EVALUATING THE IMPACTS OF ENTERPRISE RESOURCE PLANNING ON ORGANIZATIONAL PERFORMANCE FOR SMALL TO MEDIUM ENTERPRISES IN MANUFACTURING

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EVALUATING THE IMPACTS OF ENTERPRISE RESOURCE PLANNING ON ORGANIZATIONAL PERFORMANCE FOR SMALL TO MEDIUM ENTERPRISES IN MANUFACTURING

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BEM	Business Excellence Model
BoM	Bill of Materials
BPR	Business Process Redesign
BSC	Balanced Scorecard
CI	Continuous Improvement
CMM	Capability Maturity Model
COTS	Commercial-off-the-Shelf
CRM	Customer Relationship Management
CRR	Customer Retention Rate
CSF	Critical Success Factor
CTC	Critical to Cost
CTQ	Critical to Quality
CTS	Critical to Schedule
DM	Decision-making
DMADV	Define-Measure-Analyze-Design-Verify
DMAIC	Define-Measure-Analyze-Improve-Control
DPMO	Defects per Million Opportunities
ERP	Enterprise Resource Planning
ES	Enterprise System
FM	Facility Management
IC	Inventory Cost
ICT	Information and Communication Technology
ISO	International Organization for Standardization

IT	Information Technology
JIT	Just-in-Time
KM	Knowledge Management
KPI	Key Performance Indicator
LSS	Lean Six Sigma
MDI	Micro Depot, Inc.
MES	Manufacturing Execution System
MT	Manufacturing Throughput
NAM	National Association of Manufacturers
NPD	New Product Development
OP	Organizational Performance
OC	Operating Cost
OTD	On-Time Delivery
PCE	Process Cycle Efficiency
PDCA	Plan-Do-Check-Act
PLR	Production Loss Rate
PLT	Process Lead Time
PMM	Performance Measurement and Management
PMS	Performance Measurement System
PV	Process Velocity
QC	Quality Control
QMI	Quality Management Initiatives
QMS	Quality Management System
QR	Quality Rate
RBV	Resource-based View

SA	Strategic Alignment
SCM	Supply Chain Management
SCR	Satisfied Customer Ratio
SI	System Integration
SME	Small to Medium Enterprise
SR	Scrap Rate
SRR	Stability and Reliability Ratio
TED	Training and Education
TPMC	Total Product Manufacturing Cost

SUMMARY

Today’s fast-paced global economy has intensified the demand for manufacturing companies to make their products more quickly and with higher quality to meet heightened consumer expectations while reducing costs. Globalization of the market place is presenting new markets for small to medium enterprises (SMEs) to enter the manufacturing environment previously controlled by large enterprises. This competitive environment requires SMEs to design and implement well-designed business processes and leverage information technology (IT) to become more agile, flexible, and integrated to meet changing market demands. However, research has identified challenges that manufacturing SMEs face when implementing best practices and IT including significant resource constraints, a lack of connectivity among stakeholders, and process complexity due to inadequate operational transparency and product variability.

Research shows that an IT system, specifically Enterprise Resource Planning (ERP) systems, provides the necessary foundation for increased visibility leading to better control as well as the effective and efficient management of internal and external facility operations (Chapman & Kihn, 2009). A well-managed ERP can be a determinant of strategic competitive advantage as they have the ability to automate and integrate a variety of business processes, provide support for the usage of best practices, and share common real-time data throughout the organization. Facility managers and other decision-makers are provided with accessible information and enterprise-wide visibility into operations to ensure well-informed operational, tactical and strategic decisions (Chand, Hachey, Hunton, Owhoso, & Vasudevan, 2005). Although the positive effects of successful IT and ERP implementation in large firms are recognized, there is a general

lack of empirical IT productivity literature focusing on SMEs. The ongoing debate remains whether ERP systems can enable SMEs to overcome business challenges and achieve better organizational performance.

This research contributes a framework for performance measurement of a manufacturing company, providing facility decision-makers with significant metrics for analyzing their firm's performance according to universally recognized competitive priorities. Employing the Delphi process, key performance indicators (KPIs) including time, quality, cost, and flexibility, and corresponding performance measurement metrics, investigations are conducted between traditional manufacturing processes in SMEs and processes enhanced through ERP adoption. In this longitudinal case study, continuous improvement of organizational performance is evident in operational measures related to quality and on-time delivery.

CHAPTER 1 - INTRODUCTION

Today's fast-paced global manufacturing economy has intensified the demand for companies to produce their products more quickly and with higher quality while reducing costs to meet heightened consumer expectations. While outsourcing, downsizing, and other quick one-time fixes may provide temporary relief against rising costs; they are not solutions for attaining long-term growth and profitability. Hayes and Wheelwright (1984) suggest that world-class manufacturing practices include the skills and participation of the workforce, managerial competence, proficiency to meet clients' meet quality expectations, investment in strategic development, and establishing flexible operations that quickly respond to the demands of the market. Facility management (FM) is quickly gaining attention as an area of management actions that improve the performance of organizations by ensuring the functionality of the business environment by connecting employees, departments within the enterprise, processes, and technologies (Slaichova & Marsikova, 2013). According to Vetrakova et al. (2013), the primary purpose of FM is to support organizational strategy and its core business while Becker (1990) notes FM's goal of improving an organization's ability to successfully compete in a rapidly changing environment. However, a lack of managerial tools and performance measurement dashboards currently limit the manager's capability to optimize operations.

Manufacturing companies encounter a series of challenges that affect the pursuit of business objectives including operational effectiveness and strategic positioning. A 2011 study by the National Association of Manufacturers (NAM, 2011) highlighted the glaring need for available skilled labor as nearly 5% of all manufacturing jobs are vacant and 82% of all manufacturers have a shortage of skilled production workers. The complex and dynamic nature of project and process management further stresses the need to find a solution for poor visibility of enterprise-wide business functions. Additionally, the uncertainty and variability arising from internal and external sources related to operations management complicates the management, coordination, and effectiveness of business processes (Klassen & Menor, 2007). Untimely and fragmented communication among upper management, employees, and other stakeholders contributes to decreased productivity and process inefficiencies as well. Sufficient training and education (TED) can maximize the performance of employees by reducing the time required to learn and operate new systems, however, due to limited budgets and resource considerations, companies are often forced to only partially fulfill training needs.

Globalization of the market place is presenting new markets for small to medium enterprises (SMEs) to enter the manufacturing environment previously dominated by large enterprises. Criteria such as size, number of employees, volume of sales, and capital requirements distinguish small companies from large ones. The Small Business Administration (SBA) defines a small business as "one which is independently owned and operated and which is not dominant in its field of operation" (U.S. Small Business Administration 2006). According to the European Commission, SME organizations have fewer than 250 employees and either annual turnover less than 50 million euros or an annual balance sheet total less than 43 million euros. SMEs face challenges due to various resource constraints hindering their project and performance capabilities yet they still serve a major role in supporting the competitiveness of larger organizations. Therefore they must focus on providing high quality products with consistent, reliable delivery to their customers to stay ahead of increasing competition (Thomas, 2007).

Competition is increasingly becoming knowledge-based as companies learn, develop, and utilize capabilities faster than their rivals (Lane & Lubatkin, 1998; D. Teece & Pisano, 1994). In this case, a company's competitive advantage comes from its unique knowledge and how it can be managed (Spender, 1996). Companies acquire knowledge through the experiences of management and employees internally and externally, however, information is often fragmented. Failing to interpret and disseminate information across business entities can negatively affect performance as valuable knowledge is withheld. ITs capability to facilitate knowledge-sharing and information management can be utilized to ensure the creation and maintenance of competitive and strategic advantages and improve performance (Lawler, Mohrman, & Benson, 2001; Mata, Fuerst, & Barney, 1995). Firms must design and implement thorough business processes and leverage information technology (IT) to become more agile, flexible, and integrated to meet changing market demands. Determining competitive priorities based on specific company objectives is essential for making structural and infrastructural decisions. Structural decisions are often strategic with long-term considerations of the facility's location, capacity, integration, and processes. Meanwhile infrastructural decisions are more tactical in nature and relate to organizational structure, workforce skills, operations planning and control systems, inventory systems, quality issues, and reward systems (Yen & Sheu, 2004). Research has confirmed that company's need an alignment of structural and infrastructural decisions with competitive priorities to ensure its competitiveness (Yen & Sheu, 2004). Strategic alignment (SA) of a firm's IT system and its business strategy is regarded as the most important issue in North America and Europe (*Critical Issues in Information Systems Management*, 1998). Prior research supports this claim by attributing missed IT investment goals to poor SA (Henderson & Venkatraman, 1993). Literature cites that the SA between market goals and process management is the key for facility managers making process management decisions (Bower & Christensen, 1995; Klassen & Menor, 2007).

A few early competitive priorities suggested were cost, quality, delivery and flexibility (Skinner, 1974). Additional research has identified and accumulated into a more comprehensive list. Figure 1 defines these priorities that are commonly accepted in manufacturing firms.

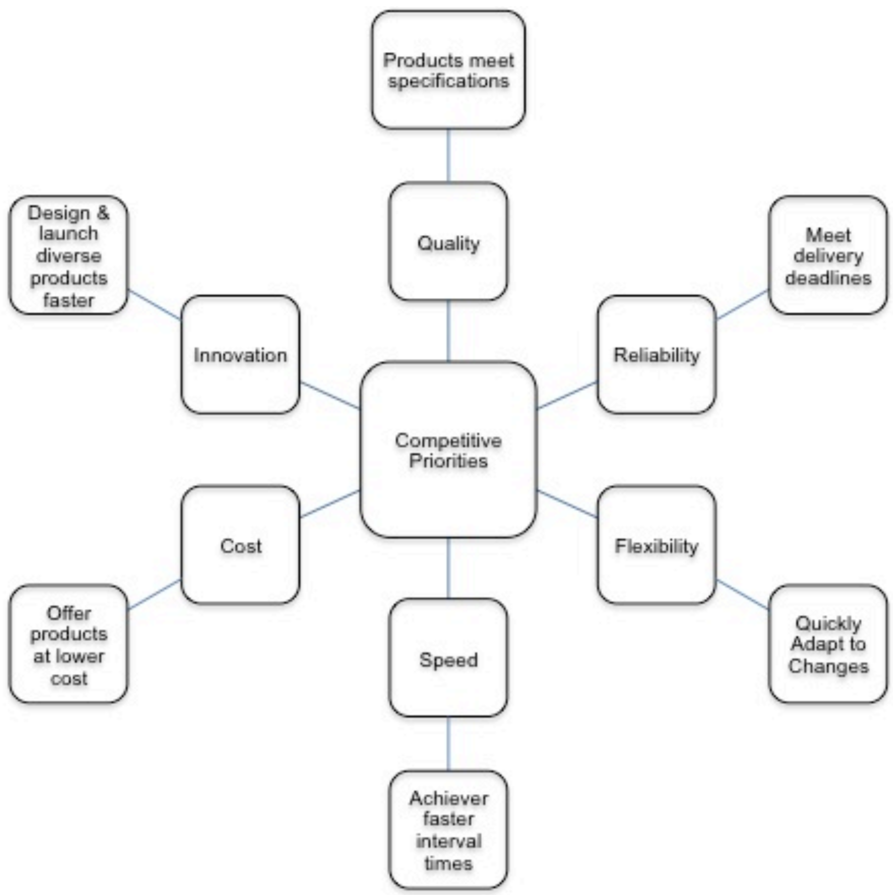


Figure 1: Competitive Priorities (Adapted from L. J. Krajewski & Ritzman, 2001)

Issues emerge when facility managers lack reliable data on performance and costs, which subsequently impairs even basic decisions for resource allocation or process improvement. This issue extends to difficulties with making improvement recommendations (Barret & Baldry, 2003). In order to maximize organizational performance and maintain a competitive advantage, manufacturing firms seek process-focused quality management systems (QMS) or initiatives including Six Sigma, lean production, and ISO 9001. These initiatives generally stress continual improvement of key processes by identifying and removing non-value added activities and measuring a dashboard of key performance indicators (KPIs). While the benefits of these initiatives have been noted in previous research, the resource costs incurred from hiring expert consultants, training internal employees, or attaining certification is high.

Enterprise software offers a shared data infrastructure within and across an organization, providing access to all functional data needed to complete tasks and sharing information with employees in a timely manner and regardless of location. More specifically, Enterprise Resource Planning (ERP) has grown in adoption over the course of the last decade. An ERP is an information system that manages all aspects of a business through integration of data throughout the entire enterprise and provides managers with direct access to real-time information and activities. Through data integration, ERP removes wasteful processes and cross-functional coordination problems that hinder the integration of the organization (Scalle & Cotteleer, 1999). An ERP system provides the foundation for firms to control and exploit their internal and external operation and resources effectively and efficiently (Hakim & Hakim, 2010). However, it is not a solution by and of itself but a tool to advance organizational performance.

Motivation and Impact

In order to survive the competitive manufacturing environment, firms need to establish an operations strategy capable of running with greater speed and reliability, while enabling continuous improvement and change (R. H. Hayes & Pisano, 1996). The importance of this study is reflected by the need for SMEs to improve operational effectiveness to reduce costs, which results from reducing variability and increasing transparency in processes and procedures (Parast, 2011). A well-managed ERP system can be implanted into the organization's key processes to leverage performance and could be a determinant of strategic competitive advantage (Pereira, 1999; Rajagopal, 2002; Zhu & Kraemer, 2005). Previous studies have recognized the benefits of ERP implementation in larger enterprises as improved customer service, better production scheduling, and reduced manufacturing costs (Zhang, Lee, Zhang, & Banerjee, 2002). Although these studies have produced some positive results, there are fundamental differences between large enterprises and SMEs including additional challenges in needs, operating requirements, and monetary resource making these findings inapplicable to smaller enterprises (Buonanno et al., 2005; Laukkanen, Sarpola, & Hallikainen, 2007).

SMEs make up the bulk of companies while raising the competitiveness of larger organizations through their essential role in the supply chain and high-quality input (M. Kumar, 2007; Thomas & Webb, 2003). Several differences between small and large firms concerning IT productivity have been established in research. Empirical research shows that SMEs have lower returns in value from IT adoption due to a deficiency of complementary assets such as company culture, practices, and worker composition (Giuri, Torrisi, & Zinovyeva, 2008). Due to budget constraints, SMEs have been limited in the adoption of QMS initiatives for organizational performance improvement. The costs associated with Six Sigma black belt certification, ISO 9001 certification, and implementing lean production concepts often force these smaller enterprises to choose one quality management initiative rather than incorporating multiple simultaneously as some larger enterprises have done. In terms of ERP implementation, SMEs are confined to a piecemeal adoption approach instead of installing the full suite of modules into their facility (Ferman, 1999). It is also believed that the low IS staffing in SMEs is insufficient for the rigorous IT training and requirements for ERP development (Hill, 1997).

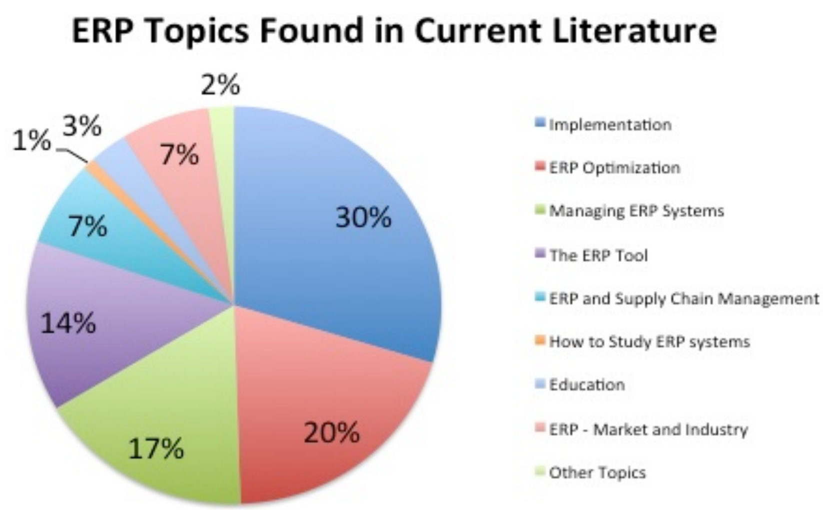


Figure 2: Papers Covering Specific ERP Topics (Schlichter & Kraemmergaard, 2010)

Esteves and Pastor (2001) and Shehab et al. (2004) found few journal publications concerning ERP implementation in manufacturing prior to the year 2000. There has been a significant increase in the amount of published research since 2000. However, there is a scarcity of empirical evidence showing a positive relationship between IT adoption and performance including a lack of empirical IT productivity paradox literature that focuses on SMEs (Sandulli, Fernandez-Menendez, Rodriquez-Duarte, & Lopez-Sanchez, 2012).

The lack of research on integrated enterprise-wide management systems extends to China as well (Jie & Weihui, 2010). Furthermore, an ongoing debate is whether potentially costly ERP systems lead to better firm performance as research to date supports both sides of the debate (Hunton, Lippincott, & Reck, 2003; Kambawi, 2006; Nicolaou, Stratopoulos, & Dehning, 2003; Ossimitz, 2006; Park, Lee, & Jeoung, 2002; Sodhi, 2001; Themistocleous, Irani, & O'Keef, 2001; Wieder, 2006). Esteves and Bohorquez (2007) emphasize the importance of future research on the benefits of ERP-installation in SMEs. This is due to the fact that ERP implementation in SMEs is low in comparison to large companies (Buonanno et al., 2005).

State of Knowledge

The current state of knowledge presents mixed reviews of IT adoption in manufacturing enterprises. Thus the business case for IT adoption has yet to be influential for SMEs. IT investments often require substantial time to learn and effectively use new systems to realize a positive impact on performance (Kohli & Devaraj, 2003). Based on a rigorous literature review, Eckartz et al. (2009) categorized three dimensions of potential benefits from ES-adoption. The first is operational, managerial, and strategic benefits. Second, firms can strive for process, customer, financial, innovation benefits as well as diminish an employee’s reluctance to changes, which is needed to maximize an ES. The third dimension includes IT infrastructural benefits, often intangible, such as organizational learning and CI. A study by the London School of Economics found that only 25 percent out of 659 CEOs were satisfied with the performance of their investments in IT (*International IT Survey Census*, 1999).

Results of ERP system adoption within the manufacturing industry have been mixed as well. A majority of existing research covered substantial ERP installations with investment costs above $100 million signifying that these systems cover large organizations (Muscatello, Small, & Chen, 2003). Firms and consultants generally believe that the usage of ERP systems enable more efficiency with organizational work and, consequently, better financial and operational performance than non-adopting organizations (E. W. N. Bernroider, 2008; Sneller, 2010). There is support behind the notion that ERP systems help users collaborate throughout and across departments, companies, and the industry network, increasing productivity and the performance of firms and their clients (Calisir & Calisir, 2004; Gattiker & Goodhue, 2005; Ruivo, Oliveira, & Neto, 2012). It is also widely held that ERPs solicit more reliable information recording and exchange in an enterprise (Shang & Seddon, 2002). ERPs enable data to be analyzed simply and quickly to improve managerial decision-making and attain advantages in performance (Chiang, 2009; Ruivo & Neto, 2010). A majority of this knowledge was observed in case studies of large enterprises. The last two decades have seen ERP systems become ubiquitous and vital to the operation or large enterprises (Dawson & Owens, 2008).

Past research has focused on the critical success factors for successful implementation. Chang and Hung (2010) report that the compatibility of legacy IT systems and work processes and an ERP system is essential in SMEs. Bernroider and Koch (2000) reveal that system adaptability and flexibility are among the most important selection criteria for SMEs with system customization being crucial to SMEs impacted by limited resources and IT expertise. Singla (2000) offers some important ERP considerations including its flexibility and scalability, functional fit with the adopting company's business processes, extent of integration between various components of the system, user friendliness, client and server capabilities, amount of customization needed, availability of upgrades, local support infrastructure, and total cost. Table 1 shows some benefits gained by large organizations.

Table 1: Observed Benefits in Previous Studies

Organizational Gains	Source
Improved coordination	Alsene 2007
Improved performance across financial metrics	Hitt et al. 2002
Reduced operational costs from daily quality checks	Gupta et al. 2004
Continuous improvements in operational performance	Cotteleer and Bendoly 2006
Advanced competencies of SCM through process integration CRM	Su and Yang 2010
Profitably gains from efficient use of information	Bendoly et al. 2009 (Bendoly, Rosenzweig, & Stratman, 2009)
Increased flexibility, integration, & decision-making in accounting	Spathis and Constantinides 2004

While ERPs often help manufacturing SMEs to improve their strategic and competitive capabilities (Jenson & Johnson, 1999; Smith, 1999), there are reasons why firms are hesitating to install these systems. ERP implementation is complex and requires considerable investment in software and consulting services thus making it more attainable to larger enterprises than SMEs (Andriole, 2006). Previous research of ERP implementation has identified challenges leading to disappointing results. One reason is that some larger enterprises have only realized partial implementation success and, in some cases, abandoned their efforts. Trunick (1999) reported that 40 percent of all ERP installations only achieve partial implementation while nearly 20 percent are dropped as complete failures. Caruso (2007) found that over 51 percent of ERP implementations are considered failures. Additionally, a separate study noted that roughly 90 percent of ERP implementations are over budget or exceeded completion dates (Al-Mashari, Zairi, &

Okazawa, 2006; Hong & Kim, 2002; Martin, 1998) and ERP implementation success is only about 33 percent. Another reason is that the low staffing levels for IS in SMEs is inadequate for the rigorous IT training and project development requirements (Hill, 1997). Yen and Sheu (2004) attributed poor achievement of ERP adoption from a lack of alignment of implementation practices with competitive strategy. Other prior studies have stated problems including implementation costs may rise exponentially, employees may resist change and reject the new system, and integrating data between legacy systems and new systems may be troublesome (Botta-Genoulaz & Millet, 2005; Hunton et al., 2003; Nicolaou et al., 2003; Sneller, 2010). Recent research notes that configuring and employing these systems can be expensive, which is even more so for smaller companies (Koh & Simpson, 2007; Mabert, Soni, & Venkataramanan, 2001; Quiescenti, Bruccoleri, LaCommare, Diega, & Perrone, 2006). Despite the cost of ERP systems and the potential for a failed implementation, SMEs are steadily adopting enterprise systems ("ERP and small and midsized businesses: The 2004 benchmark report," 2004; Report, 2007). Small businesses need to fit and optimize success factors of ERP adoption to grow, remain competitive, and exceed bottom-line expectations (Jha, Hoda, & Saini, 2008).

Gaps in Knowledge

Although small businesses drive an important part of the global economy, research on technology-related topics has focused on large enterprises. Prior studies on ERPs mainly focus on the adoption phase with little analysis conducted on these systems post-implementation (Cereola, Wier, & Norman, 2012). Booth et. al (2008) suggested that there is a lack of an analytic framework to identify measures for evaluating the benefits of ERP systems post-implementation. Additionally, few studies have analyzed the impacts of ERPs on SMEs, the importance of the team on the installation, or implementation and assimilation of IT investments (Bassellier, Benbasat, & Reich, 2003; Thong & Yap, 1995). Existing literature falls short of establishing a business case for ERP adoption by manufacturing SMEs. Currently there is no framework based on academic studies offering reliable metrics to determine impacts on organizational performance.

Existing literature lacks analytical studies on ERP's impact on continuous improvement in SMEs. There is no evidence that successful firms earned any performance-improvements due to quality management programs (York & Miree, 2004). The adoption of quality management was not the main factor for a high-performance firm to maintain their competitive advantage.

Research Objectives

This research contributes a framework for performance measurement of a manufacturing company, providing facility decision-makers with significant metrics for analyzing their firm's performance according to universally recognized competitive priorities. Employing the Delphi process, key performance indicators (KPIs) including time, quality, cost, and flexibility, and corresponding performance measurement metrics, investigations are conducted between traditional manufacturing processes in SMEs and processes enhanced through ERP adoption. The study provides empirical evidence regarding the impact of an ERP system on a manufacturing SME. Analytical tools offered by Minitab software were used to calculate descriptive statistics and perform time series analysis, hypothesis testing, and regression analysis. The production process before and after ERP implementation was mapped out to determine whether performance improved as management and employees gained experience using the ERP system. This research investigates the evolution of product processes over the course of multiple years following ERP implementation to gain insight into the potential of a SME sustaining performance improvements over time.

CHAPTER 2 - LITERATURE REVIEW

The literature presented in this section represents the foundation upon which this study is developed. A systematic method was used to guide the literature review for assessing the impact of ERP investment on manufacturing SMEs. This method, depicted in Figure 3, is divided into four phases of problem definition, literature identification, eligibility assessment, and analysis. Systematic review is a means of summarizing research evidence with the level of thoroughness as used in producing the research evidence originally (Hemingway and Brereton, 2009).

Figure 3: Literature Review Methodology (Yao, Chu, & Li, 2011)

1) *Choosing and Defining the Research Question*: Selecting and defining the question guides the direction of the research. The problem was identified in specific terms with all the necessary variables included and defined. Tentative hypotheses were then prepared regarding the relation of the variables to the potential solution of the problem. Explicit research questions were posed and then assessed in order to seek explanations, and ultimately answers. Finally an evaluation of the problem for its research impact was conducted.
2) *Literature Search and Collection*: The literature search was conducted using library search engines available at the Georgia Institute of Technology. Professional databases were used including Web of Science, Elsevier (ScienceDirect), Medline, IEEE Explore, Springer, and PubMed. Google Scholar

and other general search engines were used as well. Sources include publicly available papers form practitioner magazines and websites of companies developing ERP technology and offering services. Relevant journal or conference papers after 2000 were considered in the ERP research. General facility management, performance management, process management, QMS, lean manufacturing, Six Sigma, ISO 9001, organizational learning, performance measurement, and supply chain management topics in manufacturing as well as IT business value assessment included research after 1974. Technical reports were included due to the lack of published journal or conference papers regarding ERP in manufacturing SMEs for facility management and process management. In order to perform a comprehensive and updated review, the search was conducted in June 2013 and again in October 2013, February 2014, and July 2014. More than 200 articles were found and reviewed including research conducted in China, India, Indonesia, United Kingdom, Netherlands, Portugal, and Canada.

3) *Eligibility Assessment and Research Framework*: After identifying all relevant studies, an assessment was conducted on the quality of the papers and articles. Poor quality studies with sizeable gaps in knowledge were excluded to ensure the use of accurate information and data.
4) *Analysis and Implications of Literature*: This final phase included an impartial analysis of published journal papers, conference papers, white papers, and case studies. The results are presented in the following sections:

Facility Management

The facility management (FM) field has been striving to progress from being considered as a trade industry to being regarded as an educated, scientific, and analytical field. According to Regterschot (1990), facility management (FM) is defined as "the integral planning, realization and management of buildings and accommodation, services and resources which contribute towards the effective, efficient and flexible attainment of organizational goals in a changing environment." It is the "practice of coordinating the physical workplace with the people and work of the organization" as defined by the International Facility Management Association (2003). Another definition by Alexander (1996) maintains that FM is "the application of the total quality techniques to improve quality, add value and reduce the risks involved in occupying buildings, and delivering reliable support services." It involves the integration of people, facilities, technology, and operations. The British Institute of Facilities Management adopts the definition for FM from the European Committee for Standardization as "the integration of processes within an organization to maintain and develop the agreed services which support and improve the effectiveness of its primary activities" (BIFM, 2013).

Facility managers are responsible for ensuring that facilities are built, managed, and maintained efficiently while lowering operational costs without conceding performance. FM is expected to understand the core business of the organization in order to align company goals and needs. Researchers maintain that insufficient strategic alignment diminishes a company's ability to realize value from IT investments and quality management initiatives (Henderson & Venkatraman, 1993; Woolfe, 1993). By adhering to the operations-focus of IT, firms can increase productivity and quality while reducing operating costs (Strassmann, 1997). Overall, having an understanding of the company's strategy helps improve productivity, revenue generating capacity, and even the image of the company (Jensen, Voordt, & Coenen, 2012). The primary motives for developing FM performance assessment techniques involve changes in external demands and organizational roles, increases in domestic and global competition, and the advancement of IT (Neely, 1999).

Strategic, Tactical, and Operational FM Activities

As businesses begin to understand the potential for IT in delivering strategic impacts, executives and facility managers engage in a more active role in determining how, when, and where to use resources. Langston and Lauge-Kristensen (2002) divide FM activities into the three categories of strategic, tactical and operational level issues. Process management has strategic and operational implications that interact with all levels throughout the organization (Benner & Tushman, 2003). Effective process management requires a trade-off at both strategic and operational levels. In other words, it is finding a balance between the strategic, long-term impact of the process with the operational, short-term aspect (Klassen & Menor, 2007). An example can be seen in inventory management since it requires accounting for the cost of holding inventory while simultaneously considering the necessary safety stock to maintain adequate levels of customer satisfaction. In this example the cost of holding inventory is considered operational while maintaining acceptable customer satisfaction is strategic.

Strategic FM commonly refers to high-level corporate goals and planning. These strategic activities are implemented to progress the facility toward achieving the organization's long-term goals. Strategic level activities could incorporate planning for growth and expansion, positioning the organization to enjoy competitive advantages over others, and establishing revenue-maximizing policies. At this level, research shows that process management programs such as Six Sigma and lean manufacturing positively impact business results and enhance profitability (Das, Handfield, Calantone, & Ghosh, 2000; Hendricks & Singhal, 1996; Kaynak, 2003; Powel, 1995).

Operational FM covers short-term and routine management activities that maintain facility operations. The focus of operations management is the transformation of inputs such as labor or materials to outputs including products and/or services, where it is responsible for evaluating, integrating, and coordinating activities that translate inputs into outputs (Silver, 2004).

Tactical FM activities are directed at helping an organization operate at a desired level of performance. Organizations have goals for how they want the facility to operate and perform. Through organizational planning, FM associates should help achieve these levels of performance on a consistent basis. Tactical FM issues also include management of processes and support services. Amaratunga and Baldry (2000) describe successful FM as the achievement of the firm's goals at "the best combination of efficiency and cost".

A management system assists upper management and facility managers in integrating a set of processes and tools within the organization to develop its strategy, apply it into facility operations, and monitor their effectiveness (Robert S. Kaplan & Norton, 2008). Moreover, performance measurement and management (PMM) helps decision-makers make both strategic and operational choices as it can be defined by an organization's ability to track its performance by supporting internal and external communication of results (Patrizia Garengo, 2009). The ability of ERPs to collect, interpret, and distribute performance information, among other functions, qualify it as a useful PMM. Table 2 organizes various benefits of ERPs within the operational, tactical, and strategic FM activities.

Table 2: ERP Benefits on Business Processes (Adapted from Chand, 2005)

ERP Benefits Framework for Process Management			
	Operational Benefits	**Tactical Benefits**	**Strategic Benefits**
Process Goals and Outcomes	Improve Process Efficiency	Improve Decision-Making	Adjust to Environment Changes
	Reduce Errors & Rework	Improve Work Scheduling	Adapt to Technology Upgrades
	Reduce Processing Time	Increase Information Access	Adapt to Competitive Pressures
	Increase Throughput	Improve Quality Management	Adjust to Regulatory Changes
	Consistent Data	Improve Control	Improve Flexibility

Organizations that create processes and utilize systems to capture the value of organizational transparency and access to operational information are able to make the important decisions that lead to the realization of business goals.

Assessing the Business Value of IT in Manufacturing

The main focus of IT investment studies to date has been directed at productivity. As a result there has been increasing interest in a comprehensive method to measuring business value based on broader economic and strategic impacts of IT (Brynjolfsson & Hitt, 1993; Lucas, 1999). This includes measuring IT's impact on customer service, inventory management, and greater product diversity. Businesses invest in IT for a variety of benefits, however, this study will focus on IT systems that enable process-level improvements through better management, process redesign, and performance evaluation along with other functions offered by an ERP system. Brynjolfsson and Hitt (2000) argue that a large part of an IT investment's value is its ability to enable changes in the business practices and processes of companies, which may lead to higher productivity by reducing costs or improving the timeliness, quality, and variety of existing products. The past two decades consists of research identifying the benefits of IT that allows firms to redesign their processes, referred to as Business Process Redesign (BPR). In fact surveys by the Ziff Davis company (Hertzberg, 2007) and CIO Insight (Alter, 2008) revealed that business executives view process improvement as the single most important type of project. Upon optimizing processes and implementing them, firms can achieve expected performance and flexibility.

Implementing IT with BPR brings automated, informational, and transformational change to firms. The primary focus of automated change in this context is that of labor reduction as manual labor inputs are removed from activities. Informational effects result from the application of IT and work practices that advance a company's processes related to information collection, processing, and dissemination capabilities. Transformational effects generate process innovation and change. These enterprise-level effects are summarized as customer value, efficiency, and profitability improvements (Kohli & Hoadley, 2006). A company's goals for IT-enabled BPR influences the type of benefits gained. For example, a company will focus on redesign that adds value to customers in order to gain market share. A focus on improving productivity or reducing costs may target operational efficiency. Higher profitability will concentrate on improving both market share and productivity. Figure 4 provides a list of dimensions to consider when evaluating the business value of IT.

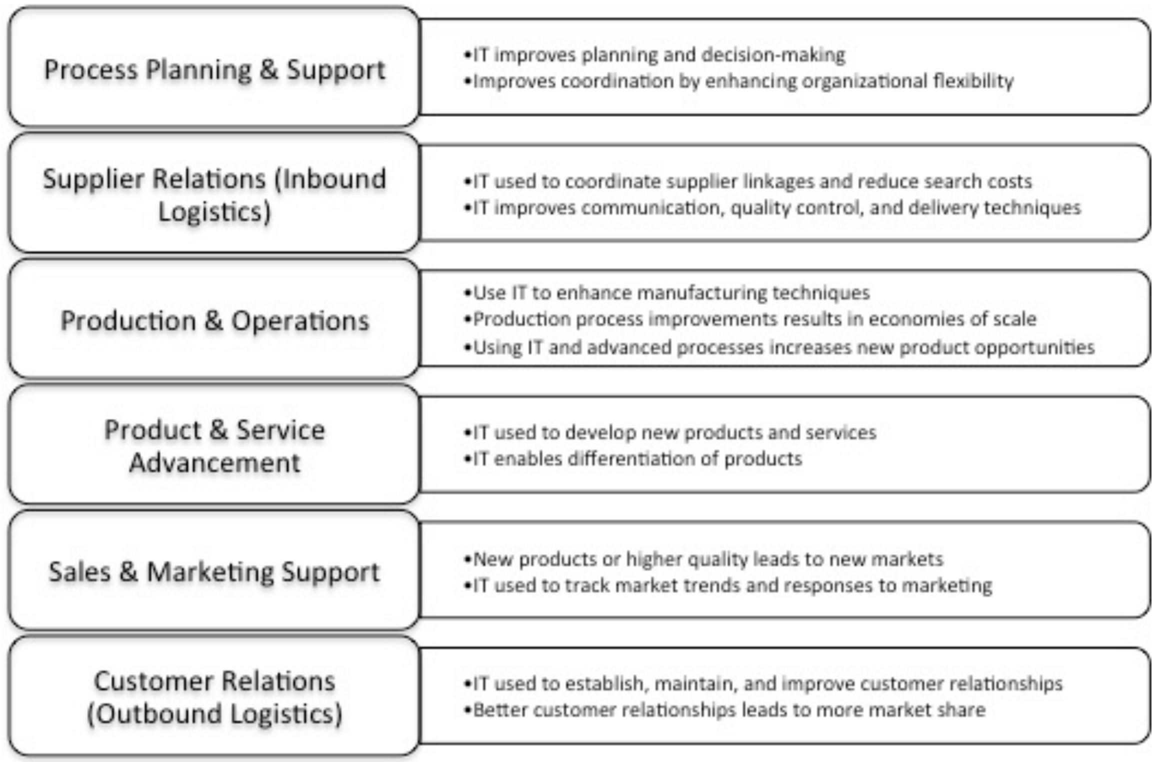


Figure 4: Dimensions of IT Business Value (Adapted from Tallon, 2000)

Sethi and Carraher (1993) found that firms with greater amounts of IT investment are beneficiaries of decentralized decision authority, increased usage of self-managed teams, and have a greater application of cross-functional teams. Although SMEs often struggle to finance significant IT investments, they stand to gain from the decentralized decision-making as it unburdens the Owner/CEO from trivial day-to-day decisions leaving additional time for strategic planning or other important business-related tasks.

