to cost engineering methods education for Six Sigma participants, but there is general support suggesting that a critical success factor for a Six Sigma project is adequate training of team members (Antony & Gupta, 2019).

Suggestions from the cost engineering experts about how to educate Six Sigma practitioners about the value of cost engineering methods should be carried out by one of the company cost engineers. The purpose of the class would be to educate the Six Sigma participants on the various costing methods and when to use them.

Theme 2: Benefits of using a cost practitioner/engineer

The next theme in order of importance from this study is *the value and benefit of utilizing a cost engineering practitioner on Six Sigma projects.* As described below, this theme was expected, but not to the degree that the findings exposed. The benefit and value of using cost engineering practitioners as an effective approach to reducing Six Sigma project failures was sufficiently answered by the interpretation of the qualitative interviews conducted in this mix-methods study.

According to the cost engineering experts the most accurate data comes from a person whose performance is measured against cost accuracy. The cost engineer is the responsible for giving the financial estimates for the project. They find and validate the cost data from various departments and from past projects or from a cost management system. Cost engineers may take a little more time assembling a cost report, but it should be more accurate than simply pulling number together from historical reports. Observations from the interviewees noted that cost engineers have a unique role where they span many functions. They act as a communication bridge to those discrete functions in many organizations. A skilled cost engineer should be able to talk with a manufacturing engineers about a manufacturing process. Meet with procurement about supplier negotiations and make-versus-cost costing. In addition, they should be able to talk with financial planners about budgeting and forecasting. So, they act as this bridge to all these functions that wouldn’t necessarily come together to do a project. This finding was supported by literature noting the view that having a skilled cost engineer with a wide variety skills is beneficial to design projects (Hollmann, 2006).

Pertaining to cost engineering practitioners involved from the beginning many of the failure causes related to cost estimating can be avoided, not always, but enough of the time. The cost engineering experts noted that having a cost practitioner on a Six Sigma project enabled the team to begin building process for cost verification throughout the product design process. Furthermore, there is not a special moment during the project when they are needed, rather they should be on the project from the beginning until the end and the cost engineer should be a neutral role in the organization where they use develop cost estimates based on proven cost models. This claim is also supported by literature as noted in Domanski's writings (Domanski, 2020).

The benefits of having a cost engineering practitioner on Six Sigma projects was evident from the interpretation of the findings into theme pertaining to the benefit of utilizing cost engineering practitioners on Six Sigma projects as supported by the literature.

Theme 3: Benefits of using cost engineering methods

The next theme in order of importance from this study is the value and benefit of utilizing a cost engineering practitioner on Six Sigma projects. This theme was expected, but not to the degree that the findings exposed. The benefit and value of using cost engineering practitioners as an effective approach to reducing Six Sigma project failures was sufficiently answered by the interpretation of the qualitative interviews conducted in this mix-methods study. Cost engineers stress the value of using the right costing methods on Six Sigma projects at the right time even though not all costing experts agree on which costing method to use in each phase, they all share the same sentiment that having an accurate cost model from the beginning may have prevented some project failures. There is no perfect fit cost engineering approach that will fit all every situation, every methodology has pros and cons. The literature supports this finding by noting that Cost engineering is gaining respect now more than it did 5-10 years ago, it's a growing discipline within most companies with methods and models maturing for each industry and product line (Hueber et al., 2016). A best practice could be for companies to use a cost engineering expert who can develop cost models for their line of products and industry. Cost models are predictive, so the impact of a change can quickly be calculated into the updated product design. This is supported by literature for the claim that the model you used to create the estimate is very important because you can get a good answer processing poor data in a in a valid model. Then, when you put in perfect data in an invalid model (Smith & Mason, 1997).

The benefits of using cost engineering methods on Six Sigma projects was also very evident from the results of the nine cost engineering interviews. Even though all cost engineers did not agree on which methods to use they do all agree that merely using cost engineering methods will increase cost estimating accuracies. Several recommendations emerged including the use of cost modeling and recruiting costing resources that know costing methods for their industry.

Theme 4: Benefits of using a cost management system

The next theme in order of importance from this study is *the value and benefit of utilizing a cost management system on Six Sigma projects.* This theme was expected but not with much enthusiasm by the Six Sigma practitioners as from the cost engineering experts. The benefit and value of using a cost management system as an effective approach to reducing Six Sigma project failures was sufficiently answered by the interpretation of the qualitative interviews conducted in this mix-methods study.

Cost engineering experts recommend using a cost management system as a systematic approach to managing cost throughout the life cycle of any project. Over the past few decades, the automotive industry has been under tremendous cost pressure and has slowly started to adopt a bottoms-up costing approach using product cost management system. Companies buy commercial product cost management systems because they do not really have a single source of truth. A cost management system provides a single source of truth with regards to costs as well as other business intelligence s the findings indicate, you cannot do accurate costing without a cost management system (Hiller, 2019). The last finding of the survey study indicated that only 31% of Six Sigma practitioners would definitely use a cost management system on future projects, this was viewed as possibly being something that older Six Sigma practitioners wouldn't understand or trust. Several from the group of interviewees did note that older Six Sigma practitioners are not big software supporters. They do not want trust data that is not on an accounting report or purchase order. Further it was noted that many companies believe that it is more beneficial to have a costing expert rather than to try to use some system where they cannot explain where the data comes. This is a finding that should be addressed in the initial theme on the topic of education as this is one of the three key approaches.

The benefits of using a cost management system on Six Sigma projects was positively viewed by the interviewees. The single source of truth for data was frequently noted as the best method for performing a bottoms-up or part by part cost estimation for products. Additionally, a cost management system provides other business information that might be valuable as new caron footprint regulations begin. Also, the respondents noted that even with some older Six Sigma leaders reluctant to try new technology, some embrace it assurance of cost accuracy.

Conclusions Based on the Findings

The literature accurately identified the relationship between Six Sigma project failures and poorly implemented critical success factors. The relationship between poorly implemented success factors and the subsequent impact on failure rates of Six Sigma projects is aligned with research conducted in prior published studies Antony et.al. (2019). Like the histories of lean and Six Sigma, cost engineering is a relatively new discipline, but it doesn't garner near the attention in organizations as do its quality counterparts.

Given this general lack of awareness, companies need to educate themselves on the value of using cost engineering approaches to compete in the marketplace. These approaches include the utilization of cost engineering practitioners, methods and cost management systems. The use of any of these approaches is a huge step forward with improving the success rate of Six Sigma projects. For those companies that have embraced cost engineering principles they understand that every decision made is based on a cost.

As a result of this research there are several avenues that can be further explored to take this research to the next level. Namely, adding badly needed costing tools to matrix of Six Sigma methodologies. Secondly, encouraging cost engineering professionals to actively engage in Six Sigma projects and to create as much awareness as possible within the organization. Thirdly, expanding this research into the full breadth of the digital thread. Based on the literature review, survey with Six Sigma professionals, interviews with expert cost engineering professionals and results from the thematic analysis, this study provided evidence that a relationship exists between the failure to implement cost engineering approaches and the failures associated with Six Sigma relate projects in the manufacturing industry.

Limitations of Research

The first limitation was the virtual distribution of the survey questionnaire. The use of an internet distribution method was very beneficial in with regards to efficiency and limitation of observation bias, it produced a greater probability of specification errors and recall bias among participants (Pattern & Newhart, 2017).

This second limitation was based on a delimitation of this study with its restriction to participants from the US. This restriction eliminated the need for a language interpretation which may prevent response misinterpretation. But this restriction also limited the generalizability of the results to US manufacturing companies.

