ENHANCING ENGINEERING CHANGE MANAGEMENT PROCESSES OF SMALL MANUFACTURING ENTERPRISES (SMEs): A CASE STUDY

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The identification and verification of a reliable approach for manufacturing enhancements is a major topic of study that can be observed in abundant academic research efforts and resulting publications. However, it appears that excessive volumes are focused on a rather limited number of advanced quality and process applications within large companies. While implementation of such sophisticated methods will undoubtedly prove beneficial in many process improvement and quality control efforts, any favorable results from these tools will be impeded without a robust engineering change management (ECM) system. Additionally, most research conducted on large businesses does not consider the unique aspects or idiosyncrasies present within a typical Small Manufacturing Enterprise (SME). The objective of this study is to employ simple steps for identifying areas within the engineering change (EC) processes of an SME which are likely contributing to issues in production. The primary purpose is to use the information collected to validate a basic approach in support of ECM enhancements for existing processes. By employing simple methods of random sampling, the author gathers documentation on order packages, and analyzes those using straightforward tools that should be easy to comprehend. These steps encompass the identification of failings associated with poor ECM and estimates of their possible financial impact. Additional steps include a series of inquiries devised to identify possible root causes to roadblocks impeding production. The findings highlight areas that are contributing to waste, due to failings inherent in poorly developed ECM processes. These deficiencies do lead to financial shortcomings commonly detrimental to an SME with limited access to resources.

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With the data collected and findings reviewed, a series of guiding steps are developed to help in developing an ECM system that can be applied by those associates typically found working at an SME. By examining representative procedures within the selected SME shortcomings are identified that are principally linked to the current ECM processes in place. From the data collected the researcher generates estimates of the financial impact in support of developing basic ECM protocols for the SME, and potentially others. Across this study the author highlights step to alleviate many negative aspects of EC which often plague smaller manufacturing enterprises. It is clear to this researcher that without the advantage of a solid ECM system the hurdles faced by the average SME, due to poorly communicated EC, will persist. At the conclusion of the paper, one should be able to understand the value of solid ECM in small manufacturing enterprises and will hold a simple guide for one basic approach to developing or improving ECM processes in future SME endeavors.

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Chapter 1 - Introduction

1.1 Background – Manufacturing:

When one considers the many tasks implicated in manufacturing, they may frequently find themselves including several facets which do not appear to directly involve the manufacturing process itself, but these aspects are nonetheless required for a viable business to produce quality usable products at reasonable costs. Costs of course being a major driver in both the decision to purchase on the part of the customer, and any profits realized on the part of the business. For those even slightly familiar with the basic processes of manufacturing, it should be clear that there are many considerations that go into determining the final cost of a product, among those most generally considered are labor, materials, manufacturing processes, and expected volume (Eggert, 2010). There are likewise a variety of procedures which a business might employ when a product is manufactured. Generally, most manufacturing endeavors will need to incorporate some forms of engineering, purchasing, fabrication, assembly, warehousing, and distribution (Eggert, 2010). Consideration could also be given to different phases of an item's lifecycle, depending upon the distinctive characteristics of the product. Product lifecycles are said to progress much like that of a human life, and the time involved in each phase of their lives varies depending on the nature of the product (Newnan, Lavelle & Eschenbach, 2014). Clearly the aspects of a lifecycle can be influenced by numerous differences found in the designed form, fit, and function of the product. Product lifecycles can often be further compounded by any dissimilar needs of the customer, the expectations of the customer, the manufacture's abilities, and the simple nature of humankind to change. As you may be aware, change is all around us and this has apparently always been the case. So much so that one is readily able to find instances of the ancient Greek philosopher Heraclitus credited with proclaiming, "change is the only constant in life" through a simple Internet search (Heraclitus, n.d.). This inexorable proclivity for change creates requirements which are quite important to the different departments within most manufacturing organizations; a need to understand what should change, why it should change, when it should change, what is affected by that change, as well as who should be responsible for the various stages of the change process. In a nutshell, it creates a need for engineering change management.

1.2 Background – Change Management:

Change Management is a vital tool for modern manufacturing companies which should never be underestimated or ignored. The fact is, any product which one considers, looks at, or uses, has more than likely gone through several changes before it makes its way to the end consumer. Likewise, it will probably go through additional changes before its manufacturer(s) decide to cease production. These are simple, and largely undisputed, facts that almost everyone should be able to comprehend. Because change happens, companies have a need to manage that change. Subsequently, there are several steps involved in a robust engineering change management system which should be clearly identified, studiously maintained, and understood by all the pertinent stakeholders within the organization. Some of the basic steps to consider incorporating whenever one is setting up a engineering change process involve, who identifies the potential need for a change, how to identify the potential need for a change, how to convey that potential need, how to evaluate that potential need (including its total impact), what the processes are for acceptance or denial of that prospective need, how to communicate that a need is present (if approved), and how/when to implement that potential need. In addition to the steps already mentioned, there are other aspects which should be considered in a change management system including, different options for dispensation of exiting items impacted by any engineering changes, and how items already in the field might need to be addressed because of any changes.

Clearly, engineering change can be a far-reaching process which needs to be managed so that everyone involved in the manufacturing process can be successful at providing their direct customer, and/or the end customer, with the right product at the right time.

1.3 Purpose of the Research:

The primary purpose of this research is to identify potential areas where the subject manufacturing organization has failed to sufficiently recognize the impact of not developing and implementing a viable approach to engineering change management. By focusing on those distinguishable shortcomings, the resulting paper considers sources of potential waste and poor quality that might otherwise go unnoticed. It is the view of the author that an identifiable amount of quality issues within SME's is likely occurring because of the approach those companies take regarding inevitable engineering changes. After a thorough examination of the existing change processes the researcher identifies how the overall progression of product and information are impacted. From there an uncomplicated scheme is advanced which includes developing foundational questions and guidelines for building a robust engineering change management system which would be advantageous for this SME, as well as others.

1.4 Objective of the Research:

The primary purpose of the research is to develop a simplified and understandable approach to establishing an Engineering Change Management program which, in the author's view, is critical for the long-term success of most manufacturing endeavors found in our modern global business environment. The study encompasses the relationships between engineering, purchasing, fabrication, assembly, warehousing, and distribution in their role of ensuring maximum profitability of the organization which is based within the North American manufacturing industry. At the conclusion of the research, the author presents valuable information, that is applied to develop a base series of questions and simple steps. These should aid any small manufacturing enterprise in working out a simple engineering change management system for their own benefit. The specific objectives of the research are as follows:

- Identify areas for potential deficiency in the subject SME's overall engineering change process.
- Identify where shortcomings in the process may contribute to waste.
    - Time
    - Material
    - Money
- Estimate the potential value for improving those existing methods through a robust change management process.
- Develop a basic series of questions to address change management guidelines which can be applied by SME's for employing a streamlined ECM system.

1.5 Significance of the Research:

While there have been many studies that consider different approaches to quality and processes in manufacturing environments, they seem to have been largely focused on specific aspects of advanced methodologies like statistical process control, Six Sigma, total quality management, the cost of poor quality, or the many barriers which exist when implementing those quality control processes. It further seems that even for studies which do address engineering change issues in manufacturing, the majority appear to be focused on processes within larger organizations. By concentrating on large enterprises, those papers generally ignore the unique circumstances found within the numerous SME's that contribute so much to American productivity. After working many years at several different SME's, and personally witnessing the negative impact of inadequate engineering change management processes, it has become clear to the author that new research needs to be focused on that very underappreciated aspect of quality manufacturing within smaller enterprises.

The idea that ECM procedures are often overlooked in academia and are generally lacking from many SME's business practices grew from those years of professional experience, and that idea has been reinforced over an academic career exploring a good amount of the available literature on manufacturing processes and quality. Time and again it has been observed that proper consideration of ECM is dubiously absent from processes which are otherwise geared at safeguarding products in manufacturing and business. When the prevailing approach in research is largely focused on more advanced aspects of statistics, total quality management, and the application of advanced tools within larger business environments, many facets of manufacturing in America are left unexplored. The void created is generally comprised of smaller manufacture's, which according to The National Association of Manufacturers (NAM) website, most manufactures in the US are SME's (NAM, 2019). In fact, the numbers presented are quite telling. We learn on the site that the U.S. Census Bureau, Statistics of U.S. Businesses, identifies nearly 250,000 manufacturing companies in America, and of those only about 4,000 have greater than 500 employees (NAM, 2019). On top of the fact that most manufacturers appear to fall under the SME umbrella, we find in a September 2017 monthly labor review from the U.S. Bureau of Labor Statistics, that the most common levels of education required for entry into positions with smaller companies are a high school diploma at 36% and no formal educational credentials at 28% (Watson, 2017). It therefore does not seem unreasonable that one might deduce that many of the associates employed within SME's probably do not have much formal education beyond a high school diploma.

Yet another interesting aspect, which can be found in much of the existing papers, involves an amount of ambiguity in what will be discussed in the text. While it may ostensibly seem easy to locate research literature which will cover engineering change management, that is often not the case. In the experience of this researcher, many studies which at first appear to include engineering change have tended to largely focus on other approaches to improving processes, and quality while leaving change, at best, as a side note within the overall research effort. One study for example, which before review was hoped might include a solid look at engineering changes, because Product Lifecyle Management (PLM) is prominently mentioned in the title, it turns out does not cover engineering change to any substantial degree. In fact, the only mention of engineering change comes in the following sentence: “Commonly cited quality measures include measures of conformance to product design, such as the number of engineering change orders per work package and the number of development orders started and completed versus planed” (Hines, Francis & Found, 2006). As an experienced design engineer, and someone who does place a great deal of importance on properly identifying the root causes of poor quality, the idea of considering Product Lifecycle Management without adequately touching on engineering change management is perplexing, to say the least. Another example was found in a journal focused on “Making the ‘MOST’ out of RFID technology”, which stands for Radio Frequency Identification technology. From that paper one learns that RFID technology can improve the level and amount of data accessible for any items which can be physically tagged, and subsequently scanned (Curtin, Kauffman, Riggins, 2007). Still, there is only one paragraph found in the paper that makes mention that products can “change states over time” (Curtin et al., 2007). While these are but a couple of examples, they do demonstrate how the engineering change process itself is sometimes overlooked, or at least under considered, in much of the research related to manufacturing processes and quality. The researchers of those papers cannot be held at fault though, as they were probably not presented information on the full impact of change management during their respective academic careers. Even the author, behind the paper in-hand, has only seen very brief introductions to engineering change processes throughout a multitude of rather extensive academic forays within the fields of engineering and technology. It is recognized that such widespread academic shortsightedness could be a result of many contributing factors. Perhaps the existence of consensus standards organizations has led some in academia to believe effective change management will be covered elsewhere during one's professional career, or perhaps it is believed such things are covered in the more advanced course work of one's academic career. It could be a fallacy attributable to "common sense" which is the culprit; after all, does it not seem logical that changes in designs should be tracked and managed? Unfortunately, a belief that there is some common knowledge, or an understanding of the importance of something does not necessarily make it so. Attempting to identify a plausible cause for such a lack of consideration may be a good subject for further research, but that is beyond the scope of this paper.

For the present research project, its significance lies in being focused on a considerably underappreciated aspect of quality in small manufacturing enterprises. The author has found Engineering Change Management within SME's to be subjects that are too often overlooked in research and academia, and this study was created to emphasize just how vital ECM should be to any SME. The points identified herein are ultimately crucial for organizations striving to achieve consistent communication between different departments needed for manufacturing their products. By considering important processes that, all too often, are tacit within many small organizations, the author shines light on a powerful set of tools geared at improving communication, reducing waste, and enhancing quality for the various departments which are generally found within many small organizations.

1.6 Organization of the Research:

The thesis is organized in chapters, which are laid out to provide adequate insight to the processes undertaken in completing the various steps of the project. Those chapters are as follows: Chapter 1 contains a brief look at the problem within manufacturing and provides some background into change management. That chapter also includes brief sections on the research purpose, the research objective, and the significance of the research. Chapter 1 is wrapped up by including a section on the organization of the thesis. Chapter 2 contains an examination of existing peer-reviewed literature on various topics which contribute to the subject of quality and engineering change management. Within that chapter, some limitations are identified in the writings mentioned earlier, and the notions behind this thesis are expounded further. Chapter 3 offers a case study of the selected small manufacturing enterprise, which includes information collected from various departments within the organization regarding the impact of their existing processes. Chapter 4 presents a base template for ideas and questions which could be used by any SME in the development of a robust engineering change management process. The thesis is wrapped up in chapter 5 where a conclusion is presented, along with some discussion on the limitations of this research and some different ideas for future research.

Chapter 2 - Literature Review

The purpose of this section is to identify some general steps, found through searching trustworthy sources, which can be useful in helping an SME recognize their need for a simplified engineering change management system. In completing that aim, the researcher discerns the areas of an existing engineering change process, within one small manufacturing enterprise, which are likely impacting the different stakeholders of production, as well as different facets of product quality. It has been surmised that much of the available literature on quality fails to adequately consider the special ways a poorly executed ECM system might adversely affect separate processes found in SME's, including engineering, purchasing, fabrication, assembly, warehousing, and distribution to list a few. Despite any disproportion found in available literature, it is believed that a viable selection of research can still be identified which would prove useful in considering aspects of quality as they relate to ECM systems at SME's. Simply put, the fact that a study was designed to consider a different tool, or was focused on activities within larger enterprises, is no indication that the information found therein will not be beneficial for a study focusing on other attributes. By reviewing a relatively diverse assortment of literature, we should be able to identify useful information about standard approaches to quality and relate different facets to an ECM process applicable for SME's. With that premise in mind, the process of probing various depositories, accessible through university libraries, or Google Scholar, for literature which might be useful to this study commences.

Several peer-reviewed journals were identified as possibly including different facets of engineering change as it relates to quality. While many of those papers ostensibly appeared to cover some aspects of engineering change within their text, it can generally be found they are usually focused on the more familiar areas of quality and quality control, and often only gloss over the topic of engineering change. For this writer, these findings are not surprising, but they might leave one wondering why so many have opted to center their own research on the classic quality tools, while only rarely considering other factors which could clearly impact manufacturing processes and quality. That might be another good point of research for a future study, but it is not considered within the text of this paper. Moving forward the researcher takes a closer look at different approaches, and the correlating opinions, on various process and quality tools within manufacturing.

The writer finds there usually are no shortages of opinions about what approach will best contribute to good manufacturing processes and product quality, and some quality sponsors even foster convoluted ideas while struggling for quality enhancements. It probably doesn't help that the definition of quality could seem ambiguous to less informed individuals; one technical definition found in a book by Donna Summers, defines quality as "the characteristics of a product or service that bear on its ability to satisfy stated or implied needs" (Summers, 2018); While another, more modern, definition can be found in a book by Douglas C. Montgomery which identifies quality as "inversely proportional to variability" (Montgomery, 2013). Still, there is nothing in most definitions which should preclude one from considering non-typical ideas that can influence product quality in manufacturing enterprises. Apparently, that observation has no impact on the fact that there does not appear to be an abundance of literature focusing on approaches outside of those standard areas of process and quality control. Of course, that does not mean we cannot find good information within a piece written on those standard aspects, but one may need to look closely at passages which at first only seem incidental to the overall object of the writing.

The instigation of this phase sees the author searching for keywords, such as engineering change management, and quality, among the many peer-reviewed journals available. As a result, several plausible papers are identified which indicated they might include aspects of interest regarding the goals of this research. Ultimately the results yield several studies which contain analogous approaches within the domains of processes and quality. Due to the similarities among the selected literature, the reviews in this chapter will be grouped based on the larger subject covered in the writings. The first section is comprised of conventional approaches to quality, such as Six Sigma and continuous improvement. The second section reviews the literature encompassing topics related to the more modern tools of Product Data Management (PDM) and Product Lifecycle Management (PLM). The third section focuses on aspects of engineering change found in peer-reviewed literature. The fourth section looks at some of the more common traits of the different approaches to identified problems and solutions. The final section of the literature review portion is a brief overview of the information covered along with some initial thoughts on the overall results of the literature search, and selection process.

2.1 Conventional Approach to Quality:

There are three (3) peer-reviewed journals selected that focus on more of a conventional approach to quality. The conventional approach includes those areas previously mentioned, such as Statistical Process Control (SPC), Six Sigma, and Continuous Improvement. The results of the author’s review on those pieces are covered in the next section.

2.1.1 Conventional Approach - Six Sigma:

Some of the more prevalent themes regarding optimization in product quality seems to revolve around statistical process control and the Six Sigma methodology. The idea of Six Sigma has really taken hold in business, as we can read in one paper about how that approach is getting increasingly adopted by more manufactures across the planet (Anand, Shukla, Ghorpade, Tiwari & Shankar, 2007). In their model, these authors explore the Design, Measure, Analyze, Improve, and Control methodology (DMAIC) of Six Sigma. While the steps of a DMAIC approach can be beneficial when concentrating on process capability, they do not possess a strong practical advantage without the beneficial properties of some form of ECM process being implemented. Clearly the Improve and Control phases of a DMAIC should necessitate the development of change management at some point. Even though they do not go into details about managing the inevitable changes introduced through a DMAIC, these authors do highlight some important aspects of quality which obviously correlate to robust engineering change management systems. In their conclusion they point out that markets are becoming more quality-conscious, and industries need to adopt techniques for maintaining satisfied customers and lower costs (Anand, et. al., 2007). The information found within the Anand research, like a great many studies, was largely concentrated on tools covered in the typical university program’s process/quality-oriented course work. Unfortunately, any aspects gleaned from it for use in ECM systems are limited in their application.

In some instances, when a paper ventures outside the normal realms of quality, it still seems the researchers do not tend to go too far from those established methods. One paper, which contends variation management through good tolerance is central to manufacturing, references revisioning but it does not delve into any substantial aspects of engineering change or the ideology of version control (Krogstie & Martinsen, 2013). While it is interesting that Krogstie and Martinsen make mention of a drawing revision process, they completely skip the opportunity to provide real details as to what those processes might entail, or how they can impact the steps discussed in their study. Despite the initial impression their research would implicate the revising of engineering drawings; the overall gist of the work mainly focusses on different aspects of Six Sigma and SPC. The paper does point out that there is a scarcity of academic literature available covering engineering tolerances, another non-standard aspect of quality, but the main execution of the research still seems to be dependent on classic quality tools (Krogstie & Martinsen, 2013). These authors conclude with a brief mention of change on product performance and functional behavior; stating that the impact of change "cannot always be quantified" (Krogstie & Martinsen, 2013). But again, the final passages of the conclusion fall back into those standard areas of quality, and the overall message seems to be focused on process capabilities through Lean and Six Sigma methodologies (Krogstie & Martinsen, 2013). While both are admittedly quite valuable to good process and quality programs, the paper may have been better served had the writers included more on change and drawing revisioning processes as well. Upon reading the study, one could be left wondering why the drawing revision process was introduced at all.

2.1.2 Conventional Approach - Continuous Improvement:

Another often-seen concept when one investigates different aspects of quality and process improvements within manufacturing is the technique of continuous improvement, also referred to as the lean approach. Upon reading one 2019 study, it was found this approach involves a systematic means of describing processes using one or another method of visualization, like a flow-chart (Akhtulov, Ivanova & Charushina, 2019). In lean, the flow-charts are called value streams and are a set of all actions in the production of goods or services (Akhtulov, et. al., 2019). The processes of lean are not dissimilar to those of ECM, in that each step in the flow passed through important stages of management (Akhtulov, et. al., 2019). There could be reason to suggest the visual approach in lean might also be applicable to ECM systems, especially within the typical SME environment. Utilizing a visual map, so to speak, to describe the different steps within a change process could seem like a natural fit to proponents of ECM. It only makes sense that such a practice could be beneficial where a workforce may be comprised largely of blue-collar positions. Afterall, simple to understand visual maps posted in strategic locations are already quite prevalent in American manufacturing environments, just consider the requisite OSHA posters that virtually every HR department has hanging all over company breakrooms. It seems a similar tactic could surely be implemented to spread the word regarding the company's engineering change processes. While that 2019 paper did a good job of laying out the purpose, along with some of the benefits and methods utilized in continuous improvement, it stopped short of venturing outside of standard quality methodologies extensively covered in many other writings. So, we have a paper that presents ideas which could likely prove beneficial if properly applied outside of the studies focus, and we should take note of those steps and consider areas where they might be implemented when developing our engineering change management system.

Keeping with the Lean approach to quality, which as we have seen in the paragraph above, has aspects that could prove promising if applied to ECM. A study completed in 2016 was selected for review in which the authors proport to work at connecting Lean Product Development with the Engineering change process (Lodgaard, Ringen, Larsson, 2016). The approach taken might provide some validation of the notions that instigated the study in-hand, as those researchers declare "[e]ngineering change… has a major impact on the overall success of companies due to aspects of quality, productivity, time-to-market, customer value, and profitability" (Lodgaard, et. al., 2016). We further learn about conventional approaches to product design (PD), which hold that specifications on products are to be frozen as early as possible in the design process, and we read such an approach often leads to multiple iterations later in the development/manufacturing process (Lodgaard, et. al., 2016). Though the authors methods are focused on a “medium sized subsidiary of a larger multinational company”, and not on an SME, many useful findings could nonetheless be applied to smaller entities, if only within some scaled-down approach (Lodgaard, et. al., 2016). Ultimately, the article is concentrated on the front-loading approach to product development and how that process can enable, or disable, the existing engineering change management within the company modeled (Lodgaard, et. al., 2016). The Lodgaard paper provides good insight for consideration, but it is clear the organization and processes in the author’s model probably does not fit in with the knowledge base of most SME’s.