Early approaches to IT evaluation were based on perceptual measures from facility managers and management. DeLone and McLean (1992) determined that executives are well-positioned to make qualitative assessments of IT impacts on their companies. However, the validity of such perceptions on IT value has been questioned for two reasons. The first reason is due to the potential of company executives to exaggerate their views on IT, as is the situation with any self-reported data. The second reason is due to the complexity of organizational structure and market uncertainty that affect present-day companies (Tallon, Kraemer, & Gurbaxani, 2000). Therefore quantitative analysis of objective measures is preferred to establish business value but both perceptual and objective measures can coexist. Conducting both pre- and post-implementation assessments is key when determining the extent of value produced by an implementation of IT (Earl, 1989). Reviews used prior to IT installation are similar to IS planning with attention given to technical, organizational, and financial aspects. More importantly, post-implementation reviews allow for the evaluation of realized IT benefits against pre-determined objectives to initiate any necessary changes.

Resource-Based View Theory

Resource-based view (RBV) theory is widely-recognized as a way to assess the business value of IT and its resource capabilities (Hedman & Kalling, 2003). RBV asserts that a firm's resources determine its performance. Therefore, IT's business value is dependent on the extent to which a company utilizes it on key activities. Firms are more likely to generate unique capabilities from IT applications as usage increases (Antero & Riis, 2011; Zhu & Kraemer, 2005). Within RBV exists resource theory, which holds that organizations create value for their resources by effectively managing them. Resource theory targets efficiency, competitive advantage, and profit growth (Kor & Mahoney, 2004). Penrose (1959) proposes a causal link between resources, capabilities, and competitive advantage. In this case managers are responsible for converting the firm's resources into capabilities. Interestingly Wicks (2005) suggests that SMEs have an equal chance to compete with larger firms due to greater innovation, flexibility, and adaptability to change.

The resource-based concept focuses largely on increasing the organization's knowledge stock and reusing knowledge repositories (Barney, 1991). Based on this idea, knowledge management (KM) refers to the development of methods, tools, techniques and values through which organizations are able to provide a return on their intellectual assets (Snowden, 1999). Knowledge management is now considered a critical strategy for organizations seeking a competitive advantage (King, 2001; Ofek & Sarvary, 2001). The KM strategy focuses on acquiring, clarification, and communication of task-specific, mostly tacit knowledge. The key purpose of KM is to transform the tacit knowledge held by individuals into explicit knowledge that can facilitate a competitive advantage. This strategy is defined as a reflection of an organization's competitive strategy to support its dynamic capability to create and pass knowledge to deliver superior value and meet the expectations of customers (Yang, 2010). According to O'Leary (2002), KM includes efforts to capture knowledge, convert personal knowledge to group-accessible knowledge, connect people to others and information, and measure that knowledge to facilitate resource management.

Resources are considered any asset, capability, organizational process, attribute, or knowledge that a firm's controls and uses to carry out desired tasks or objectives. Barney (1991) notes four characteristics that resources must have to meet the requirements of resource theory. First, the resource must possess strategic value by improving upon efficiency and effectiveness. Second, it should not be common. Third, the resource should not be easily imitable and, fourth, it should not be something that can be substituted. Although ERPs meet the criteria for strategic value by promoting efficiency, generic systems are widely available on the market meaning they would not meet the second, third, or fourth requirements of resource theory (Kocakulah, Embryh, & Albin, 2006; McAfee, 2000; Stratman, 2007). However, others contend that ERPs can be tailored to fit a firm's specific business needs, which would then qualify it. This customization of an ERP to fit the needs and processes of a company establishes heterogeneity. Packaged ERP systems are expensive, rigid and require a vendor's expertise to operate successfully. These proprietary systems offer generic solutions with the vendor determining best practices rather than tailoring it to the needs of the organization. SMEs are likely to install a commercial open-source ERP, which is low cost, easy to access, provides quality and security, and does not necessitate vendor dependence (B. Johansson & Sudzina, 2008). Commercial open-source ERPs have the flexibility to allow firms to align the system to their specific business process needs and meet the requirements to quality for resource theory.

The Role of ERP Technology in Manufacturing Facilities

Firms can obtain business value from processes, company structure, and IT applications that allow and encourage employees to utilize their creative capabilities and experience. Leveraging ERP systems can help achieve this by allowing free and timely flow of knowledge across organizations. By improving knowledge sharing and creation, firms can realize improvements in flexibility and innovation (Krogh, Ichijo, & Nonaka, 2000). An ERP system is often described as a business software system that facilitates the efficient and effective use of labor, financial, and material resources through a process-oriented perspective by providing an integrated solution for a corporation (Nah, Lau, & Kuang, 2001). An ERP system automates the flow of information and resources throughout all functions of an organization using a common database (C.-C. Wei, 2008).

Two separate studies applied a framework for organizational and business resources and concluded that ERP systems should be considered as IT resources that can produce sustainable competitive advantages (Fosser, Leister, Moe, & Newman, 2008; Hedman & Kalling, 2003).

ERPs Impact on Organizational Value

An enterprise's goals for IT are guided by their main two business objectives of operational effectiveness and strategic positioning (Porter, 2010). Operational effectiveness can be described as performing similar activities better than competitors and focuses on efficiency and effectiveness of operations. Strategic positioning entails performing activities in strategically different ways and consists of structure and accessibility goals.

Table 3: Breakdown of IT Business Objectives

Business Objectives - Goals for IT			
Operational Effectiveness		*Strategic Positioning*	
Efficiency	Reduce Operating Costs	Structure	Improve Practices
	Increase Productivity		Create Competitive Adv.
Effectiveness	Increase Flexibility	Reach	Increase Geographic Reach
	Increase Responsiveness		Increase Customer Access

Companies have adopted several pillars of operations strategy such as continuously improving, running operations at minimal costs yet with speed and high reliability, and the ability to change (Datta & Roy, 2011; R. H. Hayes & Pisano, 1996; C. A. Voss, 2005; Ward & Duray, 2000). The business value of ERP systems is gaining recognition among both large firms and SMEs. Between the years 1997-2007, companies spent more than $70 billion on ERP software licenses around the world (Welch & Kordysh, 2007). Investment growth in this technology is partly a product of expanding global strategic partner networks. SMEs are able to attract business form larger customers previously believed to be out of reach. Simply defined, they connect both humans and applications with structured communication to provide the desired information at the right time. This collaborative environment results in increased efficiency and effectiveness (Bjorn Johansson, Ruivo, Oliveira, & Neto, 2012). Table 4 provides a list of studies that demonstrated various benefits of ERP implementation for organizations.

Table 4: Prior Research Citing Benefits of ERP in Manufacturing Facilities

Organizational Gains in Large Firms	Source
Improved coordination	Alsene, 2007
Improved performance across financial metrics	Hitt et al., 2002
Reduced operational cost from daily quality checks	Gupta et al., 2004
Continuous improvements in operational performance	Cotteleer and Bendoly, 2006
Advanced competencies of SCM through process integration CRM	Su and Yang, 2010
Profitably gains from efficient use of information	Bendoly et al., 2009
Increased flexibility, integration, & decision-making in accounting	Spathis and Constantinides, 2004

Along with enriching basic business functions and streamlining integration with customers and suppliers, these systems also link system usage to the firm's performance (Rajagopal, 2002; Zhu & Kraemer, 2005). The overall range of strategic objectives for ERP implementation are described as (Wei, 2008):

- Satisfy business strategy: Adapt to dynamic business environment and fulfill business goals.
- Enhance business process performance: Integrate business systems and procedures while enhancing information transparency.
- Improve operations quality and efficiency: Standardize operations flow, increase quality and lower lead times.
- Decrease turn-around time to the customer: Analyze customer information efficiently and respond to customer needs quickly.
- Support globalization: Support business operations worldwide.

Chand et al. (2005) produced a framework of ERP benefits with a focus on financial, customer, the internal process, and learning improvements through the automated accumulation of data, the improved sharing of data and decision-making, and the ability to transform the organization into a flexible and competitive player in the market.

The capabilities of ERPs support the implementation of other QMIs discussed in this paper. Effectively using Six Sigma for manufacturing operations requires a facility to have the ability to measure its current performance, analyze operational processes, and identify improvement opportunities. ERP systems record detailed data concerning productivity, quality, which can be combined with other parameters including levels of inventory, margins, process situations, and costs.

Supply Chain Management

Large enterprises are dependent on SMEs for delivery of high quality products at lower costs. Increasing demand from the global market for these products has raised awareness of the significance of supply chain management (SCM) issues and the need for SMEs to invest in IS and QMS. Recording and sharing real-time information has become crucial to improving performance in supply chain management. Facility managers who receive timely information are able to accelerate decision-making, which can lead to shorter lead times and smaller batch sizes (Cachon & Fisher, 2000). Poirer and Quinn (Poirier & Quinn, 2003) noted that most firms are installing technology to upgrade web-based applications, inventory planning and optimization, advanced planning and scheduling, and e-procurement systems. The web-based capability of ERPs enhances efficiency to these needs by providing real-time information related to product availability, inventory levels, the status of shipments, and production requirements (Chen

& Paulraj, 2004; Lancioni, Smith, & Oliva, 2000). Managers can benefit from reduced uncertainty with forecasting in part due to the sharing of master production schedules with suppliers and clients. This empowers detailed production quantity and timing decisions (Krajewski & Wei, 2001; J. Wei & Krajewski, 2000). In addition, processing purchase orders and tracking shipments have been identified as critical integration tools (Barua, Konana, Whinston, & Yin, 2004; Frohlich & Westbrook, 2002).

Customer Relationship Management (CRM)

Superior customer satisfaction is critical for companies looking to survive a competitive global manufacturing environment. In fact, CRM has been increasingly considered a core business strategy (Lindgreen, Palmer, Vanhamme, & Wouters, 2006). The business value of having loyal customers and the cost of replacing former ones emphasizes the importance of minimizing defections as research shows high customer retention achieves above-average profits and higher growth in market share (Reichheld & W. Earl Sasser, 1990). Customer service, product quality, and on-time delivery, are several aspects of business that influence the level of satisfaction. In terms of customer service, web-based platforms can improve customer relations by providing easy and immediate access to information from any location inside or outside of the facility. Customers, suppliers, and other stakeholders provided with security clearance are able to access desired information as needed. In addition ERPs afford flexibility in responses to customer information requests. The benefits of speeding up communication and transaction times with customers can shorten product cycles (Lederer, Mirchandani, & Sims, 2001). Kumar and Antony (2008) conducted a survey and performed a comparative analysis of lean, Six Sigma, and ISO certified firms to capture the opinions and voice of manufacturing customers in the U.K. The results identified the three most important criteria to win customer loyalty as manufacturing quality, product reliability, and on-time delivery of the final product. Despite increases in CRM investment by companies, the success rate for implementations is below 30% (Rigby, Reichheld, & Schefter, 2002). Thus there is room for improvement in this area.

Inventory Management

Inventory management is concerned with the status and quantity of all assets made or used in production including any operations from the time raw materials are received to finished products being shipped to customers. Traditional inventory control systems rely on periodic counting due to the tedious nature of manual systems. Although labor-intensive and costly, periodic counting is necessary to determine how many assets are in stock and where they are located throughout the facility. Cycle inventory counting is another costly strategy that is commonly used in facilities. In this system, items are classified based on their frequency of use and cost expense. Items with higher usage or higher costs are checked more often. Both periodic counting and cycle counting fail to optimize asset utilization and availability of inventory. Meanwhile, studies show that a continuous review policy supported by real-time automated updates decreases on-hand inventory needs, reduces the likelihood of having an inventory shortage, and lowers the order frequency and matching costs (Cakici, Groenevelt, & Seidmann, 2010). Inventory discrepancy is a problem that begins from the time a shipment of equipment is received. Research shows that deliveries which are timely, undamaged, and that contain the exact quantities, products, and shipping documentation only arrive to facilities 40 to 60 percent of the time (Sahin, 2004). The availability of automated, timely, and relevant data can lead to improved reliability of inventory status, better management of quality problems, improved compliance to regulations, efficient product recalls, and reduced budget redundancies of assets.

The impact of ERP technology on inventory management extends beyond continuous review. Companies have implemented error-proofing functions to automate the prevention of mistakes in operational processes thereby meeting standardized work practices. During production, employees are able to consult with the automated system to determine the exact piece of equipment needed, locate it within the warehouse, and quickly refer to a step-by-step guide for assembly negating potential mistakes such as choosing the wrong piece for assembly.

Employee Management

The complexity and dynamic nature of activity within a manufacturing facility makes it difficult for centralized facility managers to effectively manage the firm's employees. A lack of visibility across business functions also adds to the adversity that managers face on a daily basis. Employees of small businesses are often encouraged to perform multiple work functions, which promotes quick adaptation to external and internal changes. For example, during a period of global economic recession, companies receive fewer purchase orders, which results in companies looking to cut staff to meet reduced demand. As demand for products increases, companies utilizing ERPs can make important decisions such as whether to hire temporary or full-time workers. The user-friendly nature of ERP systems and its integration with organizational processes minimizes the time-consuming process of training and education and allows managers to choose temporary workers to keep costs low yet not suffer from delayed productivity. Performance monitoring of employees is another benefit of ERPs. This type of control provides useful time-sensitive information such as tracking a worker's progress with an assigned task, identifying the other team members collaborating on the task, and storing any communication between the employee and clients, suppliers, or staff. Also, employee monitoring ensures that appropriate company standards are being followed (Ramirez, Melville, & Lawler, 2010). While there is research noting the workforce's general dislike of monitoring, an ERP's monitoring capabilities are less intrusive since they focus on employee productivity rather than tracking their physical location.

Although further research is needed to provide evidence, Anand (2009) noted the possibility in that ERPs can effectively fulfill CI requirements and capture employee tacit knowledge and facilitate bottom-up process improvement ideas. Pearlson (2001) asserted that an enterprise's only sustainable competitive advantage arises from the knowledge and experience of employees who are able to direct that knowledge to business problems. Furthermore, Barney (1991) recognized human capital as a critical resource due to its impact on strategic decision-making by managers.

Facility Maintenance

The increase in competition and the shift to a more customer-centric focus has caused manufacturing companies to adopt more open system-orientations. In this type of system, advanced operational technologies are combined with real-time information and communication capabilities to integrate and coordinate resources, operational processes, and activities. This allows for the creation of value-added operations aimed at producing and maintaining a competitive advantage (Simoes, Gomes, & Yasin, 2011). In recent years maintenance-related costs have been increasing and are estimated to be about 25 percent of the overall operating cost (Komonen, 2002; Parida & Kumar, 2006). Therefore it is important for facility managers and upper management to devise maintenance performance measures and a method for control. An ERP can support the effectiveness of a maintenance strategy by integrating maintenance-related functions. Data collected, stored, and analyzed by the system can produce statistics for the most important measures including those within the dimensions of performance such as technical, economic, safety, and human resources. It is critical for an integrated information system to make available any data needed for information sharing, collaborative functionality, time-related issues, processes and activities. The availability of a database enables current activity monitoring and indicates potential areas for improvement. Implementing quality improvement initiatives like continuous improvement or information systems promotes the proliferation of maintenance performance measurement (Bamber, Sharp, & Castka, 2004; Cua, McKone, & Schroeder, 2001).

Process Management Considerations in Manufacturing Companies

Traditional management methods often involve top-down strategic planning. Systems are set to guide and control actions of middle managers and employees to ensure adherence to plans. This method is poorly suited for developing dynamic capabilities (Montgomery, 2008). Dynamic capability is defined as a "learned and stable pattern of collective activity through which the organization systematically generates and modifies its operating routines in pursuit of improved effectiveness" (Zollo & Winter, 2002). The dynamic capability approach stresses the capacity of firms to accumulate, deploy, and reconfigure resources in response to external environmental changes (D. J. Teece, Pisano, & Shuen, 1997). Developing dynamic capabilities in an enterprise relies on methodically recording and tracking the results of repeated cycles of knowledge gains (Bendoly & Swink, 2007). Otherwise any innovative ideas or corrective actions are likely to be excluded from future projects. According to Pfeffer (2005) and Tourish (2005), there are three reasons why traditional management methods integrate poorly with development of dynamic capabilities and overall organizational learning. The first reason arises from the need for information to pass through several layers of the firm's hierarchy; therefore it takes more time for upper management decisions to reach front-line employees. This affects the speed and accuracy of communication (Beer, Voelpel, Leibold, & Tekie, 2005). The second reason is that multiple environmental factors affect organizational levels, making it difficult for top management to keep track of the multiple environmental factors affecting each organizational level (Elenkov, 1997). Third, conventional top-down structures hinder bottom-up communication regarding environmental changes, which results in slower organizational learning. The reason bottom-up communication is important is explained by Ghoshal and Bartlett (1994) in their conclusion that employees have an impact on dynamic capabilities. They state that the learning capabilities of employees determine a firm's ability to adapt in response to demand through changes to operational processes. Therefore continuous improvement (CI) must incorporate mechanisms linking vertical organizational levels to raise participation from middle and front-line managers (Forrester, 2000). This type of linkage may generate discussion relating to the direction of the CI initiative while also garnering support and involvement from employees (Evans, 2004). Hence it is important for a CI initiative to provide the organization with a mechanism spurring employee interaction with upper management. Continuous improvement is one of the more efficient ways to increase competitiveness in an enterprise (Pettersen, 2009; Shah & Ward, 2007). Successfully incorporating CI concepts through standardized processes and improvement-seeking methods requires ongoing evaluation and, in relation, demands the efficient and timely collection and distribution of information. The importance of consistent information flow is rooted within operation management theory. Based on this theory, the productivity of a process increases as the flow of materials through a process becomes faster and more even (Schmenner & Swink, 1998). Performance impacts include improved quality, and value for stakeholders (George, 2002; Naslund, 2008). In order to progress with CI efforts, managers need sufficient training and education as well as committing to meeting external and internal client needs (Oakland, 2003). Furthermore, management must consider key components of CI facility requirements for data collection, online controls, business functions and processes, and maintenance of databases. Ensuring that information is available across the organization and to decision-makers without delays can accelerate the firm's process improvement efforts (Davenport, 2006). Creating a new generation of informed managers provides the foundation for resilient SMEs to achieve long-term sustainability. Effective and sustainable process management requires flexibility and adaptability in markets with rapidly changing customer preferences and high rates of product innovation.

Strengths and Weaknesses of SMEs

The 2011 United States Census Bureau data provided insight into the importance of SMEs domestically as well as in the global market. According to the data, 99.7 percent of the 5.68 million employer firms in the U.S consist of 500 employees or less while 89.8 percent of firms have less than 20 employees ("Small Business Facts," 2011). Nearly 97 percent of U.S. manufacturers that exported goods were SMEs, which accounted for 33 percent of the goods exports in 2011. Despite the economic impact of small to medium-sized businesses, the majority of organizational performance and ERP research is directed towards its effects on larger firms (J. Esteves & Bohorquez, 2007). Research on larger firms does not accurately identify with SMEs as there are distinctive general characteristics to consider. Garengo, Biazzo, and Bititci (2005) listed the following distinctive attributes: (1) the ability to reach quickly and be flexible with change; (2) a lack of structure in organizational processes; (3) decision-making processes focused on the owner; (4) a concentration on production and technical aspects; (5) learning by doing a task impacting organizational learning; (6) a scarcity of time for non-operational tasks. Research shows SMEs follow less structured processes, which leads to informal communication between management and employees. This manifests to less bureaucratic management systems thereby diminishing the need for formal processes and controls and allowing for dynamic and innovative manufacturing environments (Battaglia, Bianchi, Frey, & Irlando, 2010; Castka, Balzarova, Bamber, & Sharp, 2004; Murillo & Lozano, 2006). Shin (2006b) found that SMEs benefit more from IT improving inter-firm relationships.

While smaller companies are more agile and can gain support and commitment for new initiatives with greater ease than larger ones, training is more difficult for SMEs since they have less available human and financial resources to allocate for education in quality management programs (Kaushik, Khanduja, Mittal, & Jaglan, 2012). An important factor that SMEs must consider is their tolerance for risk. Prior studies show that SMEs have low risk propensity since owners often contribute a considerable portion of their own capital (Bharati & Chaudhury, 2009). Budget restraints often limit SMEs to poorer information systems than large firms (Cocca & Alberti, 2008). Also, SMEs are susceptible to short term fluctuations in the market without readily available funds to absorb the impact. Shortages of labor resources necessitate multi-tasking from employees, which limits any time for strategy implementation (Jenkins, 2009). In addition, SMEs tend to be reactive and engaged with “fire-fighting” short-term problems rather than allocating resources to strategic planning, managerial activities, and IS implementation (Pollard & Hayne, 1998). There is usually weaker alignment between performance measures and strategy than in large companies (O'Regan & Ghobadian, 2004). PMM is viewed as a potential stimulus to support the improvement of managerial activities in SMEs although a majority of research focuses on the practices of large companies. It upholds the main focus on operational aspects that characterize small companies while promoting the aligning of its strategy and operational activities (Hudson-Smith & Smith, 2007). Finally, SMEs often operate in smaller markets and rely on fewer customers. This issue raises the importance of maintaining high customer satisfaction to survive the competitive landscape. Ultimately a lack of resources and "fire-fighting" are mentioned as reasons why smaller firms struggle to implement quality management initiatives compared to larger firms (Grolleau, Mzoughi, & Pekovic, 2007). Research has suggested that small manufacturers are less likely to implement lean principles than large manufacturers (White, Pearson, & Wilson, 1999).

Quality Management Initiatives and Continuous Improvement

Companies strive to achieve continuous improvement because it can deliver dynamic capabilities for the organization when successfully undertaken. Upton (1996) defines continuous improvement as an active systematic effort to seek out and apply new ways of doing work while repeatedly making process improvements. Another definition states that CI is the ability to consistently improve current processes and learn new ones (Ittner & Larcker, 1997). Successful CI implementations help integrate operational processes and advance the firm's ability to make quick changes to enhance performance. Although top management and facility managers are beginning to understand the importance of continuously improving processes (Kiernan, 1996; Pullin, 2005), this task has proven to be a challenge due to the difficulty of creating an infrastructure to manage continuous improvement projects (Choo, Linderman, & Schroeder, 2007). Empirical research has shown that quality management practices, supported with integrated process management, increase firm performance (Hendricks & Singhal, 1996; Kaynak, 2003). Interestingly, a study by Sterman et al. (1997) claims that quality management initiatives only improve operational performance in the short-term and fails to maintain in the long-term. Several theories have been stated to explain the long-term underperformance. One argument is that firms fail to fully implement ERPs when they choose not to adopt all requirements of quality management (Easton & Jarrell, 1998; Westphal, Gulati, & Shortell, 1997). Another explanation is that upper management and/or facility managers fail to bridge the gap between their intentions for quality and the actual reality of implementation across organizational departments. Beer (2003) notes further complications when firms fail to establish a balance between process improvements through increased control, commitment, and innovation from employees.

Existing literature has attributed the poor adoption rates of QMIs in SMEs to complex reasons beyond of the usual concerns of high cost, time, and low relative impact (Gome, 1996). One reason mentions the difficulty to distinguish between different QMIs such as Six Sigma, ISO, and lean concepts considering there is little evidence to support improvement claims. Second, some SMEs are confident in their existing system and, in the case of ISO 9000, believe it is sufficient to meet their business needs. A final idea is the misconception that these initiatives involve a significant amount of statistics, which extend beyond their domain (Antony, Kumar, & Labib, 2008; Husband, 1997; Thomas & Webb, 2003).

Six Sigma

Six Sigma is a rigorous and highly effective application of techniques and principles to deliver nearly error-free business performance (Pyzdek & Keller, 2010). Harry and Schroeder (2000) describe Six Sigma as a breakthrough business improvement approach that offers companies simple and powerful statistical methods for attaining and maintaining operational excellence. Evans and Lindsay (2005) explain Six Sigma as a process improvement method that looks to identify and remove causes of defects and errors, reduce cycle times, reduce operational costs, improve productivity, consistently meet customer expectations and accomplish higher asset utilization. It attempts to improve facility processes by reducing variability in routines (Linderman, Shroeder, Zaheer, & Choo, 2003). Companies are able to significantly improve their performance by developing and monitoring daily business functions in ways that minimize waste and resources yet also improve customer satisfaction. The goal of Six Sigma is to design processes that operate as desired with high reliability, which results in the production of consistently high quality products (Coronado & Antony, 2002). Numerically, Six Sigma's objective is to reduce defects to 3.4 parts per million, or defects per million opportunities (DPMO), reduce cycle time, and reduce costs (Behara, Fontenot, & Gresham, 1994). Thus a company operating at a ± six sigma variation of the process will produce 99.99955 percent of the products within the limits of the specifications. Three important deliverables of Six Sigma are critical to cost (CTC), critical to quality (CTQ), and critical to schedule (CTS). CTC include parameters that impact finished goods inventory, overhead, delivery, material and labor, and work in progress. CTQ metrics compare process performance with process requirements and determine whether the process meets expectations sufficiently or fails to meet expectations. CTQ parameters impact the requirements chosen by customer and CTS factors impact the delivery time of the product or service.

The Define-Measure-Analyze-Improve-Control (DMAIC) methodology of Six Sigma is applied for the performance improvement of a product, process, or service. The DMAIC method initially focused on reducing variation in manufacturing processes. It has since then evolved to include quality improvement, efficiency improvement, cost reduction, and solving other issues affecting operations management. Table 5 depicts an overview of the steps taken and potentially useful tools used in a Six Sigma Project.

Table 5: DMAIC and Common Tools (adapted fromPyzdek & Keller, 2010)

DMAIC Framework	
Define	Define Project Scope, Objective and Schedule
	Identify Process and Stakeholders
	Determine/Rank Customer Needs/Requirements
	Obtain Authorization from Sponsors
	Provide Business Case for Project
Measure	Define Process
	Define Metrics
	Establish Process Baseline
	Evaluate Measurement System
Analyze	Benchmark Against Best in Class
	Determine Process Drivers
	Analyze Sources of Variation
	Analyze Value Stream
Improve	Evaluate for Risks and Failure Modes
	Optimize Process/Product Settings
	Define New Process or Product Redesign
	Prioritize Improvement Opportunities
Control	Approve Deliverables
	Document Lessons Learned
	Develop and Implement Control Plan
	Validate New Process/Product

Companies aim to reduce or even eliminate customer complaints due to the idea that fewer complaints will equate to more customer satisfaction. Gaining knowledge regarding customers' perceptions of the company and its products greatly improves the likelihood of better decisions by managers and employees. According to Harry (1998) Six Sigma recognizes a direct correlation between the amount of errors and wasted operating costs and the extent of customer satisfaction. Wilson (2004) notes the following additional advantages for SMEs pursuing Six Sigma: stronger and closer relationships with customers, a limited number of sites, less layers in management's hierarchy, faster and effective communication, and stronger influence from the owner.

Although Six Sigma has had a significant impact on the industry, there is a shortage of systematic research from the academic community that investigates its benefits (Antony, 2004; Linderman et al., 2003; Schroeder, Linderman, Liedtke, & Choo, 2008). Schroeder (2008) reinforces this statement by claiming the need for research to determine the impact of Six Sigma on performance improvement. Enterprise-wide adoption of Six Sigma usually demands significant investment in consulting, training, firm restructuring, and IS, which often occurs in large companies. Since most of the Six Sigma success stories are observed in large enterprises, more analysis of SMEs is needed to verify its benefits after planning, implementation, and deployment (M. Harry & Crawford, 2004). Despite the lack of rigorous research Kumar (2008) produced results demonstrating that Six Sigma can be successfully implemented in organizations of any size as long as there is strong leadership and commitment from upper management.

Lean Production

Manufacturing companies are pursuing optimization through increased product development speeds, production flexibility, improved process control, efficient resource utilization, waste elimination and advanced global reach to gain an advantage on competitors. These firms are adopting the methods of lean manufacturing to achieve this optimization through continuous improvement and the streamlining of business processes (Womack, Jones, & Ross, 1990). Its core objective is to create a streamlined high-quality system within a facility that produces quality products in an efficient and economic manner and at the pace of customer demand with minimal waste (Shah & Ward, 2003). The goal of lean manufacturing is to eliminate all wasted time, materials, and movement.

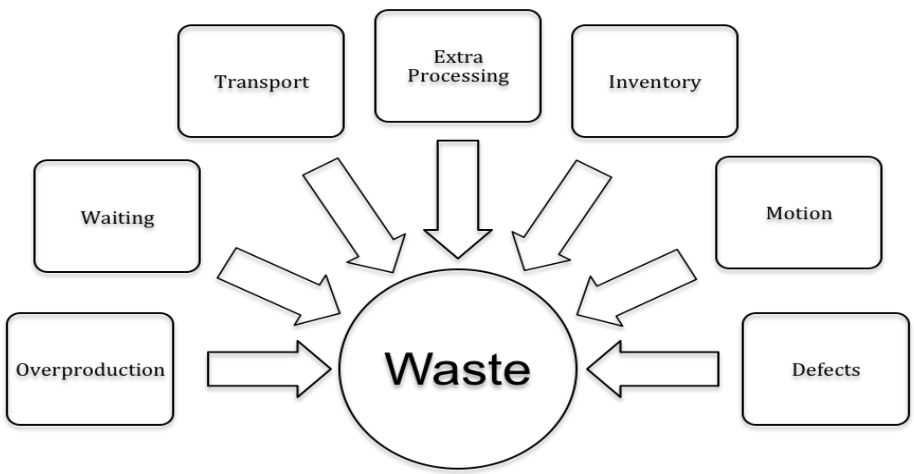


Figure 5: Types of Waste (Adapted from Toyota Production System)

It contributes to a firm's competitive advantages through increased capacity and inventory turns, reduced work-in-process, reduced cycle-time reduction, and improved customer satisfaction. Currently, literature lacks a systematic methodology for implementing lean strategies although lean performance is often measured based on productivity or operational efficiency (Kuhlang, Edtmayr, & Sihn, 2011; Leung & Lee, 2002; Mejabi, 2003). Forty companies participated in a survey and reported lean manufacturing improvements in operations such as reduced lead time, increased productivity A study by XR Associates (2003) reported waste reductions of 40 percent, a decrease in inventory and space requirements of 60 percent, and reducing process changeovers by 60 percent. Shah and Ward (2003) employed lean practices in a study of continuous improvement, total preventative maintenance, and the employee management and found a positive relationship with operational performance. Hon (2003) evaluated leanness through time, cost, flexibility, and productivity.

A 2007 survey of U.S. manufacturers found that 70 percent of facilities had employed lean manufacturing, however, 74 percent of these were unsatisfied with the progress being made (Pay, 2008). Critical success factors (CSFs) for lean manufacturing implementation are listed as strong leadership, sound project management, availability of financial resources, enterprise culture, and skills and expertise (Timans, Antony, Ahaus, & Solingen, 2012). While it is difficult to apply the lean philosophy to environments with high product variety and low volumes due to dynamic schedules, designs, and product mixes (Jina & Bhattacharya, 1997), IS systems such as ERPs are enabling companies to overcome these obstacles.

Lean Six Sigma

Similar to Six Sigma's CTQ, CTS, and CTC deliverables, many previous lean models and methods used performance indicators for quality, cost, value-added time, lead time, and operational time (Kuhlang et al., 2011; Shah & Ward, 2003). In terms of quality, lean production adds to Six Sigma by reducing process variability and streamlining workflow. Meanwhile Six Sigma's impact of improving quality by decreasing variability and errors complements the lean strategy of speed, delivery, and cost effectiveness by reducing delays, minimizing rework of finished tasks, and confirming the quality of shipped products (Al-Aomar, 2012; Arnheiter & Maleyeff, 2005). The complementary nature of lean production and Six Sigma produced the concept of Lean Six Sigma (LSS). LSS combines Six Sigma's focus on strategic alignment, customer focus, and analytical tools with lean's focus on speed and delivering strong results (Agarwal & Bajaj, 2008).

ISO 9001

The ISO (International Organization of Standardization) 9001 QMS are predicated on a process-model that entails identifying, documenting, controlling, and continuously improving all processes and activities that impact the customer. Literature shows that SMEs and larger enterprises strive for ISO certification to improve market share and retain existing clients, facilitation of standardization and documentation of procedures in place, eliminates bureaucracy, and applies more of a proactive approach to data collection and continuous improvement (Swink & Jacobs, 2012). Other benefits include enhanced business performance, improvements in operational effectiveness, variance reduction in production, cost reductions, reduced waste, and improved system quality (Deangelis, 1991; Dzus, 1991; Vermeer & Frederik, 1992). Upper and middle management also view ISO 9001 as a means to develop the structure and necessary processes for a foundation to begin Lean and Six Sigma (Maneesh Kumar & Antony, 2008). Prior research regarding potential organizational performance improvements resulting from ISO 9001 standards are mixed. Chiarini (2011) conducted a nine-year study of European companies that are ISO 9001-certified and in the late stages of lean implementation. The author determined that the integration of ISO 9001 and lean management systems enabled organizations to improve efficiency and standardize lean production practices. Naveh and Erez (2004) reported a positive relationship between ISO 9000 certification and improved process control. Meanwhile Terziovski (2003) found a positive relationship between organizational performance and management's purpose for attaining ISO 9000. In addition, Corbett et al. (2005) revealed that ISO 9000-certified manufacturing companies produced considerably better financial results after three years of maturity within in the firm. Through a combination of quantitative and qualitative analysis, Wu and Chen (2011) determined that ISO-certified enterprises achieve better overall performance through the enhanced operational efficiencies and product quality, customer satisfaction, and standardized processes than ISO-uncertified companies. Unfortunately for SMEs, the likelihood of earning ISO 9001 certification increases with the size of the firm (Koc, 2007; Pekovic, 2010). In contrast, separate studies by Terzioski et al. (1997) and Singels et al. (2001) were unsuccessful in finding evidence in any relationship between ISO certification and organizational performance.

Despite the positive effect on guiding operational improvement within a facility, ISO 9001 quality standards are limited by a lack of tools and models to manage performance and a lack of connection between monitoring strategy and performance (Patrizia Garengo & Biazzo, 2013). These weaknesses create the need for an additional framework to guide upper management and facility managers with their evaluation of organizational performance.

Results of Existing QMI-related Analysis

Quality management initiatives create a culture of continuous improvement, customer-centric goals, worker empowerment, and information-based decision-making (Dassisti, 2010; Tan, Kannan, Jayaram, & Narasimhan, 2004), all of which can be supportive of PMS implementation without the need for such a PMS to pre-exist. Meanwhile efforts to attain CI have multiplied among manufacturing facilities worldwide (C. A. Voss, 2005). Enterprises are seeking the ability to continually improve business processes to keep up with the fast pace and complexity of the industry. To date studies have reported both positive and negative results. It is important to consider that these results may not be conclusive since it is common for companies to avoid reporting failures. Therefore it is possible that a skew exists in literature toward positive studies. A study by Mendelbaum (2006) found that only 11% of companies considered their continuous improvement projects as successful. Current research finds that resource constraints are one of the barriers to successful QMS implementations (Antony et al., 2008). Looking beyond cost and time, another critical reason for unsuccessful implementation is the lack of understanding and experience of CI initiatives (Antony et al., 2008; Thomas & Webb, 2003). Timans et al. (2012) revealed two areas of weakness in Six Sigma's DMAIC methodology. Pertaining to the Improve and Control phases, project goals usually aim for solving existing problems rather than focusing on strategic opportunities. The second limitation is its inability to effectively control and assure realized improvements. Although Six Sigma falls within the quality management movement, it is different than other QMIs like lean concepts and ISO 9000 due to the limited time-frame, measurable goals, and project structure (Andersson, Eriksson, & Torstensson, 2006; Dahlgaard & Dahlgaard-Park, 2006). Nonthaleerak and Hendry (2006) noted that an emerging trend of Six Sigma is its integration with QMIs especially the ISO standard. Warnack (2003) states that a successful Six Sigma program will enrich the CI goals within the ISO 9001 QMS by applying techniques and tools in a structured way. De Mast (2003) further supports this relationship by stressing the importance of quality improvement projects that rely on statistical methods. In return, ISO 9001's review is closely monitored by facility managers and top management, which allows them to review the progress of Six Sigma and make suggestions to continually improve the initiative. Limitations in lean manufacturing include a deficiency of statistical analysis, no standard approach to problem-solving, and no emphasis on process variability reduction (Nauhria, Wadhwa, & Pandey, 2009). These limitations can be overcome with the analytical tools of Six Sigma. Despite the support that these QMIs offer each other, there are no specific case studies evaluating LSS as a focused strategy for competitive manufacturing (Sheldon, 2005).