The third limitation was the use of two different groups for participants for each of the two phases of this study. Phase 1 of this study used Six Sigma practitioners to confirm that the research questions were valid for additional study. With the confirmation from the survey analysis a set of explanatory questions was developed for cost engineering experts for use in a semi-structured interviews.

Implications for Practice

The results of this study have direct practical implications Six Sigma related projects being carried out in manufacturing organizations. The results of this study provide manufacturing organizations as well as Six Sigma practitioners with evidence that will allow them to understand the value and benefits of utilize cost engineering practices and approaches. This information provides manufacturing organizations the opportunity to understand how they can maintain, control and improve the cost of producing products across its lifecycle. Additionally, the results of this study have practical implications for cost engineering professionals in the manufacturing industry who need to be aware of the relationship between poor costing practices and Six Sigma project success and failures rates. The information provided by the participation of 177 Six Sigma survey participants and 9 cost engineering experts will assist leaders in the manufacturing industry by improving their awareness and knowledge of cost engineering practices.

Contribution to the Body of Knowledge

As a result of this study this research intends to live up to the standard set for Ph.D. level research by contributing something of value to the related body of knowledge. Any contributions from this research are based on the insights gained from the themes developed as a result of the data collected, analyzed and interpreted from this study.

Building off the work of Antony, et.al. (varies), the foundation of this study was to determine what underlying causes created such low success rates in Six Sigma projects. Using that as a springboard for additional research, this study looked at how the lack of or poorly implemented cost related practices may have contributed to six Sigma project failures. Given that lack of research in the area this research was carried out using a mix methods design as outlined by Creswell (2015). As a result, the following themes emerged providing important areas that contribute to the body of knowledge related to cost engineering and Six Sigma project performance. These themes were arrived at using Braun and Clarke's (2016) thematic analysis methodology.

The first contribution is the recognition of an immediate need to educate manufacturing organizations as well as Six Sigma practitioners about the value of cost engineering practices. Organizations need to be clear about the value of cost engineering practices and then take action to incorporate these practices into their Six Sigma and other design projects to have a clear understanding of what costs are going into their products. The incorporation of an education and awareness program in addition to cost engineering approaches into Six Sigma projects would positively impact the outcome of designed-based projects.

The second contribution to the body of knowledge is the results and explanation of the benefits from using cost engineering approaches. The first approach is the value of utilizing a trained, skilled and certified cost practitioner who can add tremendous value to Six Sigma projects from the development of cost estimates and models for quickly evolving designs. The second approach is the value of utilizing proven cost estimating methods and techniques. This is especially important for design-based methodologies used by Six Sigma design-based methodologies like DFSS and DfX. Product design projects are very cost-orientated with costs emanating from many sources across the product lifecycle. Cost estimating methods are well-documented and utilized in many industries and have clear value with improving cost estimates. The third approach pertains to raising awareness about the use of a cost management system as a cost engineering approach. This is the most recent addition to cost engineering and has very little coverage in the literature. As a technology cost management systems will allow the design process to report accurate costs as the design changes.

The third contribution relates to the uniqueness of this study. The use of a mixed-methods design to study the research and literature gap for using cost engineering practices to improve six Sigma related project failures may allow other researchers to use this study to validate that the problem they intend to research is valid using an explanatory design to answer the question of “what” with a subsequent study to answer the question of “why”.

Recommendations for Further Research

Recommendations for future research are broken down into two primary categories based on the research carried out from this study. The categories of recommendations for future research are recommendations developed directly from the data and recommendations based on delimitations or ideas from the initial literature review. The results of this research provide multiple avenues for new studies to expand upon the current literature for cost engineering practices in the manufacturing industry. Cost engineering is gaining respect now more than it did 5-10 years ago, it's a growing discipline within most companies and industries alike. The field is one that is becoming more prevalent as organizations are tasked with meeting higher demands at lower costs. Expanding upon the original proposed research questions in this study would lay the groundwork for new results and inferences. The following are future research recommendations based on the results from this study.

Develop an education program about the benefits of cost engineering

Based on the findings from this study research should be undertaken to create awareness and educate the organization in the value of cost engineering practices. More detailed education and training should be made available to Six Sigma teams based on the type of project that is being undertaken.

Integrating cost reviews throughout Six Sigma methodologies

This recommendation is the result of the analysis from the cost engineering expert interviews. Many product design methodologies incorporate cost reviews throughout the process either at a stage gate or other review step. Six Sigma methodologies seem to ignore cost as a practice, tool or role. Research should look at adding costing at various points throughout Six Sigma methodologies.

Expanding this study to include international

This recommendation is based on a delimitation of this study with its restriction to participants from the US. This restriction eliminated the need for a language interpretation which may prevent response misinterpretation. But this restriction also limited the generalizability of the results to US manufacturing companies. Therefore, the recommendation for future research based on delimitations is to expand the population to include international participants to a similar study thereby increasing the overall generalizability of the study.

Merging cost engineering with digital twin cost models

This recommendation is a result of an idea from the study's initial literature review. Creating a digital twin allows you to simulate what is happening on the plant floor which also be used to simulate the costs. Costing information is maintained in a database which, if done properly, can be an attribute for parts in a bill of material. As a 3-D cad model is developed the cost associated with that part is carried along and changes as the assembly and subsequent manufacturing processes are changed. Beyond a basic part or assembly, we can now create a full shop floor environment with machines and infrastructure. The use of digital twins in design and manufacturing is here today, researchers should be consider developing costing models that are integrated into the simulation software that instantaneously updates costs with changes in the 3-D model.

APPENDIX A: SIX SIGMA DEMOGRAPHICS SURVEY QUESTIONS

Personal Demographics

How many years have you been in a Six Sigma role?

- < 1 year
- 1 < 3 years
- 3 < 5 years
- 5 < 10 years
- 10 < 15 years
- 15 < 20 years
- > 20 years

How old are you?

- Under 18
- 18-24 years old
- 25-34 years old
- 35-44 years old
- 45-54 years old
- 55-64 years old
- 65+ years old

What Six Sigma certifications do you hold?

- ☐ Master Lean Six Sigma Black Belt
- ☐ Master Six Sigma Black Belt
- ☐ Lean Six Sigma Black Belt
- ☐ Six Sigma Black Belt
- ☐ Lean Six Sigma Green Belt
- ☐ Six Sigma Green Belt

What other industry certifications do you hold?

____

Number of Six Sigma projects that you have participate?

- ○ 1
- ○ 2 - 5
- ○ 6 - 10
- ○ 10 -15
- ○ 16 or more

How many Six Sigma projects have participated that were design projects?

- ◯ 1
- ◯ 1 -5
- ◯ 6 - 10
- ◯ 11 -15
- ◯ 16 or more

How many non-Six Sigma projects have participated that were design projects?

- ◯ 1
- ◯ 1 - 5
- ◯ 6 - 10
- ◯ 11 - 15
- ◯ 16 or more

Organizational Demographics

What country is your corporate headquarters located?

____

What country are you located?

____

Approximately how many employees does you company have worldwide?

- < 100
- 101 - 500
- 501 - 1000
- 1001 - 1500
- 1501 - 2000
- 2001 - 2500
- 2501 - 5000
- 5001 - 10,000
- > 10,000

Approximately how many employees does you company have in your country of employment?

- < 100
- 101 - 500
- 501 - 1000
- 1001 - 1500
- 1501 - 2000
- 2001 - 2500
- 2501 - 5000
- 5001 - 10,000
- > 10,000

Approximately what was your company's revenue in the last fiscal year?

