Evaluating the Systems Engineering Problem Management Process for Industrial Manufacturing Problems

by Dennis A. Perry, III

B.S. in Psychology, May 1996, Virginia Commonwealth University
B.S. in Mechanical Engineering, May 2000, Virginia Commonwealth University
Master of Engineering Management, August 2007, Old Dominion University

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Dissertation directed by

Bill A. Olson
Professorial Lecturer in Engineering Management and Systems Engineering

and

Paul Blessner
Professorial Lecturer in Engineering Management and Systems Engineering

The School of Engineering and Applied Science of The George Washington University certifies the Dennis Alton Perry, III, has passed the Final Examination for the degree of Doctor of Philosophy as of August 4, 2016. This is the final and approved form of the dissertation.

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Dennis A. Perry, III

Dissertation Research Committee

Bill Olson, Professorial Lecturer in Engineering Management and Systems Engineering, Dissertation Co-Director

Paul Blessner, Professorial Lecturer in Engineering Management and Systems Engineering, Dissertation Co-Director

Shahram Sarkani, Professor of Engineering Management and Systems Engineering, Committee Member

Thomas Mazzuchi, Professor of Engineering Management and Systems Engineering & of Decision Sciences, Committee Member

Ekundayo Shittu, Assistant Professor of Engineering Management and Systems Engineering, Committee Member

Dedication

This dissertation is dedicated to my family, friends, colleagues, team mates, advisors, mentors, teachers, and pets, for all the joy, fun, accomplishments, victories, advice, recommendations, knowledge, and pet hair you've provided me throughout my life.

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Abstract

Evaluating the Systems Engineering Problem Management Process for Industrial Manufacturing Problems

Problems are common in nearly all complex organizations. A Systems Engineering Problem Management Process (SEPMP; Olson et. al., 2012) was proposed in 2012, and the research in this dissertation presents an empirical analysis couple with a case study to validate and challenge the model. In order to evaluate the SEPMP, which extends a risk matrix to problem management in order to monitor problem timeliness and impact, it is necessary to define the significance of communicating these components of the SEPMP model. A correlation and regression analysis is employed using a set of observed problem data including the communication of impact and timeliness components as independent variables. The dependent variable is the problem management effectiveness, modeled as a function of the problem timeliness, process improvements accomplished, training actions completed, and delay to the process as a result of the issue. Timeliness communication and impact communication are revealed to be significantly predictive of effective problem management. Finally, a plan for additional research is suggested, including potential future analyses to include further empirical research and case studies of the employment of a robust problem management process, all of which may encourage recognition of the SEPMP as a standard tool for systems engineers.