Upon analyzing the strengths and weaknesses of different QMIs, it is apparent that integrating the concepts and tools of multiple programs together can bolster a firm's pursuit of CI and process-improvement. Cua et al. (2001) investigated the connection between integrating multiple QMIs and manufacturing performance. The author's results indicate that higher levels of performance are attainable when multiple CI approaches are used simultaneously. Continuing with the idea that Lean, Six Sigma, and ISO support each other's process improvement efforts, Pfeifer et al. (2004) believes that the process management activities that are conducted under a ISO 9001 QMS aids Six Sigma in identifying the necessary participants to carry out a project and selecting the scope. The results of the Six Sigma project then contribute to the continual improvement of QMS. Dey (2002) views the DMAIC framework as a means between QMS and the customer. This author's model draws a relationship between the "measurement, analysis, and improvement" requirements of ISO 9001 and DMAIC's "measure, analyze, and improve" phases. The role of ERPs in current implementations is that of providing real-time accurate data. ERPs enable capabilities that are vital to the success of LSS such as common work processes, application integration, real-time order management, real-time data-sharing, data integrity, visibility of inventory, business intelligence, and analytics (Nauhria et al., 2009).

Cost Considerations

Business executives and facility managers must factor in the costs associated with implementing enterprise-wide QMS. Consulting services, training, restructuring of operations, and information-reporting systems involve substantial investment. Antony (2006) and Fahmy (2006) found Six Sigma training costs alone to reach as much as $50,000 per trained employee. Other specific resources need to be in possession or attained to successfully reach Six Sigma goals. Attaining ISO quality certification also requires a substantial investment.

Most enterprises are aware of the value of FM and the associated costs (Then & Chau, 2012). While staffing costs often can represent up to 80% to 90% of an organization's total expenditures, costs of facilities are often the 2nd largest expenditure (Langston & Lauge-Kristensen, 2002). ERPs can reduce the number of employee hours through automation and other process-improvements. In order for a manager to determine whether or not to cut back on staff and implement IT, cost considerations for IT adoption must be listed. A full cost-benefit analysis is beyond the scope of this research. However, some cost considerations that are noteworthy include initiation costs, capital costs, and implementation costs.

The Role of Performance Measurement

The purpose of performance measurement is to understand the impacts of management decisions on the success or failure of QMI and identify areas of need to make improvements (Cable & Davis, 2004). Evaluating performance helps guide necessary change by providing information for decision-makers to choose the best course of action to position the organization for the future. The indicators represent the current status of manufacturing, help observe and control operational efficiency, and gauge the effectiveness of decisions (Hon, 2005). Tatikonda (2007) identifies three meanings of performance measurement. First, it can imply a definable metric for a specific measure. Second, it can signify the process of measurement such as the systems and company processes used to measure performance. Lastly, it can suggest an important part of a strategic planning process. For example, the management process of evaluating an organization's performance based on appropriate targets in order to verify or change the overall strategy. Hon (2005) noted the following four generic functions of manufacturing performance measures: (1) to represent the current state of the production situation; (2) to monitor and control operational efficiency; (3) to push improvement programs; and (4) to determine the effectiveness of manufacturing decisions.

The primary objectives of a balanced performance measurement system in a facility are monitoring historical performance for management and customers, controlling by tracking ongoing performance and making appropriate adjustments to improve processes, and directing operations with attention on motivating personnel and reallocation of resources (Driva, 1997). Due to the dynamic nature of manufacturing, it is unlikely that a single measure will fulfill the evaluation goals of an enterprise. Facility managers must utilize a comprehensive dashboard of measures to gain a true representation of performance. For example, simply applying cost measurements would fail to identify any areas of improvement in efficiency or quality. Therefore industry professionals and academic researchers attempt to produce a set of measures for monitoring, controlling, and directing operations related to internal business processes, customer service, and financial dimensions. Neely (1998) listed seven reasons why facility managers care to include performance measurement in their agenda. He identifies the changing nature of work, changing organizational roles, changing external demands, increasing competition, national and global quality awards, specific improvement initiatives, and the powerful capabilities of IT. Companies seeking to measure their performance using a QMS monitor the progress of the results through a dashboard of KPIs to promote change and improvement of day-to-day process management. Generally, performance indicators are applied to measure and analyze organizational processes expected to meet the needs and requirements of customers, enable the development and deployment of organizational goals, analyze the results of the processes and facilitate decision-making, and check the efficiency and effectiveness of the enterprises' processes (Lahoz & Camarotto, 2012). Currently, a performance measurement framework offering the most important measures for manufacturing companies does not exist and there is a tendency for organizations to utilize more than 50 financial and non-financial measures (Hon, 2005). This high number puts a strain on company resources and detracts focus from the critical measures.

Literature has examined other performance measurement models including the Balanced Scorecard (BSC) and the Business Excellence Model (BEM). Table 6 summarizes different performance measurement models and lists them based on the year of origination. Although detailed explanations of these models are beyond the scope of this research, it is important to distinguish certain weaknesses of the previously used models.

Table 6: Summary of Performance Measurement Models (Adapted from Hon 2005)

Model	Source
Performance Criteria System	Globerson, 1985
Performance Measurement Matrix	Keegan et al., 1989
PM for Work Clearance Management	Maskell, 1989
Performance Measurement Questionnaire	Dixon et al., 1990
Business Excellence Model (BEM)	European Foundation for Quality Mgt 1990
SMART pyramid	Lynch and Cross, 1991
Results & Determinants Framework	Fitzgerald et al., 1991
Balanced Scorecard (BSC)	Kaplan & Norton, 1992
Capability Maturity Model (CMM)	Humphrey, 1993
Performance Prism	Neely & Adams, 2000
Performance Measurement System	Medori & Steeple, 2000
Integrated Performance Measurement System	Bititci et al., 2000

One of the most widely utilized, the BSC assists in rationally defining strategic objectives for the company and introduces a number of indicators related to those strategies. An important weakness is its lack of integration between the different systems. Also, it is considered unsuitable for SMEs as they tend to a shorter-term strategic focus than larger firms (Hvolby & Thorstenson, 2000; McAdam, 2000). The BEM model provides managers with guidance for effective administration and introduces several indicators based on the company's processes. However, it has a tendency to unnecessarily increase the number of indicators without considering their effectiveness. Also, there is a lack of connection between monitoring and performance management as well as inadequate measurement of the processes.

Research has distinguished KPIs as the most widely accepted method for measuring FM performance (Meng & Minogue, 2011). It generally targets process efficiency and effectiveness, the customer's level of satisfaction, product consistency, and supplier's performance. In order to determine a company's capabilities with respect to these, performance metrics must be developed to express operational strengths and weaknesses in a holistic manner. According to Lahoz and Camarotto (2012), research literature distinguishes five main types of performance indicators of production processes. Strategic indicators show "how much" the organization is achieving its critical success factors in regards to its vision. Productivity indicators assess efficiency through the proportion of resources consumed to the output processes. Quality indicators concentrate on customer satisfaction as well as product or service characteristics. Indicators of effectiveness focus on the effects of products or services and taking action in the correct manner. Finally, capacity indicators measure process responsiveness with the relationship of the output produced per unit of time. Relevant, clear, and compatible performance metrics expose the driving forces of a firm and its facility's performance. These metrics measure short and long-term monetary and performance-related goals, and are necessary to determine the health of relationships between the customer and service provider (Baldwin, Camm, & Moore, 2000). Moreover these measurements address whether current operating processes and QMS are providing expected results on decisions.

Table 7: Performance Measurement Benefits (Adapted from Meng, 2011)

Clients	Service Providers
Improved Client Focus	Better Understanding of Client's Objectives
Increased Value for Capital	CI Capability within the Organization
Higher Standard of Service Delivery	Competitive Advantage over Competition
Tender Selection based on Performance	Additional Business Opportunities from Clients

FM requires a set of different quantitative and qualitative measures to produce useful data comparisons. Important properties of a performance measure include its simplicity or ease for data collection of informative statistics, its predictive ability as a look-ahead function to guide for planning, and its ability to be applied throughout the organization for comparison (Hon, 2005). According to Nenadal (2008), there are key features that any capable measurement system will possess. The system must establish validity through objective indicators and produce results that are accepted by the facility management and staff. Reflecting every important aspect of the process assures the completeness of the indicators that are used to measure the manufacturing performance. Next, the detail and accuracy of data gathering and analysis must be sufficient. The timeliness of accessing data by facility management and staff is another notable characteristic. Finally, applying terms that are easily understood and explained by users enhances the impact of the measurement.

Metrics allow for business planning and execution based on data while enabling organizational and individual learning and improvement. A couple of examples include metrics comparing actual versus past performance, actual versus anticipated performance, and benchmarking a facility with other similar ones (Kincaid, 1994; Macsporran & Tucker, 1996; Preiser & Schramm, 2002). Operational Performance (OP) is commonly assessed along the dimensions of cost, quality, flexibility, and delivery (Devaraj, Hollingworth, & Schroeder, 2004; Hudson, Smart, & Bourne, 2001; Vickery, Droge, & Markland, 1993). These dimensions can be broken down further. Figure 6 shows the breakdown of performance measurement into KPIs and subsections.

Comprehensive Performance Measurement Dimensions and Priorities			
Deliverable	**Six Sigma**	**KPI**	**Competitive Priorities**
Quality	Critical to Quality	Quality	Quality

			Customer Satisfaction
Cost	Critical to Cost	Cost	Fixed/Variable Costs
			Waste
Schedule	Critical to Schedule	Delivery/Time	Effectiveness/Efficiency
			Speed
		Flexibility	Flexibility

Figure 6: Performance Measurement Dimensions

Performance Measurement Systems (PMS)

A PMS gathers, processes, and analyzes information regarding performance and communicates it to decision-makers as a concise overview for review. Facility managers use the system with both financial and non-financial metrics to support the improvement of strategy deployment and alignment of key business processes (Taylor & Taylor, 2014). Flapper et al. (1996) state:

> "A good manager keeps track of the performance of the system he or she is responsible for by means of performance measurement. His/her staff carrying responsibility for certain activities within the system need performance measurement to see how well they are performing their tasks. This also holds for the employees

actually executing the various process steps. So performance indicators are important for everyone inside an organization, as they tell what has to be measured and what are the control limits the actual performance should be within."

The successful implementation of a PMS can support decision-making processes in SMEs and enable improvement of their management processes and strategic control (Bhimani, 1994). However, Taylor and Taylor (2013) found that SMEs are less likely to successfully implement a PMS in their organization than large firms. Generally, a PMS follows a top-down process to define objectives that are derived from strategy and KPIs. Following implementation of the PMS, a bottom-up process of determines whether the different KPI measures associated to the strategic objectives are being attained or not. A PMS requires support from an information system in order to be effective. Table 8 lists important characteristics for an effective information system.

Table 8: Effective Information System Characteristics (Taylor & Taylor, 2014)

Information System Characteristics
Ability to handle integrated data from different systems and sources
Have the capacity to present information and data in real-time
Provide dynamic responsiveness to changes in the business environment
Prevent data overload by supplying the right users with performance data
Deliver accurate performance information with sufficient reliability
Facilitate easy access to information

An inadequate information system has been deemed one of the main impediments to performance measurement particularly with SMEs (Bititci, Turner, & Begemann, 2000; Bourne, 2002; Hudson et al., 2001; Neely, 1999). Several important considerations for the design of a PMS include the timeliness of information, the relevance of data in regards to decision-making, implementation costs, and the range of coverage. Despite a variety of PMS options, Hon notes that few systems are designed for the purpose of FM in the manufacturing industry. In fact a majority of companies use a static PMS, which limits their responsiveness and flexibility. A lack of a structured framework, a rigid platform, and the incapacity to quantify the measures act as barriers to implementing a more dynamic approach. Kaplan (R.S. Kaplan, 1983, 1984a, 1984b, 1986) adds to the increasing recognition that companies have traditionally been using inappropriate performance measures in the manufacturing industry due to the following:

- A focus on the short-term by delaying capital investment;
- A lack of strategic focus with an inability to provide quality, responsiveness, and flexibility data (Skinner, 1974);
- Encouragement of managers to maintain standard practices rather than seeking continual improvement;
- A failure to produce information regarding customer wants and competitor's actions.

Along with these weaknesses, Kim identified the need for additional emphasis on measuring the customer's perspective. He reviewed research on strategy, operations, and production and noted that evaluating in terms of the customer linked the gap between corporate strategy and organizational performance.

CHAPTER 3 - METHODOLOGY

A combination of the Facility Performance Measurement Methodology, LSS and ISO methods and tools, and KPIs are used to analyze the performance of an ERP in a SME manufacturing facility. The triangulation approach was utilized to produce robust results for this research. This approach includes quantitative and qualitative research through an extensive literature review, the Delphi process, and the case study. Analysis and interpretation of the results are produced from published journal articles, observations and face-to-face interviews during site visits, and querying of information through the MOMS database.

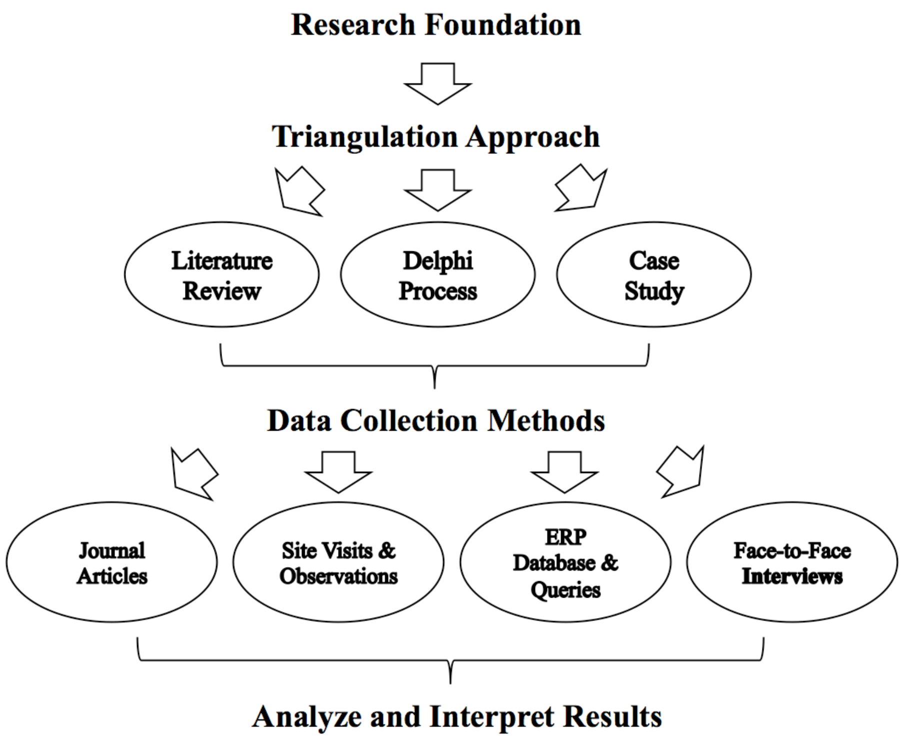


Figure 7: Triangulation Approach for Research Methodology

The Facility Performance Measurement methodology is applied to guide the phases of the study. Within this methodology, the DMAIC structure is utilized as a “gated process” to ensure that criteria for completing a particular phase has been defined and achieved before moving to the next phase. The performance evaluation framework that directs the quantitative assessments consist of KPIs identified in the literature review and metrics validated through the Delphi process and LSS.

Facility Performance Measurement Methodology

There are several key features of any measurement system (Nenadal, 2008). In terms of validity, indicators must be objective and the results accepted by the users. Next, indicators must reflect any important aspects of process performance to ensure completeness. Adequate detail and accuracy of data gathering and analysis usually requires many labor hours. Fortunately the ERP system in this study expedites this process and has accurately recorded and disseminated data. Another key feature is the frequent or even continuous measurement of the system to obtain a clear idea of performance. Timeliness is important in that it provides facility management and senior managers with easy access to data as needed. Lastly, the items being measured and anyone using the measurement data should be able to easily explain it. While there is no true systematic approach to developing process performance measurement, Figure 8 shows the structure of a proposed measurement framework used to guide the analysis of ERPs impact on organizational performance, beginning with the first step of Process Description.

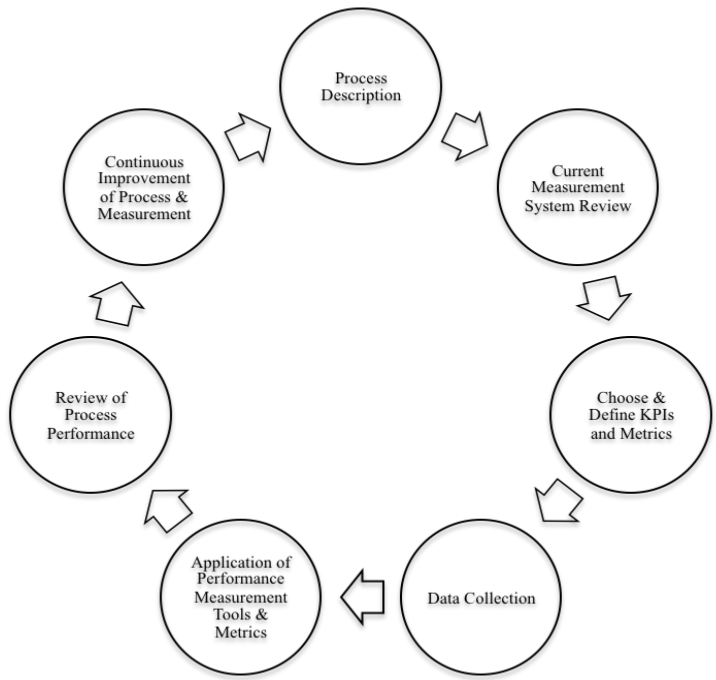


Figure 8: Facility Performance Measurement Methodology (Adapted from Nenadal, 2008)

The outputs of performance measurement model provide valuable insight into performance through data analysis and will underpin the following activities: process audits within the firm's QMS; self-assessment of QMS maturity; process oriented benchmarking; and process efficiency and effectiveness. The model requires the mapping of a process baseline and the post-ERP implementation process for comparative purposes. KPIs are selected based on the competitive needs of the company. Once the appropriate KPIs and performance metrics are defined, data over the span of several years is automatically collected through the ERP and analyzed according to the metrics. Prior to utilizing the ERP, data collection was carried out by manually opening and reviewing spreadsheets, digital documents, and manual entry. Recording and storing data within the ERP database allows for analysis through statistical software. Ultimately a review of the outputs provides a comprehensive evaluation of the facility's performance. The DMAIC methodology is integrated with the Facility Performance Measurement Methodology to enhance the robustness of the study.

A series of face-to-face interviews with employees of the facility being studied provided an accurate description of the production process prior to and post-ERP implementation. Each step in the baseline process and ERP-enabled process is mapped into a process flow chart.

Table 9: Process Description Procedure and Corresponding Action

Phase of DMAIC Model	Structure of Procedure	Action
Define: Problem selection & benefit analysis	1. Identify & Map Relevant Processes	Map Traditional vs ERP-enabled
	2. Identify stakeholders	Owner, Facility Manager, Staff, Customer
	3. Choose & Prioritize Customer Needs & Requirements	Choose and Define Competitive Priorities & KPIs through Lit Review & Interviews
	4. Determine the research questions	Did MDI improve upon Quality metrics? What are areas of strengths/weakness? Is post-ERP performance improved over pre-ERP? Has MDI continuously improved based on metrics

Current Process Measurement System Review

According to Nenadal (2008), there are key features that any capable measurement system will possess. The system must establish validity through indicators that count objectively and produce results that are accepted by the facility management and staff. Reflecting every important aspect of the process assures completeness of the indicators used to measure the performance of the production process. Next, the detail and accuracy of data gathering and analysis must be sufficient. Another feature is measuring the indicators regularly or with sufficient frequency to gain a true perspective of real performance. The timeliness of accessing data by facility management and staff is an important characteristic. Finally, applying terms that are easily understood and explained by users enhances the measurement regime.

Choosing and Applying KPIs & Performance Metrics

The number of KPIs and metrics used in performance measurement must be enough to provide a comprehensive representation of process performance while not exceeding a necessary amount. Too many metrics requires additional utilization of resources and time while potentially overwhelming the users of the measures. Overall the goal is to choose and apply measures that collectively describe and explain process behavior, and eliminate wasteful reporting of unnecessary metrics.

Table 10: Process Measurement System Review and Corresponding Action

Phase of DMAIC Model	Structure of Procedure	Action
Measure: Translate problem into metrics, measure current processes	1. Select the deliverables	Literature review of CTC/CTQ/CTS & KPI metrics; Competitive Priorities; Delphi Process to validate
	2. Explain operational definitions for deliverables	Define performance metrics & equations; Identify inputs/outputs
	3. Validate measurement systems of deliverables	Cross-check official documents with ERP data; Ensure accurate & reliable data
	4. Assess current process capabilities	Assess changes
	5. Define Objectives	Collect & Analyze organizational performance data

Data Collection and Analysis through ERP Technology

Data triangulation, the combination of multiple methods to study the same phenomenon, was utilized through the use of several sources to ensure data quality and robust results. Company records including detailed documentation of process descriptions, forms, and deliverables were gathered and analyzed. Numerous face-to-face interviews and discussions with upper management and employees provided further insight. Six site visits over the course of eleven months offered additional observations of MDI's facility operations. The MOMS (MDI Operations Management System) ERP that has been developed and implemented in MDI's manufacturing facility is built upon a relational database that is used for all business operations. Other applications including MDI's product testing system (Mothership) and Quality Control system (MDI Deployment Manager) are integrated with MOMS and contribute to this database. An in-house application was developed to query, collate, and export data from these databases to produce the results for the KPI metrics. This application's integration with MOMS uses a simple interface, which allows performance metrics measurements to be generated on demand and be made available to customers of MOMS. The quality of data is essential to the effectiveness of any performance indicator while the quality of the indicator is dependent on the timeliness and validity of the data.

Table 11: Inputs and Outputs for Performance Metrics

Metric	Inputs	Outputs
Defect Rate	D (Number) = Number of Defects (per source)	DR (Ratio [0,1]) = D / M
	M (Number) = Number of Measurements (per source)	
Product Failure Rate	PD (Number) = Products Delivered	PFR (Ratio [0,1]) = PF / PD
	PF (Number) = Products Failed (Returned)	
Quality Rate	ND (Number) = Number of Products with no defects	QR (Ratio [0,1]) = ND / P
	P (Number) = Number of Products	
Customer Retention Rate	RCEP (Number) = Returning Customers at End of Period	CRR (Ratio [0,1]) = RCEP / CSP
	CSP (Number) = Customers at Start of Period	
Satisfied Customer Rate	C (Number) = Total Customers	SCR [Ratio (0,1)] = (C - UC) / C
	UC (Number) = Unsatisfied Customers	
Total Product Manufacturing Cost	PSC (Currency) = Production Set-Up Cost	TPMC (Currency) = PSC + CPC + AC + QCC
	CPC (Currency) = Component Production Cost	
	AC (Currency) = Assembly Cost	
	QCC (Currency) = Quality Control Cost	
Operating Cost	FC (Currency) = Fixed Costs	OC (Currency) = FC + FIC + VC + PC + UC
	FIC (Currency) = Financial Costs	
	VC (Currency) = Variable Costs	
	PC (Currency) = Payroll Costs	
	UC (Currency) = Utilities Costs	
Inventory Cost	IC (Currency) = Total Cost of Components	IC (Currency) = Total Cost of Components
System Stability & Reliability	OH (Hours) = Operated Hours	SSR (Ratio [0,1]) = (OH - HH) / OH
	HH (Hours) = Halted Hours	

Table 11 continued

Production Loss Rate	PLT (Days) = Process Lead Time	PLT (Days)
	PLTO (Days) = Process Lead Time Optimal	PL (Production Loss) = PLT - PLTO
	Note: PLTO = 3 days	PLR (Production Loss Rate) = (PLT - PLTO) / PLTO
Scrap Rate	IC (Currency) = Inventory Cost (or Total Component Cost)	SR (Ratio [0,1]) = (SCS + ICS) / (IC + SC)
	ICS (Currency) = Inventory Cost Scrap	
	SC (Currency) = Supply Cost	
	SCS (Ratio) = Supply Cost Scrap	
Process Lead Time	PLT (Days) = Shipped Date - Start Date	PLT (Days) = Process Lead Time
Process Cycle Efficiency	PLTO (Days) = Process Lead Time Optimal	PCE (Ratio [0]) = PLTO / PLT
	PLT (Days) = Process Lead Time (Actual)	
On-Time Delivery	PDO (Number) = Product Deliveries On-Time	ODP (Ratio [0,1]) = PDO / PD
	PD (Number) = Product Deliveries (Total)	
Manufacturing Throughput	PLT (Days) = Shipped Date - Start Date	MT (Number) = Period Business Days / PLT
Process Velocity	PLT (Days) = Process Lead Time	PV (Stages per Day) = PS / PLT
	PS (Number) = Number of Production Stages	(Note: PS = 8 stages)
New/Approved Development Requests	ANDR (Number) = Approved New Development Requests	NDRAR (Ratio [0,1]) = ANDR / TNDR
	TNDR (Number) = Total New Development Requests	

Data Collection Prior to MOMS

As noted throughout manufacturing literature, a majority of companies do not employ processes to record operational performance data often due to the limited availability of labor and monetary resources. Fortunately for the purposes of this study, MDI developed and used a system of spreadsheets named “Production Information Core,” “Purchasing List,” and “Quote Buddy” in September 2005 through March 2008 when MOMS was implemented. Collating this data by hand from the large quantity of spreadsheets has produced pre-MOMS data for the following metrics: customer retention rate, production loss rate, process lead time, on-time delivery, manufacturing throughput, and process velocity.

Application of Performance Measurement Tools & Metrics

The purpose of analyzing process performance in manufacturing stems from activities such as performing audits on the process within the overall organization management system, conducting self-assessment of the management system, benchmarking with a focus on the process, and evaluating the improvement of process efficiency and effectiveness. The metrics identified through the Delphi Process and presented in Table 11 will guide the evaluation of MOMS' impact on MDI following its implementation in 2008.

Review of Process Measurement System

Analyzing the system using exploratory and descriptive analysis helps one understand the data. Statistical tools guide the analysis and leads to identification of ways to identify the positive or negative gap between organizational performance before and after ERP implementation and process change. Depending on the nature of the performance gap, facility decision-makers can determine whether additional attention is necessary to address facility issues or inefficiencies.

Table 12: Review of Process Measurement System and Corresponding Action

Phase of DMAIC Model	Structure of Procedure	Action
Analyze: Identify influence factors and causes of behavior	1. Determine the degree of impact of process changes	Compare with prior research; Evaluate pre- and post-ERP performance data; Prioritize impacts
	2. Investigate the performance impact over time	Use statistics to quantify metric and time relationship

CI of Process Performance Measurement

This step includes finding new methods to help a facility achieve better performance, however, this is beyond the scope of this research. The analysis of performance over a span of several years allows one to determine whether continuous improvement was achieved by the organization. This is accomplished by determining whether there is a statistically significant relationship between the performance metric and time. The results of this study will identify areas needing improvement for the MDIs management. Owners and facility managers can assess the level of importance for areas of improvement by investigating the analysis and communicating with employees and customers for feedback. The organization must record any feedback to increase organizational learning and make use of tacit knowledge.

Table 13: Continuous Improvement of Process & Measurement and Corresponding Action

Phase of DMAIC Model	Structure of Procedure	Action
Improve: Design and implementation of adjustments	1. Prioritize actions based on ranking of needs	Where are improvements? Setbacks? Prioritize needs
	2. Implement improvement actions	Changes integrated, Redesign processes
Control: Design and implementation of adjustments	1. Approve Deliverables	Communicate with customers & staff
	2. Document Lessons Learned	Collect and record employee feedback
	3. Validate new process/product	Carry out performance measurement

Longitudinal Case Research

The research methodology in this paper follows the positivist model, which measures variables and tests a pre-specified hypothesis (Kauber, 1986). A single longitudinal case study was conducted with thorough analysis performed on production process data from 2005-2014. Despite criticisms of lack of rigor and an inability to generalize knowledge in single case studies, this paper pursues exploratory research for the following reasons: (1) there is a lack of studies that explore the impact of ERPs on organizational performance in SMEs; (2) manufacturers do not share detailed data with the public for competition reasons; (3) archived data is minimal in SME manufacturing facilities and thus yields few indicators for impacts on the organization; (4) the difficulty of generalizing for the manufacturing industry when companies vary from one facility to another. Differences include financial and labor resource availability, types of products, and batch, mass, or one-of-a-kind project. According to Voss et al. (2002), single cases provide greater depth, an ideal supported by Lyytinen (1987) who states, "this research strategy seems to be the only means of obtaining sufficiently rich data." Case research is appropriate for acquiring the knowledge of practitioners and developing theories from it. Benbasat et al. (1987) offers three occasions for carrying out a case study: (1) the study occurs in a natural setting; (2) the case method allows the researcher to answer "how" and "why" questions, thus understanding the nature and complexity of the processes; and (3) case studies are appropriate to research areas in which few previous studies have been carried out.

Table 14: Checklist of Key Characteristics of Case Studies (Adapted from Benbasat, 1987)

Key Characteristics of Case Studies	MDI Case Study
Phenomenon examined in natural setting	Yes
Data collected by multiple means	Yes
One or few entities examined (Organization)	Yes
Complexity of the unit is studied intensively	Yes
Investigator should hold a receptive attitude towards exploration	Yes
No experimental controls or manipulation are involved	Yes
May not specify independent & dependent variables in advance	Yes
Results derived depend on the integrative power of investigator	Yes

A longitudinal case study involves the repeated observation of the same variables or metrics over long periods of time. Lawler, Nadler, and Mirvis (1983) designated that "the only way to capture the change program and its effects is to assess the program before, during, and after the intervention." Few information technology studies are longitudinal. This study analyzes the impact of ERP implementation and utilization on the organization's performance over a span of nine years to create new knowledge regarding the degree of improvement or of lack thereof on an annual basis. The benefit of analyzing data over the course of several years is seen in the following example. In this case, a change program in the production process initiated by ERP implementation may initially affect the employees and their work routines negatively resulting in a lag in improvements in performance. As employees become accustomed to the new changes in their routine, their efficiency and effectiveness improves. Also, there may be initial performance improvements that begin to fade over time.

Case research has been used for hypothesis generation and exploration as it adds to the body of knowledge in information system research. The top priority of case studies is to generate knowledge on the topic (Stake, 1995), which then leads to analytic generalization. Recently there has been a greater interest in quantitative and qualitative academic research. Maxwell et al. (1986) appealed for the integration of both methods to provide a deeper, contextual basis for the interpretation and validation of results (Cook & Reichardt, 1979; Meyers, 1981). Studies are provided with testability and context as a result.

Company Background

Micro Depot, Inc. (MDI), located in Norcross, GA was the manufacturing company used in this research study. Based on the conditions set by the European Commission and Jha (2011), MDI qualifies as a SME as it consists of less than 250 employees and earns revenue under $100 million. MDI's manufacturing facility occupies

12,000 ft^2. MDI's internally-developed and operated ERP system, called MDI Operations Management System (MOMS), is a web-based system for managing the company's processes and operations in an automated, transparent way. MOMS was developed and continuously improved to meet ISO 9001:2008 compliance. MDI was awarded its ISO certification in 2009 despite the fact that MDI does not have any organizational infrastructure, which is defined as the number of trained quality personnel accountable for implementing Six Sigma, Lean, or ISO and pushing CI efforts within the company (Maneesh Kumar & Antony, 2008).

CEO and manager Hamid Hashemi initially chose to develop and implement MOMS upon observing the need for an automated, real-time management system that could offer increased transparency of facility operations and meet customer requirements for high-quality products. The goal for the ERP was to improve upon quality and on-time delivery. The analysis of the other metrics in the framework will be used to strengthen strategic and tactical decision-making for the company.

Traditional Manufacturing Process Baseline

MDI's traditional manufacturing process consisted of a variety of non-value-added (NVA) steps and manual tasks. Inefficiencies in the production process negatively affected the quality, cost, and timing. In fact this situation convinced upper management at MDI to develop their in-house ERP system called MOMS. Pyzdek and Keller (2010) describe a process baseline as "what were things like before the project" and listed several reasons for determining the process baseline in a study. First, it is important to determine if the project should be pursued. While a project charter provides a business case for the project, other details may fail to support it or the project may be addressing an unimportant part of the problem. Second, a process baseline aids the project team with identifying CTQs and other tangible metrics. Historical performance information on these metrics may reveal useful strategies for improvement. An example would be differentiating strategies for a process that was consistently operating at a poor level as opposed to a process that is erratic. The third reason for a process baseline is to provide information to find the extent of time, cost, and quality improvement. Without the baseline process information, benefits upon completion of a project will be unknown. Process baselines are essential for any process improvement initiatives. They serve as a reference point for proof of benefits gained. It has been noted that SMEs, and in many cases larger companies, do not have the resources or technology to accurately record manufacturing data for analysis. However, as previously explained, a former process has provided data for customer retention rate, production loss rate, process lead time, on-time delivery, manufacturing throughput, and process velocity. This data allows for the accurate statistical comparisons shown in the Results/Analysis section of this paper. Figure 9 shows MDI's traditional manufacturing process prior to the implementation of MOMS.