- ○ < $10 Million (M)
- ○ $10 M - $50 M
- ○ $51 M - $100 M
- ○ $101 M - $250 M
- ○ $251 M - $500 M
- ○ $501 M - $1 Billion (B)
- ○ $1 B - $5 B
- ○ $5B - $10 B
- ○ > $10 B

What is the primary industry of your company?

- ☐ Aerospace and Defense
- ☐ Automotive
- ☐ Construction
- ☐ Electronics/Semiconductor
- ☐ Medical/Biomedical
- ☐ Telecommunications
- ☐ other, please specify

____

APPENDIX B: SIX SIGMA FOCUSED SURVEY QUESTIONS

Which of the following Six Sigma and/or DFSS methodologies have you used?

- ☐ DMAIC (Six Sigma)
- ☐ DMADV
- ☐ IDOV
- ☐ DMADOV
- ☐ DMEDI
- ☐ CDOV
- ☐ other, please specify

____

For projects that failed, in which phase was the failure determined?

- ☐ During project proposal (in the approval cycle)
- ☐ During the first phase (usually Design, Concept or Identify)
- ☐ During the second phase (usually Measure or Development)
- ☐ During the third stage (usually Analyze, Optimize, Explore)
- ☐ During the fourth phase (usually Optimize, Verify or Implement)
- ☐ Project the final phase (usually Validate or Control)
- ☐ After the project was completed

For failed projects, please cite the most likely factor:

- ☐ Lack of commitment and support from top management
- ☐ Failure to deliver on promised value
- ☐ Inadequate training and learning
- ☐ Incompetent teams (lack of skills)
- ☐ Faulty selection of a process improvement methodology
- ☐ Sub-optimal team size and composition
- ☐ Inconsistent monitoring and control (lack of expert supervision)

Failures can be attributed to many factors.
Were any of the failures associated with poor or lack of or cost estimation techniques. (i.e., using old costing data, poor costing estimation techniques, etc.)?

Please explain

____

For products (not processes) that were designed or re-designed, who was tasked with estimating the costs associated with the design, manufacturing, assembly and sustainment of that product?

	Design (prototyping)	Manufacturing	Assembly	Support/Sustainment
Cost Engineer	☐	☐	☐	☐
Cost Analyst/Estimator	☐	☐	☐	☐
Sales/Marketing	☐	☐	☐	☐
Designer of the Product	☐	☐	☐	☐
Engineering	☐	☐	☐	☐
Planner (manufacturing)	☐	☐	☐	☐
Manufacturing Engineer	☐	☐	☐	☐
Procurement	☐	☐	☐	☐
Finance	☐	☐	☐	☐
other, please specify	☐	☐	☐	☐
not sure	☐	☐	☐	☐

If the estimating task involves more than one person, please explain.

____

Cost data is used throughout the design process to determine manufacturing, assembly and sustainment costs.

Where do you get cost data?

- ☐ Prior projects - Analogous Estimating
- ☐ Prior Projects - Parametric Estimating
- ☐ Estimate individual parts - Bottoms up
- ☐ Cost Accounting Reports
- ☐ Activity Based Costing (ABC)
- ☐ Target Costing model
- ☐ Should Costing model
- ☐ Value Engineering Analysis
- ☐ We do not consider costs during the design process
- ☐ other, please explain

____

Was a Cost Engineer/Analyst/Estimator(Practitioner) brought onto the project? If so, at what point during the project?

- ○ During project proposal (in the approval cycle)
- ○ During the first phase (usually Design, Concept or Identify)
- ○ During the second phase (usually Measure or Development)
- ○ During the third stage (usually Analyze, Optimize, Explore)
- ○ During the fourth phase (usually Optimize, Verify or Implement)
- ○ Project the final phase (usually Validate or Control)
- ○ Post Project
- ○ Not Utilized the Project

If a Cost Practitioner were brought onto the project, would they be considered:

- ○ A member of the Six Sigma team
- ○ External to the team, more like a company resource
- ○ other, please explain ____

Would you consider adding a Cost Practitioner to the Six Sigma project team in the future?

- ○ Yes
- ○ No, If no, why? ____

Do you think that a Cost Practitioner may be able to improve the accuracy of costing data improving the likelihood of a successful project?

- ◯ Yes
- ◯ No, If no, why? ____

Would a Product Cost Management (PCM) system allow you to obtain more accurate cost information?

- ◯ Yes
- ◯ No, If no, why? ____

Are you open to using cost engineering approaches on future projects?

	Definitely	Maybe	Not Needed
Cost Engineering Practitioner	◯	◯	◯
Cost Engineering Methods and Techniques	◯	◯	◯
Product Cost Management (PCM) system	◯	◯	◯

APPENDIX C: COST ENGINEER DEMOGRAPHIC QUESTIONS

Section A: Informed consent and contact information

1. Informed consent: do you agree to be part of the study? Yes or No
2. What is your first name? Click or tap here to enter text.
3. What is your e-mail address? Click or tap here to enter text.

Section B: Demographic Study

4. How old are you?

☐ Under 18

☐ 18-24 years old

☐ 25-34 years old

☐ 35-44 years old

☐ 45-54 years old

☐ 55-64 years old

☐ 65+ years old

5. What is your role?

☐ Cost Engineer

☐ Cost Analyst

☐ Cost Estimator

☐ Other (please specify) Click or tap here to enter text.

6. How many years have you been in a Cost Engineering role?

☐ < 5 years
☐ 5 < 10 years
☐ 10 < 15 years
☐ 15 < 20 years
☐ > 20 years

7. Where did you earn your certification?

☐ Association for the Advancement of Cost Engineering (AACE)

☐ The Society of Product Cost Engineering & Analytics (SPCEA)

Other (please specify) Click or tap here to enter text.

8. What cost engineering certification(s) do you hold?

☐ Aerospace and Defense

☐ Automotive

☐ Construction

☐ Electronics / Semiconductor

☐ Medical / Biomedical

☐ Telecommunications

☐ Other (please specify) Click or tap here to enter text.

9. How many Six Sigma projects have you taken part? Click or tap here to enter text.

10. How many Six Sigma projects have you personally been part of that were product design/redesign focused? Click or tap here to enter text.

11. How many non-Six Sigma projects have you personally been part of that were product design/redesign focused? Click or tap here to enter text.

APPENDIX D: COST ENGINEER SEMI-STRUCTURED QUESTIONS

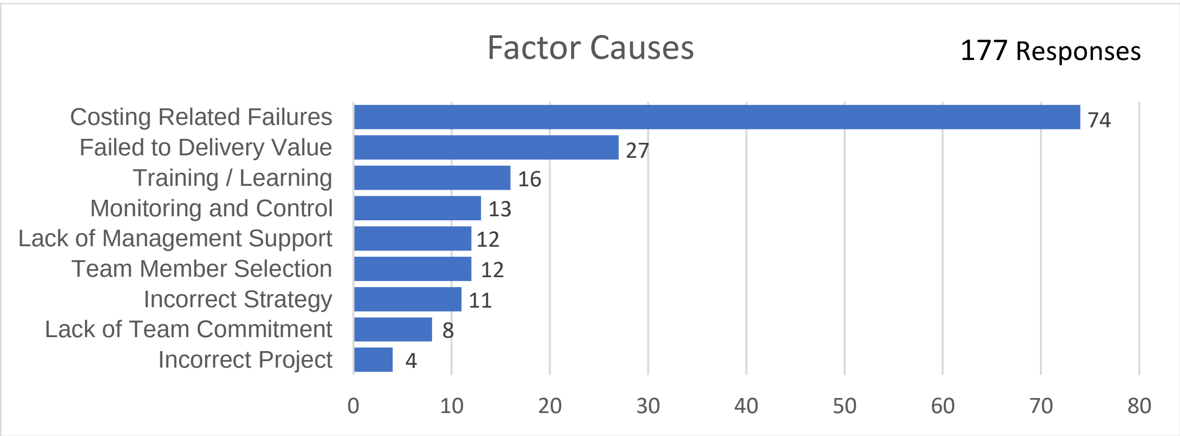
Section C: Focused Interview Questions

Question 1: How would you explain these failure factors and underlying causes associated with poor or lack of cost estimation methods and techniques?