In addition to the modern tools discussed in the introduction section of the current paper, there are newer tools identified in some literature, that is included in the review phase, which are quite thought-provoking for this author. In those papers the researcher recognizes familiarities to several experiences had throughout a career in the fields of engineering and manufacturing. Some of the papers were largely dedicated to more modern software tools, which can sometimes unwittingly become associated with conventional manufacturing quality goals in SME’s. One of the more prevalent modern tools which the author had experience with is called Product Data Management (PDM) and/or Product Lifecycle Management (PLM). The following section considers some of the literature identified which focuses on those modern tools in manufacturing environments.

2.2 Modern Tools – Product Lifecycle Management:

It has been observed that there are research papers published which attempt to link aspects of conventional quality approaches to more modern tools as well as computer applications. The 2006 paper by Peter Hines, Mark Francis, and Pauline Found, which was introduced earlier, focuses on frameworks for guiding research within new product development, is one such paper (Hines, Francis, Pauline, 2006). The authors claim their study is a precursor to carrying out the lean procedures within product lifecycle management (PLM) (Hines, Francis, Pauline, 2006). In reading this work, we find the authors of the paper feel existing technical PD literature has several gaps and weaknesses, and much of it tends to get dictated by approaches geared at marketing or quality/engineering (Hines, Francis, Pauline, 2006). They further go on to state that literature is overwhelmed by a lack of focus on real-world applications which, the authors declare, generally involve high volume and medium to low innovation products being created at the same time (Hines, Francis, Pauline, 2006). Among the development problems highlighted in the paper are an apparent lack of process standards, the existence of ineffective controls, a preponderance of poor communication, and an overall lack of shared devotion to success among teammates (Hines, Francis, Pauline, 2006). It is the opinion of this researcher that all these aspects should be considered when ECM systems are developed. The issues covered by the research of Hines, Francis, and Pauline, make it clear that there are aspects which could be beneficial in ECM's if they are given proper attention in the design of such a system.

The next journal review for this study is titled "Product Lifecycle Management as Data Repository for Manufacturing Problem Solving" and was developed by Alvaro Camarillo, José Ríos, and Klaus-Dieter Althoff and published in 2018. The authors identify manufacturing failures as events wherein some part of the system does not perform according to specifications, and these failings can occur within identifiable manufacturing situations (Camarillo, Ríos, Althoff, 2018). In their attempt to address such failings, the researchers consider different protocols for PLM programs, which could serve as repositories for part data collection and management. We learn from the writing, that there are currently no sufficient models for effectively collecting and managing all the pertinent data which accumulates along a products lifecycle (Camarillo, Ríos, Althoff, 2018). Of course, as we have touched on, the data which would tend to change throughout the lifecycle of a product is largely tied to engineering change. With a proclamation like the one just identified from these authors; one could argue there can be no sufficient models for PLM's if there is not a robust ECM system in place. As Camarillo, Ríos, and Althoff point out; any approach needs integrated management for product-related data which requires full standardization (Camarillo, Ríos, Althoff, 2018). From that study, it seems clear the presence of modern tools, like a PLM program, could contribute to better access to information and ultimately better products. However, we see that without a solid foundation for product data, developed from a robust ECM system, there could still be important information missing which might hinder the various contributors to the product, and ultimately impact product quality.

The literature review phase has been helpful at highlighting how different facets of conventional quality and process improvement can also relate to Engineering Change Management. In considering some modern tools of manufacturing which might cross-over and be applicable to an ECM system we learn more about possible benefits of including different tools in an ECM development procedure. Through persistent searches one can find papers that do seem to look more specifically at engineering change, which might provide additional perspectives regarding implementation of practical ECM systems for ECM's. The following section considers literature which was more engineering change oriented.

2.3 Change Management:

As we see in the text above, by continuing to conduct searches with relevant depositories, like University libraries or Google Scholar, researchers can locate studies which could touch on different usable approaches to a given topic. In conducting searches for phrases like revision control and drawing revisions, as well as engineering change, papers that appear to deal with some of the aspects of engineering change processes can be identified. It turns out, in this instance, many papers can be found. This researcher studiously keeps in mind that many of the results may or may not be completely suitable for the topic of this study. As with the earlier search results, it seems some papers only touch on pertinent subject matter very slightly, and one always needs to parse out areas which may be applicable to their end goal while maintaining objectivity regarding all viewpoints encountered. Consider one 2012 paper, which was written on managing engineering changes, and concentrated its efforts on complex new product development processes (Li & Moon, 2012). These authors also identify engineering change management as a topic that is often overlooked in academic research (Li & Moon, 2012). Though the subjects may appear to be similar, the research of Li and Moon seems to be more constrained and would tend to require more understanding of advanced tools than does the approach of the present study. In their approach, they limit engineering change to include Emergent EC; 'caused by problems across the whole design', and Initiated EC; 'caused from outside sources' (Li & Moon, 2012). The authors further build a model which involves a complex statistical analysis of those two types of change in determining how to address each of those components within an engineering change management process (Li & Moon, 2012). While this author, in approaching the research in-hand, is focused on identifying tactics for engineering change management development which might be more usable for the average layperson employed at SME's. The methods suggested by Li and Moon could almost certainly be useful for larger corporations with substantial resources and capabilities, but it is likely that their approaches lie well outside of the comfort of most SME's workforces. Even their results and conclusions are not likely to be understood by the average associate employed in smaller manufacturing outfits, if they possess a high school education or less. In addition to that, the paper does not address change management from a systematic standpoint, and it offers little practical guidance for anyone looking for assistance in developing a viable and simplified approach to handling engineering changes.

So, as we see, even though it is possible to locate research journals that cover engineering change management, simply finding something that looks promising does not always mean it approaches the problem adequately for the average SME. One 2016 paper by Alexander Stekolschik, entitled “Engineering Change Management Method Framework in Mechanical Engineering”, is another good example of such a situation. While the overall gist of Stekolschik’s research might be in line with the ideas behind the paper in-hand, there are important differences which should be apparent. In his work Stekolschik does offer some insight on important considerations which should be involved in change, like “engineering process type and change classification”, but he appears to focus most of his efforts on conditions found in large organizations with substantial resources, much like the Li and Moon paper (Stekolschik, 2016). To illustrate that observation, consider that in his model “[t]he developed change framework has been implemented at a German mechanical engineering company with 10,000 employees” (Stekolschik, 2016). Still, there is valuable information to be gleaned from reviewing the work, such as when Stekolschik points out that “changes have an impact on many different processes found both inside and outside the company, which result in most errors and time related costs” (Stekolschik, 2016). In the final passages of his paper the author identifies some of the tools utilized in his model and he indicates the use of special system-based process workflows which coincide with those tools. Though the use of such tools, in this case “Engineering Systems NX (for CAD modeling), Teamcenter (PDM), and SAP (ERP)”, can be generally beneficial, they are likely to be cost prohibitive for smaller organizations. As such, it seems that a simpler approach may be better when considering a basic change management system for an SME.

In the process of tracking down documents, which might emphasize ideas regarding engineering change management, one is sometimes introduced to new sources of information. One such location, which to some may seem an obvious choice for such a topic, is the National Institute of Standards and Technology. The document located was a 2013 publication through The United States Department of Commerce which is titled "Engineering Change Management Concepts for Systems Modeling" (Bock, Feeney, 2013). Based on the source, and the title of the document, there was considerable promise that a review could yield viable information on additional aspects of engineering change management systems. Those hopes were quickly dashed as the first paragraph touches on the demands associated with system models, modeling languages, and systems modeling language (Bock, Feeney, 2013). Still, one needs to review such works to ascertain the existence of any usefulness towards the end goal. In this case it was determined that the tools highlighted in that paper for addressing engineering changes were again probably too complex for basic SME applications. By focusing on modeling content and language development, utilizing the language of SysML/UML, the Bock and Feeney approach inherently creates a need for more knowledgeable associates (Bock, Feeney, 2013). The paper does present a good amount of information on engineering change, and anyone who chooses to read it would surely find it to be quite informative. Like was found in other journals, the overall approach considered by these authors is probably better suited for larger organizations, or possibly a well-funded SME made up of more advanced associates. For smaller companies, which are cost conscience and may only have an employee base with moderate levels of knowledge or education, the complexity of that study's approach could prove to be overwhelming.

Another noteworthy matter with respect to engineering change has to do with total impact of the change. That is, would completing the change cause other items in the design to require additional change? This topic is approached in a 2012 study called “A method to assess the effects of engineering change propagation”. The authors of that paper considered methods for predicting and managing unwanted propagation of engineering change (EC) in complex designs (Koh, Caldwell, Clarkson, 2012). In their research, these contributors focused on the processes within a larger organization that produces parts for the aerospace industry. Such consideration, on a large manufacturing company that produces items that are probably of considerable complexity, are undoubtedly not ideal for applications inside SME’s. Additionally, the means employed by Koh, Caldwell, and Clarkson relied on a matric-based approach to the House of Quality (HoQ), which would generally require some form of training for a proper application (Koh, Caldwell, Clarkson, 2012). The conclusions of their work appear to be sound, as these tools can clearly prove beneficial for effective engineering change management. Also, there are certainly helpful notions identified in their evaluation of the total impact of change, that could be considered valid contributors to a smaller organization’s success. However, it seems that their approach could also be overkill for a more simplified process, and a less advanced workforce, like many which can be found in SME’s. It seems these authors touched on that shortcoming within their conclusion, as they did point out that further research might be called for in “extending the technique to address a wider range of application areas” (Koh, Caldwell, Clarkson, 2012).

Possibly one of the more relevant papers identified was published in 2016, completed by a researcher named Karthik; it focused on reviewing engineering change in product design and included the related area of configuration management (Karthik, 2016). According to the research, engineering changes are common in product development, often due to the desire for continual improvements in systems and products, and they account for 70 to 80% of the products final costs (Karthik, 2016). Of course, those 70 to 80% figures appear to assume there is a suitable change management system in place, though such an admission was not identified in the writing. Karthik covers change management and configurations management well and provides good insight to the many aspects of engineering change. Some of the information provided certainly could be applicable to the operations generally found within SME's. However, the Karthik paper, as useful as it may be, ventures into areas which could confound many people employed at smaller manufacturing entities. By including concepts like complex (Integral) product architecture, modular product architecture, change propagation, and advanced methodologies of Product Lifecycle Management (PLM) systems, and System Modelling & Language support for ECM, the paper again appears to be more viable for larger corporations with a workforce knowledgeable in such topics, or at least for a company with the resources and mindset for proper training of their associates (Karthik, 2016). It seems even ostensibly relevant papers sometimes present more advanced tools and models for addressing engineering change management processes than would be applicable within an SME.

After reviewing several different journals which proport to cover diverse areas of quality in manufacturing, one might conclude that there are identifiable parallels in the basic facets of the conventional approaches to quality. Some of the resemblances are rather obvious while others are more elusive. The next section will look at some of the similarities identified that this author believes could prove to be applicable.

2.4 Observations – Similarities:

The researcher noticed that there seem to be some jointly shared aspects present in the different journals considered for the discussion above. Upon cursory review of several sources, commonalities do not appear to occur in an insignificant number of instances, though to truly evaluate such an observation would be outside the scope of this study. Learning of the apparent presence of reoccurring concepts within the different approaches to quality might lead one to ask the same questions that came to this author's mind; Shouldn't some of those same components of quality be applicable to an approach akin to engineering change management? If so, is that indicative of a connection worth exploring, if even a tenuous one, between some of the aspects of quality and engineering change management? In some instances, the answer to those questions may be in the affirmative, and in others possibly not. Either way, this author is determined to touch on a few similarities that could possibly lead to influential results regarding the objectives of the present undertaking.

In addition to the points identified in the reviews, there are studies that go into the areas of change management from slightly different perspectives. One of those is in a series of papers by John Parnaby and Denis R. Towill. Published in 2009, their research approach is on the influencers of concepts within manufacturing systems, and it extends into the evolution of management methodologies in business (Parnaby, Towill, 2009). While those management systems considered are mostly related to a different type of change, that of changes to processes, they still touched on a key factor which can be identified in many other writings. These authors point out that the attitude towards industrial learning within organizations needs to be highly active, and entrenched in change management, if the initiative is to be truly realized (Parnaby, Towill, 2009). They further stress the importance of promoting competence with internal experiences and the ownership of learning in the organization (Parnaby, Towill, 2009). Clearly, the inclusion of these ideas, in any type of change management initiative, contribute highly to the success of that program. However, it does not appear likely that SME's will be as quick to take this approach as larger organizations if the learning curve is perceived to be beyond their associates present abilities. As we discovered in chapter 1.5, Significance of the Research, Small Manufacturing Enterprises tend to not require higher levels of education for many of the positions found therein (Watson, 2017). In the experience of this researcher, such hiring practices often contribute to diminished appreciation of front-line associates, and lack of consideration from management whenever possible issues need to be addressed. This is unfortunate, as it can be imperative to afford front-line workers the opportunity to take ownership of any processes in which they engage, and that includes contributing ideas when problem solving steps are undertaken.

Though it may not be completely obvious when considering various approaches to improving manufacturing endeavors, one aspect of the different methodologies that does always seem to be underlying the main thoughts presented is the concept of standards. For some it may seem too apparent to include in their discussion, but without a proper appreciation for setting appropriate guidelines there is a genuine risk of seeing any initiative fail. The existence of such risk may not always translate clearly in every researcher's publication, it is nevertheless regularly distinguishable if one is studiously looking for it. There are papers that make the value of developing rules perfectly understood though, as we can read in the 2016 study "Intelligent approaches for an organization's management system change", by Kristina Zgodavova, Matus Kisela and Andrea Sutoova. These researchers are quite clear in submitting "it is impossible to work without agreeing to and following standards", and they point out guidelines that contribute to achieving desirable "productivity, time-to-market, customer value, and profitability" (Zgodavova, Kisela, Sutoova, 2016). While this author does agree with their premise regarding the presence of any guidelines being crucial for an organization's overall performance, from personal experience, the development of departmental standards should include contributions from the responsible front-line associates if they are to be accepted and effectively implemented. In addition to these views, their paper further highlights the fact that established standards "… also serve a purpose for those who already know what to do but want to make sure that they are doing it correctly or even better than prescribed by the standards" (Zgodavova, Kisela, Sutoova, 2016). The fact is, no matter which means the different researchers contemplate there is an element of standardization which must be adopted if the tactics considered are hoped to succeed. That notion applies to most any effort on which manufacturing enterprises might embark, and especially those intended to improve processes and product quality like ECM.

One might reason, from the examples presented above, that the conventional approaches to process and quality improvement are solely and inexorably connected to peer-reviewed journals and academic writings. In fact, that notion is often another identifiable piece of common understanding often found within the literature. From the 2013 article published in the Journal of Engineering Design, written by Bahram Hamraz, Nicholas H.M. Caldwell, David C. Wynn, and P. John Clarkson we read "[d]ispite the existence of numerous ECM methods in literature, there is not much published on requirement for ECM methods" (Hamraz, Caldwell, Wynn, Clarkson, 2013). While it can be an arduous task to identify peer-reviewed journals on ECM which do not more aptly cover one of the traditional areas of quality, through perseverance the researcher can still locate worthwhile messages in most any of the approaches covered. The tedium becomes evident after reviewing the third, fourth, or eighth paper to no avail, and sometimes a researcher might begin to lose hope of ever finding suitable papers on ECM. That is not to say there are absolutely no peer-reviewed journals available which venture into the engineering change management arena, but one will probably need to review any selections quite closely to make a fitting determination on its overall applicability. Fortunately, for the sake of the current research study, the researcher's motivation is not deterred by such undertakings.

2.5 Literature Review Summary:

In the preceding literature review sections, the author presents highlights pulled from a variety of sources that might seem to venture far from the objectives of a single research paper, but as we see there can be useful takeaways from seemingly unrelated approaches to quality and process control. By looking at methods that include more advanced tactics and larger concerns, one can still identify ideas that might prove useful when leveled on an approach for more simplified strategies of improvement intended to manage engineering changes within small manufacturing enterprises. The notion of reviewing literature which was largely focused on varying approaches to quality stemmed from the authors observation that there seems to be a relative scarcity of coverage on ECM systems, as a tool for process and quality improvements, in smaller manufacturing environments. In presenting reviews from sources that are focused on different perspectives, the researcher is attempting to show that aspects of various approaches might also prove useful when being applied through simper means to a more limited subject.

Upon going over several examples from the available peer-reviewed papers it is discovered that there are concepts in traditional quality tools that might potentially contribute to approaches which are not usually associated with quality, one such methodology being ECM. By identifying the existence of mutually useful philosophies within the various tactics of manufacturing quality, the author believes any notions of applying some of those ideas to a completely different tool to be a justifiable path forward. By combining the like-ideas associated with many of the customary approaches to quality with some of the different tactics to change management, the author believes the goal of developing a basic process using information from various writings will contribute to developing enhancements to the present methods for addressing engineering changes.

The next sections will present a high-level introduction to the simplified methodologies that the investigator has initially selected for use in the execution of the research. The approach will involve several steps which are designed to gather pertinent, as well as other potentially useful, information regarding the current processes exercised by different departments within one SME. While the notions of taking only basic steps may not fit with the ideology of many familiar with academic research, this author believes that there is a time and place for such an application of different approaches. The premise for starting off with extremely rudimentary processes in SME’s is based on the belief that one should not only know their audience, but in many cases, they should go out of their way to cater to the skills and abilities of that audience. This is especially true when dealing with organizations that do not value training and development.

Chapter 3 – Methodology

The methodologies employed for this research study involves the following basic steps:

1. Identify a typical small manufacturing enterprise (SME).
2. Randomly select a sample for review from that SME's documented order lists, including upcoming orders and recently completed jobs.
3. Randomly select a sample of components, from each of the selected orders.
4. Investigate the revision levels of the randomly selected parts and document any identifiable discrepancies between.
    a. What Engineering specified.
    b. What Procurement identifies in orders and work instructions.
    c. What Manufacturing produces.
5. Observe processes to identify distinguishable aspects of the existing methods which might contribute to any discrepancies found.
6. Estimate the potential amount of waste associated with any discrepancies identified that might be adversely impacting the company.
7. Develop simple questions and guiding steps for a potential ECM initiative.

As the above list implies, taking such an approach for completing the research comprises several decision-making processes. The strategy here is streamlined steps and is incorporated for completing each phase of the research development. From selecting an SME for investigation, and subsequently selecting an adequate number of order packages and parts for review, to the calculation methods chosen, every aspect is devised for greater acceptance by most SME's and their workforces. The final quantity of jobs included in the inquiry phase is based on the number of orders coming online, as well as any that have been completed within the past month or two. In reviewing the selected order packages, the plan involves performing a series of comparisons on the engineering designs for those packages against procurement's work orders, what is delivered for the final assembly steps of the manufacturing process, as well as what information in-house manufacturing associates use in making the components for the order packages. Any document review steps will require the analyst to gain an adequate understanding of the organizations file storage and retrieval structures for the different locales. They will also need to document any limitations which may exist for accessing each separate area that may be identified throughout the company's present make up.

With a proper understanding of the current arrangements developed, a series of barebones document reviews can be executed. These steps are intended to detect any revision level inconsistencies between the components that engineering designed into each order and what was identified in the work instructions. In addition to the revisions observed on each the available documents, there will be appraisals on what is delivered to the assembly areas from the various manufacturing entities. Each of the selected parts will be evaluated against what engineering specifies, what procurement orders, and what manufacturing produces. Identifiable inconsistencies in any of these aspects raise questions and highlight the presence of a potential breakdown in ECM. While basic in nature, all the steps of this approach are intended to provide the researcher the ability to distinguish possible failings in the current system. By basing the selection process on random samplings of the components, which are collected from a random sampling of current and recent orders, the researcher takes advantage of one of the simpler theories found in statistics. It is believed that the theory of normality in random sampling can be explained without causing too much strife within the environs of an SME.

The results from those initial methods are amassed for further use when identifying some potential causes to each problem found. Any instances found that are not clearly associated with the current set of samples are documented for possible use in future studies. Once the information on each identifiable deficiency is collected, a process whereby those problem items get effectively grouped will ensue. This categorization step is intended to aid the researcher in developing suitable approaches for a nontechnical form of cause-and-effect analysis. The findings from any analysis completed are then further documented and categorized for possible inclusion in later steps of the study.

As a clear part of cause-and-effect, another aspect that will need to be considered involves the impact of the identified issues on the completion of the orders. To accomplish this the researcher performs several Gemba walks which follow the manufacturing processes for the parts of each work package. During those walks one will proceed through a series of question-and-answer steps intended to identify and document the different solution processes taken for the problems encountered in the various departments. Observations made along with the results from those examinations are to be used in comprehending the amount of waste encountered by the company when manufacturing the items. With that information, an estimate is developed which should be representative of the average cost-due-to-waste that the company is likely experiencing from the production of a typical order.

In conducting each of these steps, practical findings are documented and categorized so that causes can be associated to the different failings and the resulting potential financial burden can be tracked. For moving forward business needs an understanding of the would-be impact of different areas of waste, as this is typically an important variable when problems such as these need to be identified, documented, and addressed. All the information collected in a well thought out series of steps can be further used to help identify feasible corrections to the situation. Based on the findings, the author develops questions and guidance for helping in any ECM improvements, which if realized would surely reduce the overall waste seen in future orders.