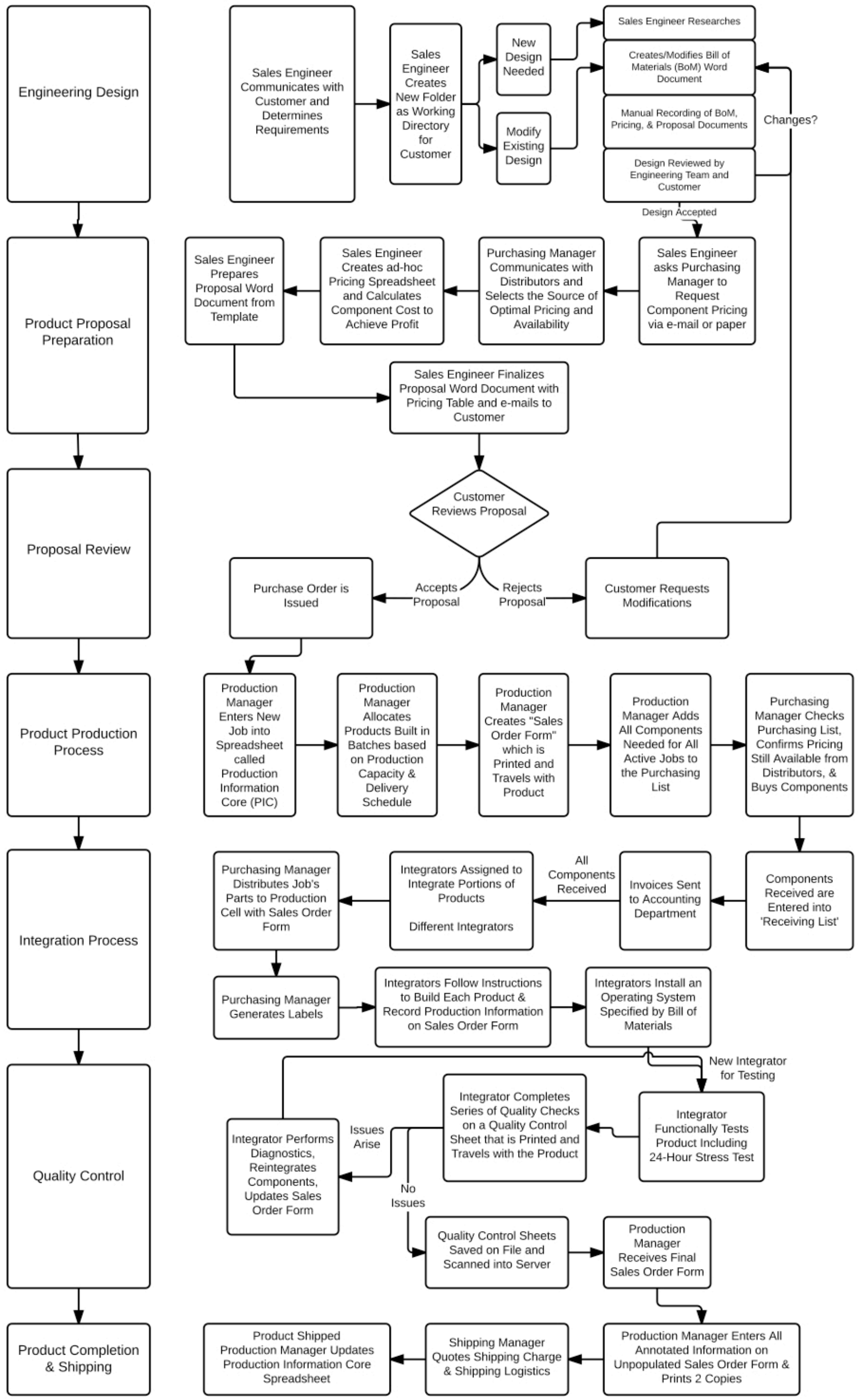


Figure 9: Pre-ERP Manufacturing Process (Baseline)

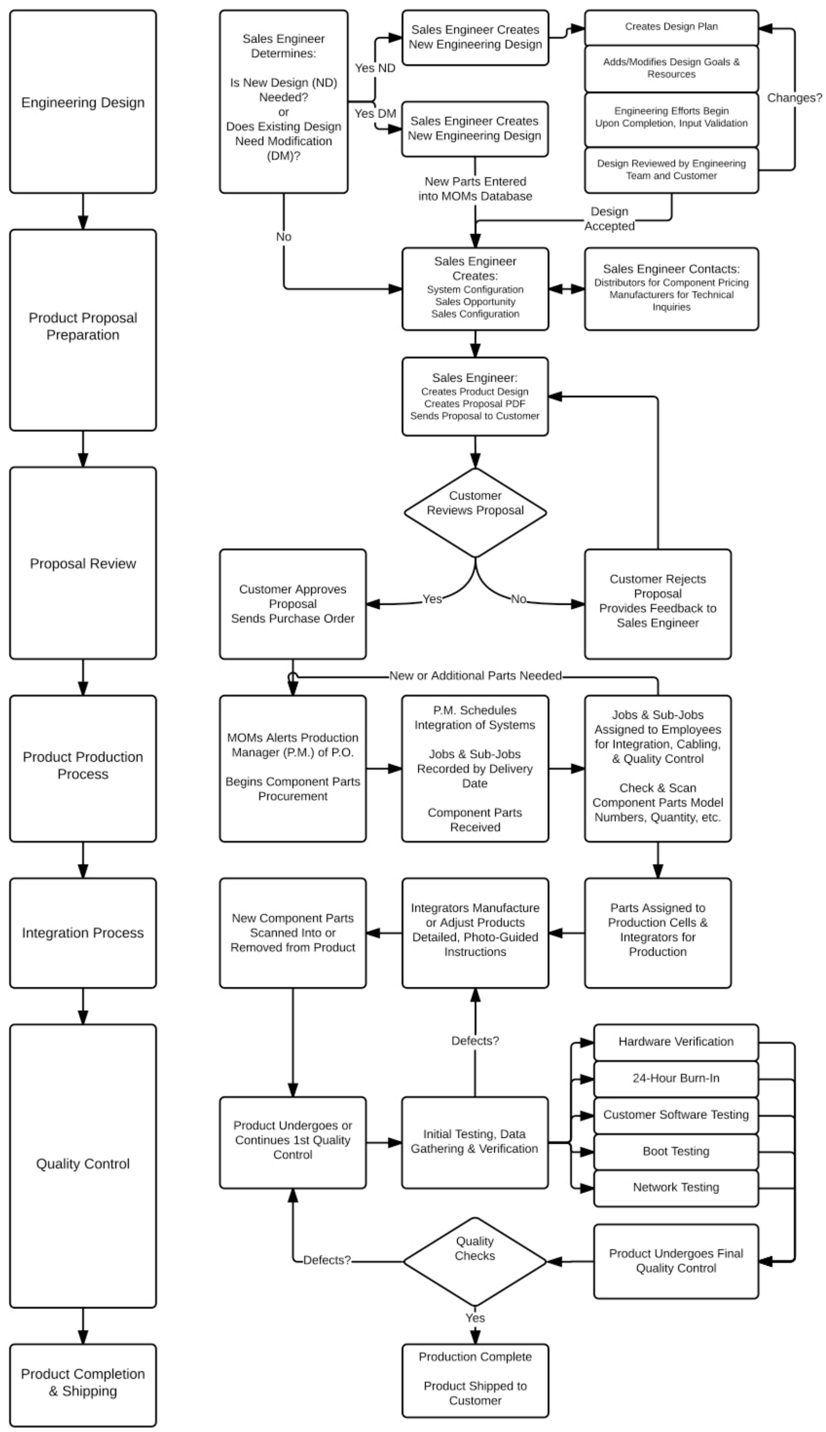


Figure 10: ERP-enabled Manufacturing Process

MDI's in-house development and implementation of their MOMS ERP system provided the company with visibility into operations and the ability to track and analyze performance. As shown in Figure 9 and Figure 10, MDI's manufacturing process consists of the following phases: (1) Engineering Design; (2) Product Proposal Preparation; (3) Proposal Review; (4) Product Production Process; (5) Integration Process; (6) Quality Control; (7) Product Completion & Shipping. Comparisons are made to distinguish the process changes that were made after the implementation of MOMS. The process comparisons are based on face-to-face interviews with current employees of MDI, all of whom have worked there before MOMS was developed and implemented and continue to work at MDI.

Engineering Design: Process Comparison

Whereas employees recorded and filed hand-edited documents for the Bill of Materials (BoM), Pricing, and Proposal documents, MOMS integrated these written forms as Engineering BoM and Sales Opportunity with each feeding into the next process. This change ensures consistency in data and processes from one document to the next, thus alleviating the need to hand-copy and edit these forms, and allows for the data to be included in reports. Prior to MOMS, the data stored within hand-written documents are mainly unusable for analysis by software as they evolve over time in a non-standard format, are not stored in a central location such as a database, and may not be complete. Meanwhile, MOMS has enabled MDI to store the data within a central database, which allows the process to strictly enforce rules such as management approvals, completing required fields, performing logical checks, as well as the ability to search through queries. Note that these data recording, storage, and analysis features apply to each following production phase. Another key difference prior to MOMS was a lack of enforcement of a formal engineering process, version control, and updating of original documents after a change to the BoM. Alternatively, the database within MOMS and the software maintaining processes creates a clear and traceable path to the original product's design and engineering requirements when cloning a product is desired. One remaining aspect of the Pre-MOMS process is that a folder is still kept for each customer on MDI's file server, although it only contains documents that are not critical to production such as generated proposals, notes, and working files.

Product Proposal Preparation: Process Comparison

MOMS provides MDI with a number of benefits and specifically to the work processes of the Sales Engineer. First, the Sales Engineer prepares a Sales Opportunity, which involves creating a pricing worksheet based on the Engineering BoM and determining component pricing from the database. This decreases the amount of effort and time spent on quoting, ensures the use of pricing formulas such as adding overhead costs, standard markup, and quantity discounts, and helps generate the proposal document. Each component that is quoted is recorded into the database, which creates a history of component pricing, and allows products to be designed and quoted without needing to re-quote recently estimated or fixed price products. In addition, the Sales Engineer is no longer required to manually send a list of parts for quoting to the Purchasing Manager. The Purchasing Manager simply must update the price in the components pricing database while the Sales Engineer only needs to accept the updated price into the Sales Opportunity.

Proposal Review: Process Comparison

The Proposal Review stage is the least affected by the implementation of MOMS. Here MOMS maintains a Customer Relations Management (CRM) module, which stores customer contact information at hand and records important customer communications such as sending a proposal.

Product Production Process

A number of improvements are made through the utilization of MOMS. Initially a hand-edited spreadsheet, the Production Information Core (PIC) document has been integrated into MOMS as the basis for the production system without any paper or significant data entry needs. Real-time tracking of progress occurs as products and parts are scanned in interactively. Bar code readers scan and store Component Serial Numbers and Installation Dates, Job Numbers, and Serial Numbers are generated automatically, enforcing uniqueness. By being stored digitally, data acquired from the process is more accessible and accurate for reporting. Rather than the Sales Engineer manually informing the Production Manager that a Purchase Order (PO) has arrived, the PO is entered into the PO Arrival form, which alerts the Production Manager that a Production Job must be created. Once the job is created, it may be "Pushed to Production" causing all components required to fulfill the job to be placed into the Purchasing List. PO numbers are generated automatically and specific important data can be presented to the Purchasing Manager at the time of quoting and receiving. A Conformity Inspection process enforces that products remain uniform through requirements for explicit part numbers, engineering revisions, firmware versions, and other identifying details. In terms of inventory control, MOMS has complete oversight of available inventory, traceability on every component, and various search capabilities of inventory. Prior to MOMS, the record of parts available was stored in the Receiving List and the number of components available was manually counted off the shelf. A final benefit of MOMS during this phase is that the Purchasing Manager no longer needs to communicate costs to the accounting department. As parts are received, they are checked against the expected parts, and if verified, scanned into the system as received. The accounting department receives notification of this event and can see the cost of purchases in MOMS.

Integration Process

Upon creating a Production Job during the Integration Process with MOMS, each product is instantiated in the database and Integrators/Testers are assigned. Batches are created as “Sub-Jobs,” which have start dates and due dates at shorter intervals than the top-level Production Job. MOMS then generates and prints label stickers automatically. The MOMS Production system absorbs the Sales Order Form and tracks the progress in real time as products have parts scanned in interactively. Component Serial Numbers and Install Dates are scanned into the system with bar code readers. Therefore there is no paper or significant data entry required to conduct this process. In addition, before MOMS, integration instructions were held in a physical binder. Separate software that is tightly coupled with MOMS and integrated with the Quality Control process now hosts these integration instructions.

Quality Control

Having previously been performed on paper, the Quality Control process is now recorded digitally and enforced through MOMS. A complete digital record of all QC procedures performed is available for every product. Whereas QC was not strictly enforced prior to MOMS and susceptible to human error such as forgetting to complete the task, MOMS does not allow a product to ship without the assigned QC process records.

Product Completion & Shipping

Since the inception of MOMS, there is no need to re-enter the Sales Order Form from the annotated printed form. MOMS updates the product's component list interactively as parts are scanned into the database. Physical paper is only printed and delivered with the product for the customer's use. A product is complete when all components are installed, all QC procedures are complete, and the product is sent into the Shipping module in MOMS. The Shipping module records all relevant shipping details required to trace a product's delivery date, carrier, tracking number, and shipping cost. The Accounting department is able to access this information, which saves the effort and potential of human error and inaccuracy in manually communicating this information between departments.

Key Performance Indicators (KPIs)

KPIs are indicators used by an enterprise to evaluate the progress or level of compliance with objectives or critical success factors (Rodriguez, Saiz, & Bas, 2009). Firms generally apply business analytics to advance competitiveness (Davenport & Harris, 2007)and focus on critical characteristics of outputs or outcomes to draw conclusions (Chan & Chan, 2004). An appropriate set of KPIs must be tracked over a period of time in order to allow for comparisons against a baseline, which provides managers with the ability to examine improvements or underperformance (Cable & Davis, 2004). Analyzing accurate and reliable data presents decision-makers with a credible evaluation of the effectiveness and suitability of QMS in a facility. As a result upper management and facility managers are able to make well-informed and strategic decisions. Meng (2011) finds the use of KPIs as performance models to be the most effective.

ERPs offer visibility and common data throughout functional departments, which allows enterprises to apply consistent and unified metrics or KPIs. The firms that utilize the analytic capabilities of these systems can quickly use data to support managerial decisions (Chiang, 2009; Ruivo & Neto, 2010). Meng (2011) developed and distributed a survey questionnaire to the majority of qualified FM professionals in the United Kingdom and Ireland to gain an understanding of their performance priorities. The results of the study provide insight into the priorities of FM consultants, service providers, clients and property management firms. Quality, cost, delivery, and flexibility are the four most commonly cited manufacturing performance indicators (Hudson, 2001). For example, Leong et al. (1990) state that it is widely acknowledged that manufacturing performance can be defined by quality, delivery or time, cost, and flexibility. Additional authors support that these KPIs embody a range of dimensions (Garvin, 1987; Schonberger, 1990 ; Slack, 1987; Stalk, 1988). Table 15 lists the four KPIs that will guide the evaluation framework for this research.

Table 15: KPIs Guiding Measurement Metrics

Key Performance Indicators in Manufacturing			
Quality	Cost	Delivery/Time	Flexibility

Hinks and McNay (Hinks & McNay, 1999) assembled a list of 23 performance indicators for managing facilities; about half of which are similar to Meng's indicators. However, a large number of performance indicators lead to an inefficient analysis process, as it would require numerous evaluations. Therefore, the list of indicators is modified to reflect the most important through analytic hierarchy process (AHP), content validity ratio (CVR), and surveys of subject-matter experts and industry professionals. AHP is a subjective technique used to quantify established relationships based on hierarchy. The CVR is the extent that a metric or measure represents all aspects of a given construct.

Delphi Study

The Delphi technique was undertaken to gain and refine the perspective of subject-matter experts in the manufacturing industry. The Delphi is an iterative, multi-stage group facilitation process designed to achieve consensus on the opinions of 'experts' through structured questionnaires (Lynn, Laman, & Englebardt, 1998; McKenna, 1994). Four research objectives of a Delphi were outlined by Turoff (1970): (1) to explore or expose underlying assumptions of information leading to opposing judgments; (2) to seek information which may generate a consensus on the part of the participant group; (3) to correlate informed judgments on a topic extending to a variety of disciplines; (4) to educate the respondent group as to the interrelated and varying aspects of the topic. Selecting respondents is a critical aspect of the process. A subject-matter expert is described as someone who has a background in the topic being presented and has qualifications recognized by the technical community (Meyer & Booker, 1991). Adler and Ziglio (1996) classified four requirements for "expertise": (1) experience and knowledge with the issues under investigation; (2) ability and willingness to participate; (3) sufficient time to participate in Delphi; and (4) effective communication skills.

The process of purposive sampling was utilized for the selection of the experts in this Delphi. Purposive sampling is a non-probability sampling technique where participants are chosen for the purpose of applying their knowledge and experience to a certain topic under review rather than being selected randomly. It is based on the assumption that the researcher has the knowledge about a population to pick the cases to be included in the sample. The pool of potential subject matter experts included manufacturing professionals from SMEs and large companies with more than a decade of knowledge in the manufacturing industry. The number of participants in the study depends on whether the group is heterogeneous or homogeneous. This Delphi consists of a homogeneous group, thus between ten and fifteen people yields sufficient results (Skulmoski, Hartman, & Krahn, 2007). Delbecq, Van de Ven, and Gustafson (1975) agree that ten to fifteen subjects can be sufficient if the group's background is homogenous while Ludwig (1997) documents that a majority of Delphi studies have consisted of fifteen to twenty participants.

The "modified Delphi" process suggested by Kerlinger (1973) was adopted in order to assess and determine the importance of various metrics established in the literature. The structured questionnaire was disseminated to 24 subject-matter experts holding a variety of positions within their respective companies. Of the 20 respondents, 15 completed the 1st round of the online survey. Five respondents submitted incomplete surveys and were excluded.

Table 16: Characteristics of Delphi Participants

Background	Characteristic	Responses (%)	Number (n=15)
Years of Experience in Manufacturing	1 to 5 years	7	1
	6 to 10 years	20	3
	11 to 15 years	20	3
	15 to 19 years	13	2
	More than 20 years	40	6
Nature of Production Experience	Project/One-of-a-Kind	50	1
	Batch	50	2
	Mass	45	2
Employer Type	SME	67	10
	Large	27	4
	Academic	7	1
Respondent Type	CEO	27	4
	Manager	13	2
	Director	13	2
	Production Engineer	27	4
	Consultant	13	2
	Academic Professor	7	1

Table 16 reveals the characteristics of the Delphi experts. In order to produce credible results, the study consisted of employees with manufacturing experience ranging from 5 years to 50 years. A majority of the respondents work in SMEs and with experiences evenly distributed between batch, mass, and one-of-a-kind manufacturing.

In terms of the nature of manufacturing experience, 9 have experience with single projects or one-of-a-kind production (60%), 8 have experience with batch production (53.3%), and 7 have experience with mass production (46.7%).

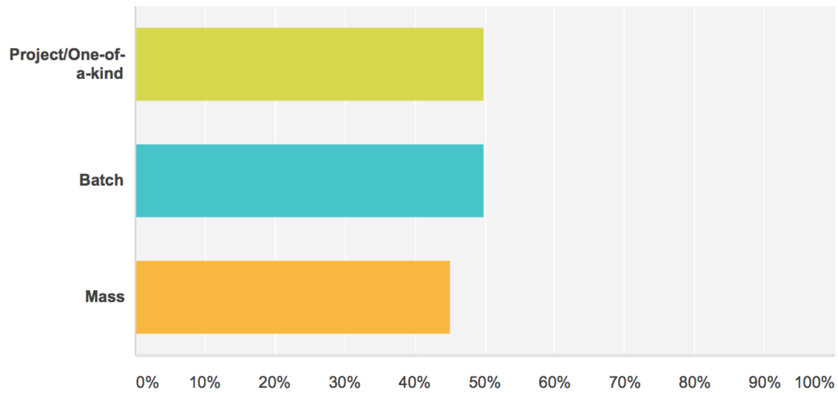


Figure 11: Nature of Expert's Production Experience

The perspectives of CEOs, managers, directors of operations, engineers, consultants, and academic professionals provide for a robust survey. The SurveyMonkey website hosted and provided analysis for this two-round Delphi study. Witkin and Altschuld (1995) explain that electronic technology allows for researchers to conduct a Delphi more easily by taking advantage of, "(1) the storage, processing, and speed of transmission capabilities of computers; (2) the maintenance of respondent anonymity, and; (3) the potential for rapid feedback." Recent literature notes that either two or three rounds are preferred (Beech, 1997; Green, Jones, Hughes, & Williams, 1999; Proctor & Hunt, 1994).

In many cases the Delphi begins with an initial questionnaire offered to participants that solicits specific and open-ended information about a topic, which is then distributed back to them with results of the initial questioning and made available for viewing before submitting the second questionnaire. However, this study incorporated the 'modified Delphi' in which an extensive literature review sets the structure for initial questionnaire. This modified Delphi process is common and accepted as appropriate when information regarding the topic is available and usable (Kerlinger, 1973). The literature review for this research project identified key manufacturing performance indicators and competitive priorities as well as offering corresponding performance evaluation metrics in the first round of the structured questionnaire. Table 17 shows the initial list of metrics.

Table 17: Initial Metrics Provided to Experts for Ranking

Performance Dimensions	Metrics
Quality	Defect Ratio
	Process Capability
	Quality Rate
	First Pass Yield
	Product Failure Rates
Customer Satisfaction	Customer Complaints
	Customer Retention Rate
	Customer Response Time (Wait Time)
	Satisfied Customer Ratio
Cost	Total Product Manufacturing Cost
	Inventory Cost
	Overhead Cost
	Employee Training Cost (per Training Day)
	Production Projects within Budget
	Operating Cost
Waste	Scrap Rate
	Rework Rate
	Production Loss (Downtime and/or Inefficiency)
	Bottleneck or Waiting Time (# of hours or minutes)
	System Stability & Reliability
Efficiency / Effectiveness	Process Cycle Efficiency
	Process Lead Time
	Overall Equipment Effectiveness
	Manufacturing Cycle Efficiency
	Cycle Time
	On-time Delivery of Product (%)
	Manufacturing Throughput
Flexibility	Process Velocity
	New Development Requests Presented & Approved
	Capacity Utilization
	Tasks Employees Complete without Supervision (%)

Previously published quantitative and qualitative studies in credible journals validated these first round performance measures through analysis of the analytic hierarchy process (AHP), content validity ratio (CVR) analysis, interviews, surveys, and questionnaires, thus establishing an initial set of measures for subject-matter experts to consider.

Table 18: Metrics and Validation

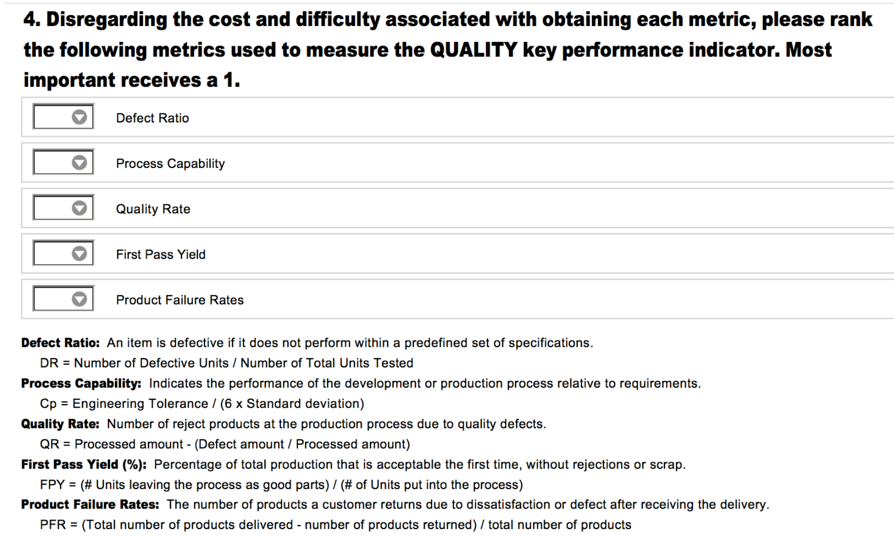
Metrics	Source	Validity Method
Defect Ratio	Hon 2005, Hudson 2001, Pawar 1999, Pyzdek 2010	Case Study, Interviews, Survey
Process Capability	Hon 2005, Pyzdek 2010	Six Sigma, Survey
Quality Rate	Hudson 2001, KPI Institute	Interviews
First Pass Yield	Davidson 2013, Unver 2013,	Case Study, Survey
Product Failure Rates	Davidson 2013, Driva 1997,	Questionnaire, Survey
Customer Complaints	Amrina 2011, Hudson 2001, Kim 2009	AHP, Questionnaire
Customer Retention Rate	Fang 2006, Kim 2009, KPI Institute	AHP, Descriptive Analysis
Customer Response Time (Wait Time)	Driva 1997, Kim 2009, Rodriguez 2009, Wei 2008,	AHP, CVR
Satisfied Customer Ratio	Bai 2009, Kim 2009	AHP, Interviews, Survey
Total Product Manufacturing Cost	Driva 1997, Hon 2005, Neely 2005, Pawar 1999	Case Study, Questionnaire, Survey
Inventory Cost	Amrina 2011, Hon 2005, Mejabi 2003	Questionnaire, Survey
Overhead Cost	Amrina 2011, Hudson 2001,	Interviews, Questionnaire
Employee Training Cost (Hrs per Training Day)	Fang 2006, Kim 2009, KPI Institute 2013	AHP, Descriptive Analysis
Production Projects within Budget	KPI Institute 2013, Pawar 1999	Case Study, Questionnaire
Operating Cost	Hon 2005, KPI Institute 2013	Survey
Scrap Rate	Amrina 2011, Hon 2005, Kumar 2009, Mejabi 2003	Questionnaire
Rework Rate	Amrina 2011, Hon 2005, Mejabi 2003	Questionnaire, Survey
Production Loss (Downtime and/or Inefficiency)	Davidson 2013, Sanchez 2001, Unver 2013, Uwizeyemungu 2010,	Interviews, Survey
Bottleneck or Waiting Time (# of hours or minutes)	Driva 1997, Pawar 1999	Case Study, Quetionnaire, Survey
System Stability & Reliability	Chand 2005, Kim 2009, Wei 2008,	AHP, Case Study, CVR
Process Cycle Efficiency	Chand 2005, Pyzdek 2010	Case Study, Literature Review
Process Lead Time	Driva 1997, Hudson 2001, Mejabi 2003, Neely 2005, Sanchez 2001, Pyzdek 2010	Interviews, Survey
Overall Equipment Effectiveness	Hon 2005, Pyzdek 2010, Unver 2013	Literature Review, Questionnaire, Survey
Manufacturing Cycle Efficiency	Davidson 2013, KPI Institute 2013	Questionnaire, Survey

Table 18 continued

Cycle Time	Amrina 2011, Hon 2005, Hudson 2001, Uwizeyemungu 2010, Wei 2008	CVR, Importance Scale, Interviews, Questionnaire, Survey
On-time Delivery of Product (%)	Amrina 2011, Davidson 2013, Hon 2005, Uwizeyemungu 2010, Wei 2008	CVR, Interviews, Questionnaire, Survey
Manufacturing Throughput	Chand 2005, Davidson 2013, Hudson 2001, Mejabi 2003	Case Study, Literature Review, Survey
Process Velocity	Pyzdek 2010	Six Sigma
New Development Requests Presented & Approved	Davidson 2013, KPI Institute	Survey
Capacity Utilization	Davidson 2013, Hon 2005	Questionnaire, Survey
Tasks Employees Complete without Supervision (%)	KPI Institute 2013, Sanchez 2001	Survey

Prior to distribution of the first round questionnaire to participants, pilot testing of the Delphi Study was conducted with a small group of academic and industry professionals to validate and improve the survey. In addition, the pilot test exposed any issues the questionnaire in terms of question comprehension, wording, and to gauge potential interest in participation. A total of seven practice surveys were carried out with pilot study participants through phone interviews to gather feedback. Ultimately, the pilot test identified areas of improvement and validated the survey. A majority of the suggestions were carried out including placing the explanations and equations for metrics below the list of answer options as well as using an open-ended question for position title of the employee.

The first round survey consisted of three general questions related to the Delphi participant followed by six questions seeking rankings of metrics grouped by a key performance indicator. According to Ludwig (1994), Delphi panelists may be required to rank items to establish priorities among them. In order to avoid general responses and determine the importance of various metrics in relation to each other, answers were based on rankings with a 1 denoting the most important metric. Figure 12 shows the layout of question 4 as an example.



4. Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the QUALITY key performance indicator. Most important receives a 1.

Defect Ratio

Process Capability

Quality Rate

First Pass Yield

Product Failure Rates

Defect Ratio: An item is defective if it does not perform within a predefined set of specifications.
DR = Number of Defective Units / Number of Total Units Tested
Process Capability: Indicates the performance of the development or production process relative to requirements.
Cp = Engineering Tolerance / (6 x Standard deviation)
Quality Rate: Number of reject products at the production process due to quality defects.
QR = Processed amount - (Defect amount / Processed amount)
First Pass Yield (%): Percentage of total production that is acceptable the first time, without rejections or scrap.
FPY = (# Units leaving the process as good parts) / (# of Units put into the process)
Product Failure Rates: The number of products a customer returns due to dissatisfaction or defect after receiving the delivery.
PFR = (Total number of products delivered - number of products returned) / total number of products

Figure 12: First Round Survey - Example

The goal of the first round of this modified Delphi is to pare down the original set of metrics compiled through the literature review. Although there were a total of 20 respondents, only 15 surveys were complete when submitted and included in the analysis.

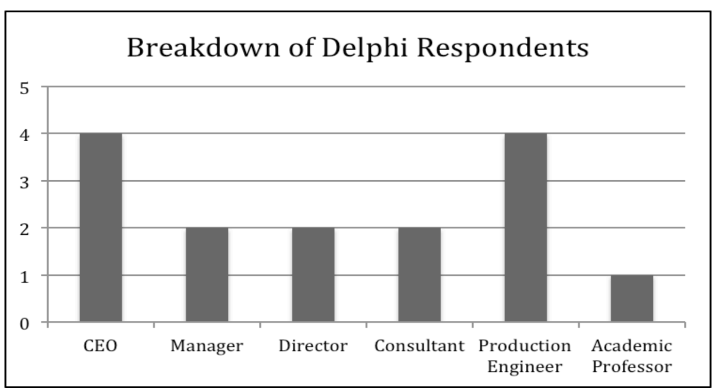


Figure 13: Number of Respondents by Position

The ‘experts’ were chosen from large companies including Lockheed Martin, IBM, Albemarle, Studsvik (Sweden), and SMEs including BeenaVision, BakeCo, Jabian, and

MDI. The survey was randomized in order to offer questions in a different order and reduce question order bias. The analysis conducted by SurveyMonkey compiled the rankings of the metrics and produced an average ranking for each to determine the importance of the metrics based on the answers provided by respondents. Due to fact that each question may have varying numbers of potential metrics to rank, a uniform average ranking limit was not used to eliminate potential metrics. However, the metric with the lowest average ranking in each question is automatically excluded from the next round in order to establish consensus among participants. In some cases the two least important metrics were deemed unnecessary for the next round of questioning, as their scores were low enough to deem them as trivial in comparison to the other metrics within the KPI grouping.

Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the QUALITY key performance indicator. Most important receives a 1.

Answered: 15 Skipped: 5

	1	2	3	4	5	Total	Average Ranking
Defect Ratio	40.00% 6	26.67% 4	0.00% 0	33.33% 5	0.00% 0	15	3.73
Process Capability	13.33% 2	26.67% 4	13.33% 2	26.67% 4	20.00% 3	15	2.87
Quality Rate	0.00% 0	26.67% 4	53.33% 8	0.00% 0	20.00% 3	15	2.87
First Pass Yield	6.67% 1	13.33% 2	0.00% 0	40.00% 6	40.00% 6	15	2.07
Product Failure Rates	40.00% 6	6.67% 1	33.33% 5	0.00% 0	20.00% 3	15	3.47

Figure 14: Results of Question 4 - Round 1

In terms of quality, the most important metric was found to be 'defect ratio' with an average ranking of 3.73 out of 5 while 'first pass yield' was found to be the least important with an average ranking of 2.07. First pass yield will be removed from the list of potential metrics in Round 2 as it is clearly the least important among these quality metrics. For the customer satisfaction KPI, ‘Customer retention rate’ was found to be the most important metric for the customer satisfaction KPI with an average ranking of 3.00 out of 4.00. The customer response time’, which can be also explained as the amount of time a ‘customer waits for a response from the company, only averaged a ranking of 2.13 and therefore will not be included in the 2nd round of the survey.

Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the CUSTOMER SATISFACTION key performance indicator. Most important receives a 1.

Answered: 15 Skipped: 5

	1	2	3	4	Total	Average Ranking
Customer Complaints	6.67% 1	33.33% 5	33.33% 5	26.67% 4	15	2.20
Customer Retention Rate	40.00% 6	26.67% 4	26.67% 4	6.67% 1	15	3.00
Customer Response Time (Waiting Time)	20.00% 3	13.33% 2	26.67% 4	40.00% 6	15	2.13
Satisfied Customer Ratio	33.33% 5	26.67% 4	13.33% 2	26.67% 4	15	2.67

Figure 15: Results of Question 5 - Round 1

In terms of the cost KPI, the ‘total product manufacturing cost’ received the highest average ranking at 4.93 out of 6. Interestingly, both ‘production projects within budget’ and ‘employee training cost’ received 7 last-place rankings and finished as the least important metrics. These two metrics received a 3.0 and 1.80, respectively. Therefore both of these are eliminated from the 2nd round of questioning.

Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the COST key performance indicator. Most important receives a 1.

Answered: 15 Skipped: 5

	1	2	3	4	5	6	Total	Average Ranking
Total Product Manufacturing Cost	46.67% 7	26.67% 4	13.33% 2	0.00% 0	13.33% 2	0.00% 0	15	4.93
Operating Cost	13.33% 2	33.33% 5	40.00% 6	6.67% 1	6.67% 1	0.00% 0	15	4.40
Inventory Cost	20.00% 3	6.67% 1	20.00% 3	20.00% 3	26.67% 4	6.67% 1	15	3.53
Overhead Cost	0.00% 0	20.00% 3	20.00% 3	33.33% 5	26.67% 4	0.00% 0	15	3.33
Production Projects within Budget	20.00% 3	13.33% 2	6.67% 1	13.33% 2	0.00% 0	46.67% 7	15	3.00
Employee Training Cost (per training day)	0.00% 0	0.00% 0	0.00% 0	26.67% 4	26.67% 4	46.67% 7	15	1.80

Figure 16: Results from Question 6 - Round 1

The waste KPI produced results showing that 'system stability and reliability' is the most important metric to this group of subject-matter experts with it receiving an average of 3.8 out of 5. Meanwhile the 'rework rate' was removed from the 2nd round survey as it finished with a 2.0.

Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the WASTE key performance indicator. Most important receives a 1.

Answered: 15 Skipped: 5

	1	2	3	4	5	Total	Average Ranking
Scrap Rate	6.67% 1	40.00% 6	0.00% 0	33.33% 5	20.00% 3	15	2.80
Rework Rate	6.67% 1	0.00% 0	26.67% 4	20.00% 3	46.67% 7	15	2.00
Production Loss (Downtime and/or Inefficiency)	20.00% 3	40.00% 6	26.67% 4	13.33% 2	0.00% 0	15	3.67
Bottleneck or Waiting Time (# of hours or minutes)	13.33% 2	13.33% 2	33.33% 5	13.33% 2	26.67% 4	15	2.73
System Stability & Reliability	53.33% 8	6.67% 1	13.33% 2	20.00% 3	6.67% 1	15	3.80

Figure 17: Results from Question 7 - Round 1

Disregarding the cost and difficulty associated with each metric, please rank the following metrics used to measure the EFFICIENCY/EFFECTIVENESS key performance indicator. Most important receives a 1.

Answered: 15 Skipped: 5

	1	2	3	4	5	6	7	Total	Average Ranking
Process Cycle Efficiency	0.00% 0	33.33% 5	6.67% 1	13.33% 2	40.00% 6	6.67% 1	0.00% 0	15	4.20
Process Lead Time	33.33% 5	13.33% 2	20.00% 3	6.67% 1	20.00% 3	0.00% 0	6.67% 1	15	5.07
Overall Equipment Effectiveness	13.33% 2	0.00% 0	26.67% 4	13.33% 2	6.67% 1	6.67% 1	33.33% 5	15	3.47
Manufacturing Cycle Efficiency	0.00% 0	6.67% 1	0.00% 0	53.33% 8	13.33% 2	26.67% 4	0.00% 0	15	3.47
Cycle Time	0.00% 0	20.00% 3	20.00% 3	13.33% 2	13.33% 2	20.00% 3	13.33% 2	15	3.67
% On-time Delivery of Product	33.33% 5	6.67% 1	6.67% 1	0.00% 0	6.67% 1	33.33% 5	13.33% 2	15	4.07
Manufacturing Throughput	20.00% 3	20.00% 3	20.00% 3	0.00% 0	0.00% 0	6.67% 1	33.33% 5	15	4.07

Figure 18: Results of Question 8 - Round 1

In terms of efficiency and effectiveness, 'process lead time' finished with an average ranking of 5.07 out of 7. Interestingly two metrics finished with the same average ranking of 3.47 and causing both to be eliminated from the 2nd and final survey. The two metrics received a 3.47 are 'overall equipment effectiveness (OEE)' and 'manufacturing cycle efficiency (MCE).'

Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the FLEXIBILITY key performance indicator. Most important receives a 1.

Answered: 15 Skipped: 5

	1	2	3	4	Total	Average Ranking
Process Velocity	66.67% 10	20.00% 3	6.67% 1	6.67% 1	15	3.47
New Development Requests Presented & Approved	13.33% 2	40.00% 6	40.00% 6	6.67% 1	15	2.60
Capacity Utilization	20.00% 3	20.00% 3	26.67% 4	33.33% 5	15	2.27
Tasks Employees may complete without supervision	0.00% 0	20.00% 3	26.67% 4	53.33% 8	15	1.67

Figure 19: Results of Question 9 - Round 1

The results for the flexibility KPI found that 'process velocity' was the most important metric with a 3.47 out of 4 average ranking while 'tasks employees may complete without supervision' will be removed from the next survey as it finished with an average ranking of 1.67.

Following the submission of the structured first round questionnaire, results were tabulated and analyzed. Each Delphi respondent received a summary of the first round results and was asked to review the statistical information before continuing with the second round questionnaire. This review allows for participants to verify that their ratings in the first round did accurately reflect their opinions while also allowing for the opportunity to change their responses. Repeated verification throughout the Delphi process is essential to increasing the reliability of the analysis (Adler & Ziglio, 1996; Delbecq et al., 1975). Completion of this step begins the second round of the questionnaire

The purpose of the second round of this modified Delphi is to approach group consensus with the remaining metrics offered thereby establishing the framework for organizational performance evaluation of a manufacturing firm (Schmidt, 1997). As a result of round 2, areas of agreement and disagreement are recognized and a consensus begins to form (Ludwig, 1994). According to Miller (2006), the criteria for determining consensus is subject to interpretation but can simply be defined as having a certain percentage of votes fall within a prescribed range. The second round of questioning confirmed the most important performance metrics for the evaluation framework. Fourteen complete surveys were collected and analyzed.

Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the QUALITY key performance indicator. Most important receives a 1.