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List of Acronyms

CAR: Corrective Action Request

CMM: Capability and Maturity Model

CMMI: Capability Maturity Model Integration

DV: Dependent Variable

EPM: Effective Problem Management

GWU: The George Washington University

INCOSE: International Council on Systems Engineering

ISO: International Standards Organization

IT: Information Technology

ITIL: Information Technology Infrastructure Library

IV: Independent Variable

KM: Knowledge Management

MS: Microsoft

OTS: Off the Shelf, or standard feature

PCAB: Preventive and Corrective Action Board

PM: Problem Management

POAM: Plan of Action and Milestones

PSL: Problem Severity Level

RADCON: Radiological Control

RCA: Root Cause Analysis

SAP: Systems, Applications & Products

SE: Systems Engineering

SEPMP: Systems Engineering Problem Management Process

UE: Unplanned Event

WSSP: Widespread Systemic Problems

Chapter 1. Introduction

1.1 Statement of the Problem

Risks are commonly managed using a matrix of two features: probability, or likelihood, of occurrence and severity of consequence (Ball & Watt, 2013). In these matrices, *Likelihood of occurrence* is a measure, often on a four or five point scale representing a degree of probability, from low to high, of the potential for a risk to occur. *Severity of consequence* is another measure, generally on a similar scale, of the effect on the venture if the risk were to come to pass, based on established criteria. When "*likelihood* increases to *certainty*, the risk becomes a *problem"* (Olson, Mazzuchi, Sarkani, & Forsberg, 2012). Olson proposes a Systems Engineering Problem Management Process (SEPMP), and the process may be added to a forthcoming revision of the International Council on Systems Engineering (INCOSE) *Systems Engineering Handbook* (Olson et al., 2012). However well-documented and defined a process becomes, it is not likely to be accepted without some evidence of its value to the stakeholders. This dissertation research is the first foray into the use of the SEPMP, using correlation, a regression analysis, and a case study of problem management practices and problems experienced at a complex industrial manufacturing organization, to establish the connection between the doctrines of the SEPMP and effective problem management.

1.2 Background

Basic textbooks on systems engineering (Sage, 2009) and the INCOSE *Systems Engineering Handbook* (Haskins, 2011) detail a process by which project uncertainty is categorized into specific risks, which are then tracked and managed. Mitigation methods for risks may include transference, avoidance, acceptance, or action to reduce the consequence (Haskins, 2011). As shown in Figure 1-1, Risk Management is one of the fundamental Systems Engineering Processes. When the likelihood of a risk becomes 100%, the risk becomes a problem. The risk management process can thus be a key source for identifying problems, but problems identified in such a manner may or may not continue to be tracked in the risk management system. Those that are no longer tracked as risks may lose visibility by the program, especially if the established problem management process is not designed to accept inputs from the risk management process. Regardless, the consequence of a risk is a counterpart to a problem's impact, and the other factor is the time remaining before the project fails. The matrix presented in the SEPMP (Olson et al., 2012) is derived from the risk matrix as described in the INCOSE *Systems Engineering Handbook*, and the SEPMP also considers the effect on the program's earned value management system.

The Systems Engineering Vision 2025, *A World in Motion*, (Hartmann, 2014) states several imperatives for the field of systems engineering over the next ten years and beyond. Among these, three clearly require additional research into new tools such as the SEPMP, and many of the principles throughout the document acknowledge the preponderance of problems in modern complex systems. The first imperative speaks to "*expanding the application of systems engineering across industry domains*" (Hartmann, 2014). Adding a system for managing problems in an organization contributes to the achievement of this imperative because it further embeds systems engineering within the realms of risk management, project management, and quality management. The second imperative, "*expanding the theoretical foundation for systems engineering,*" applies to the framework of problem management, which is not traditionally a systems engineering process (Haskins, 2011; Sage, 2009). However proposing this tool serves to expand the theory behind systems engineering. The third imperative, "*advancing the tools and methods to address complexity,*" is possibly the most direct mandate for the research contained within this dissertation. Essentially, the tool of problem management, admittedly an extension of risk management, needs to be developed and validated to improve the ability of systems engineering to address increasing complexity.