3.1 SME Selection:

To accomplish the goals of the SME selection, the researcher approaches key members of a few local companies, through a chain of professional contacts, and works to establish a relationship with different leaders within some of the departments of those entities. These leaders are approached about the likelihood of their organization having any interest in participating in the research for an academic study. The selected contacts who respond in the affirmative, are asked to investigate the potential of interest by their top management teams in undergoing such a process of examination and analysis. It is also pointed out that if the researcher is successful in the goals set forth, any results/findings could ultimately prove beneficial to the organization. Of the initial contacts approached, the ones that suggest their SME's management team either will or might have interest in participating in the project are asked to schedule meetings between the researcher and those mangers willing to consider allowing such a study within their company.

Next, a series of meetings are arranged so that the concept can be presented to the appropriate decision-makers of those organizations. Those first meetings are structured to allow this author an opportunity to present a high-level view of the plan, and to get an idea of whether there are any overwhelming signs of trepidation in participating in the study. A small informal presentation is staged by the author for each company's management team where they are apprised on the objectives and the goals of this research, as well as some of the potential risks and benefits. At the conclusion of those first meetings, the management teams are asked if they would be interested in proceeding as a willing participant in this project. It is anticipated that several back-and-forth conversations will ultimately lead to a narrowing of the field of potential participants. It is through those discussions that topics such as access/restriction to sensitive materials and discretion are covered. The researcher should be prepared to continue these steps over many iterations until a conclusion to these meetings can be achieved.

After the preliminary SME list is reduced to one company agreeing to participate in the study, and allowing sufficient access to the researcher, there will likely be some fine tuning that takes place. At that point, the parties involved set about reviewing precisely what that access will be provided to the analyst. There needs to be a clear understanding of what is required/permitted in the different departments, and within what timeframe any access will be permitted. Throughout the process the researcher and the key members of the organizations team will develop sufficient guarantees that the company and any proprietary information, as well as all observed processes and data collected will remain anonymous. The company and the researcher also agree to these arrangements through a satisfactory, albeit simple, Non-Disclosure Agreement (NDA).

It is not coincidental that the companies included in the elimination process are of a similar make-up. This is largely due to the selection process itself. As it turns out the chain of professional contacts which the author exploits are all in roughly the same type of industry, as is the researcher. As a result of taking that approach, it is understood the SME that agrees to participate at the culmination of the steps laid out above is a small manufacturing enterprise (SME). Their facility is in the continental United States, and its primary products are comprised of large to medium sized machinery and equipment made chiefly of sheet-metal and structural steel components created both in-house and by outside vendors. Most of their designs are either welded together or assembled using standard threaded fasteners, and many are a combination of these two approaches. The nature of manufacturing processes for this type of machinery and equipment generally requires consistent repeatable placement of the key features of the designs to ensure ease of the various welding and assembly steps.

For the purposes of this paper and due to strict privacy concerns, which generally will arise on the part of most management teams, the identity and location of the company will not be disclosed in these, or any, writings. The author feels this is an understandable arrangement given the nature of the study, and the fact that any failings identified could potentially be used against the company that is under review. With the simple agreement developed and duly signed by all concerned parties, the process of planning and selecting the substance for this study is permitted to commence. The steps for the order selection are laid out in the next section of this chapter.

3.2 Order Package Selection:

At the onset of the order package selection process, a series of preliminary meetings are initiated which include the various heads of engineering, manufacturing, procurement, and finance. These conferences are intended as an introduction, as well as an opportunity to explain the research goals and objectives to those that may not have been included in any of the earlier meetings with management. Those session periods are also essential for establishing agreeable limits regarding acceptable timing and scope for any prospective jobs considered.

The researcher feels it is imperative that any packages included for consideration in the analysis be properly sized and timed as to minimize any chances of exceeding the available window for completion of this work. For that reason, any jobs slated to begin later in the year or that are projected to take an excessive amount of time to complete are eliminated from the selection process. Likewise, orders of an inordinate size or complexity that would likely require an overly extended period for evaluation are excluded. By the same token, any packages that are deemed overly simplistic, being comprised of ten (10) parts or less, are also eliminated from the selection process. The department heads are approached to discuss concerns about not including orders, based on excessive timing and/or size, and to ensure the researcher that there is an adequate number of jobs upcoming, or recently completed, from which to randomly select for inclusion in the analysis phase.

After the meetings with the department heads and the list of possible orders are sufficiently pared down, the researcher requests to be assigned a point of contact for each of the departments that will be involved in the study. Those contacts will serve as liaison and will be responsible for showing the researcher around their respective departments, communicating information back and forth, as well as pointing the researcher in the correct direction to find any needed documentation or components. It is vital that these individuals be pulled from various frontline positions, and that the researcher spends ample time discussing their involvement in the project along with the desired results of each step they will be participating in. With proper encouragement their input on the existing processes be gained, and they will soon realize that the researcher is interested in learning from everyone. This researcher is a strong advocate for pulling ideas from every level within an organization, which of course includes the workers that are most familiar with each process in place. To reinforce this, each liaison should be prompted to ask for input from those they are communicating with through every phase. By welcoming ideas from different associates, the researcher gains trust which will result in greater discovery over time. Ultimately, the involvement of those associates in beginning stages will contribute to higher acceptance levels should new processes be initiated because of this research project.

3.2.1 Order Package – Phase Two:

After the elimination process is completed, a list of the remaining orders in the company's production queue is compiled and that information input to a spreadsheet, utilizing an anonymous but sequentially structured order, that will allow for consistent identification of each package. In Table 1 below we see the results that reflects the information included in the order package list that was generated by the researcher for this portion of the selection process.

Table 1, *SME Order Packages*

SME Order Packages				
Order Package Identifier	New order (N) or Repeat (R)	Sub-assembly Qty	Total-manufactured Components Qty	Job State
PJXXXXX1	N	2	75	WIP
PJXXXXX2	N	2	82	WIP
PJXXXXX3	R	1	93	Done
PJXXXXX4	N	2	94	WIP
PJXXXXX5	R	3	49	Done
PJXXXXX6	R	4	67	Done
PJXXXXX7	R	2	146	Done
PJXXXXX8	N	3	36	WIP
PJXXXXX9	N	1	148	WIP
PJXXXX10	N	1	13	WIP
PJXXXX11	N	3	42	WIP
PJXXXX12	N	3	143	WIP
PJXXXX13	N	2	45	Done
PJXXXX14	R	4	140	WIP
PJXXXX15	R	1	36	WIP
PJXXXX16	N	4	103	WIP
PJXXXX17	R	5	18	WIP
PJXXXX18	R	2	5	WIP
PJXXXX19	N	2	9	WIP
PJXXXX20	N	1	30	Done
PJXXXX21	N	3	101	Done
PJXXXX22	N	4	98	WIP
PJXXXX23	N	4	45	Done
PJXXXX24	R	2	7	WIP
PJXXXX25	N	3	113	WIP
PJXXXX26	R	5	20	WIP
PJXXXX27	R	3	163	WIP

Note. The table above shows all orders that were considered in selecting the subject packages for this research.

The total number of orders included on the list, after the elimination phase, is to be utilized in randomly selecting packages for the upcoming review phases. To complete this portion the investigator chooses to employ the Google random number generator. As with every other step of this study, the process for randomly selecting which orders are included in the study is intentionally kept quite simple. As you will see, this approach is maintained throughout the various steps of the research, so that the typical workforce found within SME's will not likely become overwhelmed by any of the tasks or information presented. It is decided to set the quantity of order packages to be randomly selected at not substantially more than, but not less than, 10% of the number of orders found in the table shown above. As can be seen, that table contains twenty-seven (27) order packages, which have been identified from the parsed-down selection of jobs associated with this SME. Based on this, it is a simple calculation to figure out the number of packages reviewed in this study should be three (3).

The plan for choosing materials in this research study has the first three randomly generated numbers correlating to three packages which are ultimately selected for inclusion in the review and observation processes. In the unlikely event the random number generation results in duplicate selection possibilities, those instances will be ignored, and a new random number will be created. Table 2 below shows the 3 final order packages selected from completing this basic routine of random selection.

Table 2, *Order Packages Selected*

Order Packages Selected				
Order Package Identifier	New order (N) or Repeat (R)	Sub-assembly Qty	Total-manufactured Components Qty	Job State
PJXXXX25	N	3	113	WIP
PJXXXXX4	R	2	140	WIP
PJXXXX14	N	4	94	WIP

Note. The table above shows the three order packages randomly selecting for review.

With the three (3) packages for review in this study selected, the steps for identifying the components from each job that will ultimately be analyzed ensues. The procedures engaged in for selecting these parts follows a similar protocol as was laid out for the order package selection process. The next section covers the means which are developed for that part identification.

3.3 Identify and Group:

Upon selecting the orders for review, the researcher begins the steps of collecting information on the different components utilized in those 3 packages. That information includes going over the engineering BOM (Bill-Of-Materials) for each of the jobs and identifying engineering-controlled drawings found within the engineering file locations, which could involve a computer network or some form of hard-copy filing method. Each item is then categorized based on specific criteria; is the component a purchased COTS (Consumer-Off-The-Shelf) item, is it a stand-alone part or is it a sub-assembly, is it an item produced In-house, or is it created and shipped in by a vendor (outsourced)? Any COTS items are consigned to a holding state, for future reference should they be needed. This course is taken because COTS items are not generally included in a basic change management system, since their designs are not controlled by the company. In other words, COTS items are not usually considered in an ECM system because those items do not generally get modified when implemented in designs. This is not to say COTS items and their relevant documentation do not require a managed system, but that is beyond the scope of this project and could be the subject of a future research study to identify best-practices where those items are concerned. If the piece is a sub-assembly, that will require additional steps so that the individual parts of that assembly can be included in the review processes. Because designs might include several layers of sub-assembly, these procedures may need to be repeated multiple times.

As mentioned above, any presence of sub-assemblies will require the researcher to perform the same general steps laid out previously. Each instance progresses based on the included componentry of the packages as specified by engineering. Reproducing these simple steps allows the researcher to create lists of all identified sub-assemblies and move this project's manufactured part identification steps forward. By digging into the identified layers in the orders, the research is assured that all manufactured parts will be included in the analysis processes. In the Table 3 below we see the results from completing these identification steps for each of the packages selected.

Table 3, *Sub-Assembly Identification*

Sub-Assembly Identification					
Package/Part Identifier	**Revision Per Engineering**	**Revision Per Procurement**	**Sub-assembly Qty**	**Manufactured Components Qty**	**Common part (C) or 1-Off (1-O)**
PJXXXX26	-	-	3	113	-
ASXXXXX1	-	-	0	34	1-O
ASXXXXX2	-	-	0	41	1-O
ASXXXXX3	-	-	0	38	1-O
PJXXXXX4	-	-	2	140	-
ASXXXXX4	-	-	0	98	1-O
ASXXXXX5	-	-	0	42	1-O
PJXXXX14	-	-	4	94	-
ASXXXXX6	-	-	0	28	1-O
ASXXXXX7	B	A	0	16	C
ASXXXXX8	-	-	0	20	1-O
ASXXXXX9	-	-	0	30	1-O

Note. The table above shows the sub-assemblies found within the selected subject package.

The next steps of the process again replicate the identification steps performed earlier, only now the focus is on those pared-down individual components included in the table above, listed in the manufacturing components quantity column for each sub-assembly. The next section goes into the simple steps for randomly selecting items to include in the evaluation processes.

3.4 Component Selection:

With the order packages selected and the different tiers found within taken down to their single component level, the process of randomly selecting parts for full evaluation can begin.

This process will again be a simple repeat of the procedures used in the package selection phase, whereby a random number generator is utilized to create numbers that correlate with an identified part from each of the 3 jobs. It should be expected that the total numbers of in-house and outsourced components which makes up the lists for each of the order packages will vary. Such inconsistency, if detected, reinforces the researcher's notion that the random component selection steps need to be carried out separately for each of the prospective jobs. When one thinks about it, this is the best-practice for an approach to randomly selecting components without replacement.

3.4.1 Component Selection – Phase Two

Because the part identification steps will be conducted for every order that has been chosen for review, the simple random number generator process is repeated for each of the three (3) instances. The purpose, of course, being to identify the parts and documents that will be examined for the next part of the study. The results of these selection processes are based only on the number of pared-down components, both made in-house and outsourced, that have been identified for each package under consideration. The researcher's goal is to conclude the part selection steps with at least, but not significantly more than, ten percent (10%) of the separate components identified in the last steps, with those items used for the analysis in each of the identified orders.

The steps taken during part selection are intended to generally replicate those of the package selection phase, with provisions for ensuring a true random selection is achieved. One of the requisites for safeguarding more able samples of the components within the overall engineering system involves understanding how common items, that is components found in multiple jobs, will be addressed. The strategy for any common parts is to include only the first instance, and to ignore or skip, any instances which come after the earliest occurrence identified.

Such a process should prevent any instances of duplication, which should work well when reviewing multiple applications such as this. By planning and designing measures for such occurrences in part selection, the researcher can be assured the resulting lists of components will provide viable data for any analysis phases. Of course, these methods could also likely reduce the number of mismatching revision levels found in subsequent packages if there are shared components across platforms. The items selected from each of the applicable orders will be utilized when completing reviews of each part's documentation and will serve to guide any observation processes for the different manufacturing areas.

By following the basic steps presented thus far it becomes a vary underwhelming chore of identifying the components to be compared form those 3 order packages. Note, the random selection process for the job components is only concerned with the documents for manufactured items produced in-house and those created by outside vendors. The methods employed will proceed in much the same manner as the package selection phase. Consequently, similar activities are undergone concerning the creation of consecutive identification numbers for the different parts, and then using a random number generator the final parts are picked and this phase can be concluded. With these steps completed we are left with three lists of parts, that are each based on ten percent (10%) of the total number of components identified in each order package. These components, and any identifiable documentation created as a guide in their manufacture, will all be put to under scrutiny in the next section of this study. The tables below (Table 4, Table 5, & Table 6) reflect the results of these steps for the packages under review.

Table 4, *Selected Parts - First Identified Order Package*

Selected Parts - First Identified Package				
Part Identifier	Revision Per Engineering	Revision Per Procurement	Common part (C) or 1-Off (1-O)	In-house (I-H) or Off-Site (O-S)
PTXXXXX1	A	-	C	I-H
PTXXXXX2	-	-	1-O	I-H
PTXXXXX3	A	A	C	O-S
PTXXXXX4	C	B	C	I-H
PTXXXXX5	-	-	1-O	I-H
PTXXXXX6	A	-	1-O	O-S
PTXXXXX7	B	B	1-O	I-H
PTXXXXX8	B	A	C	O-S
PTXXXXX9	-	-	1-O	O-S
PTXXXX10	-	-	C	I-H
PTXXXX11	-	-	1-O	I-H
PTXXXX12	C	B	C	I-H

Note. The table above shows the parts selected the first subject order.

Table 5, *Selected Parts - Second Identified Order Package*

Selected Parts - Second Identified Package				
Part Identifier	Revision Per Engineering	Revision Per Procurement	Common part (C) or 1-Off (1-O)	In-house (I-H) or Off-Site (O-S)
PTXXXX13	-	-	1-O	O-S
PTXXXX14	-	-	1-O	O-S
PTXXXX15	-	-	1-O	O-S
PTXXXX16	C	B	C	I-H
PTXXXX17	E	B	C	I-H
PTXXXX18	-	-	1-O	O-S
PTXXXX19	A	A	1-O	I-H
PTXXXX20	A	A	C	I-H
PTXXXX21	-	-	1-O	I-H
PTXXXX22	A	B	C	I-H

Note. The table above shows the parts selected the second subject order.

Table 6, *Selected Parts - Third Identified Package*

Selected Parts - Third Identified Package				
Part Identifier	Revision Per Engineering	Revision Per Procurement	Common part (C) or 1-Off (1-O)	In-house (I-H) or Off-Site (O-S)
PTXXXX23	A	A	C	O-S
PTXXXX24	B	C	C	O-S
PTXXXX25	A	A	C	O-S
PTXXXX26	E	E	C	I-H
PTXXXX27	A	-	C	O-S
PTXXXX28	-	-	1-O	O-S
PTXXXX29	D	A	C	I-H
PTXXXX30	A	A	1-O	O-S
PTXXXX31	-	-	C	O-S
PTXXXX32	-	-	1-O	O-S
PTXXXX33	-	-	1-O	I-H
PTXXXX34	B	B	C	I-H
PTXXXX35	A	A	1-O	I-H
PTXXXX36	-	-	1-O	O-S

Note. The table above shows the parts selected the third subject order.

It may seem obvious, but by now the researcher should recognize that completing the steps described thus far will require good interaction and communication, as well as direction, via their designated liaisons. Only through a good rapport with each job's responsible engineer, as well as the party's accountable for completing subsequent processes, can one expect to succeed in retrieving accurate and valuable input on these matters. It will be at this time that the researcher primarily becomes engaged with the organization's different filing systems for each of the departments encountered. It will become clear, if it is confronted, that the presence of multiple locations for files storage and access to part documents is an opportunity for trouble regarding any ECM system goals.

3.5 Component Compare:

The document/part compare stage of the analysis starts off with a review of the selected parts for their revision levels as engineering identified them in the design of each order package. Each component's revision level, as identified by engineering, is then checked against information on the revision levels based on what is specified through the procurement ordering process. Any discrepancies in what engineering identifies and what procurement orders is documented, so there might be further investigation into a possible cause for those discrepancies. The tables shown below (Table 7, Table 8, & Table 9) reflect the results of these comparisons for the three jobs under review. Note: the highlighted lines represent items which have discrepancies in their revision levels.

Table 7, *Selected Parts - First Identified Package*

Revision Inconsistencies - First Identified Package				
Part Identifier	**Revision Per Engineering**	**Revision Per Procurement**	**Common part (C) or 1-Off (1-O)**	**In-house (I-H) or Off-Site (O-S)**
PTXXXXX1	A	-	C	I-H
PTXXXXX2	-	-	1-O	I-H
PTXXXXX3	A	A	C	O-S
PTXXXXX4	C	B	C	I-H
PTXXXXX5	-	-	1-O	I-H
PTXXXXX6	A	-	1-O	O-S
PTXXXXX7	B	B	1-O	I-H
PTXXXXX8	B	A	C	O-S
PTXXXXX9	-	-	1-O	O-S
PTXXXX10	-	-	C	I-H
PTXXXX11	-	-	1-O	I-H
PTXXXX12	C	B	C	I-H

Note. The table above shows items identified with revision discrepancies, Highlighted in Yellow, from the first order.

As can be seen in the table above, of the twelve (12) parts included for the first identified package's review, there are five (5) items which show inconsistencies in the revision levels specified by engineering, when compared to the revision levels that are in the work instructions created by procurement.

Table 8, *Selected Parts - Second Identified Package*

Revision Inconsistencies - Second Identified Package				
Part Identifier	Revision Per Engineering	Revision Per Procurement	Common part (C) or 1-Off (1-O)	In-house (I-H) or Off-Site (O-S)
PTXXXX13	-	-	1-O	O-S
PTXXXX14	-	-	1-O	O-S
PTXXXX15	-	-	1-O	O-S
PTXXXX16	C	B	C	I-H
PTXXXX17	E	B	C	I-H
PTXXXX18	-	-	1-O	O-S
PTXXXX19	A	A	1-O	I-H
PTXXXX20	A	A	C	I-H
PTXXXX21	-	-	1-O	I-H
PTXXXX22	A	B	C	I-H

Note. The table above shows items identified with revision discrepancies, Highlighted in Yellow, from the second order.

As can be seen above, of the ten (10) parts included for the second identified package's review, there are three (3) items which show inconsistencies in the revision levels identified by engineering, when compared to the revision levels that are identified by procurement.

Table 9, *Revision Inconsistencies - Third Identified Package*

Revision Inconsistencies - Third Identified Package				
Part Identifier	Revision Per Engineering	Per Procuremen t	Common part (C) or 1-Off (1-O)	In-house (I-H) or Off-Site (O-S)
PTXXXX23	A	A	C	O-S
PTXXXX24	B	C	C	O-S
PTXXXX25	A	A	C	O-S
PTXXXX26	E	E	C	I-H
PTXXXX27	A	-	C	O-S
PTXXXX28	-	-	1-O	O-S
PTXXXX29	D	A	C	I-H
PTXXXX30	A	A	1-O	O-S
PTXXXX31	-	-	C	O-S
PTXXXX32	-	-	1-O	O-S
PTXXXX33	-	-	1-O	I-H
PTXXXX34	B	B	C	I-H
PTXXXX35	A	A	1-O	I-H
PTXXXX36	-	-	1-O	O-S

Note. The table above shows items identified with revision discrepancies, Highlighted in Yellow, from the third order.

As can be seen in the information provided above, of the fourteen (14) parts included for the third identified package's review, there are three (3) items which show inconsistencies in the revision levels identified by engineering, when compared to the revision levels that are identified by procurement.

Here the comparison process will start to become a bit more involved, and it requires the identified engineering-controlled components and the items indicated in procurement's documentation to all be checked against what is delivered to the assembly areas for each job. It is at this stage where the researcher will become more entrenched with the various manufacturing departments, through a series of Gemba Walks that are initiated to collect valuable information in the areas where the work is getting done. Of course, a loose interpretation of what a Gemba Walk is would be just that, "where the work is preformed". The procedures included in these walks should touch on several aspects of the manufacturing processes. The manufacturing areas for items that are produced in-house are physically walked, as well as the different assembly areas for each order package. Any walks of the outsourced manufacturing processes are either completed by visiting those sites, if they are within a reasonable distance, or by conducting a series of questions and answer sessions via phone calls and email conversations.