Answered: 14 Skipped: 0

	1	2	3	4	Total	Average Ranking
Defect Ratio (1st Survey: Most Important)	92.86% 13	0.00% 0	7.14% 1	0.00% 0	14	3.86
Product Failure Rates (1st Survey: 2nd Most Important)	0.00% 0	64.29% 9	21.43% 3	14.29% 2	14	2.50
Quality Rate (1st Survey: Tie for 3rd Most Important)	0.00% 0	28.57% 4	50.00% 7	21.43% 3	14	2.07
Process Capability (1st Survey: Tie for 3rd Most Important)	7.14% 1	7.14% 1	21.43% 3	64.29% 9	14	1.57

Figure 20: Results of Question 2 - Round 2

Defect ratio clearly ranked as most important with an average ranking of 3.86, followed by Product Failure Rates and Quality Rate. Process capability was found to be the least important of the remaining four and will be eliminated from the final framework.

Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the CUSTOMER SATISFACTION key performance indicator. Most important receives a 1.

Answered: 14 Skipped: 0

	1	2	3	Total	Average Ranking
Customer Retention Rate (1st Survey: Most Important)	78.57% 11	21.43% 3	0.00% 0	14	2.79
Satisfied Customer Ratio (1st Survey: 2nd Most Important)	14.29% 2	57.14% 8	28.57% 4	14	1.86
Customer Complaints (1st Survey: 3rd Most Important)	7.14% 1	21.43% 3	71.43% 10	14	1.36

Figure 21: Results of Question 3 - Round 2

In terms of customer satisfaction, the Customer Retention Rate and Satisfied Customer Ratio were ranked as the most important with average rankings of 2.79 and 1.86 out of 3, respectively. Customer Complaints finished with an average ranking of 1.36

Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the COST key performance indicator. Most important receives a 1.

Answered: 14 Skipped: 0

	1	2	3	4	Total	Average Ranking
Total Product Manufacturing Cost (1st Survey: Most Important)	85.71% 12	14.29% 2	0.00% 0	0.00% 0	14	3.86
Operating Cost (1st Survey: 2nd Most Important)	14.29% 2	71.43% 10	14.29% 2	0.00% 0	14	3.00
Inventory Cost (1st Survey: 3rd Most Important)	0.00% 0	14.29% 2	57.14% 8	28.57% 4	14	1.86
Overhead Cost (1st Survey: 4th Most Important)	0.00% 0	0.00% 0	28.57% 4	71.43% 10	14	1.29

Figure 22: Results of Question 4 - Round 2

The Total Product Manufacturing Cost ranked first within the cost KPI with an average ranking of 3.86 out of 4. With a low average ranking of 1.29, Overhead Cost will be removed from the final evaluation framework.

Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the WASTE key performance indicator. Most important receives a 1.

Answered: 14 Skipped: 0

	1	2	3	4	Total	Average Ranking
System Stability & Reliability (1st Survey: Most Important)	78.57% 11	14.29% 2	7.14% 1	0.00% 0	14	3.71
Production Loss - Downtime and/or Inefficiency (1st Survey: 2nd Most Important)	21.43% 3	64.29% 9	14.29% 2	0.00% 0	14	3.07
Scrap Rate (1st Survey: 3rd Most Important)	0.00% 0	14.29% 2	42.86% 6	42.86% 6	14	1.71
Bottleneck or Waiting Time (1st Survey: 4th Most Important)	0.00% 0	7.14% 1	35.71% 5	57.14% 8	14	1.50

Figure 23: Results of Question 5 - Round 2

The results of the waste KPI found System Stability & Reliability as the most important with an average ranking of 3.71 out of 4 followed by Production Loss (Downtime and/or

Inefficiency) at 3.07. The Bottleneck or Waiting Time metric finished as the least important of the four and will be eliminated from the performance evaluation framework.

Disregarding the cost and difficulty associated with each metric, please rank the following metrics used to measure the EFFICIENCY/EFFECTIVENESS key performance indicator. Most important receives a 1.

Answered: 14 Skipped: 0

	1	2	3	4	5	Total	Average Ranking
Process Lead Time (1st Survey: Most Important)	78.57% 11	21.43% 3	0.00% 0	0.00% 0	0.00% 0	14	4.79
Process Cycle Efficiency (1st Survey: 2nd Most Important)	0.00% 0	50.00% 7	28.57% 4	21.43% 3	0.00% 0	14	3.29
On-time Delivery of Product % (1st Survey: Tie for 3rd Most Important)	14.29% 2	7.14% 1	21.43% 3	42.86% 6	14.29% 2	14	2.64
Manufacturing Throughput (1st Survey: Tie for 3rd Most Important)	0.00% 0	21.43% 3	35.71% 5	21.43% 3	21.43% 3	14	2.57
Cycle Time (1st Survey: 5th Most Important)	7.14% 1	0.00% 0	14.29% 2	14.29% 2	64.29% 9	14	1.71

Figure 24: Results of Question 6 - Round 2

In terms of efficiency and effectiveness, Process Lead Time was clearly the most important with an average ranking of 4.79 out of 5. Process Cycle Efficiency, On-time Delivery of Product, and Manufacturing Throughput ranked 2nd, 3rd, and 4th, respectively while the metric Cycle Time will be removed after posting an average ranking of 1.71.

Disregarding the cost and difficulty associated with obtaining each metric, please rank the following metrics used to measure the FLEXIBILITY key performance indicator. Most important receives a 1.

Answered: 14 Skipped: 0

	1	2	3	Total	Average Ranking
Process Velocity (1st Survey: Most Important)	85.71% 12	14.29% 2	0.00% 0	14	2.86
New Development Requests Presented & Approved (1st Survey: 2nd Most Important)	7.14% 1	64.29% 9	28.57% 4	14	1.79
Capacity Utilization (1st Survey: 3rd Most Important)	7.14% 1	21.43% 3	71.43% 10	14	1.36

Figure 25: Results of Question 7 - Round 2

With an average ranking of 2.86 out of 3, Process Velocity finished as the most important Flexibility metric while New Development Requests Presented & Approved ranked as 2nd most important. Capacity Utilization will not be listed in the evaluation framework.

Framework for Organizational Performance Evaluation

In order to make informed decisions, management stands to benefit from an organized framework to evaluate, monitor, interact, manage, and forecast its organizational performance. Frameworks provide a foundation for inquiry by specifying variables and general relationships among them while guiding the attention of analysis to critical features. The variables structure and influence the actions taken by actors. However, frameworks cannot provide explanations or predications of behavior or outcomes. According to Georghiou and Roessner (2000), a valuable framework should support the choice of what to measure, how and when to measure, and how to understand the results. Globerson (1985) stresses that “the lack of well-defined performance criteria, through which performance of individuals and the organization may be evaluated, make it hard to plan and control.” The proposed framework interprets a manufacturing organization’s mission and competitive priorities including higher quality, customer satisfaction, more efficient and effective processes, more flexibility, and reduced costs and waste into a comprehensive set of performance metrics. The equal weighting given to metrics within each KPI and competitive priority gives a more complete depiction of the overall performance.

Table 19: Final Performance Evaluation Framework for Manufacturing Facilities

	Manufacturing Facility Performance Evaluation Framework		
	KPI	**Competitive Priority**	**Metric**
Deliverables	**Quality**	**Quality**	Major Defect Ratio
			Minor Defect Ratio
			Product Failure Rate
			Quality Rate
		Customer Satisfaction	Customer Retention Rate
			Satisfied Customer Ratio
	Cost	**Fixed/Variable Costs**	Total Product Manufacturing Cost
			Operating Cost
			Inventory Cost
		Waste	System Stability & Reliability
			Production Loss (Downtime/Inefficiency)
			Scrap Rate
	Delivery or Time	**Effectiveness/Efficiency**	Process Lead Time
			Process Cycle Efficiency
			On-time Delivery
			Throughput
	Flexibility	**Flexibility**	Process Velocity
			New Development Requests vs Approved

The framework proposed in this research is based on support and knowledge identified in published academic and industry research as well as from interactions with industry experts. Subject-matter experts have an important role in process of verification, validation, and accreditation as well as defining performance measurement goals based on the intended use of the framework. According to Oberkampf et al. (2002), framework validation is defined as "the process of determining the degree to which it is an accurate representation of the real world from the perspective of the intended uses of the framework." This study utilizes the knowledge and experience of numerous subject matter experts to determine validity whether the proposed framework. In this case the Delphi process produced statistical results identifying the most important performance metrics for a manufacturing company from a facility decision-maker's perspective. While there are no truly universal metrics, the measures offered in the framework can be customized to fit the organization's processes.

The explanations to the calculations for each metric are as follows:

Defect Rate

An item is defective if it does not perform within a predefined set of specifications. The defect rate is calculated by dividing the number of defects (per source) by the number of measurements (per source). Based on the operations of MDI, the two types of defect rates to consider are for major and minor defects. The major defects are the largest unit of testing that can pass or fail while the minor defects are the smallest unit of testing that can pass or fail. Defects include:

- Number of parts returned due to failure over a period (considered as both major and minor measurements). Part failures are both major and minor defects since they pass or fail completely without fine measurements.
- Number of defects related to functionality and features
- Job runs are test suites composed of tasks and checks (considered as both major and minor measurements)
- Job run tasks are tasks within test suites that gather data or perform operations and may pass or fail (considered minor measurements)
- Job run checks are checks on the results of tasks, which may pass or fail (considered minor measurements)
- Number of quality records with failed status related to pass or fail assertions about physical, electrical, aesthetic, and other aspects of a product

- Quality records are records of Quality Documents which may pass or fail in their entirety (considered as both major and minor measurements)
- Quality checks are checks within QC records on individual aspects that may pass or fail (considered minor measurements)
- A Quality Check document is a major measurement while a QC check is a minor measurement. If a product fails one QC check in a QC document then the entire QC document fails. If a product has only 1 QC document consisting of 80 checks, then it has a 1/1 major defect rate and a 1/81 minor defect rate. Note that minor defects include major defects in their count.
- Number of stress test failures measured by failures to perform under a heavy simulated performance load (considered both major and minor measurements). Stress tests are both major and minor defects since they pass or fail completely without fine measurements.

The major defect rate is the ratio of major measurements considered defects in the period versus the total major measurements. The minor defect rate is the ratio of minor measurements considered defects in the period versus the total minor measurements.

Product Failure Rate

The product failure rate is the number of products a customer returns due to dissatisfaction or defect after receiving the delivery. It is calculated by dividing the number of products delivered in a period that fail within 1 year of delivery by the total number of products delivered in that period.

Quality Rate

In this study it is considered the ratio of products in the periods in which there were no defects measured compared to the number of total products. As noted for the Defect Rate, an item is defective if it does not perform within a predefined set of specifications.

Customer Retention Rate

As previously mentioned, it is important for SMEs to give additional attention to their customer retention rate, as there is usually a smaller pool of potential customers. Customer retention rate is the percentage of original customers that return for additional business. This ratio is determined by the number of returning customers at the end of a period (who were customers at the start of a period) versus the number of customers at the start of the period.

Satisfied Customer Rate

The satisfied customer ratio represents the percentage of satisfied customers to the total number of customers. Subtracting the number of unsatisfied customers from the number of total customers and dividing this by the number of total customers (on a yearly basis) yields the ratio.

Total Product Manufacturing Cost

An organization uses this metric to find the overall cost to develop and produce the item. The Total Product Manufacturing Cost is calculated by summing the production set-up cost, the raw materials cost, the assembly cost, and the quality control cost. In order to provide granularity and exclude the impact of higher costs due to more products being produced in a given month, the total manufacturing cost per product will be used for analysis. Taking the total product manufacturing cost per month and dividing it by the number of products that given month produces this calculation.

Operating Cost

The operating cost is the expense incurred in carrying out an organization's day-to-day activities, but not directly associated with production. It is calculated by summing the fixed costs, financial costs, variable costs, payroll costs, and utilities costs. The operating cost is divided by the number of products manufactured in that month to exclude the impact of higher or lower costs based on the number of products made in that time period. Therefore analysis is conducted on the operating cost per product. This metric uses currency as the unit.

Inventory Cost

This metric calculates the total cost of ordered product components that have not been shipped over a period of time. The total cost in currency terms equals the total cost of the components. The inventory cost is divided by the number of products manufactured in that period to account for increases and decreases in quantity. Thus inventory cost per product is analyzed.

System Stability/Reliability

System Stability and Reliability refers to the stability of the process and its recovery ability. It includes all operational downtime, software errors rates, and data error rates. Subtracting the number of halted hours from the number of operated hours and then dividing this number by the operated hours calculates it. This metric uses lost hours in comparison to total production capacity hours, which is a measure of the amount of hours available in a day for products occupying integration or testing capacity. This testing capacity factors in:

- 12 production cells with 6 product integration locations
- 6 testing cells with 12 product testing locations
- 9 business hours per business day during the interval

The production capacity per day is found to be 1296 hours. [((12 production cells x 6 production integration locations) + (6 testing cells x 12 product testing locations)) x 9 hours] = 1296 hours

Production Loss (Downtime)

The production loss is defined as the unplanned loss in productivity due to equipment or labor stoppage or inefficiency. It is determined by subtracting the optimal process lead time from the process lead time and then dividing this number by the optimal process lead time. The metric reports the number of days lost to inefficient production, and the rate of those days to optimal days for the time period. Based on verbal confirmation by MDI employees, 3 days is factored in for the optimal process lead time.

Scrap Rate

The scrap rate is the percentage of products starting as raw material that are lost as scrap from all steps in the process. Currency has been chosen as the unit of measurement since it allows one to compare many different types of components including finished products with a uniform unit of measurement. Inputs in this measurement include inventory cost, inventory cost scrap, supply cost, and supply cost scrap. The scrap rate is calculated by adding the supply cost scrap with the inventory cost scrap and dividing this number by the summation of the inventory cost and the supply cost. According to MDI employees, the supply cost scrap is estimated to be 5% of the supply cost.

Process Lead Time

This metric denotes the time a product requires to flow through the process from the entry point of (product request) to the exit point (product delivered). Process Lead Time is found by finding the amount of time in days between the start date and the shipped date.

Process Cycle Efficiency

This metric measures the optimal process lead time in comparison to the actual process lead time. The Process Cycle Efficiency is calculated by dividing the optimal process lead time by the actual process lead time. The world-class process cycle efficiency for manufacturing is 25%.

On-Time Delivery

This metric calculates the percentage of products being delivered within schedule as determined by the customer. It is calculated by dividing the number of product deliveries on time by the total number of product deliveries.

Manufacturing Throughput

Manufacturing Throughput determines the process output rate per week of sell-able product. Process Lead Time is an input that is calculated by finding the number of days that pass from the start date to the shipped date. The manufacturing throughput is found by dividing the number of business days in the period by the process lead time.

Process Velocity

Process Velocity is the amount of value-added product manufacturing time completed per hour of actual manufacturing time. It is calculated by dividing the number of production stages by the process lead time. In this case, MDI counts eight distinct production stages: (1) Production Started (First part installed); (2) Ready for First QC; (3) First QC Complete; (4) Stress Testing; (5) Ready for Final QC; (6) Final QC Complete; (7) Sent to Shipping; (8) Shipped (Production Ended).

New Development Requests vs Accepted Development Request

This metric measures the total number of requests entered for new development ideas in comparison to the number of accepted requests. It is found by the ratio of Accepted Requests over the Number of Total New Development Requests.

Assumptions and Limitations

This study takes several assumptions and limitations into account. First, MDI developed the MOMS in-house and thus has overcome much of the learning curve consistent with customizing an ERP to fit specific processes and needs. Research has shown ERP consultants are limited in their true knowledge of the company being fit for the technology thereby leading to "growing pains." It is assumed that MDI has met the critical success factors identified in previous research. The same employees have worked at MDI since 2005 and have adapted to the new ERP-enabled production processes analyzed in this study. However, the learning curve commonly experienced by employees with implementing a new technology and processes remain and are shown in the data. In addition, MDI tailored the ERP system to fit their organizational needs and production process. In this case, MDI's main priority is to improve upon quality and on-time delivery. Other companies may choose to focus on improving costs or time-related metrics. A majority of other SMEs do not develop an ERP internally. As a result heavy customization of an ERP is necessary when implemented by an external company potentially leading to less performance improvements in comparison to MDI. Another assumption is that, since there are no trained or certified lean, Six Sigma, or ISO 9001 employees at MDI, the true benefits of their MOMS ERP can be analyzed with results and conclusions directly related to the ERP and not based on specific QMIs. This project also assumes the use of accurate and reliable data for the purpose of analysis.

A limitation of the study is the lack of data available to provide before and after analysis of operational performance of MDI. There are only six metrics that have pre- and post-MOMS implementation data. It is difficult to make an overall case for the ERP improving overall performance without complete before and after data. Note that a majority of the post-MOMS data samples are between 70 and 80 months. There are a couple of monthly periods were there no data is available. This is due to the fact that zero products were delivered in that period and not because the system was failing to collect data. All data is sampled over all periods in the date range, but gaps appear where no data exists during that period. Another effect to consider is a natural disaster that occurred in Thailand in October, 2011. Massive flooding affected the production of hard drives for roughly 3 months. MDI was able to produce during that disaster, however, with delayed production and late delivery for specific products. In a 2nd incident, a factory fire at a memory manufacturer affected the availability of memory components and consequently drove prices substantially higher. These events have impacted data for the corresponding months. A final limitation is that this research is conducted on one company focused on batch and one-of-a-king manufacturing projects, which makes the results difficult to generalize for other SMEs in the industry.

CHAPTER 4 - RESULTS AND ANALYSIS

Results of Investigating Operational Performance Metrics

This study utilizes Minitab to perform statistical analysis of the data collected prior to and following implementation of MOMS. Analysis of the data includes descriptive statistics, time series plots, regression analysis, and hypothesis testing consisting of Mann-Whitney and 1 and 2-Sample t tests. Descriptive statistics summarize characteristics about a set of data. While they do not allow one to make conclusions, descriptive statistics such as the mean, variance, and standard deviation will be presented to quantitatively describe the data set. Hypothesis testing, a form of statistical inference, is used for verification of the hypothesis and provides a measure of the confidence in the decision. Hypothesis testing determines if there is a significant difference between the samples of data as well as with a target value depending on the test used. The mean target values are determined by the performance data from the baseline process, which was collected prior to MOMS implementation. Hypothesis testing usually involves the following four steps: (1) formulating a hypothesis about the population; (2) collecting a sample of observations from that population; (3) calculating statistics based on the sample; (4) either accepting or rejecting the hypothesis based on a predetermined acceptance criterion (Pyzdek, 2010). This study will check for Type I error. Type I error (α) is the probability that a hypothesis that is actually true will be rejected with the value of α representing the significance level of the test. The p value will be defined as 0.05 as it is widely adopted. If the P value is less than the threshold of 0.05 then the difference will be "statistically significant" and the null hypothesis will be rejected. A 2-sample t

Test or Mann-Whitney test is performed in order to find whether ERP implementation has impacted the performance of MDI's operations.

Before choosing a hypothesis test, the condition of normality must be checked to determine if the data sample follows a normal distribution or is non-normal. While Minitab and other sources set the threshold for passing normality at $n > 15$ ("Two Sample t-Test for Difference of the Population Means,"), the Anderson-Darling normality test is applied to detect whether the specified data follow a normal distribution. The null and alternative hypotheses for this test are:

H_0: Data follow a normal distribution

H_A: Data do not follow a normal distribution

If the p-value for the Anderson-Darling test is lower than the significance level of 0.05 (95% confidence interval) and therefore statistically significant, one can reject the null hypothesis (H_0) and conclude that the data do not follow a normal distribution ("When to Use a Nonparametric Test,"). In this case the use of a nonparametric test is warranted, as it does not assume a normal distribution.

The Mann-Whitney test is a nonparametric hypothesis test that determines whether there is a statistically significant difference between independent groups on a dependent variable. There are four assumptions that must pass before using this are: (1) the dependent variable should be continuous; (2) the independent variable should consist of two independent and unrelated groups; (3) there is independence of observations; (4) the two variables are not normally distributed, which is determined by the Anderson-Darling test ("Mann-Whitney U test using Minitab," 2013). The null (H_0) and alternative (H_A) hypothesis are:

$$H_0: \eta_1 = \eta_2$$

$$H_A: (\eta_1 > \eta_2) \text{ or } (\eta_1 < \eta_2) \text{ or } (\eta_1 \neq \eta_2)$$

The Wilcoxon Rank-Sum test (W) is used in some cases as a test for the median difference between two samples. This test makes fewer and less stringent assumptions, but is likely a stronger indicator of the existence of significant differences. Minitab calculates the W and determines whether the difference is statistically significant.

For data samples that do follow a normal distribution ($p > 0.05$), a 2-Sample t test is conducted. By randomly sampling two sets of items under different conditions, the samples are independent. The measurements for one sample have no influence on the other sample's measurements. Also, the sample size of the post-MOMS implementation data is larger than the sample size of the pre-MOMS data. This assumption of independent samples validates the use of a 2-sample t test rather than a paired t test, which tests the mean difference between dependent observations. H_0 happens when the null hypothesis is true and the alternative hypothesis, H_A, occurs when the null hypothesis is not true. A p-value less than the significance level of 0.05 allows for the rejection of the null hypothesis. The hypothesis states that MDI's performance has improved with the usage of MOMS. The following null and alternative hypothesis are used:

$$H_0: \mu_{postmoms} = \mu_{premoms}$$

$$H_A: \mu_{postmoms} > \mu_{premoms}$$

Meanwhile, please find that various metrics use the following null and alternative hypothesis are

$$H_0: \mu_{postmoms} = \mu_{premoms}$$

$$H_A: \mu_{postmoms} < \mu_{premoms}$$

A 1-Sample t test is performed to test the mean of the performance metric against a best-in-class mean of the same metric. For example, 25% is regarded as world class for process cycle efficiency. The null and alternative hypothesis for PCE is as follows:

$$H_0: \mu_{postmoms} = 0.25$$

$$H_A: \mu_{postmoms} > 0.25$$

If the P value is greater than the threshold, then the difference is "not statistically significant" and the null hypothesis will not be rejected. This situation does not allow one to conclude the null hypothesis is true, however, it is possible to conclude that there is not sufficient evidence to reject the null hypothesis.

Regression analysis models the relationship between a dependent variable (response variable) and one or more independent variables (control variables). This study performed regression analysis with time series data in order to determine whether the organization improved upon its performance relative to the metric over time as well as if the improvement was sustainable. Time, or the number of months or years since implementation, is a continuous random variable rather than discrete as it can take values measured on a continuous scale. A time series data set is differentiated from a cross-sectional one due to temporal ordering, for instance we must know that data from 2008 immediately precedes data from 2009. A simple equation used to reflect the relationship of y to x is $y = \beta_0 + \beta_1 x + \mu$. The dependent or response variable is y, the independent or control variable is x, μ is the error term representing factors other than x that affect y. β_1 is the slope parameter in the relationship between y and x, and when holding other factors μ fixed, it is of primary interest. When other factors are fixed causing μ to be zero, then x has a linear effect on y: $\Delta y = \beta_1 \Delta x$. β_0 sometimes is used and is called the constant term but rarely central to the analysis. While Minitab puts the threshold for passing normality at $n > 15$, the Anderson-Darling normality test is applied to ensure each sample of data to detect whether it is from a normal distribution.

Correlation analysis is the study of the strength of the linear relationships among variables. It considers the joint variation of two variables. The measure of correlation used in this study is the statistic r, also called Pearson's product-moment correlation. When $r > 0$, then y tends to increase when x increases. When $r < 0$, y tends to decrease when x increases. The R-squared value is calculated during regression analysis and is a statistical measure of how close the data are to the fitted regression line. R-squared values are found between 0 and 100% with a value of 0% indicating that the model explains none of the variability of the response data around the mean (Frost, 2013). Generally the higher the R-squared, the better the model fits the data. It is important to note that R-squared does not determine whether a regression model is adequate. It is possible to have a high R-squared value for a poor model and a low R-squared for a good model. Also, if the value is low but the data is still statistically significant then one can still draw useful conclusions about how the changes in the independent variables are associated with changes in the dependent variables (Frost, 2013). In this case the significant coefficients still represent the average change in the dependent variable in response per unit change in the independent variable when other predictors are constant. In order to make data normal when necessary, the Minitab software offers the Box-Cox normalizing power transformation that works with data distributions.

Defect Rate

The importance of customizing the metrics that compose the performance evaluation framework has been stated. Depending on the needs of the organization, metrics such as Defect Ratio may have an alternate meaning. In this study, the defect count is deceptive, as the number of defects indicates the number of defects detected by MOMS and corrected before shipment of the product. Such defects are not passed onto the customer. Therefore all defect detections are healthy for increasing quality. These defect detections add to the continuous learning of MDI.

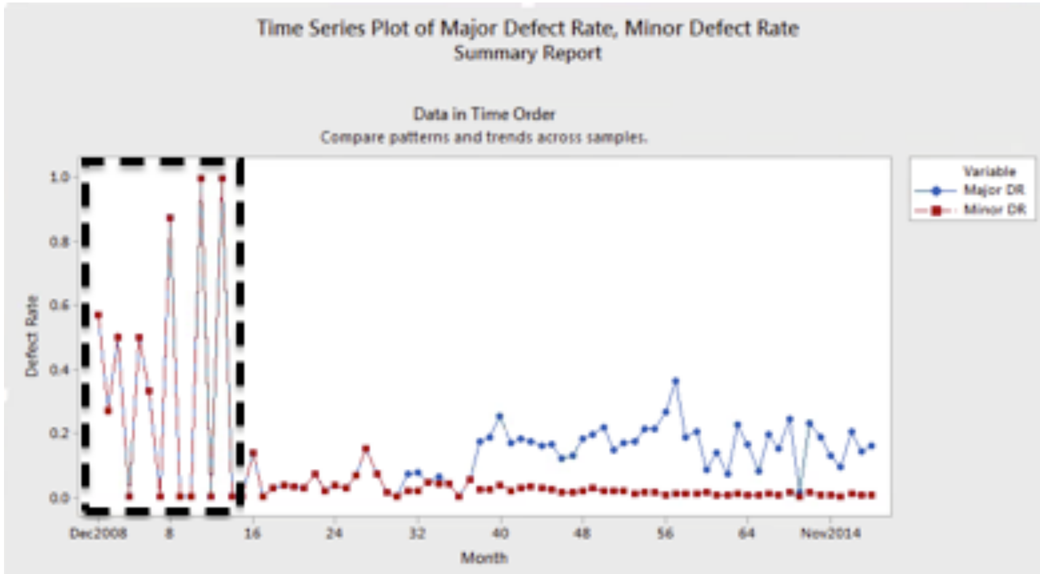


Figure 26: Major & Minor Defect Rate – Complete Monthly Time Series

Major Defect Rate (Major DR)

A time series plot of the major defect rate shows great volatility in months 1 through 15. It is apparent in the breakdown of the statistics that an extremely small number of major measurements were carried out in these months. Therefore any part defects have a significant effect on the defect rate. As an example consider that the mean and median for the major measurements are 10,916 and 2099, respectively. The highest number of major measurements was 14 in months 1 through 15. As a result this data will be excluded from the major defect rate analysis (denoted by the hashed rectangle in Figure 26). The sample from September 2009 to November 2014 (n = 61) is large enough to obtain a precise estimate of the strength of the relationship from the regression analysis. Normality is not an issue as there are more than 15 data points (Minitab).

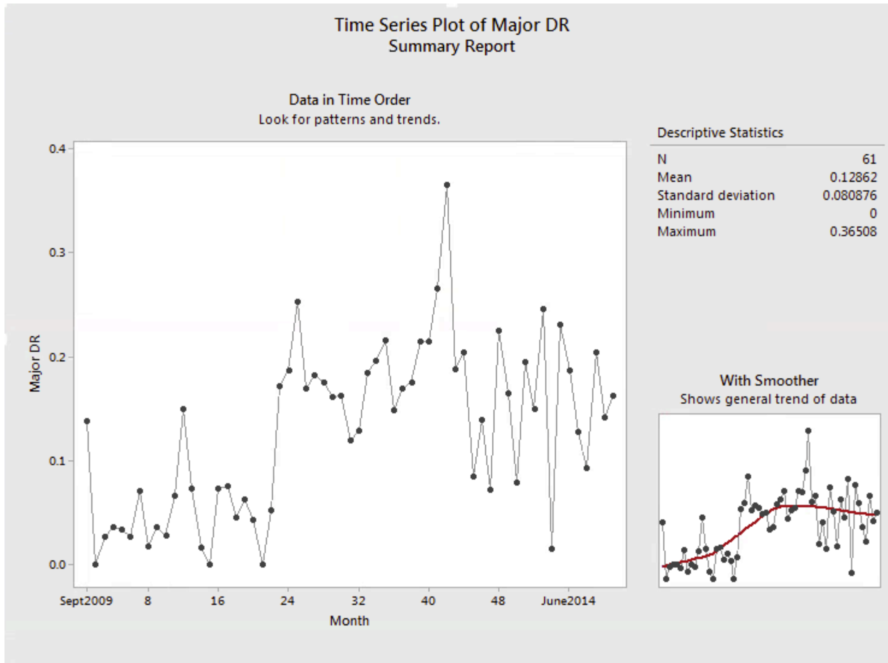


Figure 27: Major Defect Rate - Monthly Time Series

The relationship between the major defect rate and the month is statistically significant ($p < 0.001 < 0.05$). As noted previously, an increase in the defect rate indicates that MOMS identified necessary corrections before allowing the completion of the product. As time progresses from MOMS implementation, the number of defect corrections increases at a higher rate from month 25 to month 45. However, it appears the improvement is not sustainable as the major DR begins to level and then slightly decrease (i.e. the mean of major defect corrections being decreasing after 45 months). The regression model can explain 41.92% (R-squared value) of the variation in the major defect ratio.

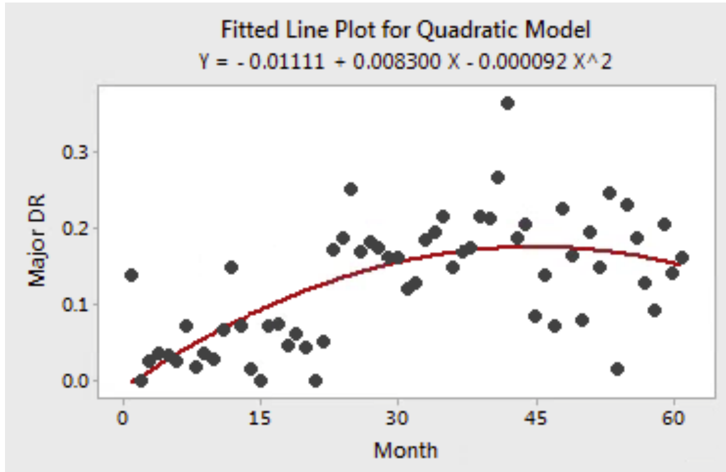


Figure 28: Major Defect Rate - Simple Regression

Minor Defect Rate (Minor DR)

Months 1 through 15 will be excluded from the regression analysis for the same reason as the major defect rate. The remaining sample of 61 begins in September of 2009 through November 2014.

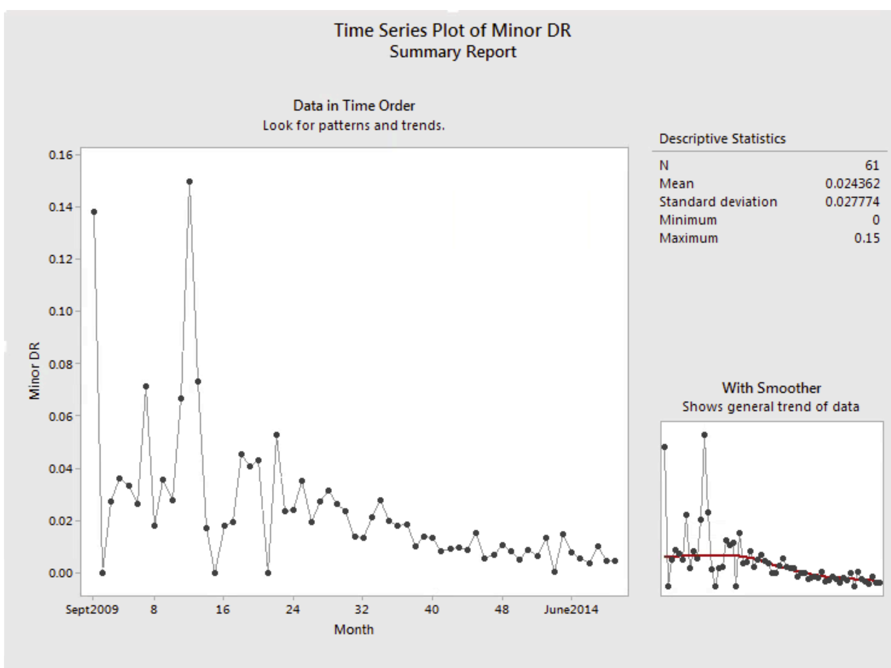


Figure 29: Minor Defect Rate - Monthly Time Series

A simple regression of the minor defect rate and the month finds it to be statistically significant as $p < 0.001$. Interestingly, there is a fairly strong negative correlation (r = -0.55), which indicates that as the months pass, the minor defect ratio tends to decrease. The analysis shows continuous improvement as fewer minor defect corrections have been needed as more time has passed since MOMS implementation. The R-squared value shows that the regression model can explain 30.4% of the variation. Minitab determined the sample is large enough to gain a precise estimate of the strength of the relationship and that normality is not an issue as there are greater than 15 data points.

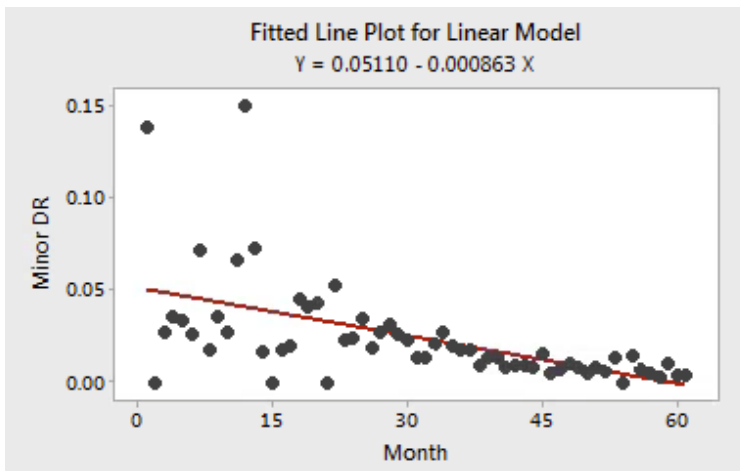


Figure 30: Minor Defect Rate - Simple Regression

Interestingly, the regression analysis for the major and minor defect rates produce different results. Face-to-face discussions with employees aided in the interpretation of the results. The minor defect rate is considered a more accurate portrayal of the weight of a single defect to all measurements. The results of the regression analysis for minor DR displays the continuous improvement in identifying and correcting minor defects during production.

The introduction of a new product or testing process increases variability. There is potential for the product to have a high number of defects, or the process may not sufficiently detect defects. However, as more of the same products are manufactured and the new process matures, knowledge is applied and the most common defects would be prevented before the product completes the integration phase and enters testing. As a result, the process will be improved to detect previously undetected defects. There are several causes of a low defect rate such as the detection process may not be working. However, if MOMS is operating as expected, more defects would be prevented before testing due to increased knowledge regarding the product and the process from past experience. Another potential cause of a low defect rate is the presence of a high number of measurements, which would dilute the contribution of defects. This is more likely to occur when new processes are introduced that contribute to a high number of measurements relative to past systems.

Product Failure Rate (PFR)

When considering the data for the first year and warranty year failure rates, note the warranty period represents an option customers have for one to three years. Therefore this metric compares the rate of products returned by customers within the first year of receiving the product shipment from MDI with the rate of products returned within the warranty year as agreed upon in the contract. Due to the extended amount of time given to customers to return products, it is expected to have a higher warranty failure rate. The samples are large enough (n=68) to find a precise estimate of the strength of the relationship and normality is not an issue for either metric according to Minitab.