Research agrees on the basic critical failure factors for Six Sigma projects. A recent survey of Six Sigma practitioners lists the top three factors as:

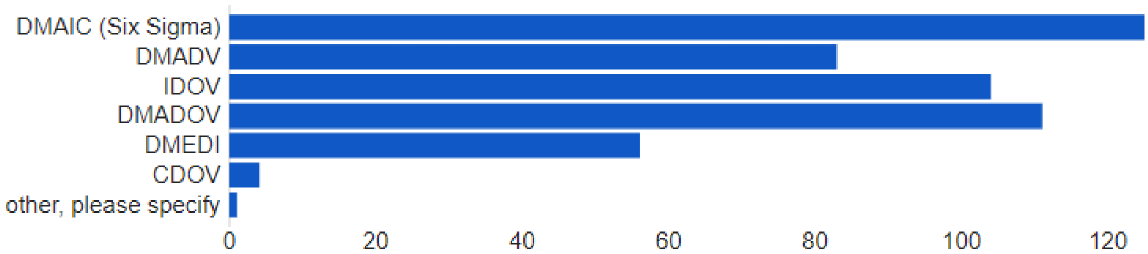
1. Inadequate training and learning
2. Failure to deliver on promised value
3. Incompetent teams (lack of a particular skill)
4. Lack of commitment and support from top management
5. Faulty select of a process improvement process or associated tools/techniques

A follow-up question to this was "Failures can be attributed to many factors. Were any of the failures associated with poor or lack of or cost estimation techniques. (i.e., using old costing data, poor costing estimation techniques, etc.)?"

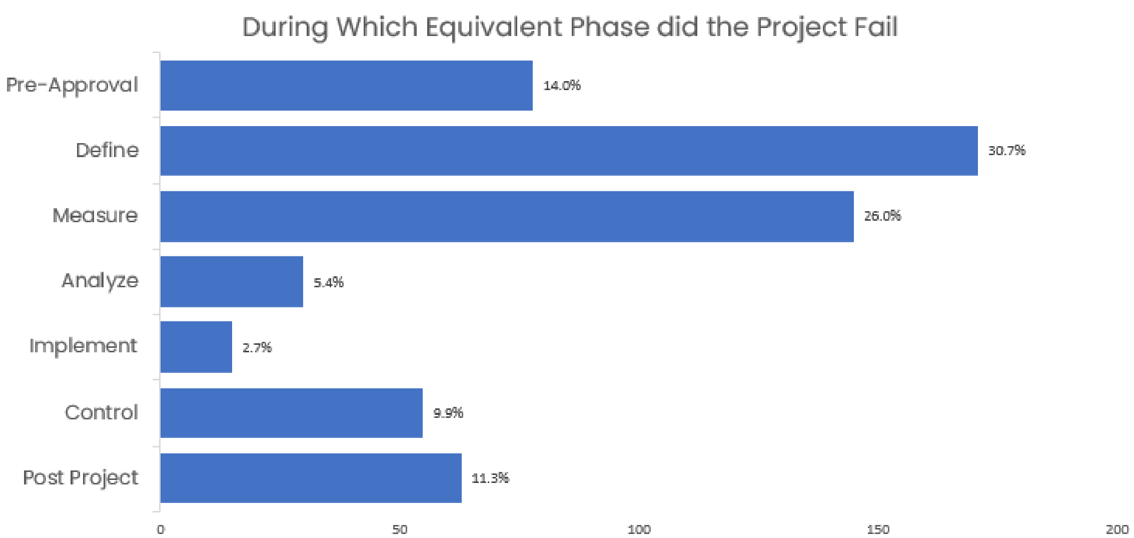


Question 2: How would you explain the failure rates at the various phases in the project? Given the results shown below.

Six Sigma practitioners were asked which Six Sigma methodology they have used on projects.



The follow up question to this was "during which phase did the failed project fail?"



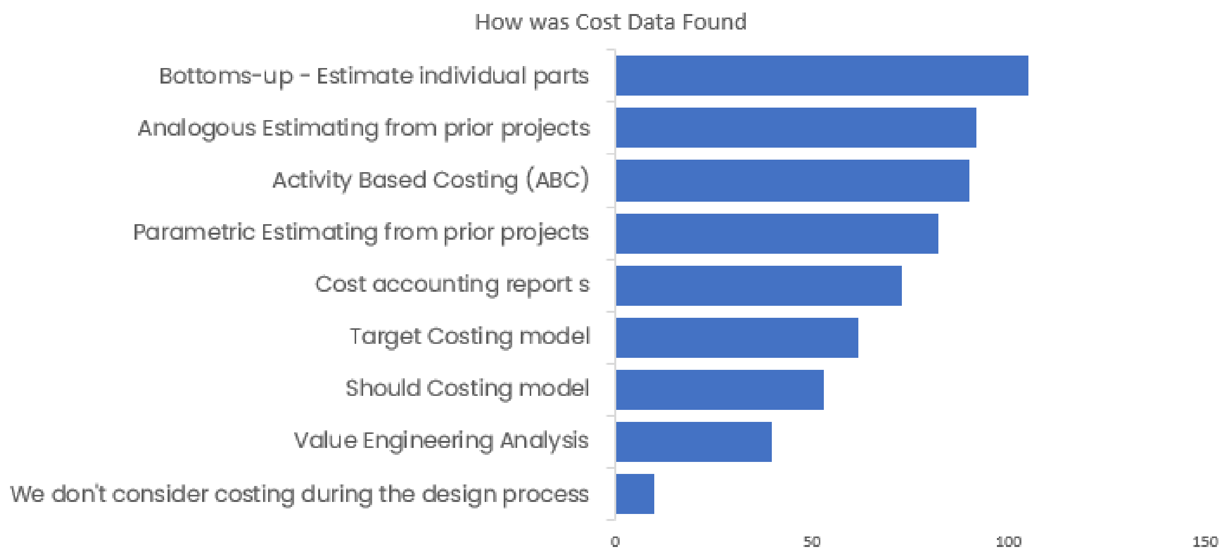
Field	Choice Count
Prior to Project Approval	78
Define (or equivalent)	171
Measure (or equivalent)	145
Analyze (or equivalent)	30
Improve (or equivalent)	15
Control (or equivalent)	55
Post Project	63
Total	557

Question 3: What is your interpretation of these results?

From the survey the following question was asked about which costing methods used during Six Sigma related projects.

Given that cost data is used throughout the design process to determine manufacturing, assembly and sustainment costs (in addition to many other costs).

Where did the Six Sigma team get cost data?



Question 4: How would you interpret these responses with regards to cost estimating accuracy?

The table below shows the Six Sigma practitioners' response as to who typically provides the cost estimate for each of the four areas noted.

The follow-up question to what methods were used was who made the estimates related to the four major areas: Design, Manufacturing, Assembly and Support/Sustainment.