Through questions and observations of the different areas involved in the manufacturing processes, for both in-house and outside sources, the researcher can further identify items that may have discrepancies, when considering what the engineering-controlled documentation has specified for each of the orders under review. The existence of any identifiable inconsistencies between what engineering expects and what is produced may require further investigation, whereby the actual items created and delivered to the assembly areas are compared against what was specified on the different engineering-controlled documents for each part.

3.5.1 Component Compare – Phase Two

To properly identify the probable cause of delivered part inconsistencies, documentation for those items produced in-house, and outsourced, will need to be evaluated. This review will include not only designated revision information, but also dimensions, tolerances, and notes to compare what was designed against what procurement expected, and what was produced and delivered to the assembly areas. Any discrepancies in what engineering identified, what procurement included in their orders, and what was delivered to assembly is noted for possible inclusion in any further investigations. While there may be aspects of the issues being considered that fit within the confines of this study, there are likely to be discoveries that are better suited for additional research. As such, there should be an effort made to document any findings that could be passed along to management at some time after the current research has concluded.

There are several reasons why a part might not match the design specifications of engineering. One possible cause involves typical manufacturing process noise, which is simply the natural variation which can occur due to the procedures employed in creating the item. This could be related to something like natural tool ware, or variations in machine capabilities due to ambient temperature changes, and/or surges or limitations in available power, all of which could affect equipment performance. Yet another influential driver on production processes involves unnecessary machine adjustments by the operator that adversely impact the final product. Reasons such as these are generally understood and are in fact often covered in academic writings and published journals. While the occurrence of such manufacturing shortcomings is surely noteworthy, and could be a viable subject for addition research, these types of impactful inconsistencies are beyond the scope of this research paper.

The scope of this research is concentrated on discrepancies between what engineering expects and what is produced based only on variations in the available documentation of those items. One aspect of engineering change and revision control in which the researcher has often seen problems involves associates in the onsite manufacturing areas obtaining documents they need to make the parts, and not properly disposing of those documents upon the completion of the job. Unfortunately, it can be common to find that front-line associates are storing old drawings and work orders in locations that are not regulated in the system. By holding on to documentation in this fashion, associates are inadvertently circumventing any engineering change notification that might be in place. This problem can be exacerbated if associates are making notes or marking-up those documents for any reason. Should that be the case, the engineering department is likely not privy to issues that may have been rightfully identified by the associates. Occurrences like this can be especially troublesome if those mark-ups have continued over a course of time where several engineering revisions have been generated. While the associated intentions may be only to address gaffes identified within the document, if there is no recognized method for relaying such findings to engineering, any future engineering changes will likely not be accurate for the intended design. For that reason, the possibility of these types of happenings needs to be kept in mind whenever an ECM system is being considered.

3.6 Part Discrepancies

Another step which may need to be conducted will involve checking any items that are found to be incongruent with the design during the assembly phase. An in-depth proactive analysis of each part that appears to be different from what Engineering specifies could require a piece-by-piece investigation against the documentation or drawings for said item. Proper investigations will provide further insight to the potential cause of the discrepancies and could better illuminate possible failings in the current processes related to engineering change. Again, while the occurrences of identifiable shortcomings are noteworthy, and could be a viable subject for addition research, many of these inconsistencies are beyond the scope of this research paper. As such, any investigating along these lines will be conducted to identify inconsistencies in the revision levels of what procurement orders, and what manufacturing produces, against what engineering has designed. The researcher may opt. to check parts against all the ‘current’ revision levels found for that item. Meaning, if engineering identifies a revision, and other departments, like procurement and manufacturing, identify different revision levels, i.e., revision ‘A’ vs. revision ‘B’, or revision ‘C’, all the revision levels could be subject to the investigation process of the problem parts. Any findings from such an in-depth investigation will be noted so the probable causes for those discrepancies can be tracked and further documented for potential inclusion in future undertakings.

The information collected from the methods laid out above will then be presented to each of the different liaisons for the various departments, and a review of the organization’s existing engineering change process will be initiated. The review includes aspects of how each department understands the current change procedures, as well as a series of investigative steps intended to highlight where the actual steps may be failing to perform as intended. In broaching the subject of the current engineering change procedures there are several questions that the researcher should identify as needing to be addressed. Some of the questions that might be presented are identified in the next section.

3.7 Current Engineering Change Process

To adequately ascertain the level of understanding held by the various associates, regarding the processes currently in place, the researcher develops some general questions that will be presented to various associates via the appropriate liaison. Because simply approaching individuals and asking a series of questions might foster some resentment or animosity, the process of presenting these questions is probably better if kept to small casual exchanges. The investigator feels taking an unassuming approach will engender more genuine awareness of any potential failings which might be otherwise obscured from view. The liaison should therefore be encouraged to mix up each probing exercise within various friendly conversational methodologies while always maintaining a proficient atmosphere. Whenever possible, the researcher should also accompany the liaison so that a report with the associates can be established, and any future material gathering phases can maintain a more sociable feel. Again, it is suspected that through such tactics better information can be gleaned because response will likely be more honest and forthright. Examples of the general questions to be asked are presented in appendix ‘A’ at the end of this report.

In addition to the input from the different questions, there are various potentially impactful standpoints which will be reviewed when scrutinizing the different parts produced. Generally, part numbering and revisioning of documents should fall under engineering’s control in these types of SME. However, those aspects sometimes are not viewed as having an integral connection to engineering, and any such cases will likely require a series of questions about each area’s approach to the objectives of the organization. The next section will address the very crucial aspect of file location, which always needs to be understood by each department when new order packages and engineering changes are initiated.

3.8 File locations

In addition to the questions discussed above, which are specific to the existing change steps, there are inquiries organized to aide in identifying the possible existence of other implicating factors. One vital aspect that is sometimes missed involves the use of more than one file storage location for component documentation/files. For those times where it is found that items are being stored in multiple locations, the researcher will need find out about access, or permissions, for the various locations. It will also need to be understood how engineering changes are addressed in those different areas, so that aspect could be included in any inquiries concerning document storage locations. Again, some of the general questions that might be asked concerning this area are presented in appendix ‘B’ at the end of this paper.

With the inputs to any of the developed questions recorded, the researcher can then take on the task of further scrutinizing the processes in each section covered in the question-and-answer phases. Taking a methodical approach of following each identified item through their various production stages, will allow the analyst to verify the information collected through the question-and-answer processes. Additionally, taking such an approach provides extra opportunities to discern between what is occurring and what is believed to be taking place. The next section identifies some worthwhile steps to undergo throughout those observation activities.

3.9 Manufacturing Observation – In-house

These steps involve the researcher monitoring the specific stages started during the manufacturing processes within the different in-house departments identified as being integral in the production of many of the organization’s order components. This phase covers observations of the actual steps taken by each team lead and/or department head, which in turn contributes to how each associate in those areas are assigned tasks specific to the different jobs. The observation process begins with conversations conducted between the assigned liaison, the identified individuals in those areas and the researcher. In these discussions the different steps taken during a typical job are initially reviewed, and after each point is sufficiently covered, a schedule for observing the actual jobs under consideration is developed. After each party agrees on a mutually doable timeline, the liaison and the observer go over a high-altitude plan for the upcoming manufacturing schedule, and they adjust the plan as needed based on input obtained through the liaison's various interactions. Once the timing and the researchers' plan are in synch, the liaison walks the researcher through each area to familiarize associates with the plan and the upcoming presence of the observer. After these actions have wrapped up the researcher proceeds with the observations of the processes as they are completed for the packages selected in this study.

Several aspects can be documented from the observation phase, including the identity and position of the responsible party who identifies which components are to be produced for each order, and the procedure for any verification steps that may be performed. Any lack of a verification process in these reviewed instances can also be documented for future reference. Next, the procedures for conveying different task information to associates are reviewed, and the documentation passed along, if any, is recorded for future reference. The parts identified for production are then compared against any work orders created for each package. The comparisons at this point involve only the revision levels found within the documents referenced for making each item, i.e., the work orders. More in-depth comparisons will also need to be conducted which will review the documentation used in the manufacturing processes and is described below.

A particularly important aspect of the manufacturing process investigation has the researcher also completing reviews of each selected part's documentation, as referenced by the associates, when completing the job assigned to them. This step is intended to verify that the revision levels designated for every component not only match what procurement identified, but that the specifications within each of the documents are the same as those shown on the corresponding revision level in engineering-controlled documents. Basically, each drawing or document is checked to verify that all form, fit, and function identifiers (dimensions) are the same as what engineering has in their documents. Any discrepancies in this stage are recorded for further investigative steps, should they need to be undertaken.

While these in-house manufacturing observations are important steps for identifying possible breakdowns in the organization's Engineering Change Management processes, there are additional areas that should also be investigated. One area which can be crucial for understanding possible issues with ECM processes is found through investigating the steps for engaging outside vendors. The following section covers the manufacturing aspects as they are encountered by outside vendors on the selected order packages.

3.10 Manufacturing Observation – Vendor (Outsourced)

Much like the in-house manufacturing observation process, this phase is intended to identify the various steps taken by outside vendors for understanding and executing what is required in fulfilling the assignments they are awarded. The task of reviewing components produced through outside vendors begins with introductions and conversations conducted between the assigned liaison, an identified contact with each of the different vendors that are conferred jobs for the orders under scrutiny, and the researcher of this study. These discussions differ from the in-house manufacturing portion in that the information sought generally revolves around the materials that are provided when a job is awarded to them from the SME. While there may need to be some formal review of the steps taken in a typical order completion process, physical observation of the manufacturing steps might not be doable. This can be the case for any number of reasons, like the vendor is not in the vicinity of the SME under review and traveling to their location might not be practical, or the vendor is concerned over proprietary information within their facility's and therefore may not be willing to provide full access to outside individuals. As a starting point, for this portion, the researcher focuses largely on understanding each vendor's protocol for handling documents from the subject SME, both before and after each part is completed and delivered to their customer. Based on the findings, recorded on how documents for completed jobs are addressed, the researcher will gain an understanding of the likelihood of any engineering change failings originating with those vendors.

Another reason behind a simplified questioning process for outside vendors is that, in theory at least, the study has already established what revision levels procurement included in the documentation for the vendors on each package, making the process of verification with the vendors a somewhat simpler undertaking. This of course will depend upon the responses received from each vendor to any questions posed. Keeping in line with a more limited or long-distance inquiry, a series of simple inquiries are developed which can be presented and answered via email, or a phone conversation. A sample of some of the general questions, that might be asked of the vendors, concerning how they handle documentation for orders from the subject SME are presented in appendix 'C' at the end of this paper.

Again, based on the answers to the questions posed, the researcher can identify potential areas of the SME's ECM protocol which could allow for uncontrolled errors to occur. The information gleaned from the in-house departments and the outside vendors is then used throughout a review of the SME's assembly areas, where the final package designs are brought together, and where many, if not most, of the engineering change failings are first identified. The next section will cover the observation of those manufacturing assembly areas.

The information that was collected from the outside manufacturing locations confirmed the initial suspicions of this researcher. The vendors working on the orders under review identified processes internal to their operations that corresponded well with a strong ECM system. In each instance, no order documentation is maintained within those organizations that could cause incorrect revision production in any way. It was conveyed that item production is only initiated upon the receipt of the required part documentation from their customer, in this case the subject SME. For the current package under review, those documents are provided via the SME's procurement department. It was mentioned that on rare occasions the vendor requests an electronic file, such as a DXF, or a Parasolid, that would be used for machine programing. In such cases, these files would be sent from either the SME's procurement or engineering department. At the conclusion of the part acceptance by the SME, the vendors invariably destroy or delete all documents and files from their respective systems. Based on such a realization, it can be decided to forego any further review of the outside vendors unless there is some compelling evidence presented which would indicate more observation or investigation is warranted.

3.11 Manufacturing Observation – Assembly

To gain a better understanding of exactly how poorly implemented engineering changes might be impacting different areas within this organization, the final assembly departments for the three orders under review are brought into the observation process. This phase is conducted much like the in-house manufacturing process observation stage. In that it also begins with identifying the steps taken by each team lead and/or department head that determine how the associates in that area are assigned tasks specific to the orders. Again, the job of reviewing each stage kicks off with a series of discussions between the liaison, the area leads, and the researcher. Through those talks the different movements required in a typical package are initially reviewed and, after each point is ruminated, a schedule for observing the jobs under consideration is developed. With key participants agreeing on a feasible timeline, the liaison and researcher go over a rough plan for the assembly observation activities. Again, after some back-and-forth with prominent stakeholders in the assembly areas, the initial plan may get adjusted as necessitated by other predominate circumstances which are presented. With the researchers' plan worked out in-line with the department schedule, and any stakeholder concerns, the liaison walks the researcher through each area to familiarize the associates with the imminent observation phase. With the preliminary and planning actions finalized, the researcher proceeds with their scrutinization of the assembly processes for the packages being reviewed in the study.

Much like the in-house manufacturing phase, the assembly process requires many similar aspects to be documented, including the identification of the responsible parties that identify and direct which components are to be pulled into the work area for each order, and the procedure for any verification steps that may need to be performed at that point. Like before, any lack of verification processes in the reviewed procedures are documented for possible future reference. Such failings are especially noted in instances where the items are later found to be incorrect, for whatever reason. Again, this information might be utilized in future research studies that do not necessarily fit with the scope of this project.

Throughout the assembly area observation phases the researcher will make inquiries regarding steps, or parts, which do not appear to work properly toward the final product. By communicating with the associates working on the different assemblies, the researcher can gain insight to various perceived shortcomings encountered in the parts needed for those assemblies. There is also ample opportunity to identify possible enhancements to the design and assembly processes themselves, but these aspects are beyond the scope of this study. Still, the researcher might document any ideas in this regard for future use, should it be determined that such information could prove helpful. Along with the procedures for assembling the order components, the researcher investigates the processes for conveying information regarding problems to any responsible associates or departments, along with noting all documentation which is typically passed along, if any, for the reporting process. Parts identified as having some problem during the assembly process are then double checked against the work orders created through the procurement department for each instance. As with the earlier observations, the comparisons at the assembly points involves only the revision levels of any documents referenced for building each package. Note, any additional in-depth comparisons at this point will only need to consider the assembly level documentation, as all identified part documentation for the items created in earlier manufacturing processes were already reviewed in those previous stages.

As with the other survey steps, there are particularly important aspects to ponder in the review process. Some involve completing in-depth comparisons of the selected documentation, as referenced by the area associates, when completing the jobs assigned to them. In the assembly areas, that step is intended to verify the revision levels designated for every assembly not only match what procurement identified, but that the specifications within each of the documents are in fact the same as those shown on the engineering-controlled documents. This entails checking each assembly level drawing or document to verify that not only form, fit, and function identifiers (dimensions) are the same, but that any bills of materials included on the documents are accurate. Any discrepancies in this stage are documented for further investigative steps, should they be undertaken.

Upon the wrap-up of the assembly observation phases, the researcher will set about going over all the information collected, up to this point, and categorizing the data from each area. The purpose of grouping the information is so that it might be used in a series of simple calculations that render confirmation on how the current engineering change processes might be affecting the organization.

3.12 Methodology - Overview

One clear goal of this study is to create usable results that are ultimately meant to be understandable by the typical associate likely to be employed at SME's. With that in mind, any advanced applications of statistics, quality control, and process control which are customarily deemed helpful in identifying areas of concern within manufacturing realms will need to be largely circumvented, and if any aspects are exercised, they will be kept basic in nature. In addressing the data collected, through the steps laid out for this study, a researcher should be well served by developing approaches that highlight the qualitative nature of the elements reviewed. That type of approach is likely to sway a greater proportion of managers than any methods built from more subjective pursuits. A case can clearly be made for maintaining such basic strategies, and there are several methods which may prove useful when one is interested in simple tactics to analyzing a process. Whether the researcher is developing descriptive measures, developing product samplings, working on the organization of data, or even creating control charts, the tactics employed will not need to be more complicated than a typical layperson working at an SME might easily comprehend.

One of the least complicated methods for supporting suppositions, when dealing with simple measurable situations like these, involves a breakdown of the data offered so the results are delivered in percentages. Of course, the advantage being our concepts of percentages are relatively simple and already largely understood by many. Using one such tactic, the data shown in the tables of the section entitled “Component Compare – Phase One” in chapter 3.3.2 is useful in yielding viable figures. Based on the information collected a researcher can identify general quantities related to revision discrepancies in the different packages. Aspects such as the first pass yield, fallout, and scrap can easily be identified in each order’s sample of production documents. In this study the first pass is the number of documents acknowledged as matching the revision levels specified by engineering. The fallout represents the number of documents that do not match the revision levels specified by engineering. Rework represents the number of fallout documents that do not require a completely new part to be produced. Scrap, on the other hand, represents the number of fallout documents that do require a completely new part to be produced and is found through the following simple calculation:

$$\text{Scrap} = \text{fallout} - \text{Rework}.$$

The results for first pass, and fallout are typically expressed as percentages of the sample size, while rework is shown as a percentage of the number of items identified as fallout.

These basic mathematical calculations can be used to present understandable findings to an SME’s management team. Knowing roughly what percentage of the tasks are identifiably impacted by aspects of the current engineering change processes should prove useful for not only this research, but for any other areas that might need to be evaluated in the future. A researcher could, if they choose, combine the data gathered to show that out of any randomly selected group of parts there is a clear percentage that will likely contain inconsistencies in revision levels. It could further be explained that, based on this assertion, future jobs might likely suffer from similar occurrences of issues between what engineering specifies and what procurement orders, and/or what manufacturing produces.

With a few relatively uncomplicated steps, one can build an argument for possible areas of improvement by showing that relatively similar results are consistently found in these different packages, from the standpoint of percentages. With a good level of basic information, it will not be too difficult to explain how such findings are likely to occur across all the orders the SME produces. If additional persuasion is needed, those numbers can be applied to a similar formula for calculating a rough estimate on the percentage of all parts manufactured that are likely to have an erroneous revision level on the documentation. Any of the findings generated could be further used to estimate some potential impact levels if the forecast results do ultimately transpire. The premise behind employing these methods is to document and potentially show managers and associates at SME's an often-overlooked view of their operations. By focusing on these types of problems, which might be occurring throughout their operations, we bring attention to obscure issues and highlight some their potential impact on the organization.

Another benefit is that such an approach can be relatively easy to explain to the average layperson, should the necessity for that arise. For example, the steps for finding the percentage on the items reviewed can be described as follows:

1. For each observation process laid out above, the researcher records the total number of documents included in that manufacturing area, we can call that the 'X' variable.
2. For the item of interest, the number of occurrences identified is observed and documented, and we can call that the 'Y' variable.
3. The objective can be calculated by dividing the number of instances identified 'Y' by the total number of observations in the count 'X', this calculation can be shown as Y/X = % of occurrences (in a decimal format).

In addition to this simple percentage explanation, there could be a high-level approach taken for explaining the basic concept of how these percentages might apply to the overall operations of production. That of course touches on the idea of normality and statistical processes, such as random samples, but it can still be presented is its basic form. The idea being simply that every subject one looks at, when all instances are considered, behaves in a predictable manor that will generally result in a normal curve. Further, by randomly selecting a sample (in this case 10% of the SME's entire production log) from the entirety of the subject you are left with a scaled down outcome that will match the findings of the whole subject being considered. Basically, randomly selecting 10% of the products and checking them will show you the same percentages as though you went through every item and performed the same review processes on each item.

There are of course other methods which might be deemed by some to be more appropriate for such a study. One approach that could be useful involves the identification of the fraction nonconforming within the different packages under review. While this method can indeed be a powerful tool, and some may feel it is a better choice over the simpler percentage calculations presented above, it requires a substantial understanding of the mathematics behind algebra and statistics, as well as advanced quality practices. It is true there could be an argument made for the simplicity of several other tools available, especially when compared to the more advanced tools utilized in other documented endeavors. This author however cautions from experience, that presenting such an approach may still alienate some of those associates within an SME that are less knowledgeable, as well as any that may not be interested in learning new skills. Likewise, if the subject SME is one that embraces training and education, there could be opportunity to advance their processes more swiftly, but in those that are chiefly concerned with getting product out the door, it is believed that any inroads will be better accomplished through the simplest means available. No matter which approaches the researcher selects for technical problem solving, they should understand that each process design needs to fit the audience for which they are intended. With the typical SME employee, that may mean it will need to be much more basic in nature, especially if the hiring requirements of the company are the relaxed levels mentioned in the review chapter of this paper.

In addition to identifying the potential occurrences of revision issues, and possibly performing simple calculations to show how often such circumstances might be encountered during a typical job, the analysist can calculate the potential costs that might be correlated with the issues unearthed. These calculations will involve considering the various steps taken when a component is found to be deficient, due to revision discrepancies. Cost calculations connected to miscommunication in the change processes will also be relatively straight forward and should be easy to explain to most of the employees one is likely to encounter at an SME. The first steps are of course to identify the problem, and one simple take on this is described in the sections above, the next step involves tracking and documenting the correction to that problem. The two common approaches to part correction in SME manufacturing environments are:

1. Rework or modify the existing piece to match what is needed.
2. Make a new item that does match what is required for the design.

For the rework option, there may need to be cost considerations for shipping and timing delays, especially if that item needs to be sent back to an outside vendor for correction. There may also be expediting fees involved, or the vendor may be busy working on other orders, causing delays that might impact the SME’s work. Such implications can be quite burdensome to an SME’s bottom line if they are encountered. If a part needs to be remanufactured, then the cost is effectively doubled. If the items are reworked, then the effect of that process will need to be documented and any time or material costs added to the package’s final costs. Either way, by including all the additional costs associated with the selected correction process, the researcher will be able to calculate a reasonable cost impact to the packages due to the identified revision discrepancies encountered.