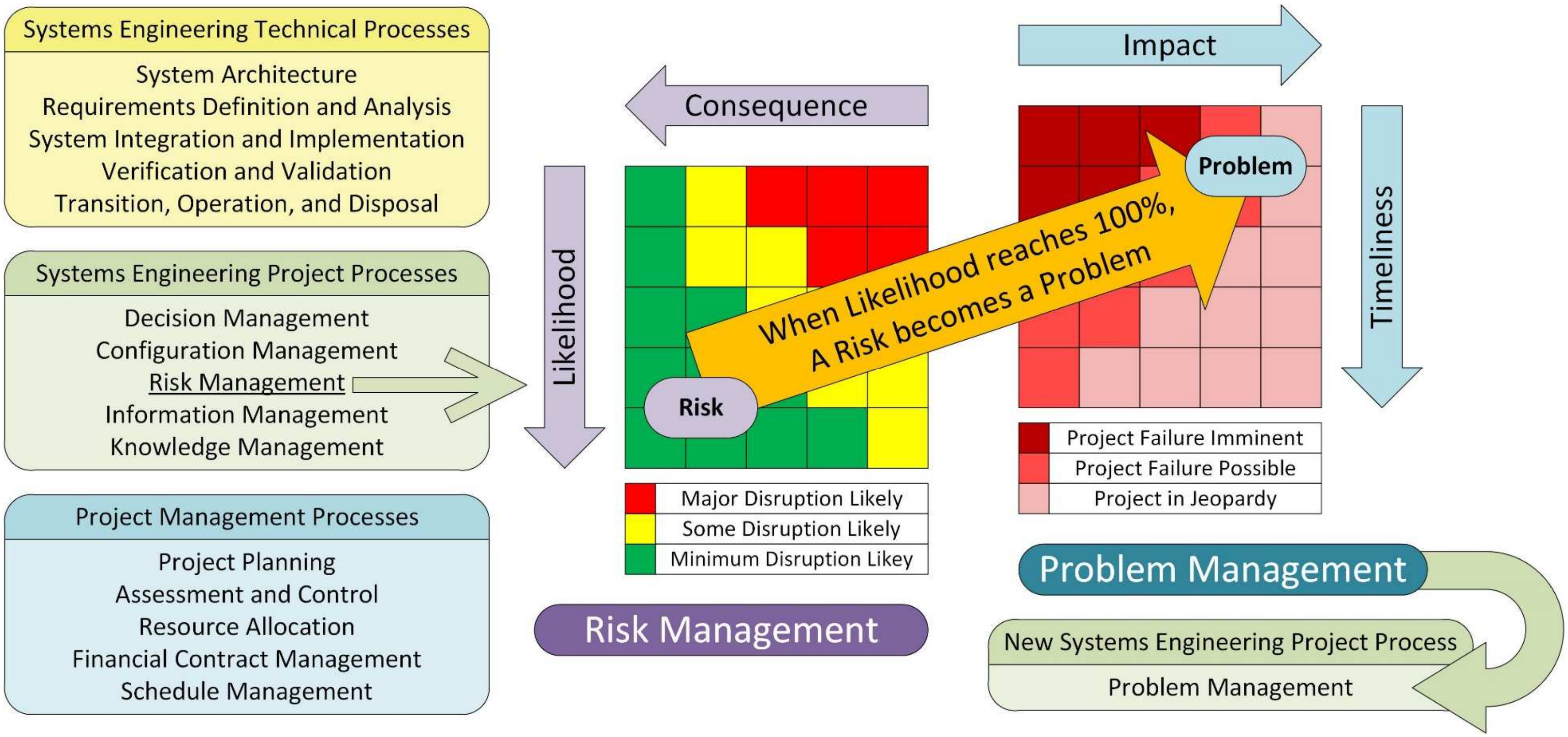

Figure 1-1: Systems Engineering Processes, Risk Management Matrix, and Problem Management Matrix

The SE Vision 2025 (Hartmann, 2014) then addresses global trends that affect systems, the current state of systems engineering, and the future state as well. The trends discussed include global challenges requiring increasingly complex systems, and many examples mention the need for systems to be capable of dealing with adverse conditions, challenges, or problems, in order to address technical, quality, safety, and cost requirements. The current state section highlights system failures and the lessons learned from these failures. Centralized problem management contributes to this goal by providing information on failures to continuously improve systems and projects. Later in the same section, the SE Vision 2025 suggests current SE practices and challenges exist because many systems are designed "*from pieces rather than from architecture, resulting in systems that are brittle*"(Hartmann, 2014). Lastly, the future state section requests "*methods and tools that will keep pace with system complexity*" (Hartmann, 2014). Based on the overall message conveyed in the Vision 2025, the author believes the future of systems engineering will include problem management.

1.3 Statement of Purpose

Problems, which may be any current impediments to the successful completion or progress of a program or project, have likely always been inescapable within complex organizations. "Problems cost money, reduce earnings, consume schedule time, and threaten projects" (Olson et al., 2012). Problem management is often inconsistent, from one project to project, from organization to organization, and even from one project manager to another project manager within the same organization. One of the goals of the systems engineering process is "to identify problems and develop solutions through a structured approach based on systems thinking" (Haskins, 2011). Therefore, a problem management process based on the principles and techniques of systems engineering is crucial to assure the success of a program.