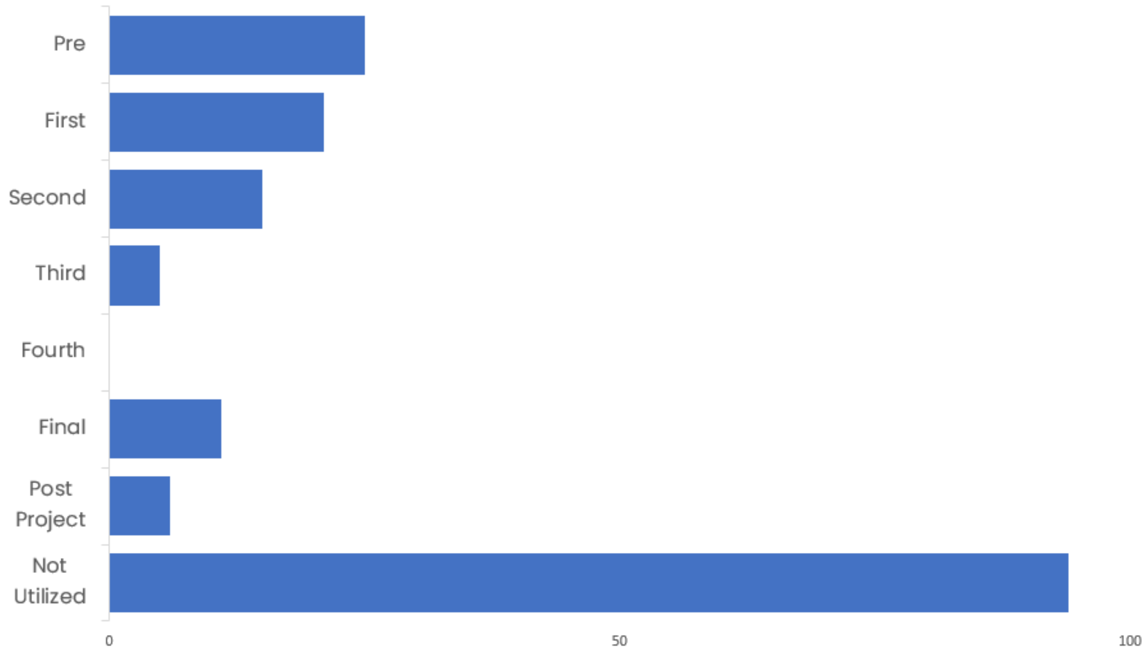
Who Estimates - For products (not processes) that were designed or re-designed, who was tasked with estimating the costs associated with the design, manufacturing, assembly and sustainment of that product?

Field	Design (prototyping)	Manufacturing	Assembly	Support/Sustainment	Total
Cost Engineer	65	90	63	13	231
Cost Analyst/Estimator	51	83	58	34	226
Sales/Marketing	44	81	70	35	230
Designer of the Product	48	68	70	44	230
Engineering	36	74	74	42	226
Planner (manufacturing)	39	78	76	45	238
Manufacturing Engineer	42	86	64	49	241
Procurement	43	80	84	31	238
Finance	33	86	83	30	232
other, please specify	0	3	2	0	5
not sure	0	2	0	0	2

Question 5: How do you interpret these results?

The chart below displays the results of the question "if utilized, when was a cost practitioner brought on the project?"

As a follow-up to the previous question: if utilized, when was a cost practitioner brought on the project?



Field	Choice Count
During Projec Proposal	25
First Phase	21
Second Phase	15
Third Phase	5
Fourth Phase	0
Final Phase	11
Post Project	6
Not Utilized at all	94
Total	177

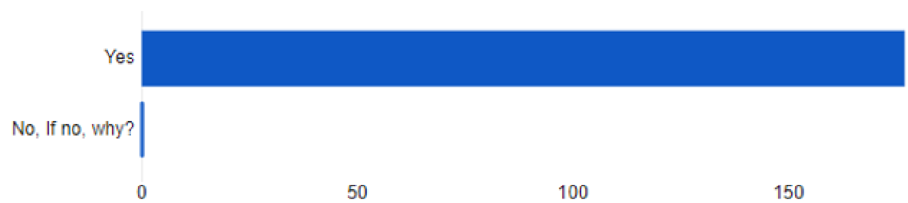
Question 6: What is your opinion on the survey question and the associated response?

The charts below indicate that 100% of the responses felt that having a cost engineering practitioner would improve accuracy and thereby improving the likelihood of success of the project. Close to 64% of the responses indicated that a cost engineering professional should be consider as a part of the Six Sigma team versus 36% of the responses indicated that they should be external to the Six Sigma team.

The next set of questions posed to Six Sigma practitioners pertained to their use of and value of using cost engineering approaches on projects.

Do you think that having a cost engineering practitioner participate on the project may be able to improve accuracy of costing data improving the likelihood of a successful project?

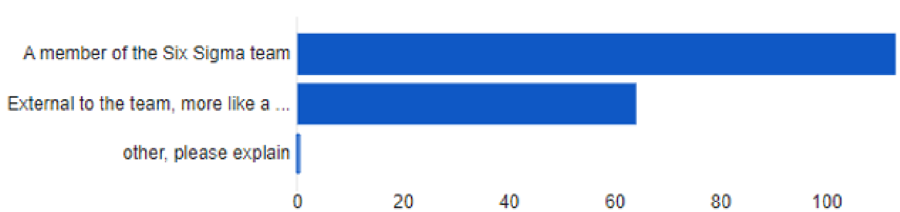
100% of respondents thought this was a good idea for improving the accuracy of costing data and thereby improving the likelihood of a successful project.



Do you think that a cost engineering practitioner should be a part of the Six Sigma team from the beginning of the project?

Member of the team = 113/177 = 63.8%

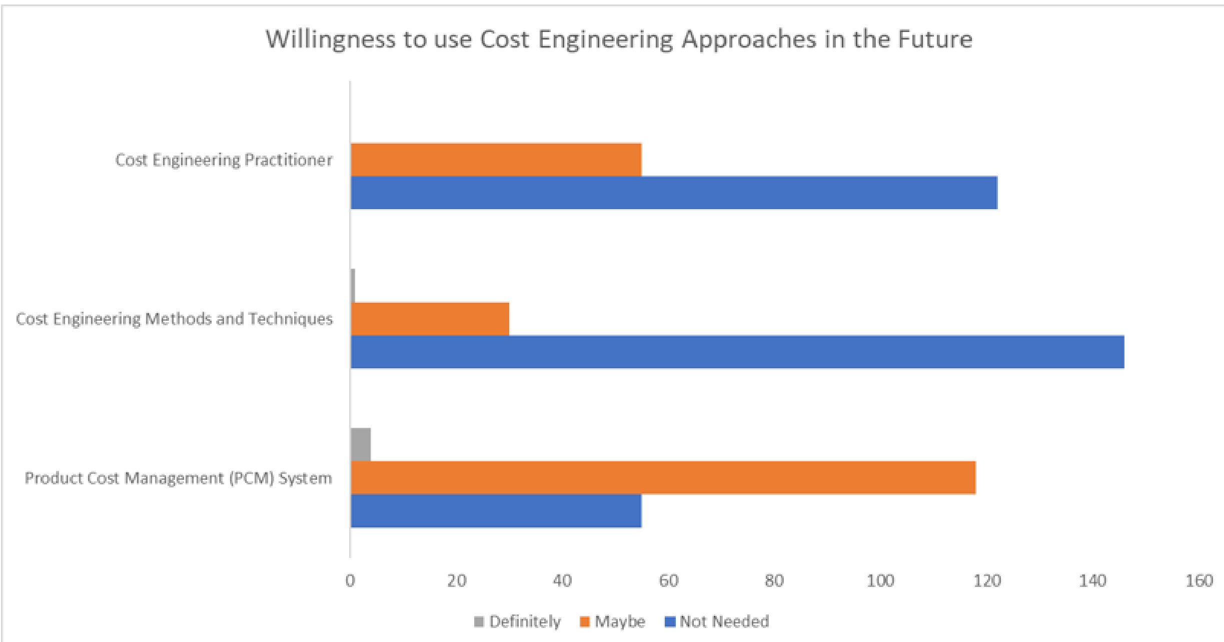
External to the team = 64/177 = 36.2%



Question 7: How would you interpret the responses from Six Sigma practitioners regarding the use and value of cost engineering practitioners?