3.13 Methodology Summary

The intent of the methodologies described in the present study is to identify possible areas where there are discrepancies between what engineering has specified in their documentation and what other departments have in their documentation for the packages in an SME. By collecting data on the engineering change related issues encountered over several packages, an easily understandable analysis is developed which shows the different areas being affected by the organization's lack of effective change management. It should be recognized that breakdowns in communication between engineering and other departments can effectively lead to poor quality parts delivered to customers, both internal and eventually external. It turns out there are many reasons a product or service might violate the tenets of good quality. One reason, as mentioned, has been recognized by this researcher as a vital tool for ensuring quality deliveries to one's internal customers, and that is ECM. Addressing quality can be tricky, as we see in looking closely at the available literature, where we find that different rationales can generally be found for addressing manufacturing practices, and a multitude of different strategies do exist for each rationale. While one should recognize the validity of more advanced methodologies, often covered in literature, for identifying and addressing possible problems, it is also crucial to recognize that such approaches are not always perfect for every situation.

One strong case for not engaging in one of the more advanced tactics involves the general mindset of the organization which is under review. If the focus is on an SME that may not embrace the notion of offering training and promoting educational opportunities, there could be substantial pushback when the topic for such activities is broached. There could also be a large void in the knowledge base of such an organizations front-line associates due to sub-standard requirements for entering the positions therein. One is equally likely to find that department leads, mid-level managers, and sometimes upper-level management might only possess a basic level of education. Such findings could result from long term employees who have made their way up through the ranks, or from nepotism, or any number of explanations. It is for these reasons, and more, that this study has intentionally focused on methods which are developed based on much simpler philosophies. By keeping with a very deliberate attitude regarding simplicity in the approaches established, the researcher presents some straightforward steps which demonstrate the potential influence that current engineering change processes can have on production efficiencies.

Throughout these methodologies there are steps for making observations, as well as for questioning processes, which are intended to gain insight to subtle influencers present in the current processes. The findings of all observations, and the question-and-answer sessions, can be categorized and documented for potential use in future studies. Any information collected might likewise prove useful in presentations or persuasive measures that could be developed to sway the subject SME’s management teams.

Chapter 4 –Analysis Review

This chapter presents the analysis conducted for the SME that was selected for this research study based on the steps laid out in section 3.1 of the previous chapter. After scrutinizing the organizations that were initially under consideration, the researcher was able to settle in and choose a local manufacturer which has been found to have enough orders available for review. With a subject company that is ready to support this research effort there is promise that reliable and usable information can be obtained. Using the steps described in the previous chapter, packages and components were identified for consideration in this study. The data presented comes from approximately ten percent (10%) of the current, and recently completed, workload identified within the subject SME's order logs. Through random selection, the packages are chosen, and from the resulting pool ten percent (10%) of the components needed to finalize each job are randomly picked for review. All available documentation regarding those components is then evaluated for irregularities in their revision levels. Observations that constitute errors with any component reviewed are based solely on the revision level of the parts as they are procured and manufactured, as compared with what Engineering has specified.

4.1 Individual Packages

Before embarking on any selections processes, the analyst engages in several steps geared at creating reliable and repeatable outcomes. For each of the selected packages, the researcher obtains an up-to-date list of the revision levels associated with the items being examined from the engineering department, via their liaison. The researcher then walks the various departments and manufacturing areas, with their respective liaison, and collects all the pertinent revision data on the components of the three orders under consideration. Throughout this collection/observation processes the investigator maintains a focus on revision levels of each component identified at those different phases, from procurement to the manufacturing and assembly areas, which culminates at the final assembly stage of the packages under review. Figure 1 below offers a step-by-step sequence for the initial part review processes undertaken in this research study.

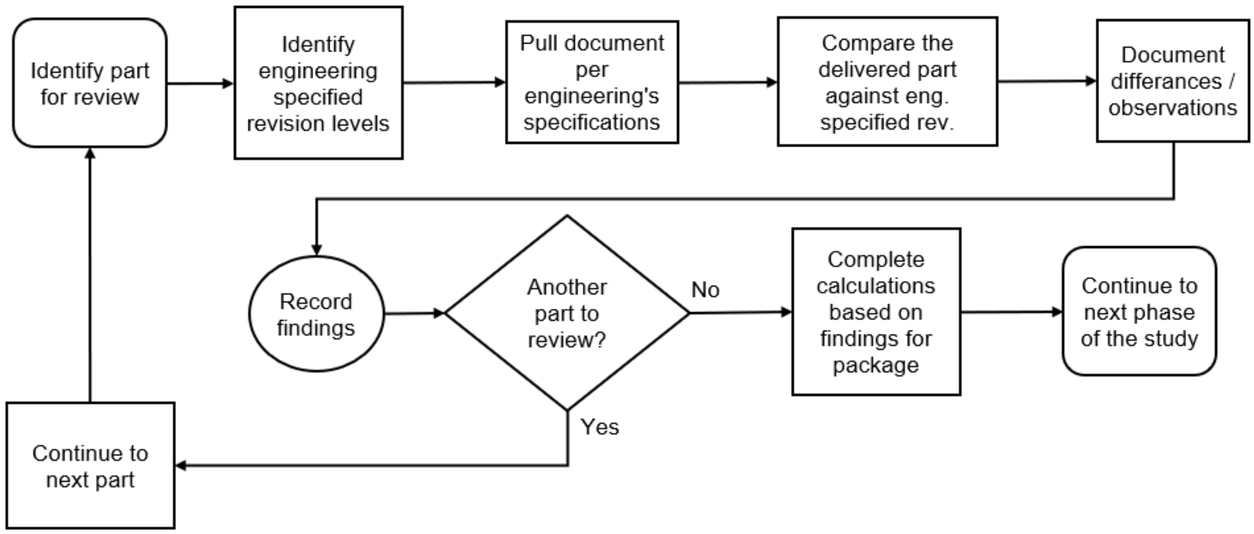

Figure 1, Part Review Workflow – Revision comparison.

As can be seen in the workflow above, each part review session is developed in a cyclical series of steps. Again, this is meant to maintain the simplicity of the research study. The researcher only needs to identify which part will be selected based on the order that is currently under review. Each step in this workflow is utilized to generate results which are discussed in the next sections of this chapter.

4.1.1 First Order Package

The first randomly selected package is comprised of three (3) sub-assemblies and a total of one-hundred-thirteen (113) different manufactured components. From that, there are twelve (12) items randomly selected to review their compliance with the revision levels specified by engineering. Out of those 12 components, the researcher identifies five (5) production documents that do not match the revision levels based on engineering's designs. By inputting these numbers into an Excel spreadsheet, built around the simple approaches and calculations discussed in chapter 3, the researcher generates findings on various aspects of those manufactured parts. As has been touched on in this text, the results can also be utilized amongst additional features within the Excel program to generate different outputs, if desired by the researcher. Table 10 and Figure 2 below represent the Microsoft Excel calculation and chart generation results, respectively, from the data identified in the first order under review. Note, the purpose behind using these outputs is to provide amazingly simple and easy to understand visual representations of the findings from the package's review.

Table 10, *Excel – First Order Package Input and Results*

First Package	Input Data	% First Pass	% Fallout	% Rework
Sample Size	12	58.33%	41.67%	60.00%
First Pass	7			
Fallout	5			
Rework	3			
Scrap	2			

Note. The first pass, fallout, and rework cells reflect the percentage calculation results for the first order.

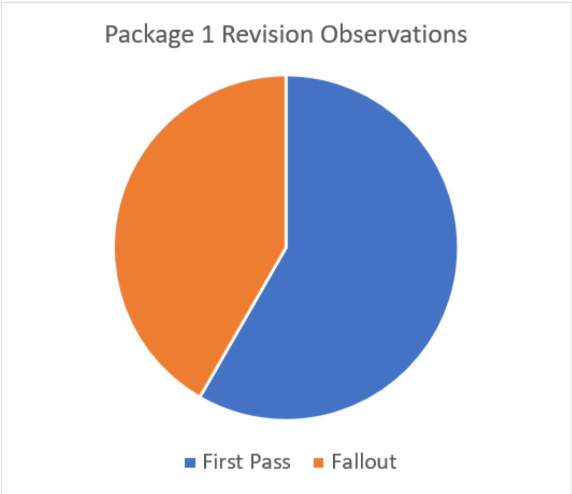

Figure 2, Pie Chart - Revision Observations, First Identified Order.

(First Pass = 58.33%, Fallout = 47.67%.)

4.1.2 Second Order Package

Continuing to the second randomly selected package, we find that it is comprised of three (3) sub-assemblies and a total of ninety-four (94) different manufactured components. In this order there are ten (10) different items to be reviewed for compliance with the revision levels specified by the engineering department. Out of those 10 randomly selected components, the researcher identifies three (3) production documents that do not match the revision levels based on engineering's designs. Again, by inputting the data to excel, the analyst generates answers for different aspects of the items under review. Table 12 and Figures 3 below represent the Microsoft Excel calculations and chart generation results, respectively, from the data identified in the second package under review.

Table 12, *Excel – Second Order Package Input and Results*

Second Package	Input Data	% First Pass	% Fallout	% Rework
Sample Size	10	70.00%	30.00%	66.67%
First Pass	7			
Fallout	3			
Rework	2			
Scrap	1			

Note. The first pass, fallout, and rework cells reflect the percentage calculation results for the second order.

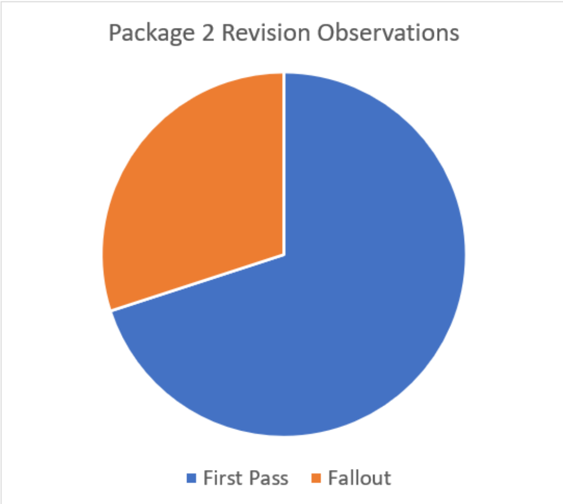

Figure 3, Pie Chart - Revision Observations, Second Identified Order.
(First Pass = 70.00%, Fallout = 30.00%.)

4.1.3 Third Order Package

With the third randomly selected package that is studied, we find that it contains four (4) sub-assemblies and a total of 140 separate manufactured components. In this instance there are fourteen (14) different items to be reviewed for compliance with engineering specifications. Out of the 14 randomly selected components, the researcher identifies three (3) production documents that do not match the revision levels based on engineering's designs. Applying the same simple process again the researcher inputs the data to excel which generates answers for the same aspects of the documents under review. Table 13 and Figure 4 below represent the results from the data identified in the third package.

Table 13, *Excel – Third Order Package Input and Results*

Third Package	Input Data	% First Pass	% Fallout	% Rework
Sample Size	14	78.57%	21.43%	66.67%
First Pass	11			
Fallout	3			
Rework	2			
Scrap	1			

Note: The first pass, fallout, and rework cells reflect the percentage calculation results for the third order.

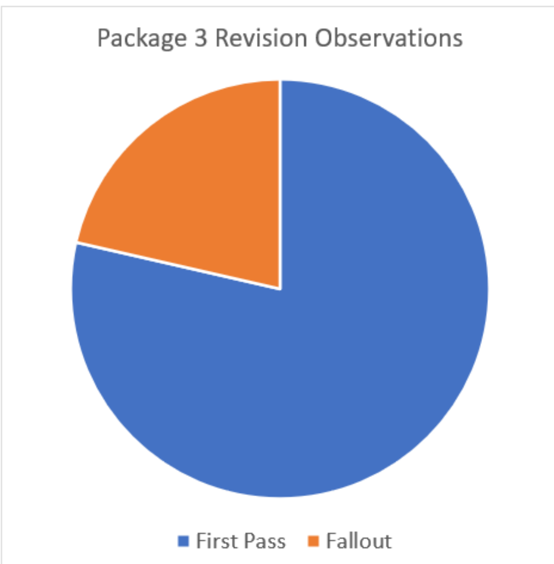

Figure 4, Pie Chart - Revision Observations, Third Identified Order.
(First Pass = 78.57%, Fallout = 66.67%.)

In reviewing the information applied in excel, we see that there is a comparable number of instances where revision level discrepancies have been encountered throughout these jobs.

4.2 Overall Numbers

After compiling the data on the three different packages, we can enter all the information into Microsoft Excel and create similar results, and a pie chart, that are based on these combined inputs. The purpose for this is to generate simple representations on the overall averages of the results seen in this study. From there it is not a far leap to explain how such results might be applicable across all components in the company's design catalog. The total numbers encountered in this study shows that we have seen thirty-six (36) randomly selected parts and out of that, there are eleven (11) with revision levels which do not match what engineering as specified in their designs. Again, using Excel to apply the data found throughout the analysis phases allows us to calculate percentages and generate a chart based on those overall observations. As with the individual packages, we can create simple visual and data representations on the totals observed, which will help the researcher to provide insight to the average number of errors that might reasonably be expected in any order, should the current processes be allowed to continue unchecked. Table 14 and Figure 5 below represent the results achieved after combining the data identified in the three packages reviewed.

Table 14, *Excel – Combined Order Packages Input and Results*

Total Packages	Input Data	% First Pass	% Fallout	% Rework
Sample Size	36	69.44%	30.56%	63.64%
First Pass	25			
Fallout	11			
Rework	7			
Scrap	4			

Note: The first pass, fallout, and rework cells reflect the percentage calculation results for all components identified for review in the three orders.

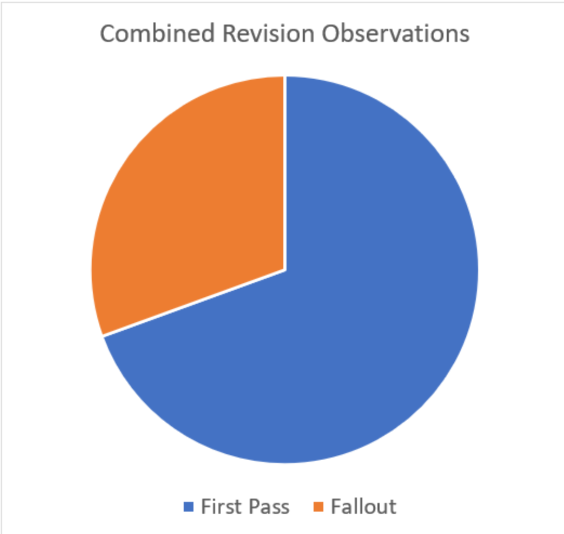

Figure 5, Pie Chart – Revision Observations, All Identified Parts.
(First Pass = 69.44%, Fallout = 30.56%.)

Based on the results of these observations, and some relatively simple calculations, we can see that, today, the SME seems to be operating with about a 30% fallout on the revision levels of the components produced, when compared to what engineering has specified. Clearly there is a failing in the current engineering change processes which are likely contributing to this problem.

The analyst then uses the information collected to develop a Pareto chart of the revision discrepancies identified based on each of the different areas judged to be their point of origin. The Pareto Chart is a feature accessible through Excel, that can identify the extent to which different factors of a given dataset are contributing to a particular problem.

By applying this tool, the author shows which areas of the overall process are most influential in creating these revision discrepancies. Figure 6 below represent the results from applying the combined data identified in the three order packages under reviewed to create that Chart.

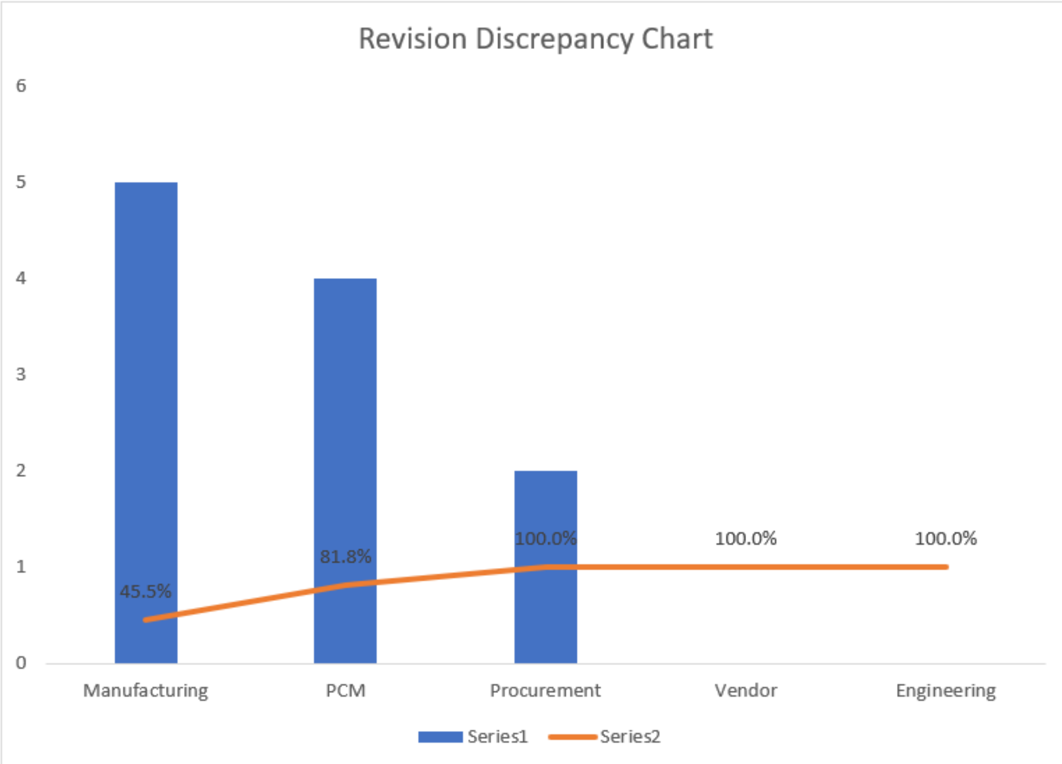

Figure 6, *Pareto Chart – Identified revision incongruencies pinpointed per department.*

Based on the results seen in the Pareto Chart above, the area of these processes that is contributing most, producing about a 45.5% of the total revision discrepancies, is the various manufacturing locations and their marked-up documents. Behind that we see that Manufacturing and PCM combine to produce 81.8% of the total revision discrepancies. By the time procurement is included, the entirety of the origins for the identified revision discrepancies have been identified. Clearly, now there is justification for some form of corrective action to the identified problem.

Quite frankly, the author feels the results provided thus far should be more than enough information to compel those on the management side of any company to at least investigate what these variances and their likely causes. Unfortunately, other factors are sometimes at play which could obscure management's view of otherwise obvious production shortcomings. Identifying those factors could be another good topic for study, but that is beyond the scope of this research.

The obvious first question related to the topic of this study is, why are these revisions not matching what engineering specified in their designs? To track that down the analyst digs into the steps taken whenever an order is initiated in the system.

4.3 Process Review

Throughout the data collection steps for this study the researcher gathers notes on observed procedures while taking a high-level look at the general tasks performed as three orders make their way through the manufacturing processes within an SME. The objective behind looking at each step is to identify areas where an opportunity to implement the wrong revision level could exist. This phase involves tracking the steps for each document associated with the parts that are required in these packages. Based on any potential breakdowns found in the steps observed during the production of these parts, the researcher can begin to develop proper alternatives to the processes currently in place.

Maintaining the approach introduced in chapter 3, the researcher poses several questions which each liaison presents to their department's frontline counterparts. The aim again is to gain more understanding of the current processes, along with the different views held by those frontline associates on important steps. As with the theme of this study, a simple approach is taken so as not to overwhelm the workers and potentially alienate them in our study. The questions put forth during this phase are presented in appendix 'D' at the end of this paper.

With each process developed the researcher consciously strives to identify basic steps that can be denoted within a workflow structure that is easily applied to the various areas of the SME. In working through the different phases of the study each workflow is adhered to as closely as is practical for the different instances under review. The purpose for creating these basic functional roadmaps for the different sessions is to provide participants with repeatable and reproducible course of actions throughout the research study. Of course, the workflows can be further used by anyone interested in conducting similar research with a clear guide that is easily followed, either through precise replication or as a general road map. Figure 7 below represents the simple steps proposed for the initial question-and-answer phases associated with the different departments involved in the processing of the different parts identified in the research study.

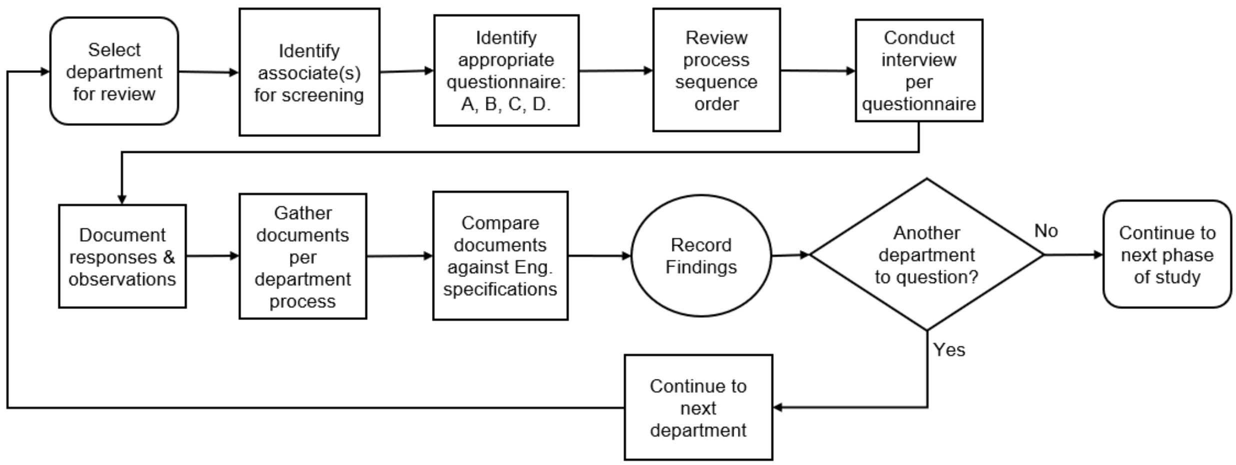

Figure 7, Project Workflow – Process Question and Answer Phases.

