IMPROVING THE OUTCOME OF SIX-SIGMA PROJECTS WITH COST ENGINEERING APPROACHES

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Abstract: The objective of this literature review is to expand upon the research associated with relationship between the use of cost engineering approaches and six-sigma project success when designing or redesigning products in the manufacturing industry. The objectives of this literature review are two-fold. First, is to analyze contextual peer-reviewed literature pertaining to the impact of using cost engineering methods and practitioners in six-sigma projects focused on new or redesigned products. Second, to identify the causes and factors for six-sigma and related methodologies failures focused on product design and redesign. As a result of this literature review this research aims to provide a cursory look at discovering research gaps that could be addressed further.

Key Words: *Six-Sigma, cost engineering, product design.*

1. INTRODUCTION

"Every system is perfectly designed to get the result that it does," this is a quote from W. Edwards Deming describing 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 for less cost. 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. 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 (Albliwi, Antony, & Lim, 2015; Antony, 2011; Imam, 2012). Or they may choose to 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 a business with this model. Most companies will choose to produce products that are high enough in quality to meet the price point for their targeted customer base. As such, clearly there needs to be a method that a company can deploy that addresses the cost of designing and producing a product without sacrificing quality.

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 creates somewhat of a paradox with six-sigma methodologies being very successful in some situations but can have staggeringly high failure rates in most other situations. 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.

2. BACKGROUND

2.1. Lean, Six-Sigma, Lean Six-Sigma, Design for Six-Sigma and Design for Excellence

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 critical 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 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 (Bhaskar, 2020).

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 may be 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 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 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 (Schenkelberg, 2016). 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.

2.2. Project Failure

For the family of six-sigma methods, success factors as well as failure factors are important topics. The top success and failure factors only 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, Lizarelli, & Machado Fernandes, 2020). Both measure and analyze requires commitments from many departmental areas from 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 recruit skilled subject matter experts too often utilize black belts to remedy all problems (Guarraia, 2008). Product cost estimation is clearly not the responsibility for one department. For example, Purchasing will sometimes chase only supplier costs and not communicate with Engineering during early in the design phase. Engineering departments do not understand cost structure and how to optimize cost with cost engineering approaches - they only work on design. Similarly purchasing departments can't recognize cost reduction ideas that won't degrade the design as illustrated in Figure 1 below. Collaboration and utilization of proper skillset is a critical factor for success (Antony & Banuelas, 2002; Sreedharan V, Sunder M, & R, 2018).

Figure 1 Skillset as a Critical Success Factor

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. Two other significant failure factors are lack of complementary skills among project teams as well as having adequately skilled team members. These are two similar but slightly different factors. Selecting team members is a critical step in aligning personnel skills for the project so that the team has the skillsets required perform all the tasks necessary for a successful project. Another critical failure factor is faulty selection of a process improvement methodology and associated tools/techniques (Antony et al., 2020). This is particularly noteworthy from the standpoint that even with all other factors deployed properly; poor tools/techniques may subvert the goals of the project through the acquisition of inaccurate data.

2.3. Cost Engineering

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, demand for military equipment spiked creating shortages in labor, raw materials and parts for military equipment. Engineers and manufacturers quickly realized that original specification parts were not readily available, but equal or better-quality parts could be substituted at lower costs. This realization ushered 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 that 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). Figure 2 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.

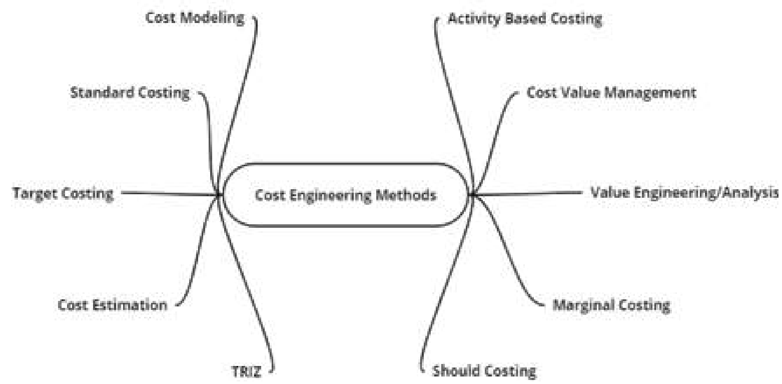

Figure 2 Cost Engineering Methods

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 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). Figure 3 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).

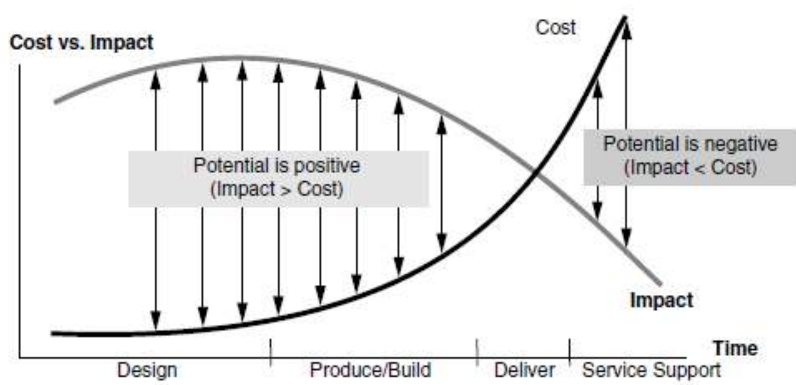

Figure 3 Impact of Cost during Design Product Life cycle. Source: (Yang & El-Haik, 2003)

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:

- Manufacturing labor rates
- Raw materials
- Purchased components
- Floor space cost
- Machine costs
- Reference process times
- Machine setup
- Tooling and fixtures

It is very likely that many of these costs will need to be considered for various regions and countries taking into consideration regulations for each (Domanski, 2020).