Based on the chart below.

The final set of questions posed to Six Sigma practitioners pertained to their use of and value of cost engineering approaches on future projects.



Field	Definitely	Maybe	Not Needed	Choice Count
Cost Engineering Practitioner	122	55	0	177
Cost Engineering Methods and Techniques	146	30	1	177
Product Cost Management (PCM) System	55	118	4	177

Question 8: What is your opinion about the impact of cost engineering approaches for improving the accuracy of cost estimates and thereby improving the success rate of Six Sigma projects?

APPENDIX E: CODES, CATEGORIES AND THEMES

Theme	
Benefits of Educating the Organization Cost engineers recommend eduation of Six Sigma stakeholders on the value of cost engineering	
Codes	**Categories**
Educate Management on the business value of using cost engineering approaches Educate SS participants on the various definitions of cost Educate SS practitioners on the value of cost practitioners Educate SS practitioners on cost engineering methods	The need for educating the organization about the value of cost engineering approaches

Theme	
Benefits of using a Cost Practitioner/Engineer Cost engineers name the specific benefits with using cost engineering practitioners to mitigate six-sigm aproject fails	
Codes	**Categories**
Using the Cost Practitioner as estimator Using the Sales as estimator Using the Designer as estimator Using the Team as estimator	Who is estimating costs in six-sigma projects Who should be estimating costs in six-sigma projects
Bringing a cost engineering on Pre-approval Bringing a cost engineering on Early Bringing a cost engineering on Middle or Late Bringing a cost engineering on Post Project Not utilize a cost engineering on Project	When should a cost engineering practitioner join a six-sigma
Retain a skilled cost engineer for the Industry/Product Retain a cost engineer for duration of the project When should a cost engineering practitioner be involved Who should be estimating costs on six-sigma projects	Retaining cost engineers on six-sigma projects
Six-sigma practitioners want a cost engineering involved - 100% Asking a cost engineering to be part of the team Keeping the cost engineering external to team Value of a cost engineering practitioner on six-sigma projects	The desire to have a cost engineering practitioners on six-sigma projects

<table>
<tr><th colspan="2">Theme</th></tr>
<tr><td colspan="2">Benefits of using Cost Engineering Methods

Cost engineers stress the value of using the right cost engineering methods on Six Sigma projects</td></tr>
<tr><th>Codes</th><th>Categories</th></tr>
<tr><td>Bottoms-up method
Parametric method

ABC method
other methods

Value of cost engineering methods on six-sigma projects</td><td>Which cost engineering methods are used

When should cost engineering methods be used

Value of cost engineering methods on six-sigma projects</td></tr>
</table>

<table>
<tr><th colspan="2">Theme</th></tr>
<tr><td colspan="2">Benefits of using a Cost Management System

Cost Engineers recommend usng a cost management system as a systematic approach to managing costs throughout the lifecycle of any project</td></tr>
<tr><th>Codes</th><th>Categories</th></tr>
<tr><td>Integrate Costing as part of six-sigma methodologies
Integrate Costing as part of Development Phase Gates

Including cost reviews as part of methologies
Using cost management systems on six-sigma projects</td><td>Integrate Costing as part of six-sigma methodologies

Value of cost management system on six-sigma projects</td></tr>
</table>

APPENDIX F: INFORMED CONSENT

UNIVERSITY OF CENTRAL FLORIDA

EXPLANATION OF RESEARCH

Title of Project: Cost Engineering and DFSS Project Success

Principal Investigator: Dennis Tribby

Other Investigators: n/a

Faculty Supervisor: Dr. Ahmad Elshennawy

You are being invited to take part in a research study. Whether you take part is up to you.

To be eligible for the study, you must be age 18 or older and meet at least one of the following criteria:

- Participant must be a certified Six Sigma Master Black Belt. Black Belt or Green Belt who has participated on a product design or redesign project
- Participant must have sponsored a Six Sigma product design or redesign project
- Participant must have been a manager of an organization that implemented a Six Sigma program involving the design or redesign of a product.

The purpose of this research is to determine if the use of one or more cost engineering approaches can improve the success rate of design based Six Sigma projects. The approaches used for this research are engineering methods, engineering practitioners and product cost database system

This research will use a remote, semi-structured interview approach with participants being asked to provide responses to questions relating to the research topic.

Interview questions will be different for Six Sigma participants and for Cost Engineer participants.

The interviews will be conducted remotely using Zoom, Web-Ex, Skype or a similar web-application that allows audio recording, or by phone if the first option is not possible. Interviews will be recorded to assist with data capture and accuracy. No video is needed for this research.

The interviews are not expected to exceed one hour in duration and will consist of five questions with follow-up questions on research specific topics.

Transcripts of the interviews will be provided to participants to review. Once transcripts of the interviews have been reviewed, the recordings will be destroyed.

Selected interview responses may be used in the researcher's dissertation. Names of the interviewees will not be provided unless the participant desires.

The privacy of participants is of immense importance. Only the required information in the study related to the participants company role, demographic, Six Sigma or cost engineering certifications, and product design project experience will be collected for this study.

All data collected in the study shall be stored on a password protected encrypted storage device with limited access given only to the researcher as well as the researcher's dissertation advisor. All private information will be immediately removed from the research data following receiving the data needed for this research study. The private information will be stored in a separate location from the data. All data will be stored for a minimum of five years from study closure per UCF policy. All relevant data will be destroyed within seven years following the publication of the study to avoid security issues.

Study contacts for questions about the study or to report a problem: If you have questions, concerns, or complaints to Dennis Tribby, Graduate Student, Industrial Engineering and Management Systems, College of Engineering and Computer Science, (407) 823-2156 or Dr. Ahmad Elshennawy, Faculty Supervisor, Department of Industrial Engineering and Management Systems at (407) 823-5742 or by email at ahmade@ucf.edu.

IRB contact about your rights in this study or to report a complaint: If you have questions about your rights as a research participant, or have concerns about the conduct of this study, please contact Institutional Review Board (IRB), University of Central Florida, Office of Research, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901, or email irb@ucf.edu.

APPENDIX G: IRB APPROVAL LETTER

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

EXEMPTION DETERMINATION

May 20, 2022

Dear Dennis Tribby:

On 5/20/2022, the IRB determined the following submission to be human subjects research that is exempt from regulation:

Type of Review:	Initial Study, Exempt category 2ii
Title:	Implications of using Cost Engineering Approaches for Improving the Outcome of Design for Six Sigma Projects
Investigator:	Dennis Tribby
IRB ID:	STUDY00004310
Funding:	None
Grant ID:	None
Documents Reviewed:	• 4310 HRP-254-FORM-Explanation_of_Research_Tribby Rev 1.pdf, Category: Consent Form; • 4310 HRP-255-FORM - Request for Exemption Rev 2.docx, Category: IRB Protocol; • Cost Engineer Questions 12May22.docx, Category: Interview / Focus Questions; • Interview Data Collection Sheet.xlsx, Category: Other; • Recruitment Message.docx, Category: Recruitment Materials; • Six Sigma Questions 12May22.docx, Category: Interview / Focus Questions;

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made, and there are questions about whether these changes affect the exempt status of the human research, please submit a modification request to the IRB. Guidance on submitting Modifications and Administrative Check-in are detailed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.   When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

Page 1 of 2

If you have any questions, please contact the UCF IRB at 407-823-2901 or irb@ucf.edu. Please include your project title and IRB number in all correspondence with this office.