As can be seen in the workflow above, each Q-n-A session is developed much like the previous workflow, in a cyclical series of steps. Again, this is meant to maintain the simplicity of the research study. The researcher only needs to identify which questionnaire (A, B, C, or D) to implement, which will be selected based on the department that is currently under review. Each step in this workflow is utilized to generate results which are discussed in the next sections of this chapter.

4.3.1 Production Control

It turns out that the first place an order goes, once it gets approved at this SME, is the Production Control Manager (PCM), which is effectively the position over all the in-house Manufacturing. As a result, the researcher proceeds to PCM office and observes the steps taken upon receipt of a work order. What was found when that process was viewed is a series of steps that could, by themselves, probably result in the wrong part revision being manufactured at any given point.

The PCM's first step involves a search through a local thumb-drive for the various assembly and part numbers known to be associated with the machine specified in the work-order. It was explained that jobs always start by looking in this isolated file system to see if the product has been built by the company in the past. If it is found that something has been made before they simply pull the documents, based on what had been created previously, and they commence with the production processes for all the parts they have the capacity to produce in-house. During the observation of these actions, there were no attempts witnessed to verify the versions of any documents pulled from the thumb-drive. The researcher noted that this could be an especially questionable method of document storage and retrieval as it is clearly vulnerable to producing items at an incorrect revision level. In fact, upon going over the notes taken during the observation phases, it was determined that of the eleven (11) total revision mismatches, five (5) of them have a connection to incorrect revision levels located on that thumb-drive, while four (4) of them came as a direct result of this thumb-drive. It was also found that one (1) of the document revision errors may be tied to another process found within production, so it cannot be solely blamed on the thumb-drive. Though with that part there is also a revision mismatch from the thumb-drive that should be noted.

While observing these steps the researcher discovered, if items exceed their production capabilities the head of production control notifies the procurement department so those parts can be ordered from outside vendors. The observer is also informed, for new packages that have never been produced they will reach out to engineering and ask them to create the new machine designs to meet the specifications of the order. If that is the case, when those designs are completed, engineering sends manufacturing an email indicating the designs are done and points them to where the files are in the company's computer system.

When questioned further, the manufacturing manager indicated that copies of any new engineering files are always pulled in and stored on the thumb-drive that is kept in their own area. When asked where, it was stated they keep the thumb-drive stored in a desk drawer in the main manufacturing office. As a point of reference, the manager was then asked about how engineering changes are handled. At that point it was stated that there is a CAD program that the PCM accesses so they can make any adjustments if they are deemed necessary. It was also expressed that information regarding change is not generally passed along to other departments, unless it is believed they will need it. One example given, something they are not capable of producing in-house has any updated files shared with procurement so they can get the part manufactured by one of the outside vendors.

4.3.2 Procurement

Based on the information gained from the PCM, procurement is the next department observed. Interestingly, it was noted that in this SME, the procurement department reports directly to the PCM. The purchasing agent stated that they create the manufacturing work orders for each package based on information they receive from their boss. The steps observed demonstrated how the associate collects the necessary document lists, or Bill of Materials (BOM), from the company's Material Requirements Planning (MRP) system. The SME has their MRP systems set up to contain data on each part created, including the part numbers, the location where the part is produced, and the material used to make the parts. It was discovered that there are fields in the MRP system for revision levels, but in most cases observed that information was omitted from entry into the system. In building the work orders, the procurement associate segregates items based on the location of their production and retrieves electronic copies of documents from a file location on the company's computer network for inclusion in the work instruction files/packet. The completed work instructions are then forwarded to the heads of each area where the items will be produced. While observing these procurement steps, it was noted that orders for outsourced components were created in the same manner. It was also observed that all manufacturing documents are sent to outside vendors after being pulled directly from procurement's own file location on the company's computer network. The procurement associate was asked how many part documents were in that location and who has access to it; the researcher was informed that it contains the documents on all parts the company produces, and no one else has access to that location for any purpose.

When the purchasing agent was asked about changes, they stated that it depends on the change. It was explained that simpler changes are usually done by hand, by the procurement associate, and scanned so the updated documents can be placed into their file location. More complicated changes are sent to the head of manufacturing, but sometimes they are directed by their boss to contact engineering to complete the changes. It was stated that if changes are done by the PCM those changed/updated documents are generally sent back from manufacturing, and they get stored in the computer file location. It was also said that for changes sent through engineering, they usually receive an email showing a location on the computer system where the corrected documents are stored, and they then go to that location and copy the files, and as before, store them in their computer file location. When asked if they ever receive any other documentation from Engineering, they replied, no they usually only send what is asked for. Procurement was also questioned about what might prompt them to ask for something from engineering. It was indicated they rarely contact engineering, unless a new design/part-number is needed that neither manufacturing nor procurement already has in the file system.

As was seen in the previous section, during the observation of these actions there were no attempts witnessed to verify the versions of any documents pulled from the network computer system. Again, it was noted that this could be an especially questionable method of document retrieval and it is clearly vulnerable to producing items at an incorrect revision level. As with the steps of the PCM, upon going over procurements procedures, it has been noted that the observation phases found that of the eleven (11) total revision mismatches, five (5) of them have a connection to incorrect revision levels located in their file location, while two (2) of them came as a direct result of this unique location. It was found that three (3) document revision errors are also associated to another process found within production, so it cannot be solely tied to this isolated file location on the computer network. Though, again, there are revision mismatches from that location that were noted.

4.3.3 Manufacturing – In-House

The next areas for observation and the data collection involves the in-house manufacturing processes of the eleven (11) items under review. In these learning opportunities we can confirm the information gathered from the procurement department and the PCM. In addition to a reaffirmation procedure, there is opportunity to learn about any steps that may fall outside of those previously described by the preceding areas. What we find is; sometimes the documents included in the work instructions are not always utilized by the frontline associates to create the different parts, and components of the three packages under review are no exception. It turns out that more than one associate in the various manufacturing areas takes steps that might circumvent the engineers design, by creating parts that may not match the engineering revision levels specified in those designs. Yet again, the findings when these processes are viewed reveals a series of steps that could, by themselves, result in the wrong part revision being manufactured at any given point.

The manufacturing steps involve the department lead searching through work orders and sorting the documentation provided therein, including the part lists and the production documents (drawings). Those documents are then doled out to the appropriate frontline associate based on the tasks that need to be completed for the parts. Through a series of various steps and procedures, the needed materials and information end up at the appropriate location/associate. In observing the different steps taken in these areas, the researcher identified some individuals reading the parts lists, and then going to a location where there appeared to be hard copies of part drawings stored. When these associates were approached, it was explained that they always start by looking for the "correct" drawings in their marked-up files before they do any other work. The researcher was shown stacks of different part drawings that all had substantial mark-ups and notes written on them. Each associate indicated in their own way that this is the procedure they always follow, and if they get a new design, those documents are gone over and marked-up as needed to make the right part. Not one associate indicated that the information on their marked-up documents is ever shared with anyone outside of their areas.

While the different associates did tend to check their work as they produced each part, it was observed that none of those checks were done to verify the completed parts matched the versions provided in the work orders. Likewise, there was no comparison made to the revision levels specified by engineering. As with the departments observed in the previous sections, the researcher noted that this could be an especially questionable method of part production, and at the least it is clearly vulnerable to producing items at an incorrect revision level. In fact, upon going over the notes taken during the manufacturing area observation phases, it was determined that along with the eleven (11) total revision mismatches identified, five (5) incorrect parts are directly connected to the differences in the marked-up documents located in the various manufacturing areas. This is an interesting finding, because those parts are technically ‘wrong’ due to both the revision levels indicated in the work orders and because they were not manufactured to the specifications in those “incorrect” documents. One could create another complete study on the different aspects of shop floor mark-ups and their impact, of course that is outside the scope of this paper. What this researcher has focused on is the revision levels specified by engineering in comparison to what is included in the procurement work instructions, what is produced, and what is delivered to the final assembly.

4.3.4 Manufacturing – Outsourced

Based on the information collected from the procurement department, and the conversations that took place between the researcher and the outside vendors, it was determined that in-depth observations of those vendor locations are not necessary. It was established that the vendors, in these instances, do not maintain any documents for manufacture beyond the time they receive sign-off and acceptance from the SME. From that information, and the steps laid out by the procurement associate, it is understood that any revision discrepancies that are generated at those outside locations are most likely the result of the documents sent to them by the procurement department. Of course, such findings are not guaranteed, and any future study will need to review the outside locations to determine the risk for revision corruption associated with their own processes.

4.3.5 Engineering

For the engineering department, the researcher asks the liaison to inquire about the steps taken for changes and new design creation. The information gathered is used to identify potential areas for improvement in those processes. What the researcher observed involved changes being made without regard for any set approval processes. The engineer indicates that changes to designs could come from any number of situations, and that there is no official process for review or approval. It was further stated that the ultimate decision lies with the engineer, and that is based on whether they feel the change is warranted or not. The researcher also learns that the engineer stores all their production documents in the same location on the company's computer network, and it is believed that everyone in the company has access to read the files in that location. The engineer assumes that fresh documents are pulled every time a job is initiated, and there was great concern expressed when they were informed by the researcher that this may not be the case.

The engineer states that they always send out email notifications to the concerned associates when they have completed a design, and they further identify any location where the documentation can be found in the system. It was acknowledged that changes are not always treated the same way, because sometime, engineering initiates the change so there is no one to send notification to. Again, it is assumed that any change originating in engineering would be picked-up the next time the applicable task is undertaken. Clearly, there is questionable methodology at play in the change process within the engineering department, and it is vulnerable to producing item revisions that will be missed in the other departments.

4.3.6 Assembly

The different assembly areas are next to be observed in the research study involving these three packages produced at this SME. What was found is; the associates are sometimes taxed with additional steps because of discrepancies in the components they are provided for their assembly work. For the orders under review, each item that has been identified as a revision discrepancy clearly adds time to the assembly processes. In some cases, the problems are quite detrimental to the workflow of the entire assembly team, as the process is stopped to assess the situation. There are instances with these packages that seem easy to resolve, and there are some that take extended time and resources to sort out. To assess the impact, the researcher engages in a rudimentary method of timing each instance and documents the cursory delay from the revision issues encountered. This process involved using a time keeping tool to measure the amount of time each process was postponed. The researcher also documented the number of associates that appeared to be directly impacted by each of these situations. The revision inconsistency tables below (Table 15, Table 16, & Table 17) show the results of these data collection processes.

Table 15, *Revision Inconsistencies - First Order Package Impact*

Revision Inconsistencies - First Package Impact					
Part Identifier	Production Impeded (Y/N)	Number of Associates Affected	Length of Impact Time (hr)	New Part Required (Y/N)	Rework Required (Y/N)
PTXXXXX1	Y	4	2.67	Y	N
PTXXXXX4	Y	5	0.88	N	Y
PTXXXXX6	Y	7	1.37	N	Y
PTXXXXX8	Y	3	0.97	N	Y
PTXXXX12	Y	8	1.58	Y	N

Note. The table above shows the impact, in hours, for the revision errors in the first order.

Table 16, *Revision Inconsistencies - Second Order Package Impact*

Revision Inconsistencies - Second Package Impact					
Part Identifier	Production Impeded (Y/N)	Number of Associates Affected	Length of Impact Time (hr)	New Part Required (Y/N)	Rework Required (Y/N)
PTXXXX16	Y	4	1.33	N	Y
PTXXXX17	Y	6	0.83	N	Y
PTXXXX22	Y	8	2.17	Y	N

Note. The table above shows the impact, in hours, for the revision errors in the second order.

Table 17, *Revision Inconsistencies - Third Order Package Impact*

Revision Inconsistencies - Third Package Impact					
Part Identifier	Production Impeded (Y/N)	Number of Associates Affected	Length of Impact Time (hr)	New Part Required (Y/N)	Rework Required (Y/N)
PTXXXX24	Y	6	0.70	N	Y
PTXXXX27	Y	10	1.20	N	Y
PTXXXX29	Y	5	2.67	Y	N

Note. The table above shows the impact, in hours, for the revision errors in the third order.

From the tables above, it is clear these revision inconsistencies are having an impact on the productive system hours (PSH) of the organization. Repeated slowdowns could also influence attitudes of associates in these assembly areas, and there is likely extra tool wear and machine hours required to rework components which are not considered in this study. The data collected in the assembly areas is then used to calculate a high-level cost due to the wasted time involved when these types of problems come up. It was often witnessed that the associates are at a standstill during the time that it takes to track down the sources of the issue, as well as the time it takes to identify a suitable course of action, and the time it takes to execute that action. Not only are the associates in the workstation where the problem is identified slowed, but many times associates in the next station find themselves waiting for work because of the problem. These issues can be more impactful in SME's than in larger organizations where they generally have standard procedures in place for addressing issues encountered in production. There are, in fact, usually systematic procedures identified in those larger companies based on several factors. There are no rules that have been established for handling dispensation or corrections to problems encountered for the SME under review. As a result, many of the associates appear to be wasting additional time by repeating similar steps when issues are faced. It is largely understood that any addition steps, or wasted time, will add to the cost of producing a product. Added costs clearly impact the bottom line of the SME.

4.4 Costs

After the discrepancies in the document revision levels, and the impact of those issues on the different production areas are identified, the next step involves calculating potential costs of these issues to the organization's bottom line. This process will involve the appropriate liaison reaching out to the accounting department to gain information on the different costs associated with the various production areas. The cost information gathered can then be applied to specific mathematical formulas to determine some plausible financial impacts incurred by the company, likely because of these many degrees of inconsistency which have been identified in the package's document revisions.

If it is deemed more acceptable, and there is ample time available, the researcher can work to obtain the actual costs for each position involved in part production and assembly for the orders under review. That information can then be utilized to possibly obtain more accurate results, but for this project it was determined that using average charges from accounting would better fit the simplified approach of the study, while still yielding suitable results for the SME being considered. After the cost data is obtained from the accounting department, the researcher works to select techniques for accurately assessing the possible costs of those revision discrepancies identified. As with every phase described above, these appraisals are handled with basic means that should be understandable by the average associate at most SME's.

4.4.1 Costs - Time

Based on the simple approach selected for this study, our liaison pulls together only the average hourly charge associated with the production departments that were subject to the observation phase. What we find is, the accounting department generally uses $85.00 per hour when they are looking for high altitude costs related to these areas of production. The liaison was also able to retrieve the average (or expected average) cost per component for each package being reviewed. There we are told that the accounting department expects the cost of each manufactured piece in the three different orders to average out as follows:

First Order Package: $1650.00 per item

Second Order Package: $2200.00 per item

Third Order Package: $2500.00 per item

Knowing these expected amounts, allows the researcher to apply the information in concert with what is understood from the observation phases to obtain some potentially useful figures. By considering the pertinent data from the steps and methodologies laid out above one can pinpoint what should be input to calculate potential costs for the issues identified in the study.

The calculation process here is focused on costs, due to the time impact, for the average part production on each order. These are very rudimentary formulas and are quite easy to apply in an Excel spreadsheet. The images below show the results of applying the company's standard hourly rate to the times identified in the revision inconsistencies tables previously shown. By multiplying the average hourly charge by the total impact time (PHS) observed in each instance we find the average cost associated with each occurrence. We can also calculate the total costs by summing those results. Below we see three tables (Table 18, Table 19, & Table 20) taken from these steps that were performed in excel.

Table 18, *Time Lost - First Order Package Impact*

Avg Cost ($/hr)	Total Impact Time (PSH)	Avg Cost Per Package ($)	
$85.00	10.67	$906.67	
	4.42	$375.42	
	9.57	$813.17	
	2.90	$246.50	
	12.67	$1,076.67	
	40.22	$3,418.42	**Totals**

Note. The table above shows the estimated financial impact from lost time due to revision errors in the first order.

Table 19, *Time Lost - Second Order Package Impact*

Avg Cost ($/hr)	Total Impact Time (PSH)	Avg Cost Per Package ($)	
$85.00	5.33	$453.33	
	5.00	$425.00	
	17.33	$1,473.33	
	27.67	$2,351.67	**Totals**

Note. The table above shows the estimated financial impact from lost time due to revision errors in the second order.

Table 20, *Time Lost - Third Order Package Impact*

Avg Cost ($/hr)	Total Impact Time (PSH)	Avg Cost Per Package ($)	
$85.00	4.20	$357.00	
	12.00	$1,020.00	
	13.33	$1,133.33	
	29.53	$2,510.33	**Totals**

Note. The table shows the estimated financial impact from lost time due to revision errors in the third order.

As we see from the tables provided above, the identified issues are clearly impacting each order financially. For example, the first package lost a total of 40.22 productive system hours (PSH) which, when calculated out using the standard charge ($85.00/hr.), shows that one package is set back $3418.42. The results here are based solely on the PSH lost in the areas observed.

We can further use the information collected to calculate costs due to time for the rework process on each component. For example, from the observations we know that there are three (3) items in the first package reviewed that require rework. The total time required for that rework can be identified by simply adding the three different times observed, in this case we find the total rework time for the first package as follows:

$$0.88 + 1.37 + 0.97 = 3.22 \text{ hours}$$

Using these results, it is possible to calculate the average cost added due to only the rework time on those 3 items. By multiplying the average hourly charge of $85.00 by 3.22 hours we find the rework time cost roughly $273.42. If that amount is divided by 3 (the number of rework items) we find the average cost of the time it takes to rework components in the first order is $91.14. Repeating these steps for the remaining two (2) packages it can be found that, for the second order that cost is $92.08, and for the third order the per component rework cost averaged out at $80.75. These amounts can be applied in later calculations to estimate the average cost per good part produced. Having that amount calculated could provide adequate motivation for the management team to pursue corrective actions that are aimed at alleviating the shortcomings identified in this study.

4.4.2 Costs – Per Good Part

At this point we have collected an adequate extent of data that can be used in other relatively simple formulas when looking for and documenting results. Doing so provides us with an additional level of reinforcement which can be further presented to support the findings of the research. One of the formulas selected provides for a basic approach to identifying the manufacturing costs for each good item produced. This formula can be found in a textbook entitled "Introduction to Statistical Quality Control" and is laid out as follows:

"manufacturing cost (per good part produced) = Cost/good part" (Montgomery 2013) (2)

By utilizing this formula, with the resulting percentages of the applicable yields calculated above, the researcher can estimate the effective first pass yield of the documents/parts for each package that is reviewed. Table 20, Table 21 & Table 22 below show subsequent findings from applying this calculation to the tables that were first identified in section 4.1. Each table also shows the result, if the average costs per item are applied to the entire job. While it is true that applying these costs to the entire package may initiate a discussion on the benefits of random selection and the concept of normality where statistics is concerned, it is believed that the simple nature of the study should alleviate any confusion which may otherwise surface because of those topics. Again, for the sake of consistency, and ease of use, these calculations are all performed in excel and the results are shown in the figures below.

Table 21, *Cost/good part - First Order Package*

First Package	Input Data	% First Pass	% Fallout	% Rework	Avg. Costs $
Sample Size	12	58.33%	41.67%	60.00%	$350.00
First Pass	7				
Fallout	5				
Rework	3				
Scrap	2				

$91.14	**Rework Costs/Unit**
$350.00	**Scrap Costs/Unit**
$517.34	**Cost/Unit**

Note. The table above shows the resulting estimated cost per good unit due to added costs from revision errors in the first order.

Table 22, *Cost/good part - Second Order Package*

Second Package	Input Data	% First Pass	% Fallout	% Rework	Avg. Costs $	
Sample Size	10	70.00%	30.00%	66.67%	$425.00	
First Pass	7					
Fallout	3					
Rework	2				$92.08	Rework Costs/Unit
Scrap	1				$425.00	Scrap Costs/Unit
					$539.91	Cost/Unit

Note. The table above shows the resulting estimated cost per good unit due to added costs from revision errors in the second order.

Table 23, *Cost/good part - Third Order Package*

Third Package	Input Data	% First Pass	% Fallout	% Rework	Avg. Costs ($)	
Sample Size	14	78.57%	21.43%	66.67%	$450.00	
First Pass	11					
Fallout	3					
Rework	2				$80.75	Rework Costs/Unit
Scrap	1				$450.00	Scrap Costs/Unit
					$531.65	Cost/Unit

Note. The table above shows the resulting estimated cost per unit good due to added costs from revision errors in the third order.

Reminder: As was mentioned in chapter 3, the first pass yield equates to the number of matching revision levels identified out of each of the random samplings, and these results are expressed as a percentage.