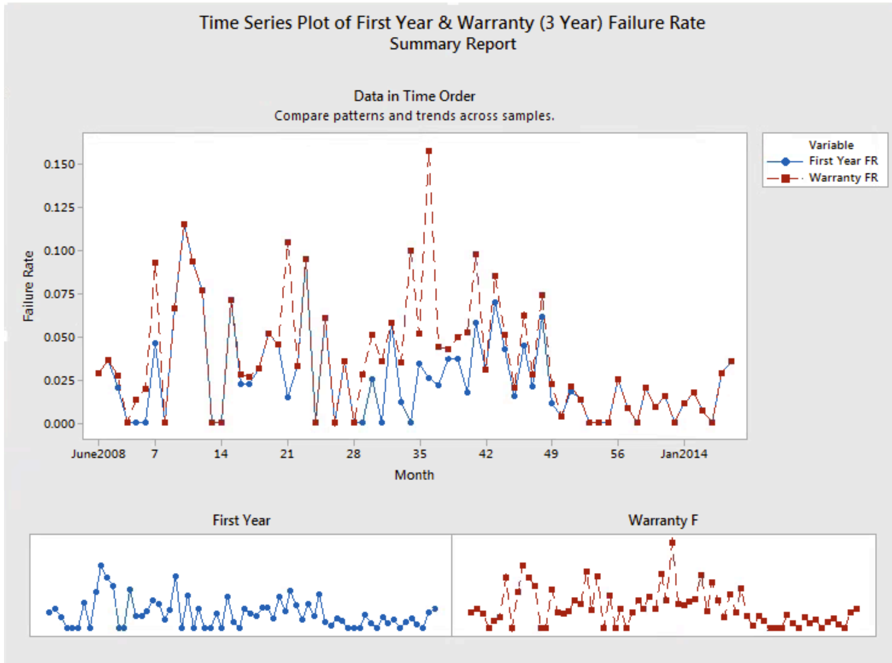


Figure 31: First Year Failure Rate vs Warranty Failure Rate - Monthly Time Series

The simple regression analysis of the first year failure rate and the number of months following the implementation of MOMS is statistically significant ($p = 0.022 < 0.05$) at significance level of 0.05. Therefore there is a relationship between these two variables. In addition, there is a slight negative correlation ($r = -0.28$) indicating that as the months pass, the first year failure rate tends to slightly decrease. While this shows continuous improvement by MDI in lowering the failure rate of products, a low R-squared value of just 7.65% shows that the variable of time only slightly explains the variation in first year failure rate. Other variables play a larger role in the improvement of this measurement.

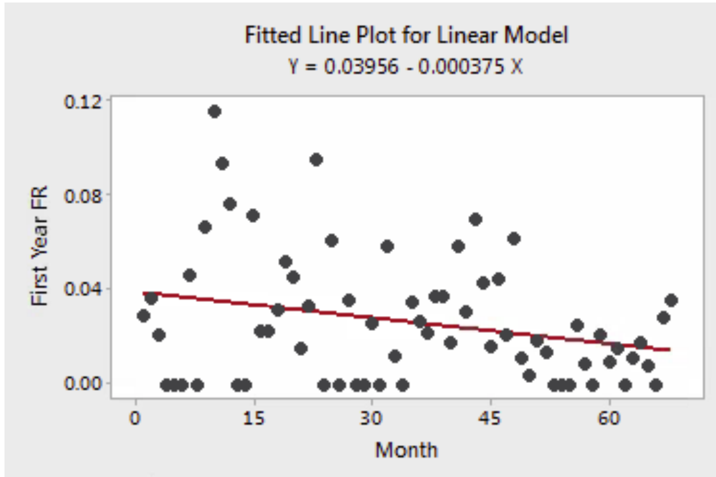


Figure 32: First Year Failure Rate - Simple Regression

Similarly, a simple regression of the warranty failure rate produces a statistically significant relationship between it and the month ($p = 0.002 < 0.05$). However, while the first year failure rate fitted to a linear model, the warranty failure rate fits well with a quadratic model. It appears that MDI underwent a learning period in the early months of MOMS utilization as the warranty failure rate increased in the few years before decreasing in the remaining months of the study. This learning curve can be expected when companies introduce new systems and undergo process redesign. Time does not represent a major reason for the warranty failure rate, as the R-squared value is just 17.27%.

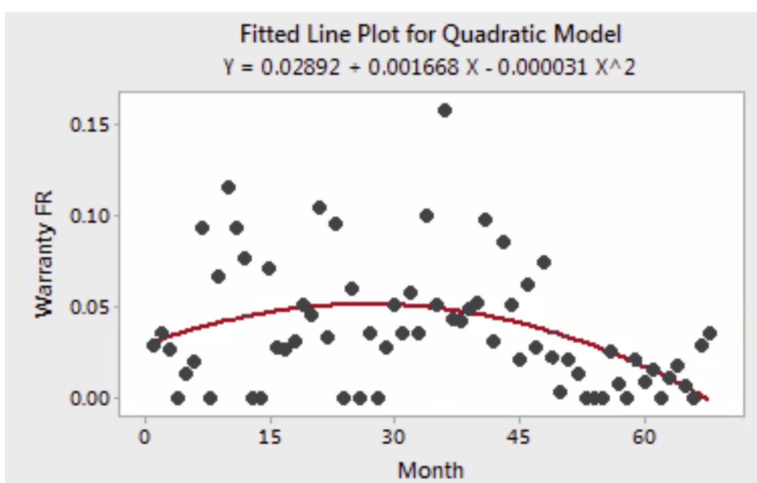


Figure 33: Warranty Failure Rate - Simple Regression

Quality Rate (QR)

After observing the time series plot, it is apparent that, following a series of fairly consistent data points, the quality rate decreases at a sharp rate and bottoms in month 41. There appears to be a defining event starting in month 39 that changed the course of the data.

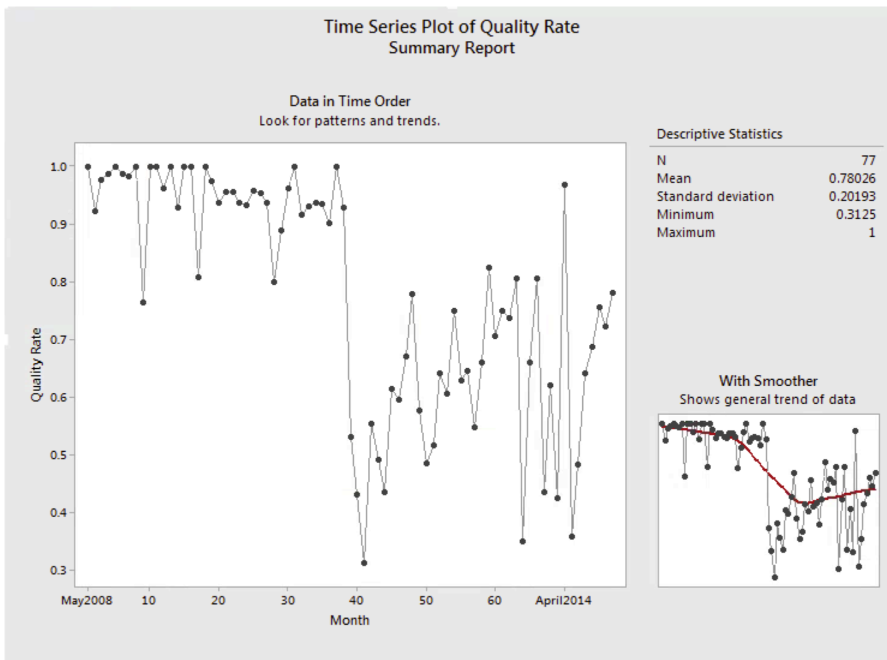


Figure 34: Quality Rate - Monthly Time Series

A face-to-face interview with the MDI's head of IT, Software, and Support, Jimmy Campbell, revealed the potential source of the variation to the launch of MDI's first digital Quality Control system. From months 1 through 38, employees were answering "no defect" to quality checks that they corrected. However, MDI changed the process to require Quality Control records to be 100%, "OK" or "N/A." Now when employees identified a failing check, they were required to make the necessary corrections, check it again, and, if it passed, change the answer to "OK" and save the Quality Control record.

Before the process change, employees would record a failed check and then fix it without updating the QC record. Now employees record a failed check, then fix it, and change the check to “OK” before finally approving the document. In order to get an accurate and consistent view of MDI’s performance following the transition to the new Quality Control system, the first 38 months of data are excluded.

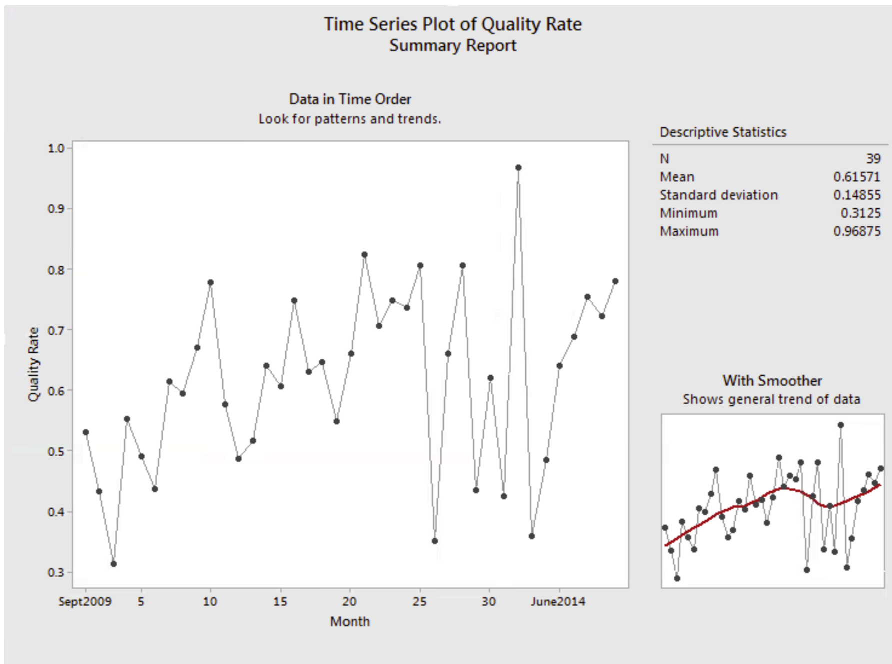


Figure 35: Quality Rate - Monthly Time Series - After QC Transition

The sample of 39 months is large enough by to obtain a precise estimate of the strength of the relationship. Normality is not an issue as there are more than 15 data points. A simple regression produces a p-value of 0.036 ($p = 0.036 < 0.05$), which shows a statistically significant relationship between the quality rate and the number of months since MOMS adoption. It should be noted that a statistically significant relationship does not imply that time since adoption causes the quality rate. The regression model can explain 11.37% of the variation in quality rate indicating that time is a minimal factor in the performance related to quality rate. A positive correlation ($r = 0.34$) indicates that as the months increase, the quality rate tends to increase as well. Based on these results it is evident that MDI has continuously improved over time in terms of manufacturing quality rate.

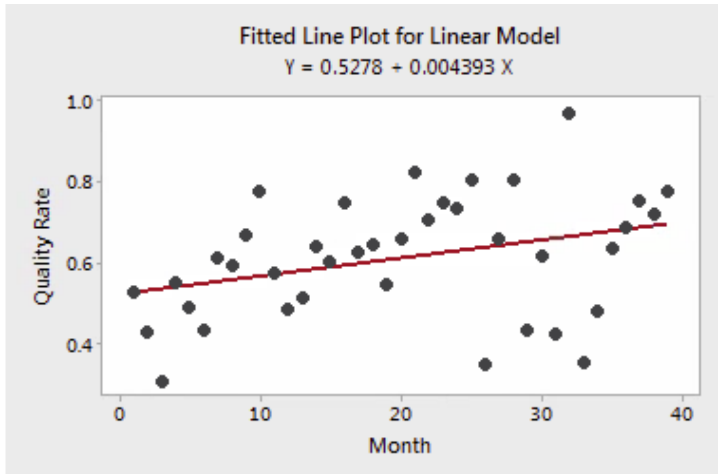


Figure 36: Quality Rate - Simple Regression - After QC Transition

Customer Retention Rate (CRR)

As an SME that manufactures complex products such as computers and telemedicine carts, MDI services a smaller number of customers annually relative to larger companies, which diminishes the results for any potential monthly data analysis. Yearly data will be used for analysis of the customer retention rate. Note that MOMS was introduced early in 2008, however, the CRR in 2008 may be slightly altered since the traditional manufacturing processes were in place in the first couple of months.

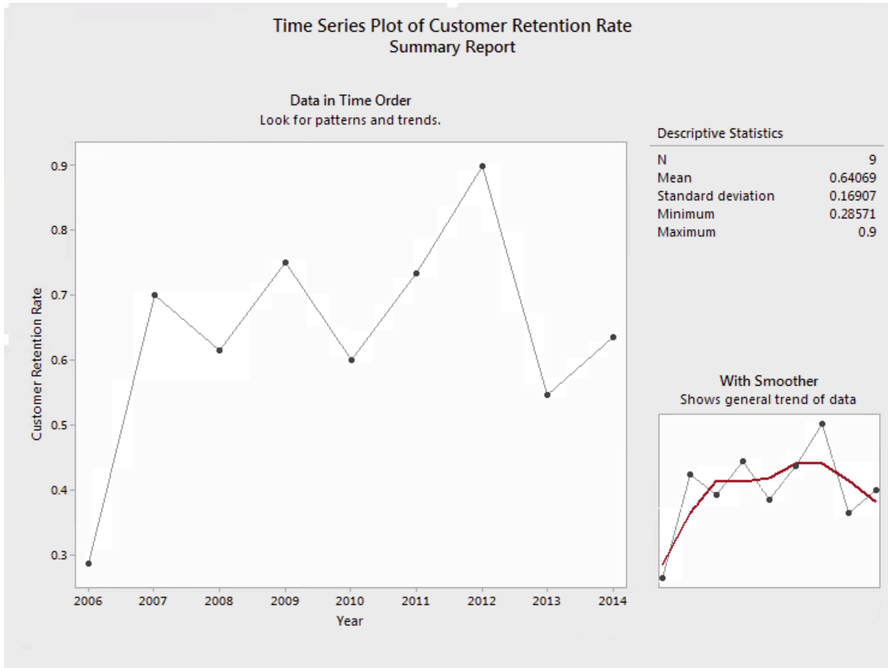


Figure 37: Customer Retention Rate - Pre & Post-MOMS - Yearly Time Series

While there are no unusual data points to influence the results, a small sample size (n = 9) is not a precise estimate of the strength of the relationship. No conclusions can be made until more data is gathered and the tests are re-run. Interpreting the p-value with such a small sample size provides minimal accuracy and is sensitive to outliers. The relationship is not statistically significant between the post-MOMS CRR and the year as p = 0.95 > 0.05. The correlation is not statistically significant as well (r = -0.03) and an extremely low R-squared value of 0.09% shows that the variation in post-MOMS is not well explained by the regression model.

Satisfied Customer Rate (SCR)

Calculating the 'satisfied customer rate' can be challenging for SMEs considering the relatively few number of customers (depending on the types of products) in a given year compared to larger organizations. The low number of customers makes the data susceptible to large swings due to the smaller sample size. In addition, the majority of projects undertaken by MDI last six months or longer. Therefore when determining the satisfied customer rate for MDI, only annual statistics were analyzed. Figure 38 shows a time series plot using Minitab software along with descriptive statistics.

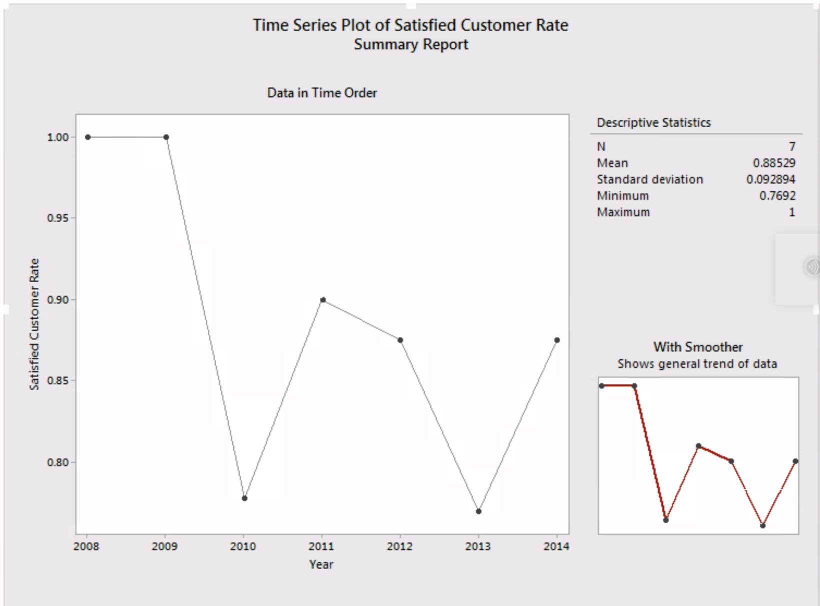


Figure 38: Satisfied Customer Rate - Yearly Time Series

The small sample size (n = 7) does not allow for a precise estimate of the strength of the relationship. No conclusions can be made until more data is gathered and the tests are re-run. Interpreting the p-value with such a small sample size provides minimal accuracy and is sensitive to outliers.

Total Product Manufacturing Cost (TPMC)

In order to gain a more granular understanding of the TPMC, this metric will be customized to analyze the total manufacturing cost per product. A sample of 76 months for total product manufacturing cost data produces the following time series chart as seen in Figure 39. The sample size is large enough to obtain a precise estimate of the strength of the relationship and this analysis passes the normality test, as there are more than 15 data points (Minitab).

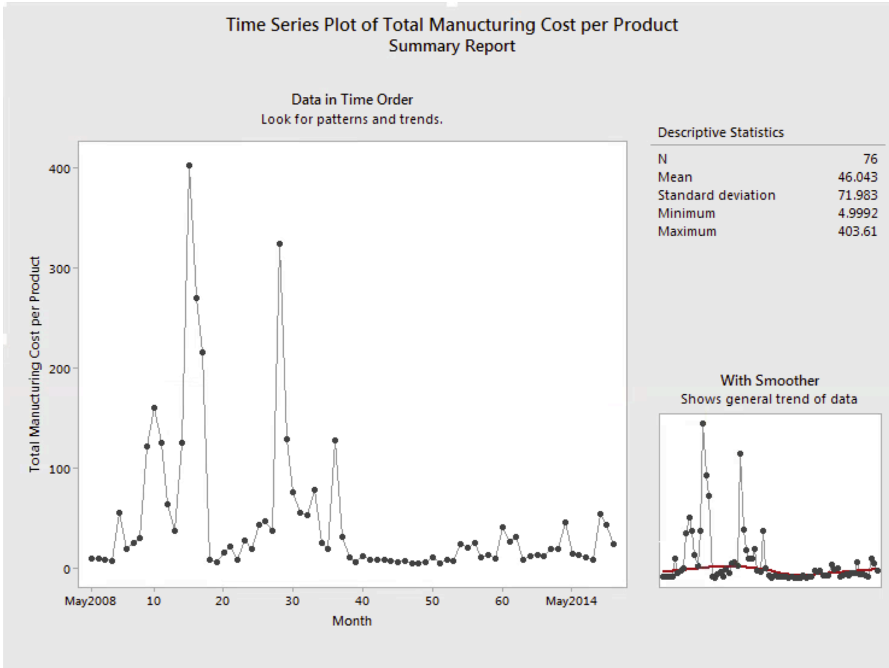


Figure 39: Total Manufacturing Cost per Product - Monthly Time Series

Simple regression analysis between the total manufacturing cost per product and number of months post-MOMS implementation finds a statistically significant relationship ($p = 0.004 < 0.05$). A slightly negative Pearson correlation ($r = -0.33$) indicates that when time increases, the total manufacturing cost per product tends to decrease. However, a statistically significant relationship does not imply that time causes this metric's performance and the R-squared value shows that the variable of time only explains 11.38% of the variation. According to Minitab, the sample size is sufficient for a precise estimate of the relationship and normality is not an issue as there are more than 15 data points.

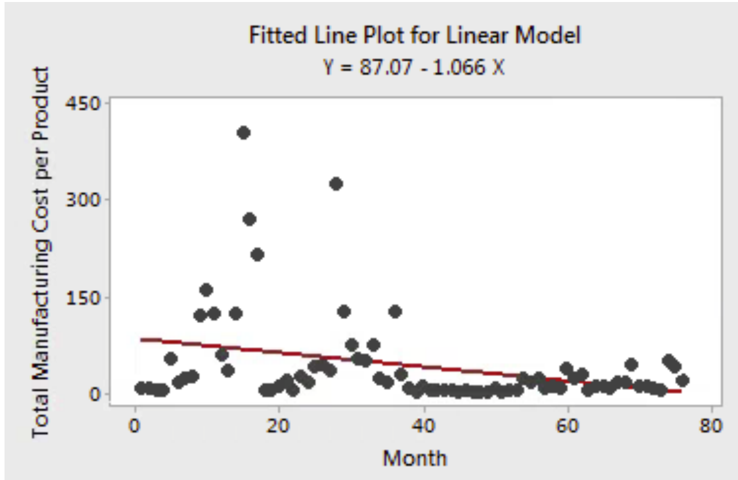


Figure 40: Total Product Manufacturing Cost - Simple Regression

The linear model shows that MDI has continuously reduced its total manufacturing costs per product since initiating MOMS. The first 40 months of data shows greater variation in costs per product before consistently producing at lower costs per product in the remaining 36 months. It is important to note that this metric fluctuates with the costs of components. Component costs, which are not a variable controlled by MDI, influence the results as the customer may choose an expensive or an inexpensive design without significantly changing the production process, time, or cost. There is a base cost of 0.5 labor hours for production set-up and 8 labor hours to assemble the product with MOMS, both of which do not change over time. Meanwhile, employee time does increase over time in the QC phase due to new processes. Employee time was 0.5 hours in 2008, 0.75 hours from 2009-2012, 1 hour for 2013, and 1.5 hours in 2014. Despite rising costs related to employee time, MDI has been able to reduce total manufacturing costs per product over time.

Operating Cost

The data for Operating Cost begins in 2012, which explains the smaller sample size of 35 months. Operating cost is a metric that is greatly affected by the number of products being produced. Therefore operating cost per product will be used for analysis.

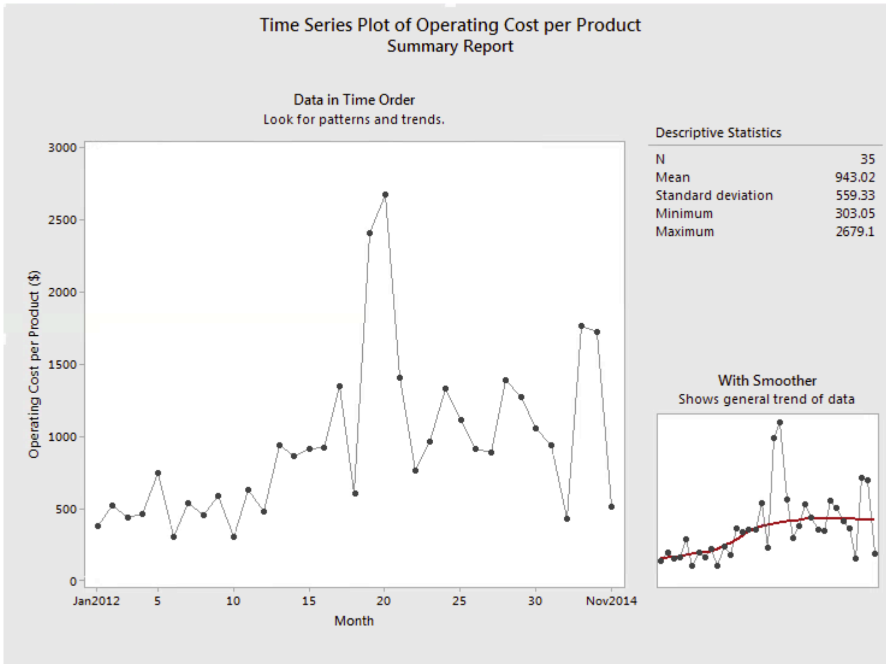


Figure 41: Operating Cost per Product - Monthly Time Series

According to Minitab, the sample size of 35 months is not large enough to provide a very precise estimate of the strength of the relationship. Typically at least 40 samples are needed. Normality is not an issue as there are more than 15 data points. The simple regression shows a statistically significant relationship ($p = 0.004 < 0.05$) between the operating cost per product and the month. Furthermore, checking the Pearson correlation finds a positive correlation ($r = 0.47$) indicating that as the months increase, the operating cost per product increases. 22.26% of the variation in operating cost per product can be explained by the regression model.

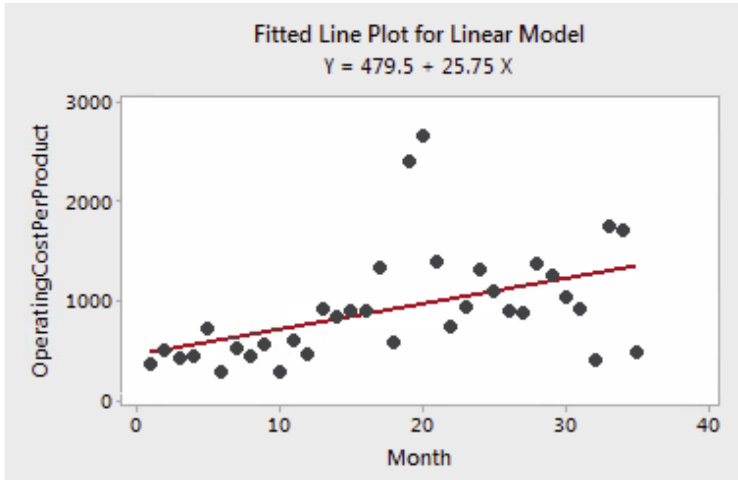


Figure 42: Operating Cost per Product - Simple Regression

Inventory Cost

Inventory cost data is available from the time MOMS is implemented at MDI and offers 76 months of data.

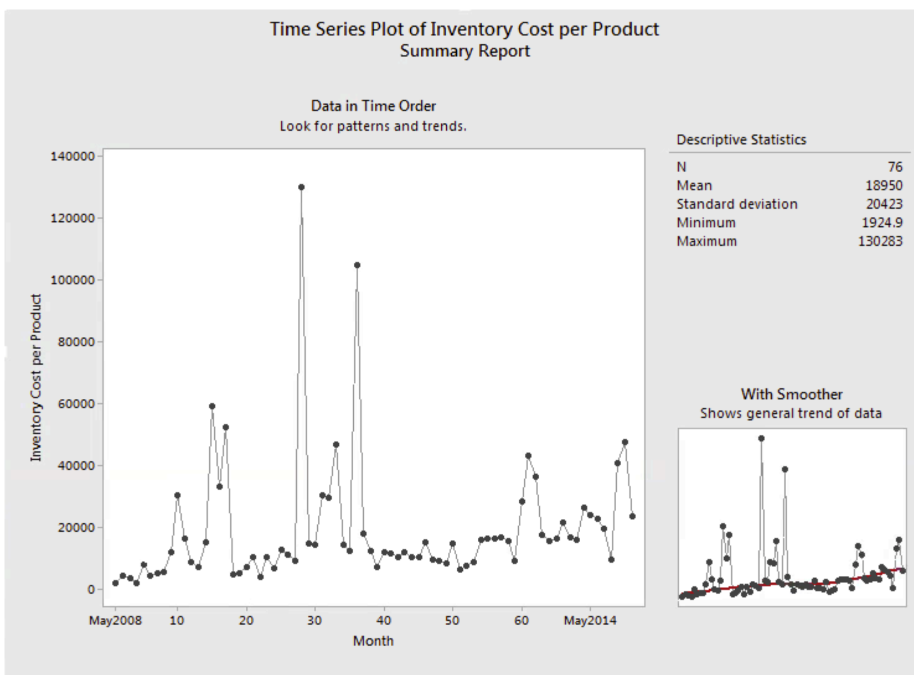


Figure 43: Inventory Cost per Product - Monthly Time Series

The sample size (n = 76) is large enough to produce a precise estimate of the strength of the relationship. The analysis for inventory costs passes the normality test since there are more than 15 data points. A simple regression of the monthly inventory cost data does not find a statistically significant relationship ($P = 0.255 > 0.05$) between the inventory cost and the number of months since implementation of MOMs at a significance level of 0.05. The fitted line plot for the linear model indicates that the inventory costs per product remain relatively even over the span of 76 months using MOMS. The Pearson correlation of $r = 0.13$ is not statistically significant and a very low R-squared value of 1.75% shows that the regression model does not fit the data well. It must be noted that a statistically significant relationship does not assume that the X causes Y.

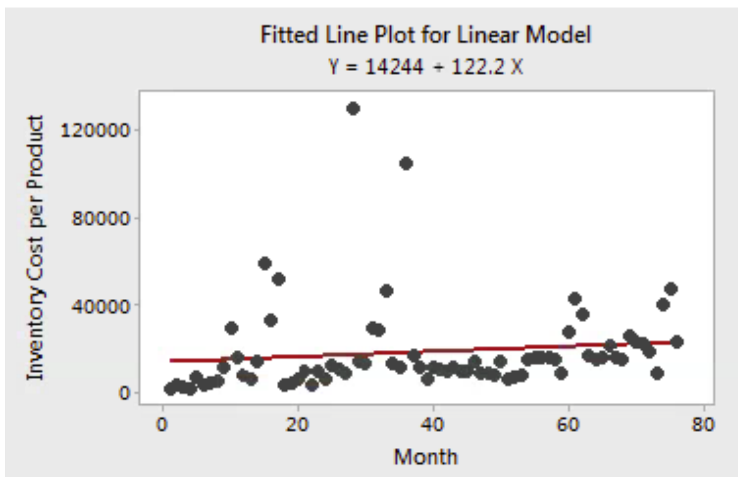


Figure 44: Inventory Cost per Product - Simple Regression

Face-to-face interviews and MDI documents reveal a production model where inventory is purchased and used just-in-time (JIT). Therefore inventory is not supposed to be stocked in the warehouse after each major production run. However, MDI occasionally is unable to use or return inventory to a distributor for credit, and is "stuck" with it. Another potential influential factor is MDI's use of its own products.

System Stability and Reliability (SSR)

The data for system stability and reliability starts in 2013. Prior to 2013, MDI assumed three days per year of downtime. Applications that were introduced and integrated later and contribute data for this metric had not been developed.

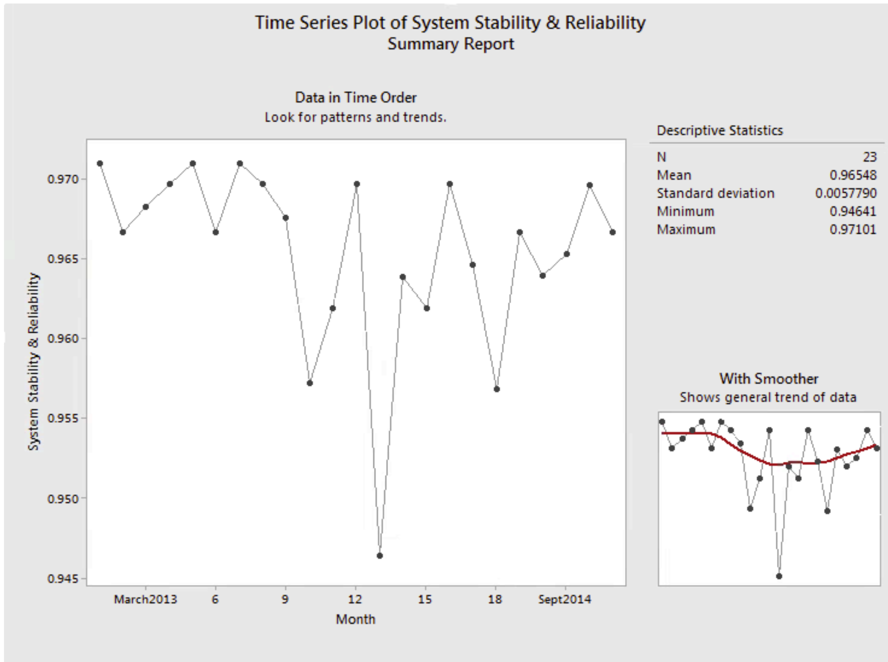


Figure 45: System Stability & Reliability - Monthly Time Series

Admittedly, the sample size of 23 months does not produce very precise data. Measures such as R-Squared and R-Squared (adjusted), which measure the strength of the relationship, can vary greatly. There are more than 15 data points, thus normality is not an issue according to Minitab. Regression analysis does not find a statistically significant relationship between the SRR and the month ($p = 0.214 > 0.05$). A Pearson correlation produces a negative correlation ($r = -0.27$) that is not statistically significant. In addition, the regression model only explains 7.25% of the SRR.

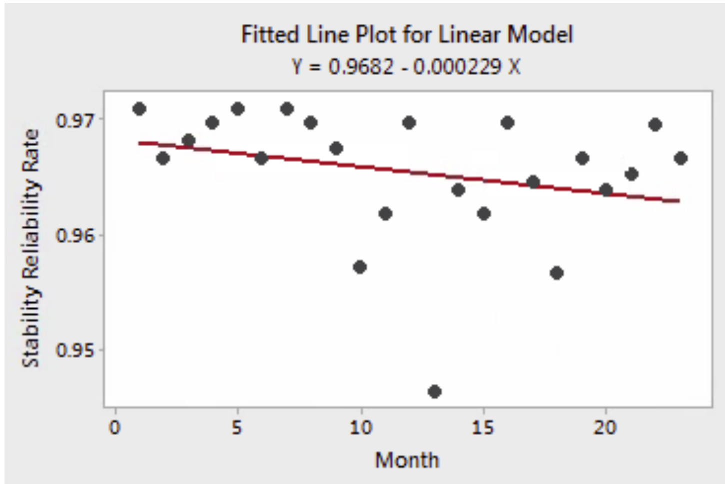


Figure 46: System Stability & Reliability - Simple Regression

Interviews with MDI employees revealed that excessively long Job Runs (which perform product validation) were the common cause of the low SSR values. For example, in months 10, 13, and 18, respectively, 410.26, 733.41 and 310.99 hours of lost production time was caused by the need for administrator action for batches of products stalled in testing over one or two days due to software errors. While the SRR is seriously impacted by these events, it did not affect MDI's ability to continue integrating other products. The products affected by the production loss only accounted for up to 1/4th of MDI's overall production capacity.

Production Loss Rate (PLR)

Production loss is one of the metrics that can be investigated between pre-MOMS and post-MOMS data. Figure 50 shows the time series of production loss since 2005 before MOMS was implemented through 2014. The red dashed line denotes the implementation of MOMS. Separate time series figures for pre and post-MOMS data are offered with a smoother to gain a better understanding of each. Consider that the units on the Y-axis are multiples of the PLTO, which is set at 3 days.

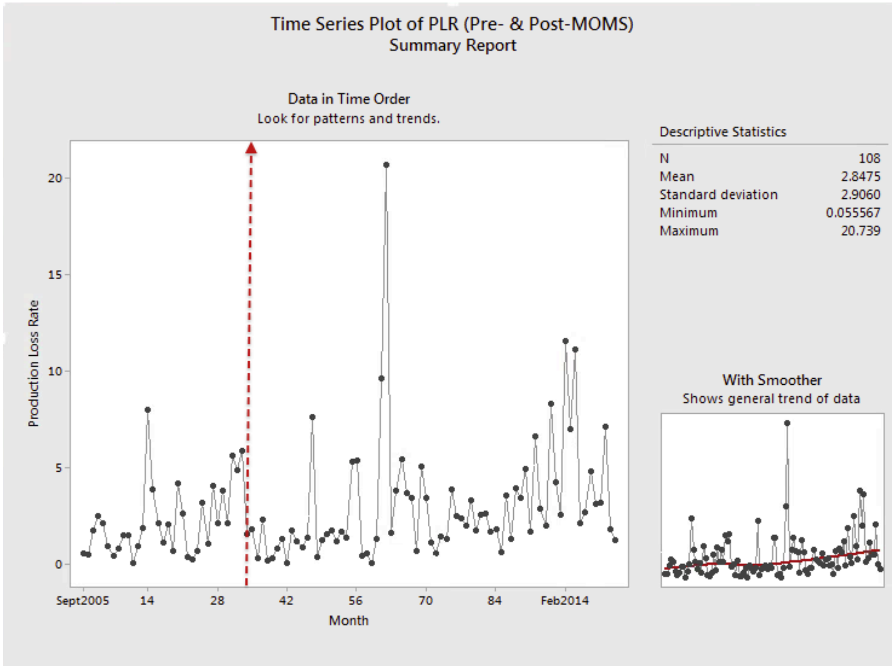


Figure 47: Production Loss Rate - Monthly Time Series - Pre & Post-MOMS

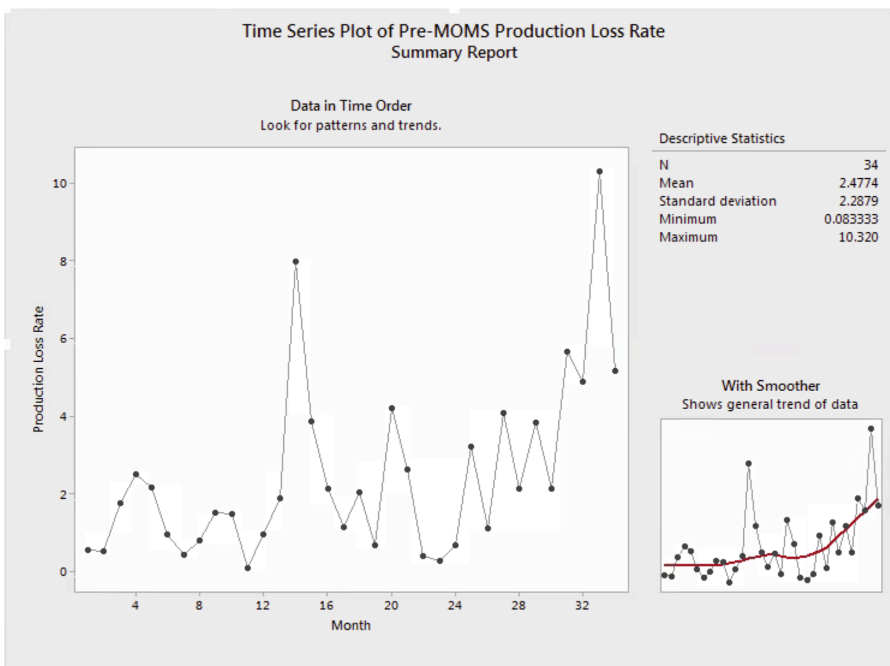


Figure 48: Production Loss Rate - Monthly Time Series - Pre-MOMS

The sample of 34 months is not large enough to provide a very precise estimate of the strength of the relationship between production loss rate and the month. Thus the R-squared measure may vary more from outliers. However, Minitab states that normality is not an issue. Pre-MOMS regression analysis shows a statistically significant relationship ($p = 0.002 < 0.05$) between the production loss rate and time. A Pearson correlation analysis identifies a statistically significant positive correlation ($r = 0.51$), which indicates that as the months have progressed, the PLR tends to increase as well. This shows that MDI's performance in this regard was deteriorating before the introduction of MOMS. The regression model explains 25.61% of the variation in pre-MOMS PLR.