The author previously claimed "effective problem management may be relevant to all projects of sufficient complexity so as to require the application of risk management or other systems engineering techniques" (Perry, Olson, Blessner, & Blackburn, 2016). According to Pennock & Haynes, "risk management is best employed early in the project" (Pennock & Haimes, 2002), and Pennock and Haynes also suggest "problem management is best employed early in the project, or at least as early as problems can be expected." The effort necessary for an organization to support risk and problem management significant; therefore, the benefit from expending the effort must add value as well. Problem stakeholders and their management will be more likely to support a process that has been demonstrated to be effective, so this research will either support the use of the SEPMP, identify areas in need of improvement, or a combination of both. Also, it seems likely that some organizations may be managing problems as risks, which would further justify a need for a valid problem management tool. Therefore, this research may be the first in a series of studies in problem management that will develop a new functional tool for the practicing systems engineer.

1.4 Organization of this Study

This document is organized to accomplish several specific tasks. The information is presented so as to initiate a discussion, establish the importance of the topic, and inform and educate on the history and current state of the systems engineering perspective on problem management in general and the SEPMP specifically. The author will present a methodology for research into the components of the SEPMP, perform the regression analysis, and present the results. The author will also address additional findings from the data, discuss additional observations independent of the primary study, and present several case studies of specific problems, including the obvious outliers in the regression results. Finally, the author will draw conclusions from the results, observations, and case studies, make recommendations for implementing the SEPMP, and identify areas for future research.

Chapter 2: Literature Review. This chapter explores the roots of problem management in risk management and quality management, and compares several problem management models with the SEPMP. The relationship between risk management and project management is established first, and information is presented on catastrophic risk and system failures. Then, risk analysis and its importance to systems engineering are reviewed, and the role of risk management as a systems engineering tool in the Systems Engineering Handbook (Haskins, 2011) is presented. The literature also contains examples of quantitative studies for risk management development, and these are highlighted. Quality Management Systems are reviewed, and comparisons are made with these systems and the SEPMP. The novelty of the SEPMP is proposed as an outcome to these comparisons. Next, problem management research is highlighted, and notes that when models are presented, empirical research follows to establish the validity of the model. Finally, several examples of problem management models are presented, and all are compared with the SEPMP to demonstrate the SEPMP as a viable model for the Systems Engineering community to embrace.

Chapter 3: Research Problem. Chapter three highlights the need for the research presented in this study, which is an empirical investigation into the efficacy of the SEPMP. The parameters of the study are identified, and the assumptions made are specified, including the characterization of the problems comprising the convenience sample and the boundaries for and implications of these problems and the associated negative effects. The conceptual model is introduced, which identifies the problem characteristics and problem management attributes used in the study.

Chapter 4: Methodology. The first topic in chapter four describes the sample used in the analysis, which is a set of problems experienced over several years. The nature of the problems is discussed, and examples are provided to demonstrate the range of issues involved, and the nature of work involved in the functional programs from which the problems in the sample were collected. The chapter then serves to define the independent variables of Impact Communication, Timeliness Communication, Complexity, Scope, Effort, and Knowledge Management, and the root dependent variables of Timeliness, Process Delay, Corrective Actions, Training Actions, and Process Improvements. The root dependent variables are manipulated in multiple stages, and the interim dependent variables of Inefficient Time Use, Efficient Time Use, Solving Actions, and Percent Solving Actions are introduced, and the combined regression dependent variable, Effective Problem Management, is presented along with the mathematical explanations of all of the interim and combined dependent variables. Finally, the chapter presents the six research hypotheses, H_1-H_6.

Chapter 5: Data Analysis and Results. The fifth chapter follows the analysis, beginning with the descriptive statistics for the independent variables, the root dependent variables, and the combined regression dependent variable. Pearson Correlations are presented to illustrate the relationships between the independent variables and the combined dependent variable. Next, the regression analysis is offered, and the research hypotheses are evaluated using the results. Then, an evaluation of the residual error offers support for the analysis, and the author discusses the implications of the results. Additional findings are presented next, showing other relationships identified through additional exploration for top and bottom quartile subsets for the independent variables.