Sincerely,

Harry Wingfield
Designated Reviewer

LIST OF REFERENCES

AACE. (2022). What Are Cost Engineering & Total Cost Management?

Ahmad, R., Lahonde, N., & Omhover, J.-F. (2014). Game methodology for design methods and tools selection. *Journal of learning design, 7*(1), 1-9. doi:10.5204/jld.v7i1.94

Albliwi, S., Antony, J., Lim, S. A. H., & Wiele, T. v. d. (2014). Critical failure factors of lean six sigma: a systematic literature review. *The International journal of quality & reliability management, 31*(9), 1012-1030. doi:10.1108/IJQRM-09-2013-0147

Albliwi, S. A., Antony, J., & Lim, S. A. h. (2015). A systematic review of Lean Six Sigma for the manufacturing industry. *Business process management journal, 21*(3), 665-691. doi:10.1108/BPMJ-03-2014-0019

Alghamdi, M. A., Elshennawy, A. K., & Rabelo, L. (2016). *An integrated Design for Six Sigma-based framework to align strategy, new process development, and customer requirements in the airline industry.* University of Central Florida, Orlando, Florida.

Alvarez, J. C. (2015). Lean design for Six Sigma. *International Journal of Quality & Reliability Management, 32*(8), 895-905. doi:10.1108/IJQRM-08-2012-0125

Alwerfalli, D., ;Lash, Trevor. (2012, July 3-6, 2012). *Design For Six Sigma (DFSS) as a Proactive Business Process.* Paper presented at the International Conference on Industrial Engineering and Operations Management, Istanbul.

Anbari, F. T. K., Young Hoon. (2014). *Success factors in managing six sigma projects.* Paper presented at the Paper presented at PMI® Research Conference: Innovations, London, England.

Antony, J. (2011). Six Sigma vs Lean: Some perspectives from leading academics and practitioners. *International journal of productivity and performance management, 60*(2), 185-190. doi:10.1108/17410401111101494

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

Antony, J., & Gupta, S. (2019). Top ten reasons for process improvement project failures. *International Journal of Lean Six Sigma, 10*(1), 367-374. doi:10.1108/IJLSS-11-2017-0130

Antony, J., Lizarelli, F. L., & Machado Fernandes, M. (2020). A Global Study Into the Reasons for Lean Six Sigma Project Failures: Key Findings and Directions for Further Research. *IEEE Transactions on Engineering Management*, 1-16. doi:10.1109/TEM.2020.3009935

Antony, J., Snee, R., & Hoerl, R. (2017). Lean Six Sigma: yesterday, today and tomorrow. *The International journal of quality & reliability management*, *34*(7), 1073-1093. doi:10.1108/IJQRM-03-2016-0035

aPriori. (2020). A Guide to Should Cost Analysis and Negotiation. Retrieved from https://www.apriori.com/should-cost-analysis/

Bergin, T. (2018). *An Introduction to Data Analysis: Quantitative, Qualitative and Mixed Methods*: Sage Publications.

Bhaskar, H. (2020). *Lean Six Sigma in Manufacturing: A Comprehensive Review* (F. P. G. Márquez Ed. 1 ed.).

Braun, V., & Clarke, V. (2016). (Mis)conceptualising themes, thematic analysis, and other problems with Fugard and Potts' (2015) sample-size tool for thematic analysis. *International Journal of Social Research Methodology, 19*, 1-5. doi:10.1080/13645579.2016.1195588

Braun, V., & Clarke, V. (2021). One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative research in psychology*, *18*(3), 328-352. doi:10.1080/14780887.2020.1769238

Braun, V., & Clarke, V. (2021). *Thematic analysis: a practical guide*: Sage Publications.

Chang, W. T., S.A. (2016). The effectiveness of customer participation in new product development: a meta-analysis. *Journal of Marketing*, *80*(1), 47-64.

Clark, F., Lorenzoni, A. B., & Jimenez, M. (1996). *Applied Cost Engineering* (Vol. 28). Boca Raton: Taylor & Francis Group.

Clark, K. R., & Vealé, B. L. (2018). Strategies to Enhance Data Collection and Analysis in Qualitative Research. *Radiologic technology*, *89*(5), 482CT-485CT.

Cooper, R. G. (2019). The drivers of success in new-product development. *Industrial Marketing Management*, *76*, 36-47. doi:https://doi.org/10.1016/j.indmarman.2018.07.005

Creese, R. C. (2000). Cost management in lean manufacturing enterprises. *AACE International transactions*, C5A.

Creese, R. C. (2018). *Strategic Cost Fundamentals: for Designers, Engineers, Technologists, Estimators, Project Managers, and Financial Analysts* (1 ed. Vol. 32). San Rafael: Morgan & Claypool Publishers.

Creswell, J. W. (2015). Revisiting Mixed Methods and Advancing Scientific Practices. In S. N. Hesse-Biber & R. B. Johnson (Eds.), *The Oxford Handbook of Multimethod and Mixed Methods Research Inquiry* (pp. 0): Oxford University Press.

Denzer, J. J. (2021). *Examining the Relationship Between Lean Six Sigma Awareness and Quality Improvement Measures.* ProQuest Dissertations Publishing,

Domanski, C. (2020). *Cost Engineering: A Practical Method for Sustainable Profit Generation in Manufacturing*. Milton: CRC Press.

Doody, O., & Bailey, M. E. (2016). Setting a research question, aim and objective. *Nurse researcher, 23*(4).

Doyle, L., Brady, A.-M., & Byrne, G. (2016). An overview of mixed methods research – revisited. *Journal of Research in Nursing, 21*, 623-635. doi:10.1177/1744987116674257

Duquia, R. P., Bastos, J. L., Bonamigo, R. R., González-Chica, D. A., & Martínez-Mesa, J. (2014). Presenting data in tables and charts. *An Bras Dermatol, 89*(2), 280-285. doi:10.1590/abd1806-4841.20143388

Eggers, F. K., S. and Covin, J.G. (2014). Traveling into unexplored territory: radical innovativeness and the role of networking, customers, and technologically turbulent environments. *Industrial Marketing Management, 43*(1385-1393).

Faul, F., Erdfelder, E., Lang, A. & Buchner, A. (2007). GPower 3: A flexible statistical power analysis program for the social, behavioral, and biomedical scienes.

Favi, C., Germani, M., & Mandolini, M. (2016). Design for Manufacturing and Assembly vs. Design to Cost: Toward a Multi-objective Approach for Decision-making Strategies During Conceptual Design of Complex Products. *Procedia CIRP, 50*, 275-280. doi:10.1016/j.procir.2016.04.190

Francisco, M. G., Osiris Canciglieri, J., & Ângelo Márcio Oliveira, S. A. (2020). Design for six sigma integrated product development reference model through systematic review. *International Journal of Lean Six Sigma, 11*(4), 767-795. doi:10.1108/IJLSS-05-2019-0052

Franke, N. K., P. and Klausberger, K. (2013). Does this sound like a fair deal? Antecedents and consequences of fairness expectations in the individual's decision to participate in firm innovation. *Oranization Science, 24*(5), 1495-1516.

Fugard, A., & Potts, H. (2015). Supporting thinking on sample sizes for thematic analyses: a quantitative tool. *International Journal of Social Research Methodology, 18*. doi:10.1080/13645579.2015.1005453

Fugard, A., Potts, H., Atkinson, P., Delamont, S., Cernat, A., Sakshaug, J., & , & Williams, R. (2020). *Thematic analysis*. London: SAGE Publications Ltd.