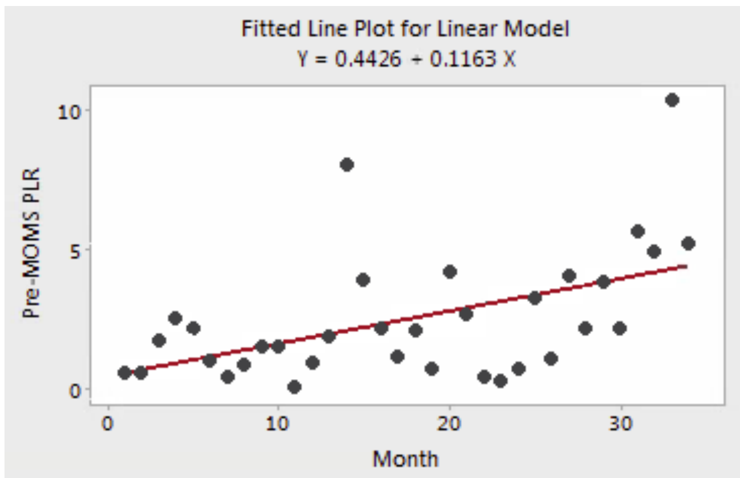


Figure 49: Production Loss Rate - Simple Regression - Pre-MOMS

Figure 53 displays the time series plot for the post-MOMS production loss rate. A separate regression analysis was then conducted to potentially gain an understanding of whether MDI was seeing progress in this metric following MOMS implementation.

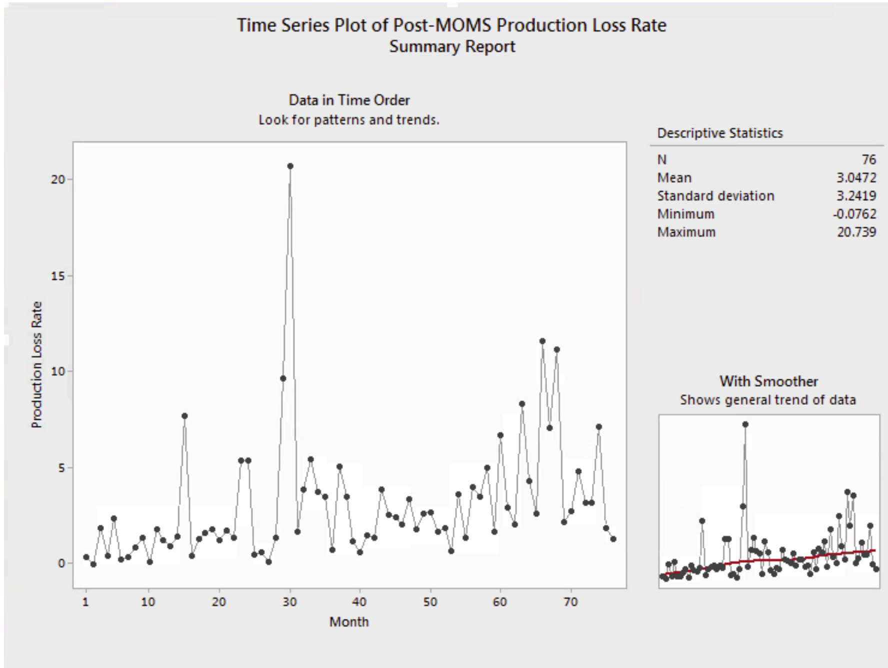


Figure 50: Production Loss Rate - Monthly Time Series - Post-MOMS

The Post-MOMS regression analysis of Production Loss Rate has a large enough sample (n = 75) to gain a precise estimate of the strength of the relationship and normality is not an issue as there are more than 15 data points. The analysis finds a statistically significant relationship ($p = 0.011 < 0.05$) between post-MOMS PLR and time. A Pearson correlation calculation ($r = 0.29$) indicates that as the months increase, the post-MOMS PLR also tends to increase. However, the regression model only explains 8.5% of the variation. Since there is a large sample and R-squared = 8.5%, time is a very small factor that is causing the increase in PLR. Interestingly, a correlation analysis of the product count and the post-MOMS production loss rate does not have a statistically significant relationship ($p = 0.241 > 0.05$) and the correlation is just -0.137. Further analysis would be needed to determine the cause of the rising PLR.

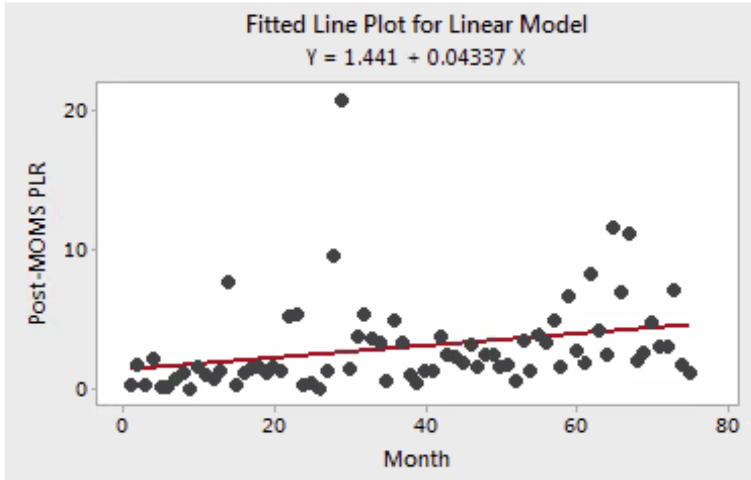


Figure 51: Production Loss Rate - Simple Regression - Post-MOMS

An Anderson-Darling Test was conducted to determine whether the pre- and post-MOMS PLR data follows a normal distribution.

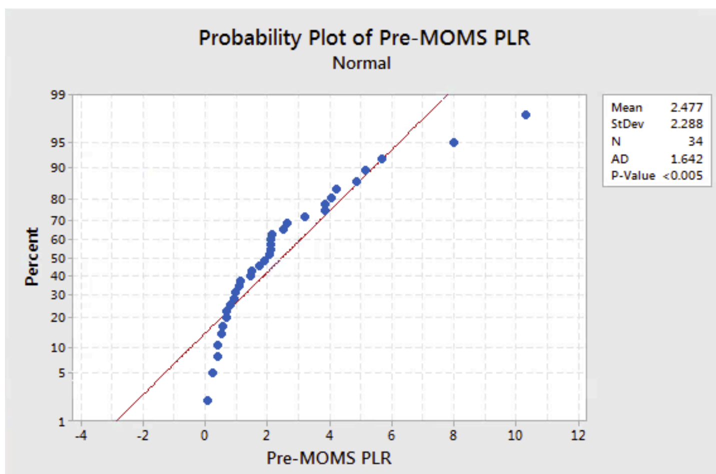


Figure 52: PLR Pre-MOMS - Anderson-Darling Test

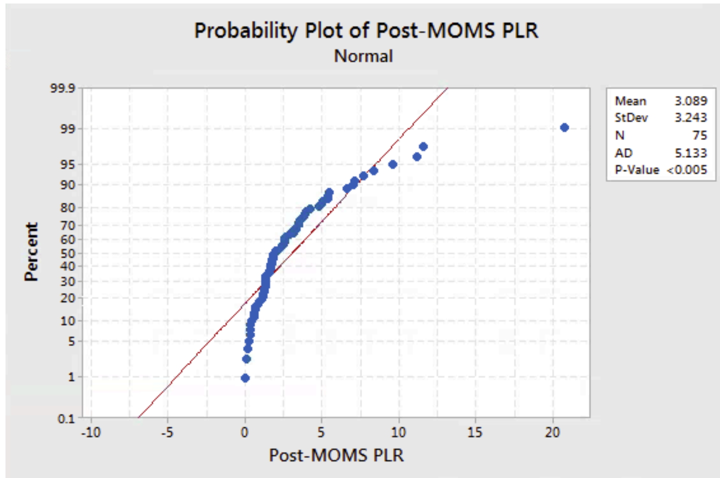


Figure 53: PLR Post-MOMS - Anderson-Darling Test

Both pre-MOMS ($p < 0.005$) and post-MOMS ($p < 0.005$) PLR data sets are found to reject the null hypothesis of following a normal distribution. Also, the requirements for meeting the other assumptions noted in the beginning of the results section are met for a nonparametric hypothesis test. Therefore the Mann-Whitney test is used to compare the performance of MDI before and after employing MOMS. This test was performed to determine if the difference between the medians of the pre-MOMS and post-MOMS PLR is statistically significant at a level of 0.05. The null (H_0) and alternative (H_A) hypothesis are:

$$H_0: \eta_{postPLR} = \eta_{prePLR}$$
$$H_A: \eta_{postPLR} < \eta_{prePLR}$$

Based on this test, one cannot reject the null hypothesis as the Wilcoxian statistic (W) = 4252 > 4125. There is not enough evidence to conclude that the median of the post-MOMS PLR is less than the median of the pre-MOMS PLR at a 95% confidence interval. The median for Post-MOMS PLR was 2.014, which is greater than the pre-MOMS median of 1.970. The median difference is 0.298 with 95% confidence intervals for the median difference in engagement of -0.378 to 1.042.

Mann-Whitney Test and CI: Post-MOMS PLR, Pre-MOMS PLR

```
              N  Median
Post-MOMS PLR  75   2.014
Pre-MOMS PLR   34   1.970


Point estimate for η1 - η2 is 0.298
95.1 Percent CI for η1 - η2 is (-0.378,1.042)
W = 4252.0
Test of η1 = η2 vs η1 < η2


Cannot reject since W is > 4125.0
```

Figure 54: Production Loss Rate – Mann-Whitney - Pre & Post-MOMS

Scrap Rate

The scrap rate is another metric that gives a facility manager insight into a company's amount of waste. The goal for manufacturers is to minimize the scrap rate in order to maintain inventory costs at anticipated levels.

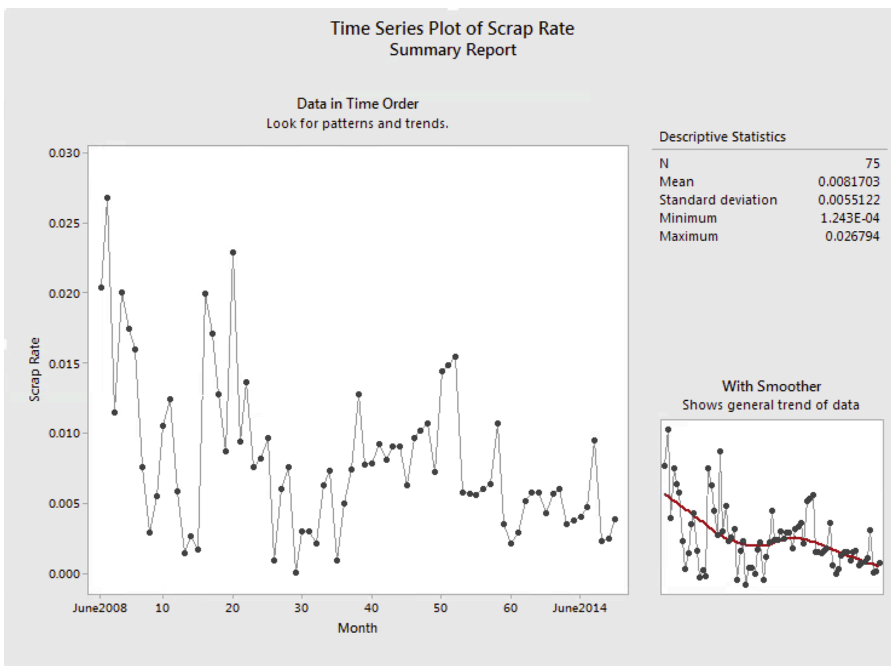


Figure 55: Scrap Rate - Monthly Time Series

The sample size (n = 75) is large enough to obtain a precise estimate of the strength of the relationship. In addition, the data passes the normality test as there are more than 15 data points. Regression analysis determines that there is a statistically significant relationship

($p < 0.001 < 0.05$) between the scrap rate and the time since MOMS implementation at an alpha of 0.05. A Pearson correlation was run and found a negative correlation ($r = -0.44$), which shows that as time increases, the scrap rate tends to decrease. This result shows indicates continuous improvement with respect to waste reduction of raw materials. The R-squared value is relatively low and signifies that the regression model explains 18.95% of the variation.

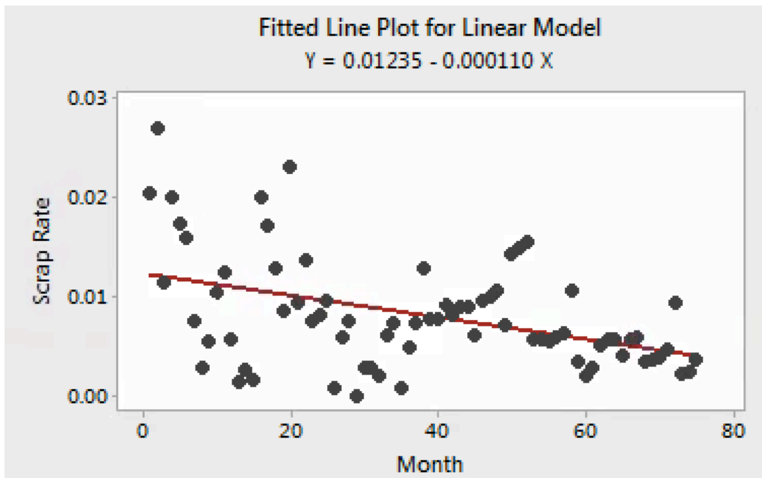


Figure 56: Scrap Rate - Simple Regression

Process Lead Time (PLT)

The analysis for Process Lead Time includes data collected before and after the implementation of MOMS. Figure 60 shows the complete time series of data with months 1-34 representing the PLT prior to MOMS adoption. The dashed line at Month 34 separates the pre- and post-MOMS data.

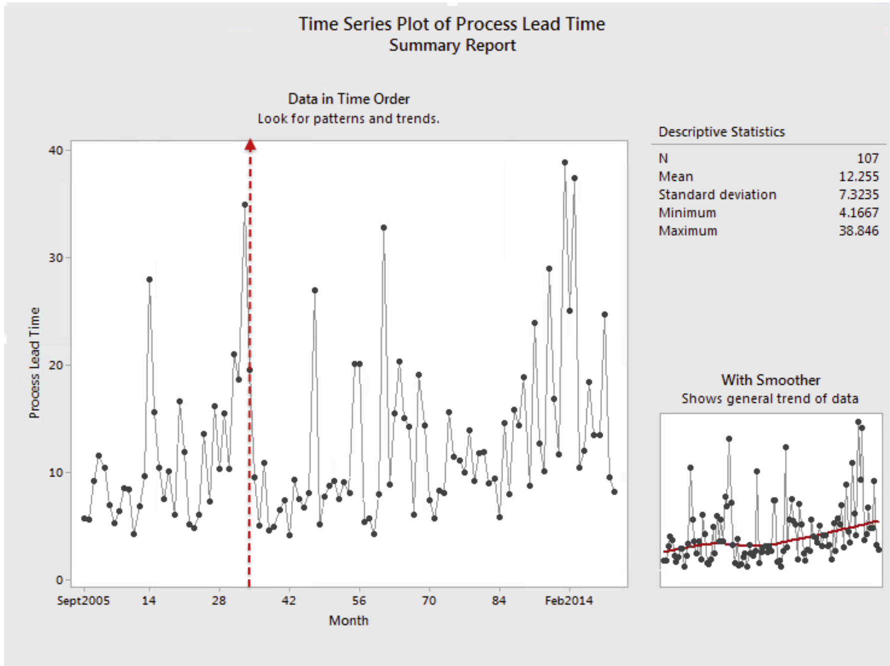


Figure 57: Process Lead Time - Monthly Time Series - Pre & Post-MOMS

The sample size (n = 34) for pre-MOMS PLT is not large enough to provide a very precise estimate of the strength of the relationship between process lead time and the month. According to Minitab, the sample passes the normality test since it is greater than 15 data points. A simple regression finds a statistically significant relationship between the PLT pre-MOMS and time. In addition, a Pearson correlation finds a positive correlation (r = 0.51), which indicates that as the months pass, the process lead time tends to increase as well. The R-squared value is relatively low as the regression model explains 25.61% of the variation.

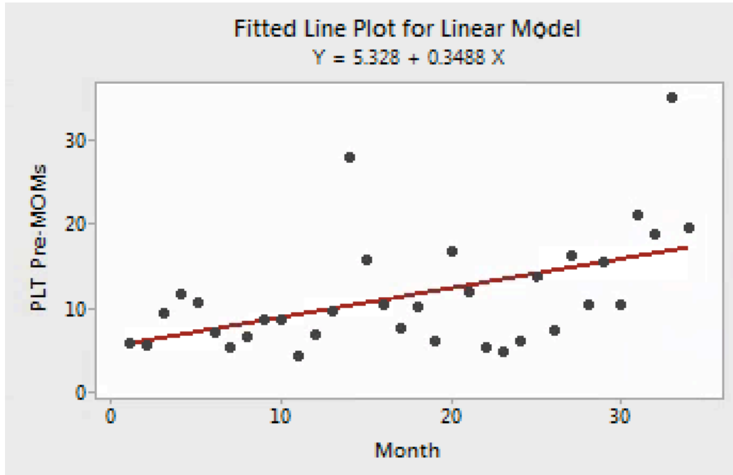


Figure 58: Process Lead Time - Simple Regression - Pre-MOMS

A simple regression of post-MOMS data finds a statistically significant relationship ($p < 0.001 < 0.05$) between the process lead time and the number of months following ERP implementation. While this does not imply that X causes Y, this relationship suggests that the process lead time has been increasing over time. The Pearson correlation finds a positive correlation ($r = 0.41$) that shows that as time passes, the process lead time tends to increase as well. While this does not allow one to conclude MDI is improving over time, the R-squared value of 16.64% indicates that other factors are greater causes the decreasing performance in regards to process lead time. Note that the month 0 in Figure 62 corresponds to month 35 on the pre- and post-MOMS time series for PLT.

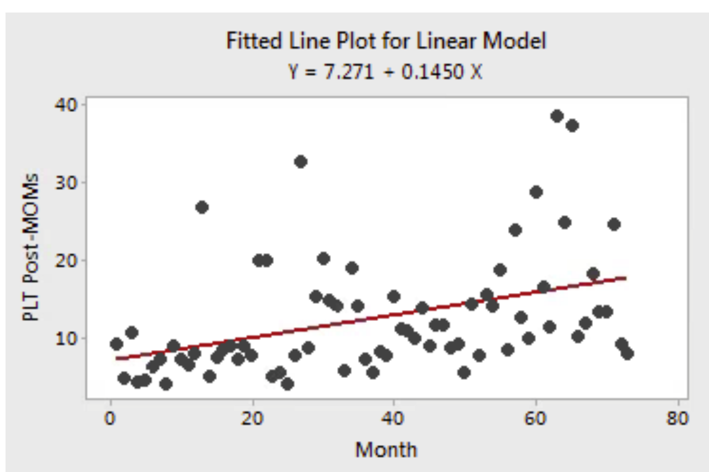


Figure 59: Process Lead Time - Simple Regression - Post-MOMS

An Anderson-Darling Test was conducted to determine whether the pre- and post-MOMS PLR data follows a normal distribution.

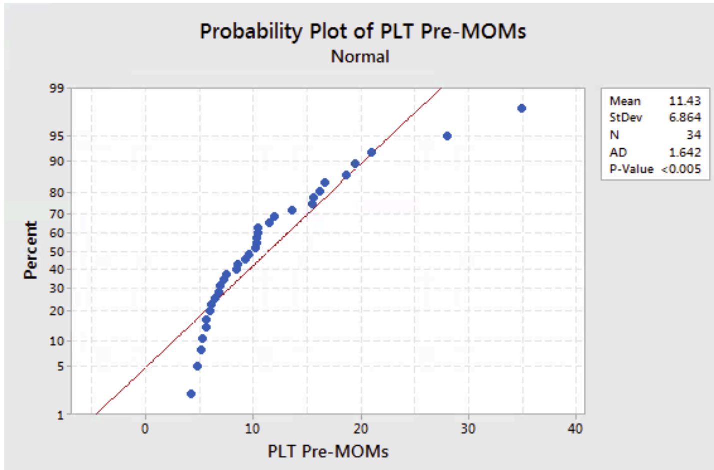


Figure 60: PLT Pre-MOMS - Anderson-Darling Test

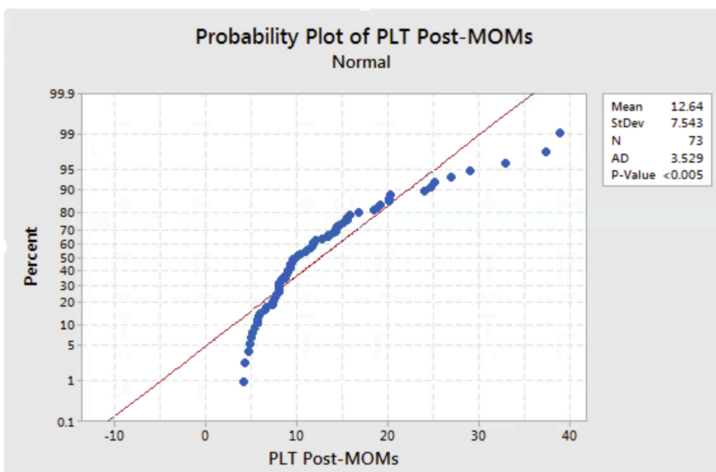


Figure 61: PLT Post-MOMS - Anderson-Darling Test

Both pre-MOMS ($p < 0.005$) and post-MOMS ($p < 0.005$) PLT data sets are found to reject the null hypothesis of following a normal distribution. Also, the requirements for meeting the other assumptions noted in the beginning of the results section are met for a nonparametric hypothesis test. Therefore the Mann-Whitney test is used to compare the performance of MDI before and after employing MOMS. This test determines if the difference between the medians of the pre-MOMS and post-MOMS PLT is statistically significant at a level of 0.05. The null (H_0) and alternative (H_A) hypothesis are:

$$H_0: \eta_{postPLT} = \eta_{prePLT}$$

$$H_A: \eta_{postPLT} < \eta_{prePLT}$$

Based on this test, one cannot reject the null hypothesis as the Wilcoxian statistic (W) = 4066.0 > 3942.0. There is not enough evidence to conclude that the median of the post-MOMS PLT is significantly less than the median of the pre-MOMS PLT at a 95% confidence interval. The median for Post-MOMS PLT was 10.041, which is greater than the pre-MOMS median of 9.911. The median difference is 0.891 with 95% confidence intervals for the median difference in engagement of -1.135 to 3.067.

Mann-Whitney Test and CI: PLT Post-MOMs, PLT Pre-MOMs

```
                 N  Median
PLT Post-MOMs   73  10.041
PLT Pre-MOMs    34   9.911


Point estimate for η1 - η2 is 0.891
95.0 Percent CI for η1 - η2 is (-1.135,3.067)
W = 4066.0
Test of η1 = η2 vs η1 < η2


Cannot reject since W is > 3942.0
```

Figure 62: Production Lead Time - Mann-Whitney Test – Pre & Post-MOMS

Process Cycle Efficiency (PCE)

The analysis for Process Cycle Efficiency includes data from operations prior to implementation of MOMS as well as after implementation. The dashed line represents the end of the pre-MOMS data (n = 34) and the beginning of the post-MOMS PCE data set (n = 72).

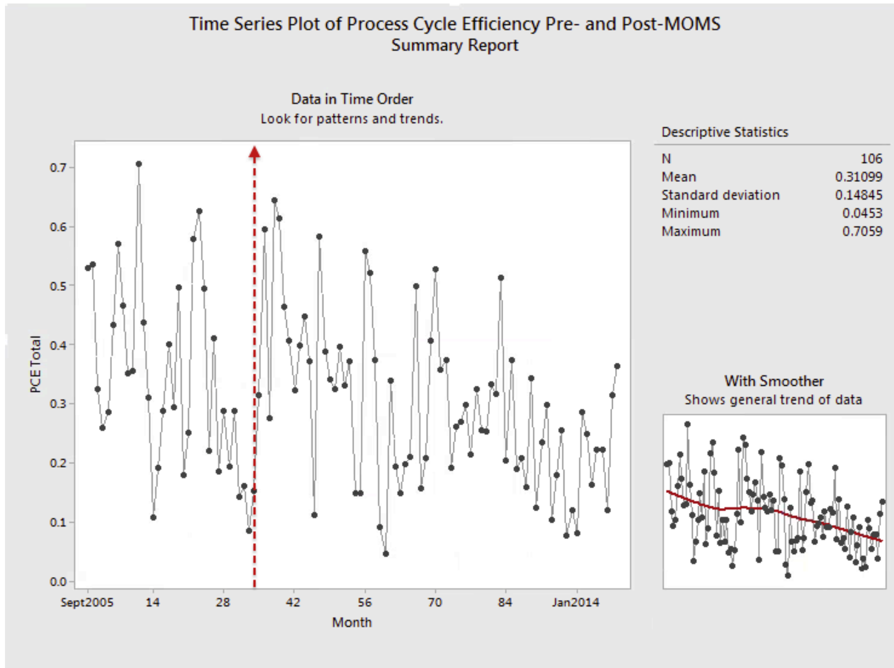


Figure 63: Process Cycle Efficiency - Monthly Time Series - Pre & Post-MOMS

The sample size of pre-MOMS data is large enough to pass for normality (n = 34 > 15), however, it is not large enough for a very precise estimate of the relationship between it and time. The regression analysis shows a statistically significant relationship between pre-MOMS PCE and time ($p = 0.006 < 0.05$). A Pearson correlation ($r = -0.46$) indicates that as months increase, the pre-MOMS PCE tends to decrease. The R-squared is low (R-sq = 21.28%) meaning the regression model does not give a good explanation of the variation.

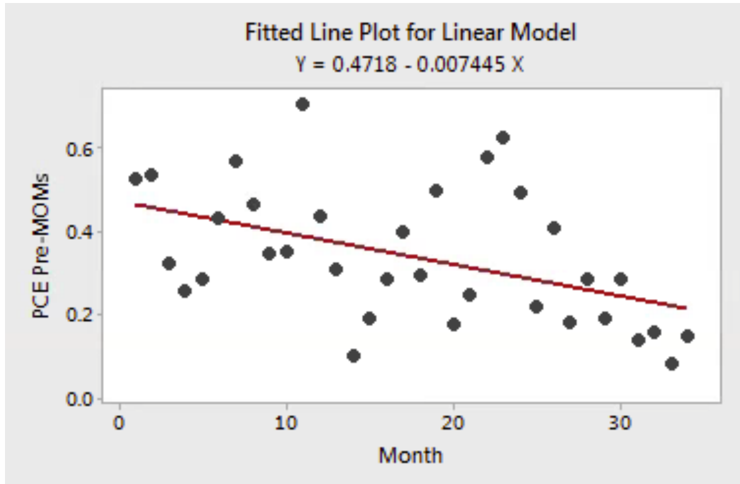


Figure 64: Process Cycle Efficiency - Simple Regression - Pre-MOMS

When investigating if the organization improved upon process cycle efficiency as time passed, a simple regression of the data collected post-MOMS implementation was conducted. The sample (n=72) is large enough to obtain a precise estimate of the strength of the relationship and normality is not an issue. There is a statistically significant relationship ($p < 0.001 < 0.05$) between process cycle efficiency and the number of months since implementation. A negative Pearson correlation ($r = -0.48$) indicates that when the months since implementation increases, the post-MOMS PCE tends to decrease. The model explains 22.83% (R-squared value) of the variation in PCE. A statistically significant relationship does not imply that time causes the PCE. Note that month 0 in Figure 68 corresponds to the month 35 in the time series figure.

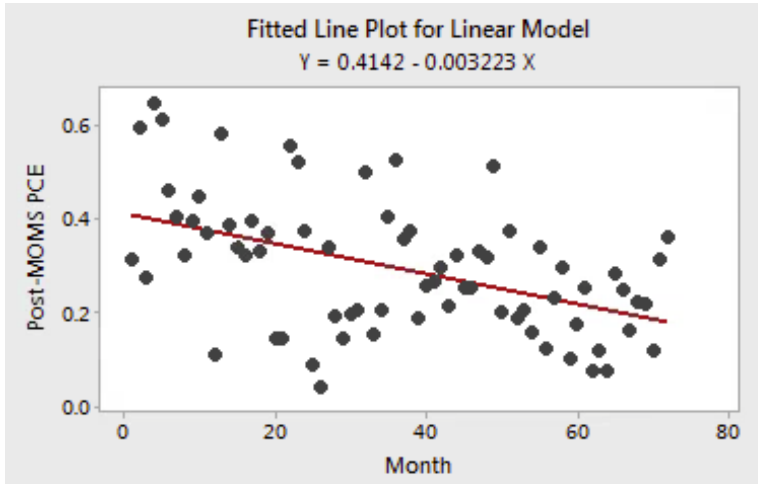


Figure 65: Process Cycle Efficiency - Simple Regression - Post-MOMS

An Anderson-Darling test was conducted to determine if the pre- and post-MOMS data sets follow a normal distribution.

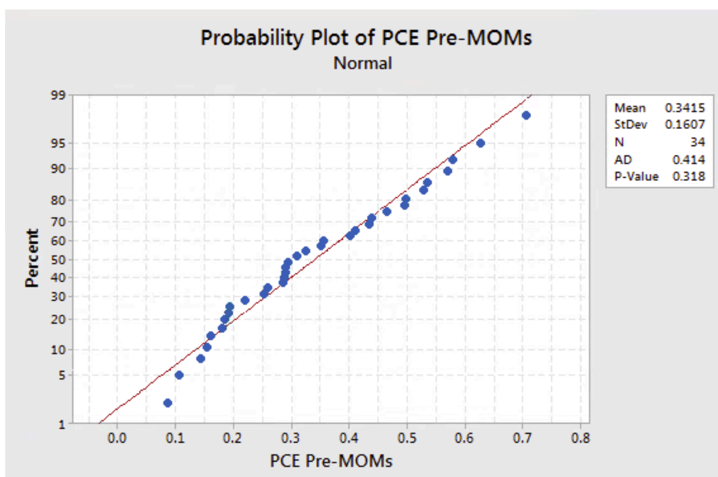


Figure 66: Process Cycle Efficiency - Anderson-Darling Test - Pre-MOMS

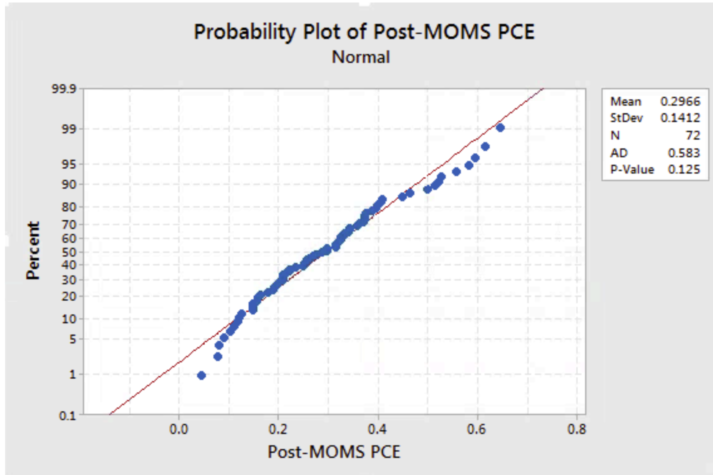


Figure 67: Process Cycle Efficiency - Anderson-Darling Test - Post-MOMS

Both pre-MOMS ($p = 0.318 > 0.05$) and post-MOMS ($p = 0.125 > 0.05$) PCE data sets fail to reject the null hypothesis of following a normal distribution. Also, the requirements for meeting the other assumptions noted in the beginning of the results section are met for a parametric hypothesis test. Therefore the 2-Sample t test is used to compare the performance of MDI before and after employing MOMS. This test determines if the difference between the mean of the pre-MOMS and post-MOMS PCE is statistically significant at a level of 0.05. The following null and alternative hypothesis was tested:

$$H_0: \mu_{postmomsPCE} = \mu_{premomsPCE}$$

$$H_A: \mu_{postmomsPCE} > \mu_{premomsPCE}$$

Based on this 2-sample t test, one cannot reject the null hypothesis ($p = 0.916 > 0.05$) that the means are equal. There is not enough evidence to conclude that the mean for PCE with MOMS is significantly greater than the mean of pre-MOMS PCE. The confidence interval quantifies the uncertainty when estimating the difference in the means. You can be 90% confident that the true difference is between -0.098817 and 0.0088427, and 95% confident that it is greater than -0.098817.

Individual Samples		
Statistics	PCE Post-MOMS	PCE Pre-MOMs
Sample size	72	34
Mean	0.29656	0.34155
90% CI	(0.2688, 0.3243)	(0.29490, 0.38819)
Standard deviation	0.14117	0.16072

Difference Between Samples	
Statistics	*Difference
Difference	-0.044987
90% CI	(-0.098817, 0.0088427)

*Difference = Post-MOMS - PCE Pre-MOMs

Figure 68: Process Cycle Efficiency - 2-Sample t Test - Pre & Post-MOMS

A 1-Sample t test was performed to compare the process cycle efficiency means for post-MOMS data against the world class efficiency of 25% for manufacturing companies as identified by (Pyzdek & Keller, 2010). The analysis shows that the post-MOMS process cycle efficiency is significantly greater than the target ($p = 0.003 < 0.05$). This suggests that MDI is operating more efficiently than world-class manufacturers while utilizing MOMS. The sample is sufficient to detect a difference between the mean and the target and it passes the normality test.

Statistics	
Sample size	72
Mean	0.29656
90% CI	(0.26883, 0.32429)
Standard deviation	0.14117
Target	0.25

Figure 69: Process Cycle Efficiency - 1-Sample t Test - Statistics

On-Time Delivery (OTD)

Due to greater than 15 data points, normality is not an issue. Months 1 through 29 represent the on-time delivery performance of MDI prior to the implementation of MOMS. The dashed line represents the end of the pre-MOMS OTD data and the beginning of the post-MOMS data set.