Chapter 6: Case Study. Chapter six provides a case study containing observations of problem management in an industrial manufacturing organization, including a deep dive into some of the problems used in the quantitative analysis. Observations are provided showing the multiple mechanisms in place for problem management, experiences in various paradigms affecting problem management, and an evaluation of the categories of problem types in practice. This is followed by an observation of a work model approach to problem solving and a consideration of problem assessment and oversight roles. This chapter closes with several case studies detailing individual problems from the sample, including some of the outliers noted in the regression analysis. The case study establishes a foundation for recommendations on improving the SEPMP and for implementing a problem management solution based on the SEPMP.

Chapter 7: Conclusions, Recommendations, and Future Research. The final chapter discusses the conclusions drawn from this study, and highlights the differences between problem solving and problem management, offering insight into the role of the SEPMP as a systems engineering tool and delineating the roles currently in place for risk management and quality management systems. Several recommendations for enhancing and implementing the SEPMP are provided as well as a recommended path for future research into the SEPMP.

Appendices: The data used in the analysis has been provided in a table in Appendix A. Appendix B contains excerpts from the Minitab session in support of the descriptive statistics, Pearson Correlations, and regression analysis.

1.5 Significance and Goals

The research presented within this study is among the first empirical support for the SEPMP. By evaluating the problem matrix characteristics of the SEPMP against a set of completed problems, the author is contributing to acceptance or rejection of the SEPMP. If necessary, suggestions will be offered to refine the process, strengthen the model, and accelerate its acceptance as a problem management device. INCOSE will be able to consider including the SEPMP in future revisions to the *Systems Engineering Handbook,* and systems engineers and program, project, and quality managers will have a method for improving problem management throughout the system lifecycle.

1.6 Limitations and Scope

The research conducted on problem management and contained in this dissertation is likely the first of its kind and is exploratory in nature. The methodology is a purposefully rigorous investigation into a new paradigm from problem management and for systems engineering. The data used was a convenience sample of completed problem reports, and the independent variables were not controlled by the researcher. However, it should be noted that the problems occurred on multiple types of projects and programs, and in all life cycle phases, including design, construction, delivery, life cycle support, and retirement. With this probing model, insights into the relationships among the variables and merits of the SEPMP can be made, but the model should not be used as a tool for prediction. The case study demonstrates additional qualitative observations and is presented to illustrate the current state of problem management in the example organization, and the ensuing recommendations for enhancement and implementation are based on the indicated efficacy of the SEPMP as well as the qualitative observations within.

Chapter 2. Literature Review

2.1 Introduction

A review of the pertinent literature was performed using the author's classroom experience, knowledge of the INCOSE organization, and desire to develop a research strategy to validate a new framework. The roadmap shown in Figure 2-1 provides a visual representation of the sources of inspiration and the logic used to establish a nexus of known information needed to support the direction of this dissertation research. The coursework indicated a need for systems engineering tools and a robust understanding of the systems designed and used in complex organizations. The understanding of statistics and experimental methods encouraged the author to assume the challenge of leading the research effort in a new direction, while the data and risk analysis courses enabled the author to model the study after similar fields. Research into risk, quality and project management provided the understanding of related fields needed to develop the plan for this research, and the tools and information on systems engineering developed by or in conjunction with INCOSE helped to create the motivation necessary to pursue this effort.

The organization of the literature review begins with a look at risk management as a basis for understanding the SEPMP, and follows with an investigation of quality management. From there, the author transitions to the known research on problem management and problem solving, and provides a comparative look at several significant problem management frameworks. A summary of the topic is presented, along with a set of conclusions drawn from the existing research.

The author's preliminary work on this research was presented and accepted for publication in *Systems Engineering* (Perry et al., 2016), and contains a smaller sample (n=232) with similar results. The purpose of the article was to evaluate the SEPMP, stress the importance of the problem management for the future of systems engineering, demonstrate how an empirical analysis can be used to study the SEPMP, and act as a call for more research on the subject.