As an example, we already know the first order we reviewed consists of twelve (12) documents/parts and of that number, seven (7) were identified as having revision levels that matched the engineering specified revisions. By applying the average cost per component, obtained from the accounting department, and the rework costs calculated in section 4.4.1 above, we find the Cost/good part of is $517.34. The formula as it is applied within Excel is laid out below:

Cost/good part = Sample Size*(Avg. Costs) + Rework * (Rework Costs/Unit) + Scrap Qty. * (Scrap Costs/Unit) / First Pass + Rework

By utilizing this straight forward simple calculation, it becomes easy for the layperson to understand each aspect that is influencing the results. Furthermore, the results found from such a calculation can be readily updated by tweaking the inputs to represent any change that might be observed at other times. For instance, as each of any potentially identified enhancements gets implemented.

In addition to the results from the three different packages, the researcher duplicated those steps using the combined data, which again further supports the results obtained from the individual calculations shown above. Table 23 below reflects the findings from applying the calculations to the combined data. Again, the figure below also shows the result if the average costs per item are applied to that combined package data.

Table 24, *Cost/good part - Combined Order Package Data*

Total Package	Input Data	% First Pass	% Fallout	% Rework	Avg. Costs $	
Sample Size	36	69.44%	30.56%	63.64%	$408.33	
First Pass	25					
Fallout	11					
Rework	7				$87.99	Rework Costs/Unit
Scrap	4				$408.33	Scrap Costs/Unit
					$529.66	Cost/Unit

Note. The table above shows the resulting estimated cost per good unit due to added costs from revision errors in the three packages combined and averaged.

As can be seen in each of the figures above there appears to be a significant amount added to the cost of each part when one accounts for the extra costs of rework and scrap that resulted from the failing of the ECM system. With this information the researcher should be able to demonstrate how the presence of a lax ECM process can negatively impact the organizations bottom line. Of course, there are always other aspects that could be presented to management that might help sway them in commencing with the various changes that are generally involved when establishing a robust ECM system.

4.4.3 Costs – Potential Impact

In the previous sections we identify some of the potential costs/unit resulting from the discrepancies identified in the three packages that were randomly selected for review. Based on those results, the researcher can show different levels of burden potentially placed on different aspects of each order under review. By considering the resulting average cost/unit results, and the average costs that were provided by the accounting department, we identify an average cost added to each unit produced. Those amounts can then be applied to show a conceivable financial impact, by considering various aspects of the different orders and their components. In Table 24, Table 25, and Table 26 below we see some examples of how this data can be employed to further support the objectives of the study. The goal in these steps is to demonstrate how great the additional costs might be, as different perspectives on the packages are considered.

Table 25, *Cost potential - First Order Package*

$167.34	**Average cost added per unit**
$2,008.10	**Costs added if per unit costs are applied to all sample items reviewed**
$18,909.65	**Costs added if the per unit amount is applied across entire package**

Note. The table above shows the resulting estimated cost impact due to added costs from revision errors in the first order.

Table 26, *Cost potential - Second Order Package*

$114.91	**Average cost added per unit**
$1,149.07	**Costs added if per unit costs are applied to all sample items reviewed**
$10,801.23	**Costs added if the per unit amount is applied across entire package**

Note. The table above shows the resulting estimated cost impact due to added costs from revision errors in the second order.

Table 27, *Cost potential - Third Order Package*

$81.65	**Average cost added per unit**
$1,143.15	**Costs added if per unit costs are applied to all sample items reviewed**
$11,431.54	**Costs added if the per unit amount is applied across entire package**

Note. The table above shows the resulting estimated cost impact due to added costs from revision errors in the third order.

The researcher can again apply this approach to the combined data, and that information can be used to reinforce the numbers in the images above. In Table 27 below we find the results from the combined data being applied to calculations.

Table 28, *Cost potential - Combined Order Packages*

$121.33	**Average cost added per unit**
$4,367.92	**Costs added if per unit costs are applied to all sample items reviewed**
$42,101.91	**Costs added if per unit amount is applied across three packages under review**

Note. The table above shows the resulting estimated cost impact due to added costs from revision errors in the three orders combined and averaged.

With the numbers shown in the above images, the researcher identifies some possible ramifications from the ECM processes in place. Clear and relatively easy to understand results such as these should prove valuable when presenting the potential downside identified. The results seem to show that various aspects of the SME's current engineering change management processes should probably be revamped to alleviate these potential issues. Of course, there are additional influences that could have contributed to these results, and a researcher is always well served if they can at least touch on some of the other factors that could be at play throughout their study.

4.4 Other Influencers

A researcher might point out that there are other considerations which could have affected the time observed in looking at these issues within the different manufacturing environments. Obviously, identifying any relationship with costs could be helpful for swaying most SME's, and the goals of the endeavor are likely to benefit if that information is brought to the table. In considering the possible costs of the challenges identified above, the researcher relates time and the associated monetary aspect to the engineering change management system, and manufacturing practices observed. The results from linking this SME's existing procedures to a latent financial burden effectively underscores how impactful such circumstances can be. By gathering information in the manner laid out, one has an uncomplicated means to relate a cost of poor quality (COPQ) with an often underutilized, overlooked, and misrepresented tool, and it shows there could be measurable benefits if a solid ECM system is implemented. As implied earlier, the researcher believes there are more feasible approaches to improvements within manufacturing environments than many published studies consider, and it is that type of thinking which will continue to motivate this author to look for those less conventional theories when approaching the subject of the research study being presented.

From the literature review section, it should be clear this analyst is not opposed to considering techniques used in different concepts, even if they do not initially appear to relate to the objectives being sought. One such idea was encountered when looking at several existing research efforts that explore various aspects of the cost of poor quality (COPQ). Many of the studies found seem to be largely focused only on hard numbers associated with actual costs. There is some research however that touches on interesting aspects which may be thought of as unrelated, or maybe it is that they are overly apparent, which could cause them to be entirely neglected. When contemplating overall costs, or the cost of quality (COQ), the author of the current study feels a few of those unusual approaches could be good to at least think about when researching processes within an SME. The idea being; if more reinforcement is needed to shore up your results, one can present those theories which might be more readily accepted within small manufacturing environments. One example was found in reviewing different writings to prepare for this research; the 2014 study by Shahid Mahmood, Syed M. Ahmed, Kamalesh Panthi and Nadeem Ishaque Kureshi was considered potentially useful, because the authors found that if associates know that a method is in place to measure COPQ, there will likely be reductions in the costs being measured (Mahmood, Ahmed, Panthi, & Kureshi, 2014). Assuming that is the case, then perhaps similar results could come from other forms of oversight in manufacturing environments. That assertion may not be too far of a stretch, because as that study points out; their findings can be attributed to a behavior called the Hawthorn Effect which basically states that fewer mistakes will be made when someone knows they are being watched (Mahmood, et al. 2014). While the overall implications of that notion are clearly outside the scope of this study, in environments like the typical SME the author feels that it may be worth presenting the notion to management, so there can be some knowledge about the existence of such an anomaly. Along with sharing the information, it could be pointed out that some of the areas observed in this research study may have been performing differently due to the researcher's presence alone. While there is no concrete data to back up any assertions, one might suggest that by being watched the associates were prompted to work faster or more efficiently, thereby affecting the lost time that was documented. Furthermore, should an ECM system be implemented, and improvements observed, the idea that some of that progress could likely be attributed to the presence of the Hawthorn Effect must be shared freely. One should assume the reductions in COPQ will garner the attention of those in positions of management, which may cause them to focus on the processes perceived to have produced those reductions, so a researcher will be better off if they can point out other possible influencers that may impact the results (Mahmood, et al. 2014). In the next chapter the author will discuss the results found from the various steps taken above. While doing so, they will present some simple questions and suggested steps designed to guide in the development of an ECM system within the typical SME's environment.

Chapter 5 – Results and Conclusion

This chapter looks at the analysis of the three packages researched from the SME presented above, and reviews the findings obtained through those processes. The data used for determining the results has come from approximately ten percent (10%) of the current, and recently completed, orders found in the subject SME's workload records. In distinguishing the various points of information shown above, the researcher scrutinizes the production documents of each randomly selected item to uncover potential discrepancies in their revision levels. This material is amassed for each package, along with evidence on conceivable shortcomings recognized within the different areas of the procurement and manufacturing processes. Based on these actions, the analyst can establish some possible sources behind any dissimilar revision levels found. Among the information assembled are the number of incongruent part documents from each job, the rough amount of time that each production area is impacted due to those mismatching component revisions, the average costs tied to each department's workforce, and the average cost that was expected in connection with the individual parts as they were originally created/implemented in the production areas. With this information the researcher can estimate some of the additional financial impact incurred because of those identified disagreements in revision levels. By accumulating useful data and applying it in some basic calculations, the researcher can accentuate both the existence of a problem as well as some basic ideas for promoting ECM implementation geared at alleviating at least some of those issues.

5.1 Problem

The problem has been identified through several separate observations made by this investigator, over the course of a long career in engineering, design, and manufacturing. While working for various organizations of differing size, it was discovered that engineering change management is a vital aspect of most manufacturing processes. Over that period the realization came that, while many larger organizations may seem to embrace the concepts of ECM, involvement with smaller manufacturing enterprises has shown that many of those companies do not. Any shortsightedness found within SME's may be understandable. Consider that ECM generally gets overlooked, or at least glossed over, in many of the textbooks and scholarly articles that are available. That would certainly imply that some educated associates in these organizations might not be familiar with the ins-and-outs of ECM. The author postulates that whenever the topic of ECM does get touched on in published articles, the focus is usually on applications within vary large companies. Unfortunately, the approaches presented in many of those papers are often out of reach for smaller companies with substantially less resources available. Furthermore, those studies tend to lack consideration for any of the less educated associates that can readily be found working in SME's. Such an approach ultimately neglects most workers found in the United States.

There may be several reasons contributing to lower ECM utilization within the typical SME. Certainly, a big factor could be the level of knowledge necessary for many of the approaches seen in those scholarly articles that do exist, even those that more aptly speak to ECM. Unfortunately, most articles do seem to focus on exceedingly complicated methodologies that will require a strong understanding of several more advanced technical functions like mathematics. When faced with higher order calculations, it is not surprising that many individuals working at SME's could be deterred from embracing any objectives being put forth. It could therefore be reasonable to assume the average education levels among SME workforces is an impediment to the adoption of advanced albeit potentially beneficial maneuvers. Likewise, many individuals in SME's may lack adequate motivation to chase new knowledge necessary for the adoption of technically progressive tactics. As this study went over in chapter 1.5 above, the general levels of education typically needed for entry into smaller manufacturers are a high school diploma at 36% and no formal educational credentials at 28% (Watson, 2017). These percentages seem particularly telling when one considers research steps that were clearly written for people with an understanding of the higher-level computations found in statistical process control and quality assurance analysis, just to name a few. The researcher here has therefore set out to create a very simplified series of steps that can be easily explained, and consequently more readily embraced by a greater portion of employees found working in those smaller enterprises. A primary slant of this study is to circumvent potentially problematic approaches to engineering change management adoption within SME's by exercising the modest document reviews, production observations, and analysis steps laid out in the previous chapters.

Of course, the objective of the document review and the production observation phases are to demonstrate that simple approaches can be useful process improvement efforts. For this study, those efforts support a less convoluted methodology for spotlighting one issue which seems to be overlooked within the confines of a specific SME. The problem is ostensibly related to the poor communication and inadequate data transfer which can ultimately stem from a weak engineering change management protocol. The implications of which are not entirely lost in the available literature, but that largely tends to go beyond any simple approaches targeted here. Like was found in one paper by Jintack Han, Soo-Hong Lee, and Purevdorj Nyamsuren that points out how miscommunication of the changes in designs is responsible for generating significant costs as well as delays in the work (Han, Lee, & Nyamsuren, 2014). That theory certainly seems to be validated in the observations and results described in the chapters of this paper. It can surely be seen that without sufficient structure and reliable means for a consistent data sharing policy among the different departments within a manufacturing organization, there are many opportunities for process breakdowns to occur.

Because ECM can be so crucial in manufacturing environments, ignoring it does not support any of the notions that correspond with generally accepted best practices of industry. Anyone with a rudimentary understanding of business principles should understand that the hurdles identified in the earlier sections of this paper will all add to the bottom line of any company. While the problem presented above has been identified in one SME, there are numerous small manufacturers that are likely plagued by similar approaches to design changes in their own production processes. As a result, there is clear opportunity for almost any SME to utilize similarly streamlined approaches for addressing production issues.

5.2 Findings

The initial results found in chapter 4 of this paper confirm that room for improvement exists in this SME's manufacturing environments and their ECM systems. One need only look at the issues identified in the preceding chapters to see that there is a clear breakdown in the process currently in place. When looking at the revision levels of the combined 36 components reviewed, only 69.44% of them achieve a first pass success rate. That is, over 30% of the part documents used to manufacture those items were at a revision level that differed from what engineering specified for the design. This fact is illustrated in the pie charts and the Pareto Chart found in chapter 4 above. The impact of such discrepancies should be blatantly obvious. Still, to reinforce the notion that these findings influence costs, calculations are run to estimate the potential financial burden that might be seen from these, and comparable, ECM problems.

An example of the potential costs is readily identifiable through calculations using what we learn in the various steps above. One approach utilizes the combined results, from the 3 packages reviewed, as input for simple formulas to produce an overall picture of the downside to poorly controlled engineering changes. By taking the amended costs per unit of $529.66 and subtracting the average predicted costs of $408.33, we easily find the potential amount added per unit produced of $121.33. If those additional monies are applied to just these samples, which was roughly 10% of the components manufactured for the orders, we see that the company's bottom line takes a $4367.92 hit. That number is only a fraction of the negative impact that could be felt by the company. In fact, if every job the company produces results in a comparable number of ECM related revision issues, the impact could be astonishing. Just consider applying that added money to the total number of parts made for the 3 packages reviewed; we quickly discover a potential loss of $42,101.91 from only 3 randomly selected packages.

5.3 Approach

As we see mentioned throughout this paper, the researcher is focused on maintaining a level of straightforwardness, so the attitude taken in the approach is therefore relatively elementary. It is widely recognized that organizations who are more adept in handling advanced methodologies will have numerous research studies which can be reviewed for guidance on setting up new or improving existing systems within their engineering and manufacturing processes. Examples of these more involved studies can be readily found, as in the 2016 piece published in the Journal of Engineering Design entitled, "Towards Engineering Change Management Maturity Grid", where the authors lay out twenty-six (26) different ECM components of varying complexity related to capabilities (Storbjerg, Brunoe, & Nielsen, 2016). As we have come to understand, smaller entities often do not have highly technical products, advanced procedures, or a particularly adept staff suited for attempting such tactics. It is for reasons like those that SME's will probably prefer less high-tech rhetoric when trying to understand their own capacities, or opportunities for improving processes. In this section we consider the approach taken with the SME under review which demonstrates that advanced jargon is not always necessary when conducting research and presenting the findings of analysis. It is true that simple approaches are not absolutely suited for papers aimed at highbrow academics and professionals. By the same token, it is widely understood that one should know their target audience, and any writings should be created with that demographic in mind. For the originator of the study laid out in these pages, applying a basic approach to the entire endeavor seems ideally suited to the demographic found within SME's. We see this realized by simply limiting focus to an identifiable area of potential problems, while pinpointing some probable causes, and then estimating the conceivable financial impact from those issues. Every step is kept intentionally uncomplicated and is intended to culminate in an extremely easy to digest set of data and estimation calculations that will reveal some generally persuasive results.

During the data collection and observation steps, which lead to those simple estimate calculations aimed at finding a potential monetary burden, the researcher taps into their own experiences with engineering change to frame some basic questions that might serve as an aide for the typical SME when considering ECM implementation. In addition to those questions, there are also some primary suggestions established for use during any initial ECM development phases, which might ensue because of this research. Again, to reduce the chance of alienation among the associates that are generally found working at SME's, any questions and/or steps utilized in such a venture should be kept very straightforward and down-to-earth. Furthermore, the question should maintain a sort of close-ended feel that will result in a relatively finite number of responses. One might even attempt to develop suitable answers for them to choose from if that will make imposing a limiting aspect more palatable for the questionees. The questions put forth to help establish a strong foundation for developing an ECM system within this SME are presented in appendix ‘E’ at the end of this paper.

As the author has mentioned, any steps or ideas that are established to guide an SME should be kept as simple as one deems practical for an initial push toward ECM implementation. For this study, the researcher has developed concepts aimed at promoting the improvements that can come through the implementation of a basic ECM system. Of course, there are any number of approaches that could be attempted, but the analyst behind this paper believes it is best to start off with easy straightforward strategies, because one can then work towards building on any little successes, or breakthroughs, as they occur. These simpler approaches also allow for easier updates throughout the setup stages, should unforeseen hurdles be encountered.

In support of the simple suggestions made thus far, there is a basic process workflow which has been developed to show at least one straightforward approach which might be taken while initiating an ECM system at a non-technical SME. That workflow reflects one relatively easy approach to managing the engineering change process. The strength behind taking such a line involves setting up the proper teams for reviewing each engineering change request (ECR), This researcher feels, based on experience, the team should be cross functional so they can adequately address the needs and concerns of each department. It is also felt that the team should meet regularly, like once a week, and there should be no exceptions, or extraordinarily small exception, for attendance. Any notification methods should be consistent with one another, and they too should be adhered to rigorously. The author believes the key for this entire notion rests on consistency, as it does in most other aspects of manufacturing.

To support the questions, guidelines, and workflow presented there is an EC request forms that is developed to serve as a starting point for an ECM initiative. There are also some visual flowcharts that are presented to illustrate how one might design the integral movements of items traveling through a basic ECM system. The flowcharts put forth represent high level steps that can always be modified or added to as the SME and their ECM matures. Additionally, more forms can be created to suite the specific aspects of any parts/design/packages/processes. The guidelines forms and workflows put forth to serve as recommendations for this SME are presented in appendices ‘F’, ‘G’, & ‘H’ respectively at the end of this paper.

The items covered in the above text, and found in the appendix of this paper, are intended to serve as one preliminary approach that could be taken when building an engineering change management system. The concepts found within each example can be added to or modified as the subject organization sees fit. Overall, any means pursued should strive to uphold the focus on basic and easy to follow methods for guiding SME’s regarding ECM practices. In this case, the suggestions are only intended to address the objectives laid out in chapter 1, while adhering to the methodologies presented in chapter 3 of this research paper. Upon completing the steps to work through each of the questions and guiding suggestions, one should be able to advance a process that can be expanded upon, or cut back, as needed to fit the operations of an SME.

5.4 Assumptions and Opportunities

As with any research study, there are some assumptions that have been made. One of the biggest assumptions here involves the average level of knowledge found among the associates employed at the SME under review. While each step of the analysis provides good insight to the people that work there, no attempt is made to find out what level of education each worker as attained. If it is determined to be useful, the liaison can be asked to collect the minimum requirements for entry into each position observed, but that is not something this researcher is comfortable pursuing for this study. Suffice to say, the observation and questioning processes of the research study are considered to provide ample insight to the overall mindset of the associates working at the company.

The elephant in the room, at least where assumption is concerned, involves the idea that engineering is correct in their designs and therefore this revision litmus test, so to speak, is the best approach. The researcher should take care to get adequate feedback when considering what area any respective revision level comparison approach should be formed around. While each SME could be different, the fact is the vast majority that this researcher has encountered were engineering driven companies. Meaning all their product designs are supposed to originate in their engineering department. The use of the engineering specifications in this study is largely for consistency in this organization, but it might as well be any other department, so long as they are identified as the main provider of guidance regarding product designs. For the SME under review that department just so happens to be designated engineering,

Another assumption is that the top management, for any given SME, is interested in identifying ways to reduce wastes and cut costs in their processes. It can probably be found that some companies are in fact happy with the status quo. Perhaps management is convinced they are running at optimum efficiency, maybe they are happy so long as the business is making enough money. While it is true that anything is possible, one will never know unless they approach those organizations with a plan for identifying possible shortcomings in their processes. Even in doing that, it may not be known because the approach my get thwarted and the researcher never told why. Take the current study, where a few different organizations are initially included for consideration; the company ultimately reviewed is only included after a series of elimination processes. Any of the entities not picked may have eliminated themselves from the process without offering a reason, and the researcher simply continued until a selection was made. As for the company under review here, this is probably a safe assumption considering they are allowing the research and analysis project to be conducted in their facility's.

In addition to the presence of assumptions, there are additional opportunities that might be identified while performing the various steps of the study. Opportunities seen in this project are many, as have been identified in some of the previous text. One big opportunity relies on the outcome of this research, and the reaction of the SME management team upon reviewing it. Should the adoption of an ECM system be the course forward for the company, and assuming there is an adequate level of identifiable improvement that results, there may be opportunity for implementation of more advanced ECM tools. One of the more obvious, based on the literature review section, could be the application of a computerized PDM/PLM program to support an even more robust ECM process. Note: if there are indeed significant breakthroughs observed, those types of items can be readdressed to pursue additional areas of potential improvement; of course, with significant breakthroughs, any push-back experienced from the different levels inside the company are likely be lessened. Still, such an enterprise would likely take a great deal of time and would probably require addition research projects to identify and estimate any potential benefits from doing so.

5.5 Final Results

Upon completing the research above, the steps and findings are presented to the Subject SME's management team. Throughout several meetings, and a series of department walk-throughs with the management team members, the researcher explains the findings of the investigation along with each of the processes taken in getting to those discoveries. There may be a short period where the research is placed on hold while the managers go over the options they see before them. It would not be unusual for this decision-making phase to take an extended amount of time, especially if the management team prefers input from the different departments prior to agreeing to any changes in their processes. For this study, it has been expressed that the efforts involved in reviewing and collecting the information presented is greatly appreciated, and they anticipate selecting a course of action relatively soon, but any change may need to run into the next quarter.