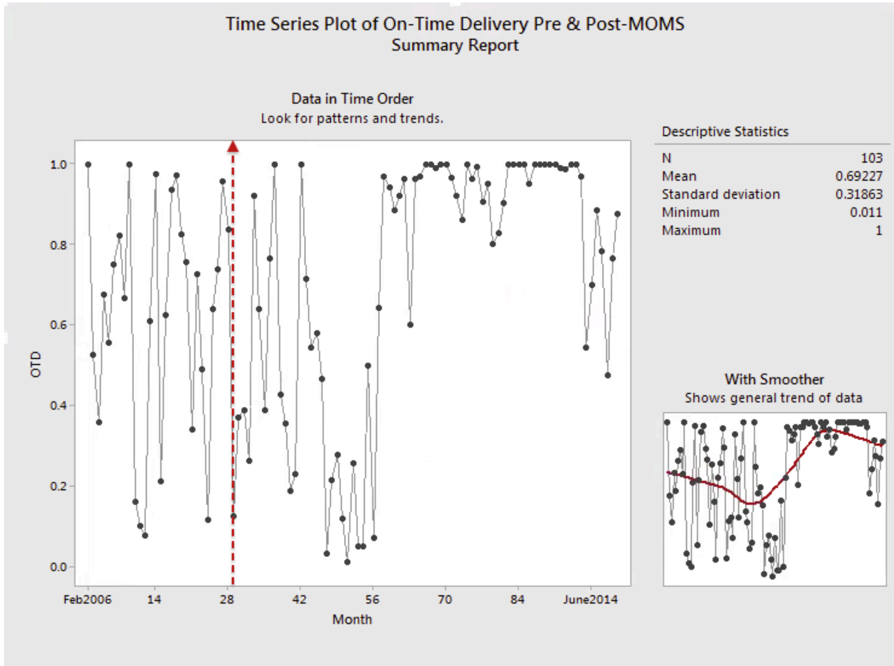


Figure 70: On-Time Delivery - Monthly Time Series - Pre & Post-MOMS

Regression analysis using pre-MOMS on-time delivery data shows that the relationship between it and time is not statistically significant ($p = 0.859 > 0.05$). Running a Pearson correlation finds there is no correlation as well (-0.03). These results are supported by the fact that R-squared = 0.12%, which shows that time has a negligible impact on on-time delivery. The regression model explains 0.12% of the variation in OTD Pre-MOMS. It should be noted that the sample size ($n = 29$) is not large enough to provide a very precise estimate of the strength of the relationship between on-time delivery and time. Measures such as R-squared are susceptible to varying greatly. However, there are no unusual data points and there are enough data points to pass the normality test (Minitab).

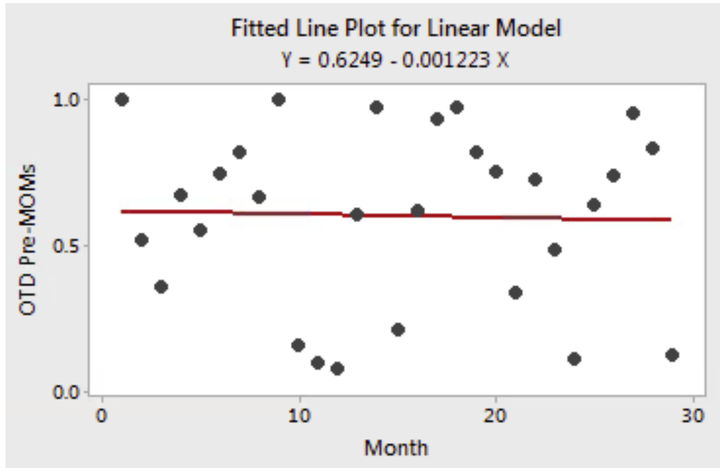


Figure 71: On-Time Delivery - Simple Regression - Pre-MOMS

A simple regression of the post-MOMS on-time delivery data can determine whether MDI has been able to improve over the course of time. Analysis shows a significant relationship ($p < 0.001 < 0.05$) between post-MOMS on-time delivery and the number of months since implementation. A Pearson correlation test finds a positive correlation ($r = 0.56$), which indicates that as the months increase, on-time delivery increases as well. This suggests that MDI has been continuously improving its performance in terms of completing and shipping products to customers within schedule. However, a relatively low R-squared value of 30.88% shows that other factors play a larger role in the improvement of on-time delivery. Note that a statistically significant relationship does not imply that time causes the OTD. According to Minitab, the sample size ($n = 74$) is large enough to obtain a precise estimate of the relationship and the data set passes for normality as there are more than 15 data points.

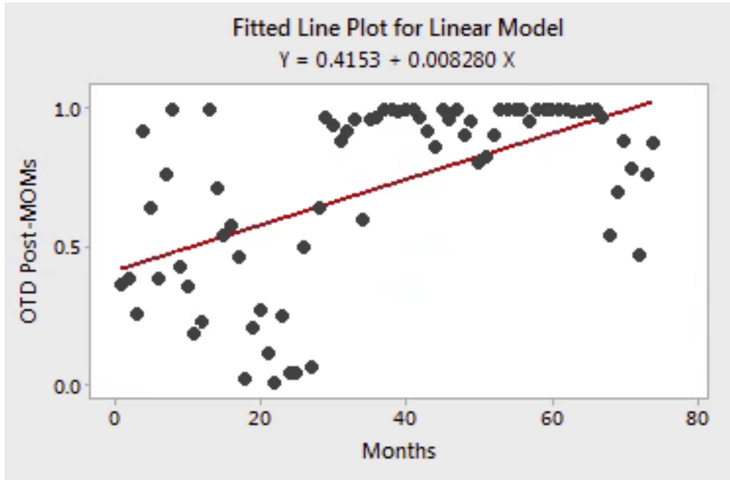


Figure 72: On-Time Delivery - Simple Regression - Post-MOMS

An Anderson-Darling test is performed to determine if the data sets follow a normal distribution.

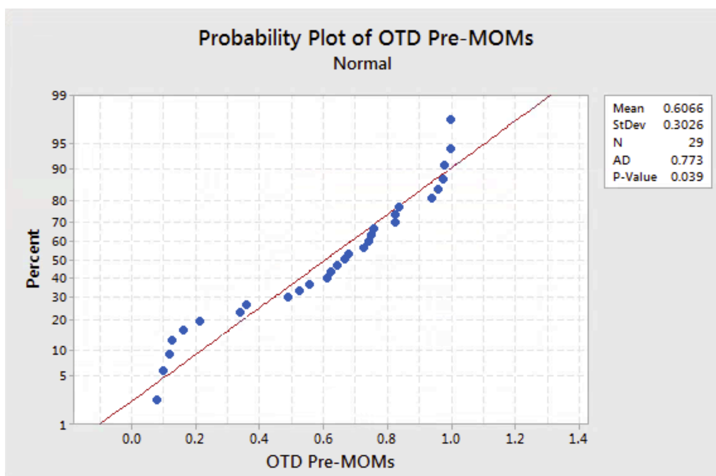


Figure 73: On-Time Delivery - Anderson-Darling Test - Pre-MOMS

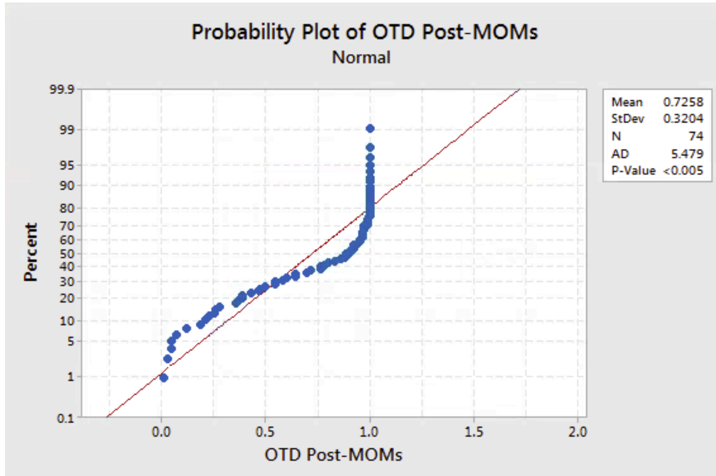


Figure 74: On-Time Delivery - Anderson-Darling Test - Post-MOMS

Both pre-MOMS ($p = 0.039 < 0.05$) and post-MOMS ($p < 0.005 < 0.05$) OTD data sets reject the null hypothesis of following a normal distribution. Also, the requirements for meeting the other assumptions noted in the beginning of the results section are met for a nonparametric hypothesis test. Therefore the Mann-Whitney test is used to compare the performance of MDI before and after employing MOMS. This test determines if the difference between the medians of the pre-MOMS and post-MOMS OTD is statistically significant at a 95% confidence level. The null (H_0) and alternative (H_A) hypothesis are:

$$H_0: \eta_{postOTD} = \eta_{preOTD}$$

$$H_A: \eta_{postOTD} > \eta_{preOTD}$$

Based on this test, one can reject the null hypothesis ($p = 0.0143 < 0.05$). There is sufficient evidence to conclude that the median of the post-MOMS OTD is significantly greater than the median of the pre-MOMS OTD at a 0.05 significance level. The median for Post-MOMS OTD was 0.8941, which is greater than the pre-MOMS median of 0.6667. The median difference is 0.1456 with 95% confidence intervals for the median difference in engagement of 0.0094 to 0.2600. The Wilcoxian (W) test statistic = 4146.0.

Manufacturing Throughput (MT)

MDI had a process for recording Manufacturing Throughput data before and after the implementation of MOMS. Months 1-34 represent the manufacturing throughput prior to the implementation of MOMS. The dashed line in Figure 78 represents the transition to MOMS-enabled production processes.

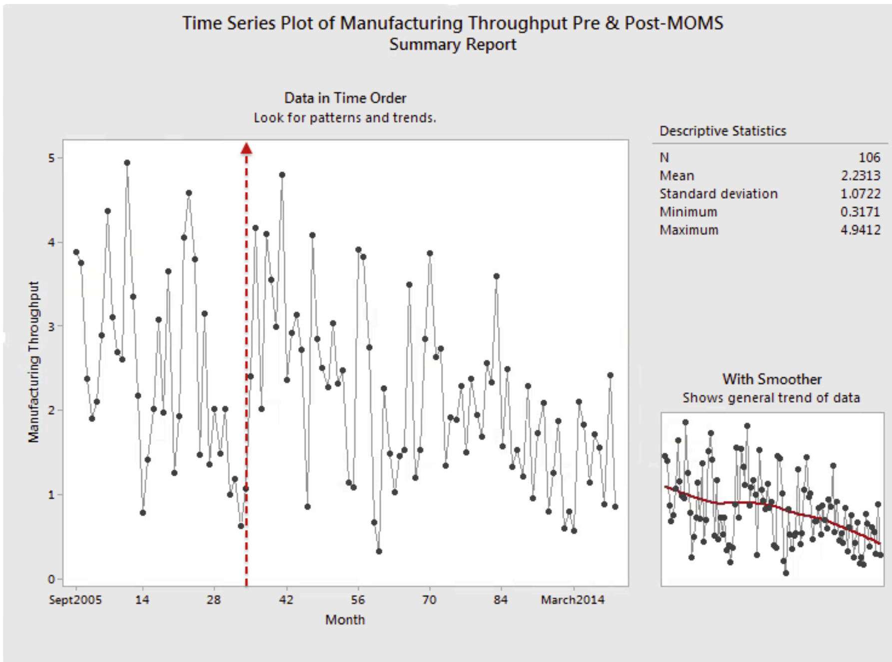


Figure 75: Manufacturing Throughput - Monthly Time Series - Pre & Post-MOMS

The sample for pre-MOMS data (n = 34) is not large enough to obtain a very precise estimate of the strength of the relationship between Manufacturing Throughput and time. However, a statistically significant relationship was found ($p = 0.007 < 0.05$) with a negative Pearson correlation of ($r = -0.45$). This negative correlation indicates that as the months increase, the manufacturing throughput tends to decrease. This regression only explains 20.43% of the variation meaning that other factors are more important to explaining MT. Note that a statistically significant relationship does not imply that time causes manufacturing throughput performance.

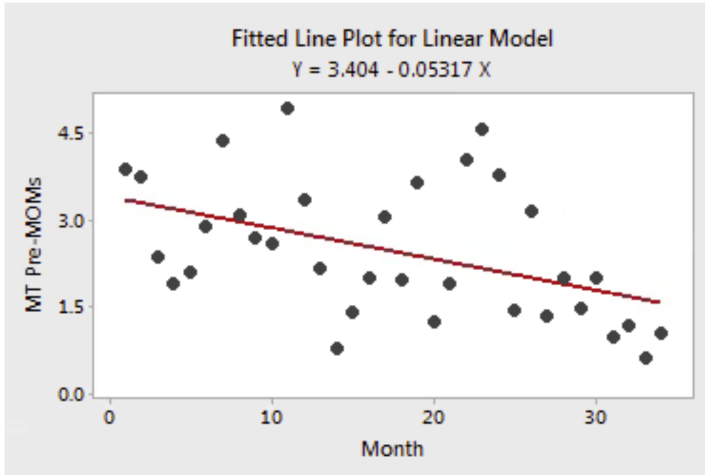


Figure 76: Manufacturing Throughput - Simple Regression - Pre-MOMS

A simple regression of the relationship between manufacturing throughput and the number of months following MOMS implementation is found to be statistically significant (P < 0.001 < 0.05). A Pearson correlation calculates a negative correlation (r = -0.52) indicating that the number of months increased, the manufacturing throughput tends to decrease. Therefore, the manufacturing throughput for MDI has seen continuous decreases while using MOMS. This regression model explains 26.97% of the variation in MT. A statistically significant relationship does not imply that time causes the MT performance. The sample (n = 72) is large enough to obtain a precise estimate of the strength of the relationship and normality is not an issue as there are more than 15 data points. Also, month 0 in Figure 80 represents Month 35 in the time series plot.

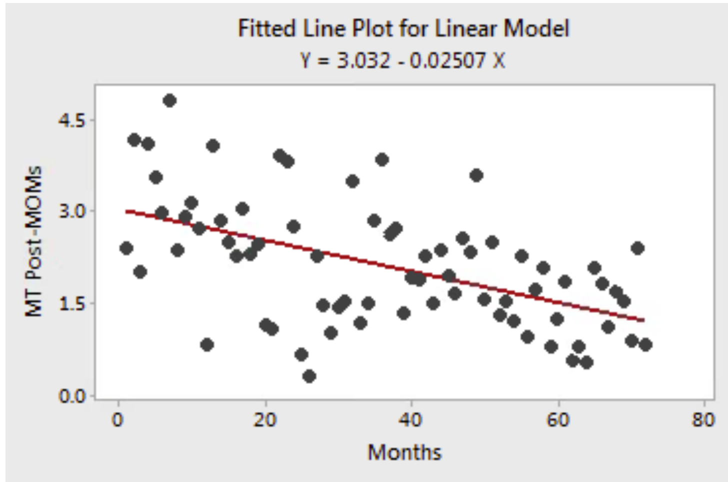


Figure 77: Manufacturing Throughput - Simple Regression - Post-MOMS

While ERP systems are expected to reduce manufacturing time, it is evident that the number of quality-improvement processes and checks performed by the system has led to an increase in overall production time. In 2009, MDI became ISO certified and implemented 24-hour stress tests. In 2011, the company overhauled the stress test system and implemented the digital quality control process followed by an additional rigorous, automated quality control testing in 2013.

An Anderson-Darling normality test was conducted to determine if the data sets for pre- and post-MOMS MT follow a normal distribution.

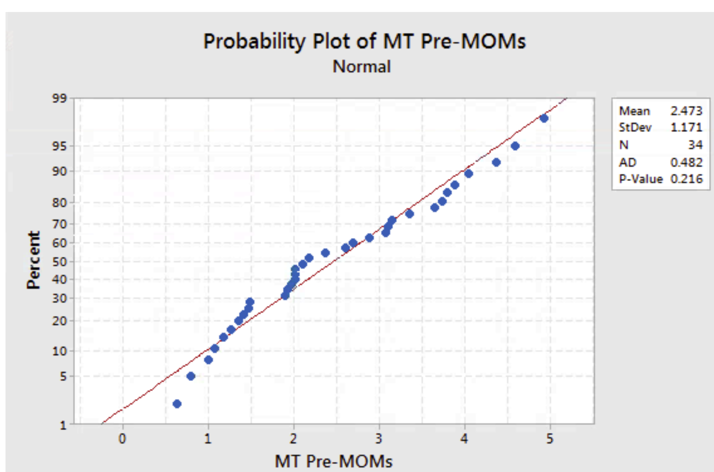


Figure 78: Manufacturing Throughput - Anderson-Darling Test - Pre-MOMS

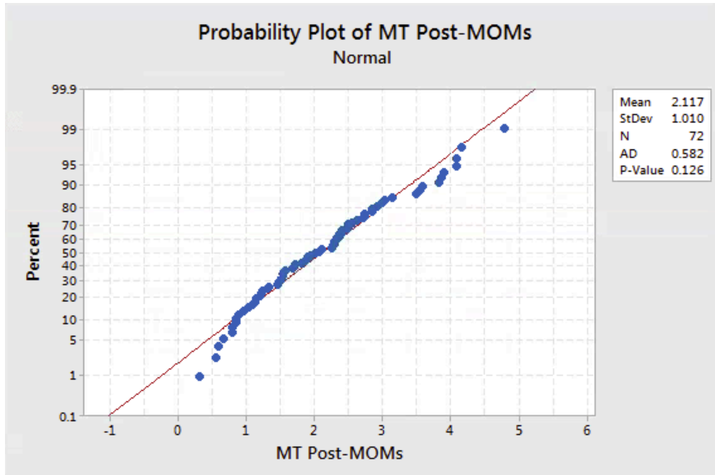


Figure 79: Manufacturing Throughput - Anderson-Darling Test - Post-MOMS

Both pre-MOMS ($p = 0.216 > 0.05$) and post-MOMS ($p = 0.126 > 0.05$) PCE data sets fail to reject the null hypothesis of following a normal distribution. Also, the requirements for meeting the other assumptions noted in the beginning of the results section are met for a parametric hypothesis test. Therefore the 2-Sample t test is used to compare the performance of MDI before and after employing MOMS. This test determines if the difference between the mean of the pre-MOMS and post-MOMS MT is statistically significant at a level of 0.05. The following null and alternative hypothesis was tested:

$$H_0: \mu_{postMT} = \mu_{preMT}$$

$$H_A: \mu_{postMT} > \mu_{preMT}$$

Based on this 2-sample t test, one cannot reject the null hypothesis ($p = 0.934 > 0.05$). There is not enough evidence to conclude that the mean of post-MOMS manufacturing throughput is significantly greater than the pre-MOMS manufacturing throughput. One can be 90% confident that the true difference between the means is between -0.74706 and 0.034166, and 95% confident that it is greater than -0.74706. Normality is not an issue as there are at least 15 data points in each sample.

Individual Samples		
Statistics	MT Post-MOMS	MT Pre-MOMS
Sample size	72	34
Mean	2.1169	2.4734
90% CI	(1.918, 2.315)	(2.1334, 2.8134)
Standard deviation	1.0104	1.1715

Difference Between Samples	
Statistics	*Difference
Difference	-0.35645
90% CI	(-0.74706, 0.034166)

*Difference = MT Post-MOMs - MT Pre-MOMs

Figure 80: Manufacturing Throughput - 2-Sample t Test - Pre & Post-MOMS

Process Velocity (PV)

Process velocity is a metric that falls within Six Sigma's CTS deliverable. Evaluating it gives facility managers a sense of the flexibility or responsiveness of the operations to customer demand. Figure 84 displays a time series plot of process velocity data both before and after MOMS implementation. Months 1 through 34 represent PV prior to MOMS.

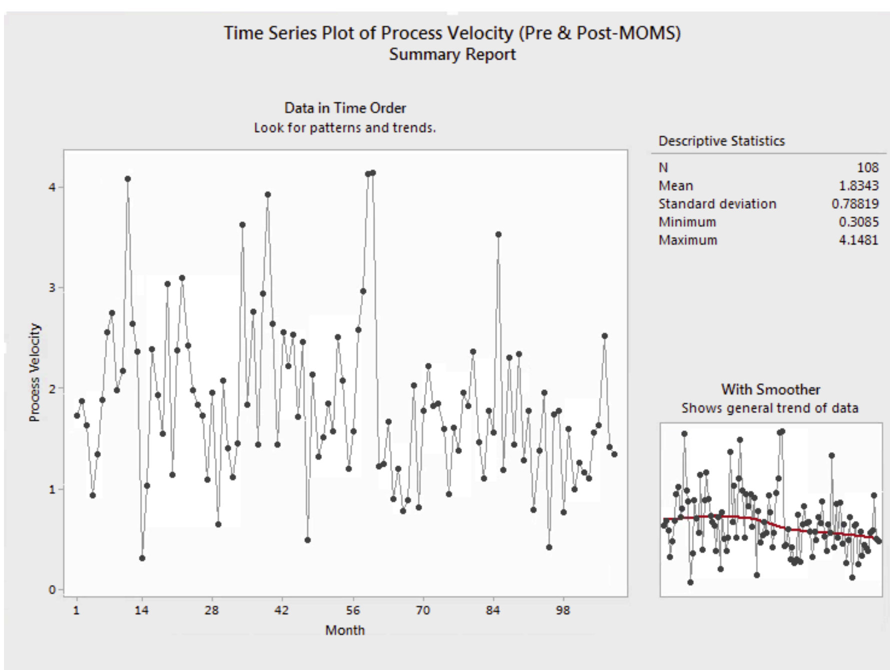


Figure 81: Process Velocity - Monthly Time Series - Pre & Post-MOMS

A simple regression of pre-MOMS PV means finds a statistically significant relationship between the PV and time ($p < 0.045 < 0.05$). The quadratic model only explains 18.09% (R-squared value) of the variation in PV. The sample ($n = 34$) is not large enough to obtain a very precise estimate of the relationship between pre-MOMS PV and time, however, it passes for normality according to Minitab. A statistically significant relationship does not imply that time causes the pre-MOMS PV.

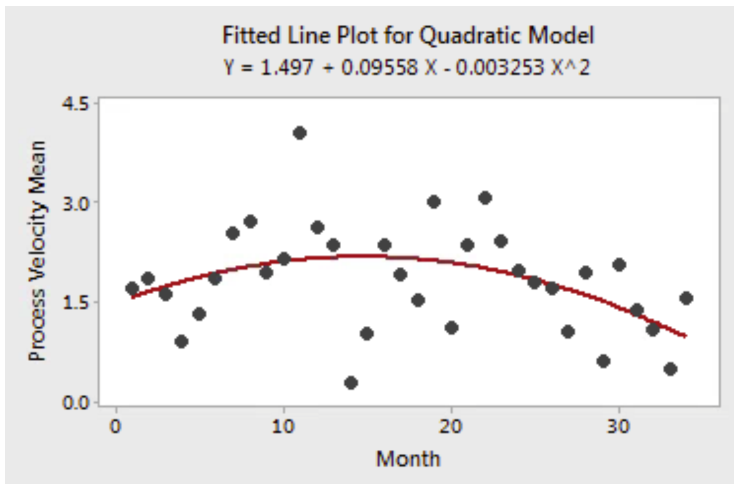


Figure 82: Process Velocity - Simple Regression - Pre-MOMS

A simple regression of post-MOMS PV means finds a statistically significant relationship between the PV and number of months following MOMS implementation ($p = 0.005 < 0.05$). A Pearson correlation finds a slight negative correlation ($r = -0.33$) indicating that as the months pass the post-MOMS PV tends to decrease. However, the predictor variable of time only explains 10.98% (R-squared value) of the variation in PV. A statistically significant relationship does not imply that time causes the process velocity. Note that month 1 in Figure 86 corresponds to month 35 in the time series plot.

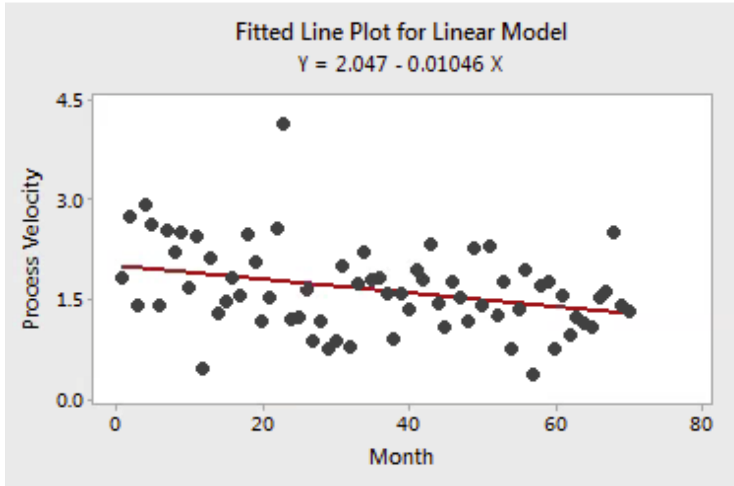


Figure 83: Process Velocity - Simple Regression - Post-MOMS

An Anderson-Darling test was conducted to determine if both the pre- and post-MOMS data sets for PV follow a normal distribution.

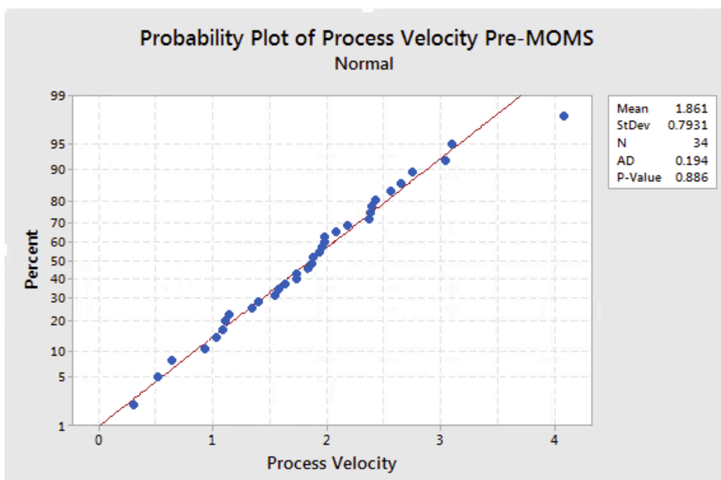


Figure 84: Process Velocity - Anderson-Darling Test - Pre-MOMS

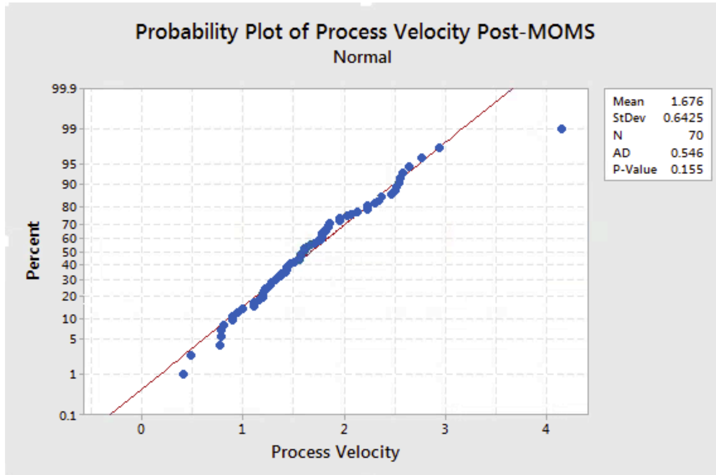


Figure 85: Process Velocity - Anderson-Darling Test - Post-MOMS

Both pre-MOMS ($p = 0.886 > 0.05$) and post-MOMS ($p = 0.155 > 0.05$) PV data sets fail to reject the null hypothesis of following a normal distribution. Also, the requirements for meeting the other assumptions noted in the beginning of the results section are met for a parametric hypothesis test. Therefore the 2-Sample t test is used to compare the performance of MDI before and after employing MOMS. This test determines if the difference between the mean of the pre-MOMS and post-MOMS PV is statistically significant at a level of 0.05. The following null and alternative hypothesis was tested:

$$H_0: \mu_{postPV} = \mu_{prePV}$$

$$H_A: \mu_{postPV} > \mu_{prePV}$$

Based on this 2-sample t test, one cannot reject the null hypothesis ($p = 0.879 > 0.05$). There is not enough evidence to conclude that the mean of post-MOMS process velocity is significantly greater than the pre-MOMS process velocity. One can be 90% confident that the true difference between the means is between -0.44642 and 0.076369, and 95% confident that it is greater than -0.44642. Normality is not an issue as there are at least 15 data points in each sample.

Individual Samples

Statistics	PV Post-MOMS	PV Pre-MOMS
Sample size	70	34
Mean	1.6756	1.8606
90% CI	(1.548, 1.804)	(1.6305, 2.0908)
Standard deviation	0.64249	0.79306

Difference Between Samples

Statistics	*Difference
Difference	-0.18502
90% CI	(-0.44642, 0.076369)

*Difference = ProcessVeloc - Process Velo

Figure 86: Process Velocity - 2-Sample t Test - Pre & Post-MOMS

New Development Requests Presented and Approved (NDR)

The NDR metric provides a facility manager with insight into the flexibility of operations. It is not uncommon for new development requests that are presented by employees to remain pending or simply ignored.

Figure 87: Net Development Requests - Monthly Time Series

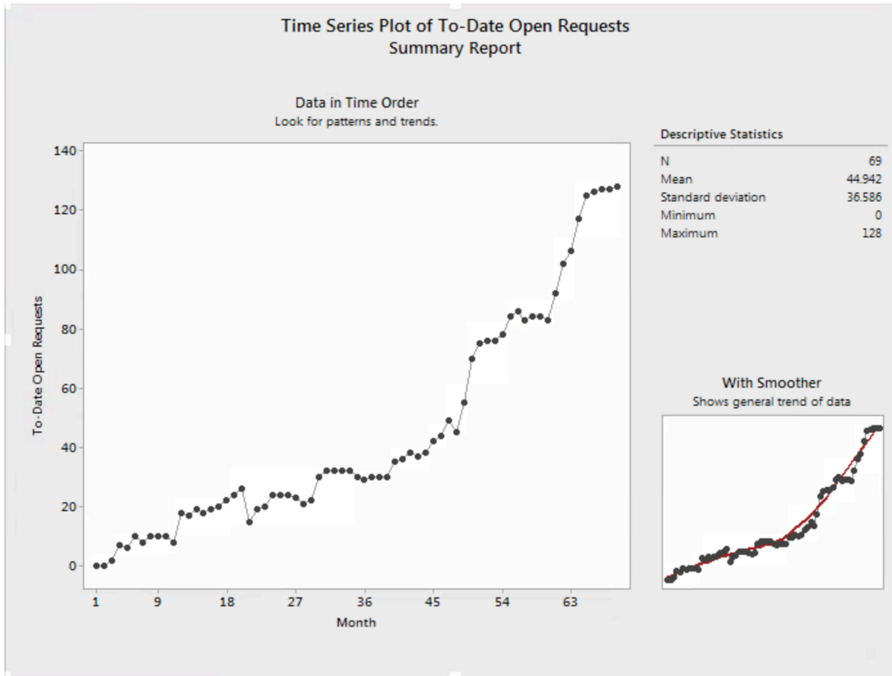


Figure 88: To-Date Open Development Requests - Monthly Time Series

A simple regression shows that there is a statistically significant relationship between the net development requests and the amount of time since MOMS implementation ($p = 0.034 < 0.05$). A Pearson correlation found a positive correlation ($r = 0.26$), which indicates that when the months increase, the net requests tend to increase as well. However, a low R-squared value of 6.56% shows that time is not an important factor in MDI's performance in terms of new development requests presented and approved. The sample is large enough (n=69) to gain a precise estimate of the strength of the relationship and normality is not an issue as there are greater than 15 data points.

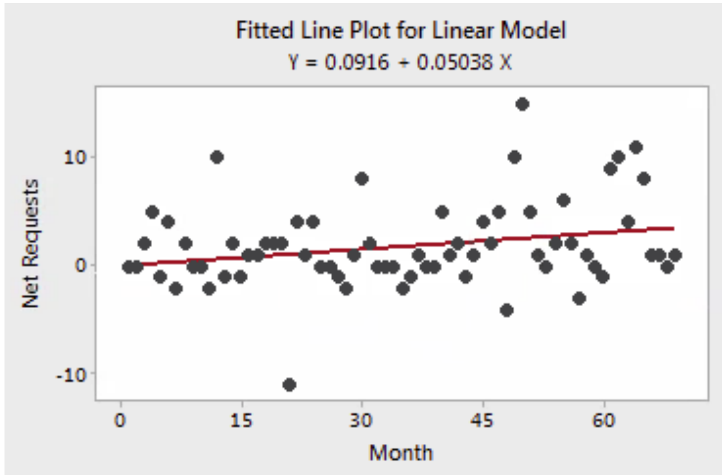


Figure 89: Net Development Requests - Simple Regression

Table 20: Statistical Summary of MDI's Organizational Performance

Metric	Regression Analysis (0.05 Significance)			2-Sample t Test (0.05 Significance)		
	p-value	Statistically Significant?	Conclusion	p-value	Statistically Significant?	Post-MOMS (H0) = Pre-MOMS (H_A)?
Major Defect Rate	< 0.001	Yes	Initial Improvement Before Leveling Off	NA		
Minor Defect Rate	< 0.001	Yes	Continuous Improvement over Time			
Failure Rate (1st Yr)	0.022	Yes	Continuous Improvement over Time	NA		
Failure Rate (Warranty)	0.002	Yes	Initial FR Increase before Major Improvement			
Quality Rate	0.036	Yes	Continuous Improvement over Time	NA		
Customer Retention Rate	Not Enough Data			NA		
Satisfied Customer Rate	Not Enough Data			NA		
Total Product Manufacturing Cost	0.012	Yes	Slight Continuous Improvement over Time	NA		
Operating Cost	0.004	Yes	Slight Continuous Increase over Time	NA		
Inventory Cost	0.001	Yes	Minimal Increase over Time	NA		
System Stability & Reliability	0.214	No	Linear Decrease in SRR performance	NA		
Production Loss Rate	0.011	Yes	Continuous Increase over Time	0.869	No	Cannot Reject Null Hypothesis
Scrap Rate	< 0.001	Yes	Continuous Improvement over Time	NA		
Process Lead Time	< 0.001	Yes	Continuous Increase in PLT over Time	0.748	No	Cannot Reject Null Hypothesis
Process Cycle Efficiency	< 0.001	Yes	Decrease in PCE over Time	0.758	No	Cannot Reject Null Hypothesis
On-Time Delivery	0.001	Yes	Continuous Increase over Time	0.03	Yes	Reject the Null, Post-MOMS > Pre-MOMS
Manufacturing Throughput	0.001	Yes	Slight Continuous Decrease over Time	0.799	No	Cannot Reject Null Hypothesis
Process Velocity	0.001	Yes	Slight Continuous Decrease over Time	0.574	No	Cannot Reject Null Hypothesis
New/Approved Development Requests	0.034	Yes	Slight Continuous Increase over Time	NA		

CHAPTER 5 - CONCLUSION

This research contributes the following:

1. An organizational performance measurement framework for manufacturing companies consisting of a comprehensive set of KPIs and corresponding performance metrics
2. Empirical evidence on the impact of ERP implementation in a manufacturing SME based on manufacturing KPIs
3. Empirical evidence on the long-term performance and sustainability of an ERP system in a manufacturing SME
4. Owner/Facility Manager can utilize the performance framework to analyze organizational performance and use statistical analysis to guide decision-making for improvements

Based on the goals set forth by MDI, the ERP has successfully achieved continuous improvement in the quality metrics of defect rate, product failure rate, and quality rate as well as on-time delivery. In addition, there is a statistically significant improvement in on-time delivery using the ERP as opposed to the performance prior to its implementation. Based on the framework of performance metrics, continuous improvement is achieved in the following:

- Minor Defect Rate
- Failure Rate (1^{st} Year)
- Quality Rate
- Total Manufacturing Cost per Product
- Scrap Rate
- On-Time Delivery
- New/Approved Development Requests

Diminishing performance is found in the following metrics:

- Inventory Cost per Product
- System Stability and Reliability

- Production Loss Rate
- Process Lead Time
- Process Cycle Efficiency
- Manufacturing Throughput
- Process Velocity

One can interpret the results to find that MDI has successfully improved upon its quality of products, while achieving mixed results in terms of the cost and at the expense of manufacturing time. The results are consistent with project and process management literature, which states that when a company improves quality, time, or cost, there are drawbacks to the other deliverables. With the evidence-based knowledge contributed through the performance evaluation framework, the owner or decision-maker can view their performance based on the remaining metrics and determine subsequent actions for improving the company.

Further research is needed to determine:

1. Investigate the organizational performance of a mass-production SME using the performance measurement Framework to investigate and compare impacts with this study
2. Investigate the degree of costs associated with adopting and implementing an ERP in a manufacturing SME.
3. Perform a cost/benefit analysis of the ERP implementation in SMEs to serve as a comparison with quality measurement initiatives.
4. Investigate organizational performance of an ERP-enabled manufacturing company and determine if quality improvements qualify as meeting the targets set by Six Sigma.

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