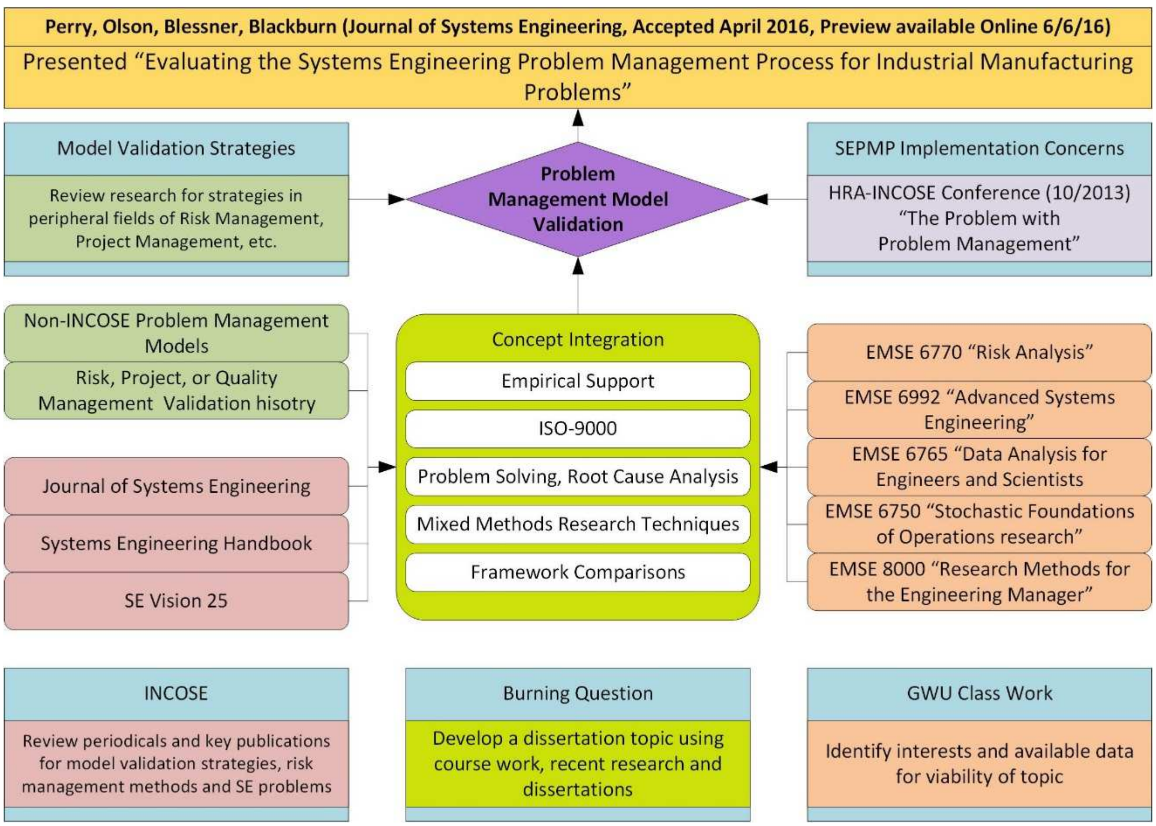

Figure 2-1: Integrated Academic, Professional, and Literature Review Roadmap

2.2 Risk Management

Risk management, an established field (Gahin, 1971) (Edwards & Bowen, 1998) (Kaliprasad, 2006), is deeply intertwined with project management (Arrow, 2008) (Berkeley, Humphreys, & Thomas, 1991) (Dey, 2002), is a key objective of systems engineering organizations (Haskins, 2011) (Sage, 2009), encompasses negative and positive (sometimes separated into opportunities) potential outcomes, and has been recently linked to problem management (Olson et al., 2012).

Recent research on risk has explored extreme risks and catastrophic system of system failures (Bristow, Fang, & Hipel, 2012), and the authors acknowledge systems theory and systems analysis to be useful in such examples. Another study evaluates resilience of a system after a cataclysmic risk (Park, Seager, Rao, Convertino, & Linkov, 2013), and focuses on "preparing a system for the unknown as well as mitigating the identifiable risks."