2.4. Cost Engineering Practitioners

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 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).

2.5. Product Cost Management Systems

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). 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 methodology.

3. LITERATURE REVIEW

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 applied)
- Data synthesis
- Data coding

Reporting the review:

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

The following was the list of keywords selected:

- Six Sigma

- Design for Six Sigma and DFSS
- Cost Engineering
- Design Cost Methods (2012 – present)
- Six Sigma Project Failure (2012 – present)

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 as shown in Figure 4 below.

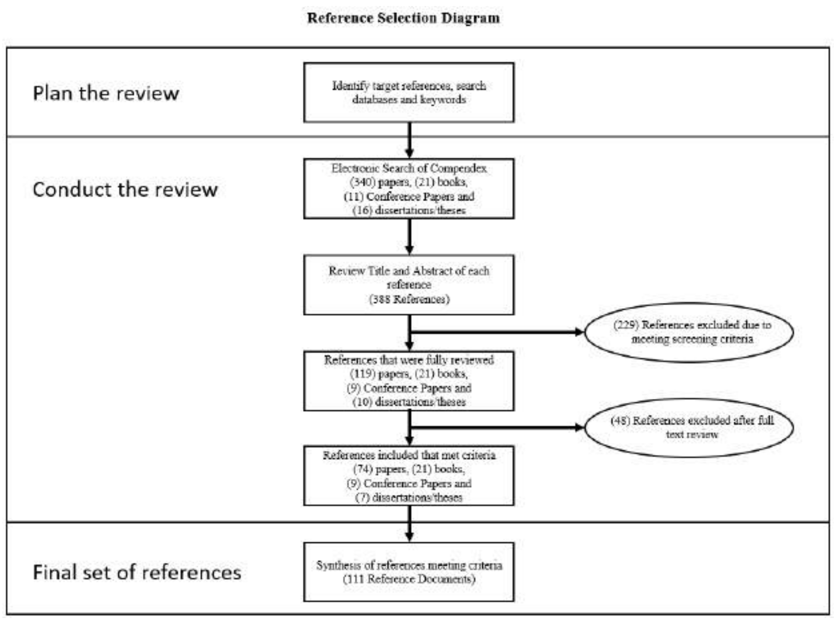

Figure 4 Literature Review Process with Document Count

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 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. 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 (Bhaskar, 2020).

Given this study 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 see Figure 5 below.

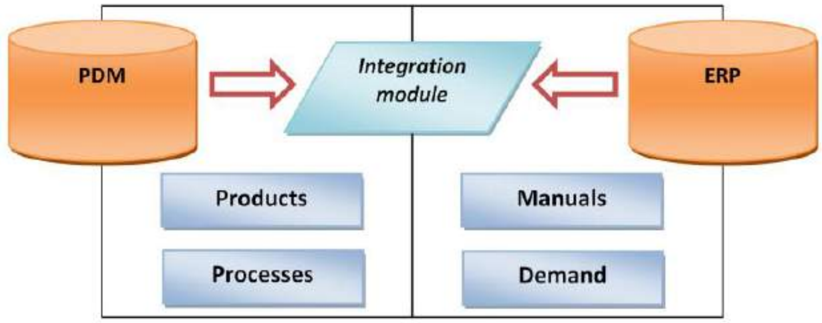

Figure 5 Integration Framework, PDM and ERP. Source: (Ostroukh et al., 2014)

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) (Ostroukh et al., 2014). The first commercial tools specializing in manufacturing cost estimating appeared in the early 1980's. These tools 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).

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).

4. CONCLUSION

Accurate cost estimates can provide a positive impact to the outcome of designed-based projects. The contribution of this literature review is to provide a look at some possible cost engineering approaches that may improve the success rate of six-sigma methodologies-based projects. DFSS and DfX product design projects are cost-oriented with costs emanating from many sources. Cost estimating methods are well documented and utilized in many industries and have clear value with improving estimates. Additionally, the use of a cost practitioner who has been trained, skilled and certified in cost engineering methods and practices can add often-lacking skills needed for developing cost models for quickly evolving designs. The last approach researched for this review is whether the utilization of an integrated Product Cost Management (PCM) system can provide a reliable and quick access to costs associated with the many factors that go into manufacturing new designed parts.

Research is sparse regarding the connection between six-sigma design related methods and cost engineering approaches. This gap provides research opportunities in the areas of building out a new framework for adding cost engineering approaches to six-sigma related methods to reduce the rate of project failures due to cost estimating inaccuracies.

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