From the input obtained through the president of the company, through a casual walking meeting, it appears they are looking at a few possibilities for addressing the findings of this study. Those options include, but are not limited to, the following:

1. Begin design and implementation of a full ECM improvement initiative as recommended.
2. Begin a partial process improvement initiative (focal point not identified).
3. Reduce redundancy by eliminating positions perceived as leading to waste.
4. Do nothing (was reassured this is not likely).

Clearly most of these choices are not what the researcher would consider ideal, and one can only hope that whatever decision the SME ultimately makes, it will result in better control with their internal processes. The president of the company did express concern over teaching “an old dog new tricks”, and while the study clearly illustrates the usefulness of simple approaches and understandable results, there appears to be trepidation regarding the learning capacity of the organization’s workforce.

It should come as no surprise to find some within the top levels of management are expressing concerns over the associate’s ability to learn and pick up new habits. If this does occur, one could find themselves involved in multiple interactions, at many levels, working to enlighten different stakeholders on why it is in everyone’s best interest to replace the existing “tribal knowledge” approach with more sound ECM processes. The maneuvers applied in the study make it a relatively straightforward affair to demonstrate the validity of the findings. While the researcher may not exactly follow the methods of other investigators, there is nonetheless a decently recognizable adherence to the science supporting each tactic. For example, the samples included for review are randomly selected, and though the calculations are kept relatively basic, they are based on proven formulas that highlight some of the effects encountered when producing components not matching what engineering specifies. The observation phase provides further insight, and though the discoveries made are not completely infallible, they do offer a rational for those issues which have been identified.

The author here is not dismayed by the divulgences of the company president. This is because it is not unheard-of for a proponent of change to wait for the decision-makers to come to a consensus about adopting an appropriate plan for moving forward. For the ECM recommendations that are being proposed at the subject SME, the researcher is slowly making headway and there are plans being formulated to incorporate the first option listed above by the president. While it seems imminent that progress will be forthcoming, it is rather apparent that there is more at play with this SME than simply providing an easy set of questions and guidelines to follow. Incidentally, strong methods for building new habits might be another good area for additional research, but that again is outside the realm of this study.

5.6 Conclusion

There have been many different aspects of manufacturing process improvement which have been topics for research with academics, as well as being a general concern for several professionals in industry. It is easy to see that of the various approaches taken in the available literature, a large proportion have their focus aimed at extremely advanced methods in larger businesses. Although advanced techniques can certainly be beneficial for those big operations, smaller enterprises seem to be left in the dark about viable ways they might improve their own throughput. This may be partially due to somewhat permissive hiring requirements with small companies, where higher education levels are not a necessarily a sought-after commodity. Furthermore, many SME's lack the financial resources, and or desire, to fully train their associates in the ways concerning advanced techniques. This attitude is somewhat ironic when one considers the potential money lost on the three packages reviewed throughout this research project. Certainly, one would think that any expense incurred for good training could quickly be recuperated through the process improvements acquired. Of course, simpler strides like those presented in this paper will probably not achieve as much, but by the same token they should not require a great deal of training. As this author learned in a discussion with the president of the SME under review, there may be other factors contributing to the hesitancy to train. The presence of such hesitancy does not mean there is no value in the elementary approaches employed in this research study. It is just another huddle that will need to be thought out and addressed when the right time comes.

The fact is, even with substantial foresight, and a long list of "all the right questions" to ask, one probably will not hit every mark in a research endeavor perfectly. No matter what plan the management team decides to pick in this instance, there will likely be progress made. All but one of those options mentioned by the president of the company constitutes a move towards improvement. True, it may not end up being the most progressive move the company could select, but it will still be a move to change their flawed engineering change management system. Ultimately that is progress, and it will be based on the results of a study built upon rudimentary ideas that were easily explained, and quickly understood by the workforce found inside this SME. On top of the results with this company, these simple steps can be taken up by any SME that is not necessarily ready to jump into the high-tech pool of advanced process improvement.

As can be seen, there are several take-aways to be drawn from the observations laid out and the calculations performed for this research study. The approach is multifaceted in that it addresses a flawed ECM system within an SME and ponders the financial impact of allowing those failings to continue. The study also considers aspects of potential acceptance and understanding difficulties which may be met from typical SME associates. These considerations are intertwined as each of the steps developed to verify the problems are conducted, and the cost estimate calculations performed. As the literature review section in this paper shows, these aspects are not always joined together in typical research efforts. Perhaps more surprisingly, they do not tend to get explored extensively in university coursework either. For the originator of the study in hand, both of those shortcomings should be undertaken through more academic research; especially focused on the baser methods available for identifying and addressing areas for process improvement in smaller companies. Until such approaches are the norm, this paper will stand as one of the relatively few alternative research studies designed to help small manufacturing businesses.

Clearly any of these humble tactics can be applied to other small enterprises with similar shortcomings in their processes. By concentrating on making only simple observations and using relatively basic calculations this study demonstrates that researchers do not need to strictly pursue advanced methods for their topics. In fact, the overall findings of the research show that these basic tactics can be quite useful if the target audience might tend to be discouraged by tackling statistical process control, or other advance philosophies of quality and process improvement. Not only are the steps described herein capable of confirming that persistent problems exist, but they can often be quite successful at estimating some feasible costs related to those problems should the current systems remain uncorrected.

In conclusion the researcher found through the steps laid out above, that the SME under review is suffering from a fundamental breakdown in their engineering change processes. As a result of poorly communicated designs and changes, there are cases where poor-quality parts are being produced which are impacting the time required to complete the average order. The ultimate costs of this persistent breakdown could be far reaching, as it is costing the company more money to produce parts. Any organization that produces engineering-based parts should engage in the steps presented herein to identify and possibly correct shortcomings in their own operations.

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Appendix

Appendix A - Questionnaire for engineering, procurement, and PCM:

Current Process Questionnaire

Date: ________________ Time: ________ Liaison: _________________

Department: ________________ Respondent: _____________________

Circle One

1. Is there a set process for identifying/initiating that an EC is needed? Yes No

Input:

2. Is there a set EC completion process currently in place? Yes No

Input:

3. Is there a process to identify when changes constitute a revision vs. new part #? Yes No

Input:

4. Is permission limited on who can apply revisions and/or part #'s? Yes No

Input:

5. Is there a process for change approval/rejection in place? Yes No

Input:

Current Process Questionnaire

Circle One

6. Is there a process for approval/review of changed items? Yes No

Input:

7. Is there a designated criterion for part dispensation in place? Yes No

Input:

8. Is there a plan for dispensation of changed items? (if yes, see 8a, 8b, & 8c below) Yes No

Input:

8a. Are adoption dates designated for the changes? Yes No

8b. Are there set plans for addressing items still in stock? Yes No

- i. Scrap
- ii. Rework
- iii. Used up (either in current application or another)

8c. Do planned dispensation designations get communicated? Yes No

9. Are major change (revisable) and minor changes (non-revisable) distinguished ? Yes No

Note: Minor changes include spelling errors and missed notes.

Input:

Current Process Questionnaire

	Circle One	
10. Is there a robust plan for informing other associates/departments of EC's ?	Yes	No
Input:		
11. Are part revision levels included in any BOM’s created by engineering?	Yes	No
Input:		
12. Are part revision levels included in any ordering documentation?	Yes	No
Input:		
13. Are part revision levels included in any work instruction documentation?	Yes	No
Input:		

Note: The input fields provided at each question are for documenting information acquired from associates, as well as for recording observed behaviors and tendencies. If required, please attach additional sheets to register all feedback and surveillance comments.

Source: Data created for audits of SME associates and generated by author

Appendix B - Questionnaire for engineering, procurement, and PCM:

File and Revision Questionnaire

Date: ________________ Time: ________ Liaison: ________________

Department: ________________ Respondent: ____________________

Circle One

1. Are Rev levels indicated/provided with part #'s for items to be created/ordered? Yes No

Input:

2. Do all applicable associates look in the same location for product documents? Yes No

Input:

3. Do you know where up-to-date, or most accurate, files are stored? Yes No

Input:

4. Is there a checking process for verifying the correct design Rev is selected/used? Yes No

Input:

5. Do you know where to get answers regarding Rev issues that are encountered? Yes No

Input:

Note: The input fields provided at each question are for documenting information acquired from associates, as well as for recording observed behaviors and tendencies. If required, please attach additional sheets to register all feedback and surveillance comments.

Source: Data created for audits of SME associates and generated by author

Appendix C Questionnaire for outside vendors:

Outside Vendor Questionnaire

Date: ____________ Time: ________ Liaison: ____________

Company: ____________ Respondent: ________________

	Circle One	
1. Do you get a full set of new documents for every project you do for this SME?	Yes	No

Input:

2. Do you have a designated file location for documents used in job part creation?	Yes	No

Input:

3. Do all documents have revision levels identified in your file storage protocol?	Yes	No

Input:

4. Do you keep part files after projects are completed /signed-off by customers?	Yes	No
4a. If so, are these same files reused on future orders when applicable?	Yes	No

Input:

Outside Vendor Questionnaire

	Circle One	
5. Do you request the missing files on orders that are lacking data?	Yes	No

Input:

Note: The input fields provided at each question are for documenting information acquired from vendors, as well as for recording other identifiable tendencies. If required, please attach additional sheets to register all feedback and surveillance comments.

Source: Data created for audits of SME associates and generated by author

Appendix D - Questionnaire for frontline associates:

Frontline Associate Questionnaire

Date: ________________ Time: ________ Liaison: ________________

Department: ________________ Respondent: ____________________

Circle One

1. Do any BOM’s you access show component revision levels? Yes No

Input:

2. Do any work orders/instructions you access show component revision levels? Yes No

Input:

3. Do you pull component documentation from Engineering's storage location? Yes No

Input:

4. Do you access other locations for the files you need? Yes No

Input:

5. Does anyone else have access to that/those location(s)? Yes No

Input:

Frontline Associate Questionnaire

	Circle One	
5. Can you make changes to designs/documents stored in any locations accessed?	Yes	No

Input:

6. If so, are others notified about changes, and are the updated documents shared?	Yes	No

Input:

8. Can you identify who is responsible for design changes?	Yes	No

Input:

9. Are you able to recommend changes in the designs/processes?	Yes	No
If yes, is there a set process for all to follow?	Yes	No

Input:

Note: The input fields provided at each question are for documenting information acquired from associates, as well as for recording observed behaviors and tendencies. If required, please attach additional sheets to register all feedback and surveillance comments.

Source: Data created for audits of SME associates and generated by author

Appendix E - Questionnaire/Guide for ECM development:

ECM Foundational Questionnaire

Date: ____________ Time: ________ Liaison: ____________

Participants: ______________________________

____

1. Who can submit change requests?

2. Who will approve or deny change requests?

3. Who will make any approved changes?

4. Where will component/project documentation files be stored (specifically)?

5. Who will have write-access to file location(s) (should be extremely limited)?

6. Who will have read access to file location(s)?

ECM Foundational Questionnaire

Date: ________________ Time: ________ Liaison: ________________

Participants: ____

____

1. Who can submit change requests?

2. Who will approve or deny change requests?

3. Who will make any approved changes?

4. Where will component/project documentation files be stored (specifically)?

5. Who will have write-access to file location(s) (should be extremely limited)?

6. Who will have read access to file location(s)?

Source: Created for SME associates to help establish ECM and generated by author

Appendix F - ECM foundational Guidelines:

ECM Foundational Guidelines

Date: ________________ Time: ________________

Developed by: ____

Approved by: ____

1. Select/create a simple Engineering Change Request (ECR) form & submission process.
    a. Make form available to applicable associates.
    b. Provide for an easy submission procedure e.g., a central drop off spot.

2. Designate approval/rejection team/associate.
    a. Set up regular meeting interval for going over submitted ECR's.
    b. Set up procedure for passing along any pertinent results.

3. Set up single location for component/project documentation files to be stored.
    a. Provide pertinent read/write access to appropriate associates.

4. Set up simple rules that apply for all future projects.
    a. Straightforward change/new-design notifications from engineering sent to pertinent department heads.
    b. Create clearance processes to be conducted at the conclusion of each project.
        i. Lessons learned.
        ii. As built.
        ii. Etcetera.

5. Set up standard training for established processes.
    a. Train all existing associates on new methods.
    b. Train new hires as a part of the onboarding process.

6. Develop visual workflow instructions and post/save discriminately, see apendix for example.

Note: It is recommended that a steering committee be formed to go over these general questions and decide on appropriate actions/answers based on input from the researcher regarding current processes. In doing so, there will be a strong starting point established for ECM development. Additional sheets should be added as needed for keeping minutes of each meeting.

Source: Created for SME to guide in the establishment of an ECM process and generated by author

Appendix G - Example Engineering Change Request (ECR) Form:

Engineering Change Request

Date: ____________ Time: ____________

Part #: ____________ Where Used: ____________

Circle One

Describe issue: Is problem hindering workflow? Yes No

Please attach additional sheets & marked-up drawing(s) to illustrate problem and suggested corrective action.

Requested by ____________ Signature ____________

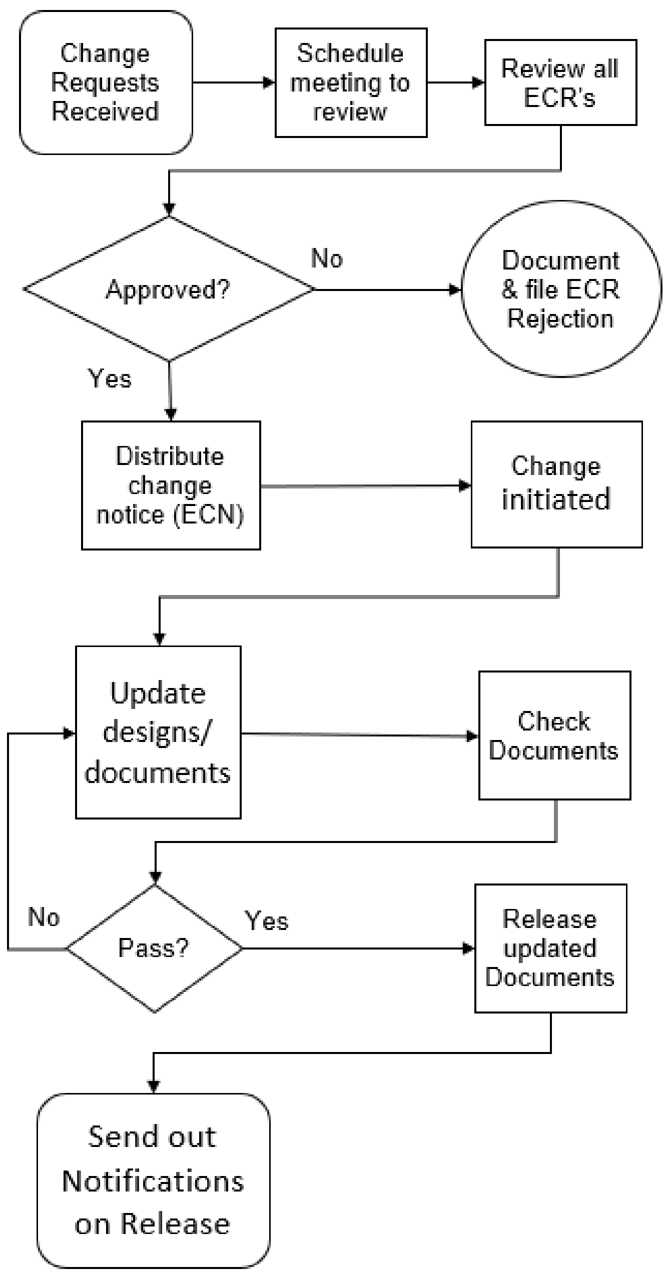
Approved ____________

Date ____________

Change Number ____________
(Applied if approved)

Source: Created for SME to guide in the establishment of an ECM process and generated by author

Appendix H - Sample Engineering Change Process workflow:



Source: Created for SME to guide in the establishment of an ECM process and generated by author

Appendix I - Example NDA form downloaded from the Internet:

MUTUAL NON-DISCLOSURE AGREEMENT

THIS MUTUAL NON-DISCLOSURE AGREEMENT (the "Agreement") made this

_____ day of_________________________, 20_____ (the "Effective Date") by and between

_________________________________ a __________________________corporation,
and

_________________________________ a __________________________,

(collectively, the "Parties" and each individually a "Party").

The Parties are exploring the possibility of engaging in one or more mutually beneficial business relationships (collectively, the "Business Relationship"). The Parties recognize that in the course of their discussions to further the Business Relationship, it will be necessary for each Party to disclose to the other certain Confidential Information (as defined below). Each Party desires to set forth the terms that apply to such Confidential Information.

NOW, THEREFORE, for and in consideration of the foregoing, of the promises and covenants set forth herein, and for other good and valuable consideration, the receipt and sufficiency of which are hereby acknowledged, the Parties do hereby agree as follows:

1. The Parties shall (i) use reasonable efforts to maintain the confidentiality of the information and materials, whether oral, written or in any form whatsoever, of the other that may be reasonably understood, from legends, the nature of such information itself and/or the circumstances of such information's disclosure, to be confidential and/or proprietary thereto or to third parties to which either of them owes a duty of nondisclosure (collectively, "Confidential Information"); (ii) take reasonable action in connection therewith, including without limitation at least the action that each takes to protect the confidentiality of its comparable proprietary assets; (iii) to the extent within their respective possession and/or control, upon termination of this Agreement for any reason, immediately return to the provider thereof all Confidential Information not licensed or authorized to be used or enjoyed after termination or expiration hereof, and (iv) with respect to any person to which disclosure is contemplated, require such person to execute an agreement providing for the treatment of Confidential Information set forth in clauses (i) through (iii). The foregoing shall not require separate written agreements with employees and agents already subject to written agreements substantially conforming to the requirements of this Section nor with legal counsel, certified public accountants, or other professional advisers under a professional obligation to maintain the confidences of clients.

2. Notwithstanding the foregoing, the obligation of a person to protect the confidentiality of any information or materials shall terminate as to any information or materials which: (i) are, or become, public knowledge through no act or failure to act of such person; (ii) are publicly disclosed by the proprietor thereof; (iii) are lawfully obtained without obligations of confidentiality by such person from a third party after reasonable inquiry regarding the authority of such third party to possess and divulge the same; (iv) are independently developed by such person from sources or through persons that such person can demonstrate had no access to Confidential Information; or (v) are lawfully known by such person at the time of disclosure other than by reason of discussions with or disclosures by the Parties.

3. All Confidential Information delivered pursuant to this Agreement shall be and remain the property of the disclosing Party, and any documents containing or reflecting the Confidential Information, and all copies thereof, shall be promptly returned to the disclosing Party upon written request, or destroyed at the disclosing Party's option. Nothing herein shall be construed as granting or conferring any rights by license or otherwise, express or implied, regarding any idea made, conceived or acquired prior to or after the Effective Date, nor as granting any right with respect to the use or marketing of any product or service. The Parties shall use the Confidential Information only for the Business Relationship.

The obligations of the Parties under this Agreement shall continue and survive the completion or abandonment of the Business Relationship and shall remain binding for a period of two (2) years from the Effective Date.

1. As a violation by either Party of this Agreement could cause irreparable injury to the other Party and as there is no adequate remedy at law for such violation, the non-breaching Party may, in addition to any other remedies available to it at law or in equity, enjoin the breaching Party in a court of equity for violating or threatening to violate this Agreement. In the event either Party is required to enforce this Agreement through legal action, then it will be entitled to recover from the other Party all costs incurred thereby, including without limitation, reasonable attorney's fees.

2. Neither Party makes any representation or warranty with respect to any Confidential Information disclosed by it, nor shall either Party or any of their respective representatives have any liability hereunder with respect to the accuracy or completeness of any Confidential Information or the use thereof.

3. Any provision of this Agreement held or determined by a court (or other legal authority) of competent jurisdiction to be illegal, invalid, or unenforceable in any jurisdiction shall be deemed separate, distinct and independent, and shall be ineffective to the extent of such holding or determination without (i) invalidating the remaining provisions of this Agreement in that jurisdiction or (ii) affecting the legality, validity or enforceability of such provision in any other jurisdiction.

4. Any notice required or permitted to be given hereunder shall be (a) in writing, (b) effective on the first business day following the date of receipt, and (c) delivered by one of the following means: (i) by personal delivery; (ii) by prepaid, overnight package delivery or courier service; or (iii) by the United States Postal Service, first class, certified mail, return receipt requested, postage prepaid. All notices given under this Agreement shall be addressed to the addresses stated at the outset of this Agreement, or to new or additional addresses as the Parties may be advised in writing.

5. This Agreement is to be governed by and construed in accordance with the laws of the state of ___________. Neither Party shall be deemed to waive any of its rights, powers or remedies hereunder unless such waiver is in writing and signed by said Party. This Agreement is binding upon and inure to the benefit of the Parties and their successor and assigns.

6. This Agreement constitutes the entire agreement and understanding of the Parties with respect to the subject matter hereof, and is intended as the Parties' final expression and complete and exclusive statement of the terms thereof, superseding all prior or contemporaneous agreements, representations, promises and understandings, whether written or oral. Neither Party is to be bound by any pre-printed terms appearing in the other Party's form documents, tariffs, purchase orders, quotations, acknowledgments, invoices, or other instruments. This Agreement may be amended or modified only by an instrument in writing signed by both Parties.

IN WITNESS WHEREOF, the Parties have caused this Agreement to be executed by their duly authorized officers on the day and year first above written.

Signature: ______________________	**Signature:** ______________________
Company:______________________	Company:______________________
Printed Name:__________________	Printed Name:__________________
Title/Role:_____________________	Title/Role:_____________________

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