In 2012, Yacov Haimes identified several likenesses and dissimilarities between systems engineering and risk analysis, and alluded to "the purpose of systems engineering as a problem-solving endeavor" (Haimes, 2012). Haimes then provided a set of principles to "facilitate and improve risk assessment, management, and communication, and align risk analysis and systems engineering to a common purpose" (Haimes, 2012).

While the INCOSE *Systems Engineering Handbook* provides significant detail on risk management (Haskins, 2011), there are many other studies exploring various relationships between systems engineering and risk management. In 1999, a risk management process, and principles for its use, were presented in the INCOSE journal, *Systems Engineering* (Hessami, 1999). This work claims the systems thinking paradigm provided the necessary structure and insight required for a successful model of the subjective nature of risk management (Hessami, 1999). While this article presented a model and logical justification, it provided no empirical evidence. Many more articles soon followed with qualitative and quantitative research to validate risk management as a systems engineering process.

Several case studies followed the declaration of the value for systems engineering in risk management. One case study on the herbicide Alachlor was published where the authors, Hatfield and Hipel, suggest the case study results may be generalized onto all complex risk situations (Hatfield & Hipel, 2002). In particular, they determined there to be explicit value in applying systems theory during risk analysis, and also warned of the need to separate problem formulation from the estimation of risk (Hatfield & Hipel, 2002). Essentially, system identification is the first stage in formulating risk problems, and the authors claimed the systems approach to risk management works well for simple and complex problems, without adding significant cost to either (Hatfield & Hipel, 2002).

Quantitative studies and simulations also exist for risk management, and they are often combined in mixed-methods research. Russell Lock studies system of system development models and risk analyses, with limited explanation of his methodology, but includes a case study on the explosion of a Nimrod aircraft used by England's Royal Air Force (Lock, 2012), which was very helpful in establishing confidence in the validity of the article. Kujawski and Angelis evaluate the use of generalized decision trees to model potential risk recovery actions (Kujawski & Angelis, 2010). The authors use Monte Carlo simulations to evaluate different risk management strategies, and breakeven points are used to establish which processes may be most effective for specific conditions (Kujawski & Angelis, 2010). This is a very thorough study, with well-planned and lofty goals, and the study results in many more questions to be answered through further research.

The use of matrices as tools for risk management is not universally accepted without concern. Smith, Siefert, and Drain identified areas where cognitive biases are likely to affect the assignments of likelihood and consequence into risk matrices (Smith, Siefert, & Drain, 2009). Anthony Cox urged caution when using risk matrices based on several factors, including the potential for similar or even identical ratings to be assigned to severely different risks, the inability to accurately categorize severity for unknown consequences, and subjectivity in providing inputs to the matrix as well as interpreting the outputs (Anthony Cox, 2008). In addition to reiterating these concerns, Duijm identified a scenario where vagueness in the representation of consequences because of multiple possibilities can result in drastically different results (Duijm, 2015).

2.3 Quality Management

In addition to Risk Management, there are many Quality Management Systems that address problem management needs, such as Causal Analysis and Resolution, Total Quality Management, and ISO 9000 (Baldassarre, Caivano, Pino, Piattini, & Visaggio, 2012; Bhatia & Awasthi, 2014). There are also specialized tools and systems commonly used in particular industries, including Capability Maturity Model Integration (CMMI) (Grossi, Calvo-Manzano, & San Feliu, 2014; Khraiwesh, 2012), Information Technology

Infrastructure Library (ITIL) (Kabachinski, 2011; Soomro, 2012), and Control Objectives for Information and Related Technology (COBIT) (Baldassarre et al., 2012).