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a Conceptual Framework for Mixed-Method Evaluation Designs. *Educational Evaluation and Policy Analysis, 11*(3), 255-274. doi:10.3102/01623737011003255

Guarraia, P. C., Gib; Corbett, Allisair; Neuhaus, Klaus. (2008). Lean Six Sigma for the services Industry. *Bain & Company*, 1.

Gupta, S. K., Gunasekaran, A., Antony, J., Gupta, S., Bag, S., & Roubaud, D. (2019). Systematic literature review of project failures: Current trends and scope for future research. *Computers & Industrial Engineering, 127*, 274-285. doi:https://doi.org/10.1016/j.cie.2018.12.002

Hicks, D. T. (2004). Cost Information and Pricing Decisions. Retrieved from https://www.dthicksco.com/whitepaper/Cost%20Information%20and%20Pricing%20Decisions.pdf

Hiller, E. (2019). The evolution of product cost management tools and the state of the ar. *Spend Matters*.

Hollmann, J. K. (2006). Total Cost Management Framework.

Hongbo, W. (2008, 2008). *A Review of Six Sigma Approach: Methodology, Implementation and Future Research*.

Hueber, C., Horejsi, K., & Schledjewski, R. (2016). Review of cost estimation: methods and models for aerospace composite manufacturing. *Advanced manufacturing. Polymer & composites science, 2*(1), 1-13. doi:10.1080/20550340.2016.1154642

Hulley, S. B. (2007). *Designing clinical research*: Lippincott Williams & Wilkins.

Humphreys, K. K., & Müller, M. (1995). *Basic Cost Engineering* (Vol. 25). Boca Raton: Taylor & Francis Group.

Imam, S. T., Ashok; Sarkar, Sudipto. (2012). Lean Sigma- Not just a whim. It is here to Stay. *Global Journal of researches in engineering, 12*(1), 23-28.

Irani, S. A. (2020). *Job Shop Lean: An Industrial Engineering Approach to Implementing Lean in High-Mix Low-Volume Production Systems*. Milton: Taylor and Francis.

Itani, A., Ahmad, R., & Al-Hussein, M. (2019). A Collaborative Scheme for DFX Techniques in Concurrent Engineering Mitigated with Total Design Activity Model. *Modular and Offsite Construction (MOC) Summit Proceedings*, 1-8. doi:10.29173/mocs70

Jones, D., T., & Womack, J., P. (1996). *Lean thinking : banish waste and create wealth in your corporation*.

Kissel, R. (2012). Guidelines for media sanitization: recommendations of the National Institute of Standards and Technology. In (Revision 1, draft. ed.). Gaithersburg, MD: U.S. Dept. of Commerce, National Institute of Standards and Technology.

Kothari, C. R. G., G,. (2019). *Research Methodology: Methods and Techniques*.

Latshaw, C. A., & Cortese-Danile, T. M. (2002). Activity-based costing: usage and pitfalls. *Review of business, 23*(1), 30.

Laureani, A., & Antony, J. (2019). Leadership and Lean Six Sigma: a systematic literature review. *Total quality management & business excellence, 30*(1-2), 53-81. doi:10.1080/14783363.2017.1288565

Lee, M., & Kulvatunyou, B. (2019). *Design-for-Cost – An Approach for Distributed Manufacturing Cost Estimation*, Cham.

Mandelbaum, J., Hermes, A., Parker, D., & Williams, H. (2012). *Value Engineering Synergies with Lean Six Sigma: Combining Methodologies for Enhanced Results* (1 ed.). Milton: Routledge.

Mayo, N. E., Asano, M., & Pamela Barbic, S. (2013). When is a research question not a research question? *Journal of Rehabilitation Medicine, 45*(6), 513-518.

McCallister, E., , Grance, T. & Kent, K. (2010). *Guide to protecting the confidentiality of Personally Identifiable Information (PII) : recommendations of the National Institute of Standards and Technology*. Gaithersburg, MD: U.S. Dept. of Commerce, National Institute of Standards and Technology.

McDermaid, D. (2019). What is design to cost? an overview with examples. *Apriori*.

Moisello Anna, M. (2012). COST MEASUREMENT AND COST MANAGEMENT IN TARGET COSTING. *Analele Universităţii din Oradea. Ştiinţe economice, 1*(1), 533-547.

Munteanu, A. M. C. (2017). Comparative Analysis between Lean, Six Sigma and Lean Six Sigma Concepts. *Management and Economics Review, 2*(1), 78-89.

NASA. (2008). *Cost estimating handbook*. Washington, D.C.

Nelson, R. D. (2004). How Delphi went lean. *Supply chain management review, 8*(8), 32.

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic Analysis: Striving to Meet the Trustworthiness Criteria. *International journal of qualitative methods, 16*(1), 1-13. doi:10.1177/1609406917733847

Ostroukh, A. V., Gusenitsa, D. O., Golubkova, V. B., & Yurchik, P. F. (2014). Integration of PDM and ERP systems within a unified information space of an enterprise. *IOSR Journal of Computer Engineering, 16*(2), 31-33. doi:10.9790/0661-16263133

Patil, A., Paul. (2013). A review of DFSS: methodology, implementation and future research. *International Journal of Innovations in Engineering and Technology, 2*(1), 369-375.

Patten, M. N., M. (2017). *Understanding Research Methods: An Overview of the Essentials* (10th Edition. ed.): Taylor and Francis.

Pepper, M. P. J., & Spedding, T. A. (2010). The evolution of lean Six Sigma. *The International journal of quality & reliability management, 27*(2), 138-155. doi:10.1108/02656711011014276

Roy, R. (2003). Cost engineering: why, what and how? In.

Schenkelberg, F. (2016). What Is Design for Excellence.

Sheridan, J. H. (2000). "Lean Sigma" Synergy. *Industry Week, 249*(17), 81-82.

Shermon, D. (2017). *Systems Cost Engineering: Program Affordability Management and Cost Control*: Taylor and Francis.

Smith, A. E., & Mason, A. K. (1997). COST ESTIMATION PREDICTIVE MODELING: REGRESSION VERSUS NEURAL NETWORK. *The Engineering Economist, 42*(2), 137-161. doi:10.1080/00137919708903174

Snow, J. (2012). *How to Use Qualtrics: Handbook for Research Professionals*: Qualtrics Labs, Inc.

Sreedharan V, R., Sunder M, V., & R, R. (2018). Critical success factors of TQM, Six Sigma, Lean and Lean Six Sigma: a literature review and key findings. *Benchmarking : an international journal, 25*(9), 3479-3504. doi:10.1108/BIJ-08-2017-0223

Stern, T. V. (2019). A Brief History of Lean and Six Sigma. In (1 ed., pp. 7-16): Routledge.

Vasileiou, K., Barnett, J., Thorpe, S., & Young, T. (2018). Characterising and justifying sample size sufficiency in interview-based studies: systematic analysis of qualitative health research over a 15-year period. *BMC Medical Research Methodology, 18,* 148. doi:10.1186/s12874-018-0594-7

Vogt, W. P. (2011). *SAGE quantitative research methods*. Los Angeles, [Calif: SAGE.

Womack, J. (2021). A Brief History of Lean. *Lean Enterprise Institute*.

Yadav, G., & Desai, T. N. (2016). Lean Six Sigma: a categorized review of the literature. *International Journal of Lean Six Sigma, 7*(1), 2-24. doi:10.1108/IJLSS-05-2015-0015

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

Zhran, M. (2021). *Analytical View of System Activity-Based Costing* (1st ed.).