The SEPMP shares with many of these systems, tools, and standards the basic concepts of problem management (Olson et al., 2012; Perry et al., 2016), including problem identification using established thresholds and decision criteria, root cause analysis, problem assessment, developing resolution strategies and deciding which to implement, and instituting corrective and preventative actions (Baldassarre et al., 2012; Khraiwesh, 2012; Olson et al., 2012; Soomro, 2012). Common problem solving devices, such as Failure Modes and Effects Analysis (FMEA), trend analysis, data mining, and more (Bhatia & Awasthi, 2014; Grossi et al., 2014; Olson et al., 2012) are also referenced.

According to Perry, Olson, Blessner, and Blackburn, “the novelty of the SEPMP lies not with the tools referenced within, but in the use of the problem matrix to support communication and decision-making for all aspects of the problem. In this case, the SEPMP is an engineered system for managing problems. The focus of this research is to demonstrate the effectiveness of the novel features of the SEPMP” (Perry et al., 2016).

2.4 Problem Solving and Management

Trouble Desks often employ processes for problem management, and ITIL is a system on which these procedures can be based (Guglielmo, 2009; UCISA, 2016). These systems address problems users experience while working on IT equipment owned by the responsible organization. The problem management functions are generally similar to the ideas presented elsewhere, especially root cause analysis, corrective actions, problem records, management reporting, and trend analysis (ISO, 2015; Kabachinski, 2011; Olson et al., 2012; UCISA, 2016; Walker, 2001).

Many of these techniques and tools may be inherently required to solve problems. Problem Solving is a well-developed field independent of problem management, with methods designed to address root cause. For example, Mark Galley advocates for effective root cause analysis to include multiple causes, and recommends prospective problem solvers understand and apply cause and effect as well as constructing and understanding a timeline of the events associated with the problem (Galley, 2007). Galley also posits that effective analysis should begin with the impact to the goals, and that simply describing the problem is insufficient (Galley, 2007, 2008). Another popular method for problem solving is Dean Gano's *Apollo Root Cause Analysis* (Gano, 1999). Gano also stresses cause and effect, but recommends using a chart to organize the cause and effect relationships, and using this chart to develop effective corrective actions (Gano, 1999).

In *Process Problem Solving*, Bob Sproull asserts the importance of understanding causes for process problems, but suggests solving actions are tested prior to implementing (Sproull, 2001). This may be feasible for some systems, but as systems become more complex, testing prior to implementing surely becomes more difficult to achieve. Chang and Kelly present six steps to effective problem solving, including "defining the problem, analyzing causes, identifying possible solutions, selecting the best solution, developing an action plan, implementing the solution, and evaluating the progress" (Chang, 1993). Each of these represents a technique for problem solving, and each could be inserted into an organizational philosophy for the technique used to solve a problem.

In 2015, the Department of Defense issued a guideline for risk, issue, and opportunity management that extends the premise of the SEPMP, and reaffirms that issue and opportunity management are complementary to the established risk management paradigm (Baldwin, 2015). However, Baldwin's guide does not embrace the timeliness component of the SEPMP; instead relying on a one dimensional consequence or impact analysis model (Baldwin, 2015). It is also worth noting that problem solving tools are not included – Baldwin's guideline is purely a management tool.

In *Problem Management: An Implementation Guide for the Real World*, Michael Hall presents a set of tools for organizational problem management (Hall, 2014). The tools focus on IT organizations, although there are caveats for other non-IT structures, but the purpose of the book is clearly on establishing a process for problem management within an organization, including problem detection, prioritization, metrics, and workflow (Hall, 2014). Hall devotes one chapter to problem solving, but ultimately suggests using other established tools for investigation and root cause analysis. Jim Bryant's *Problem Management: A Guide for Producers and Players* also defines the roles and interactions needed to occur within an organization to establish a problem management system, but does not address the details of problem solving (Bryant, 1989).

Perry et al assert that "there are also several journal articles on problem management, but in many cases, problem management appears to be more of a reactive necessity than a structured proactive approach to dealing with issues" (Perry et al., 2016). In a 1987 article, problem research was focused on decision support systems, and "problem solving was asserted to be contained in five steps: problem finding, problem representation, information surveillance, solution generation, and solution evaluation" (Weber & Konsynski, 1987). The authors propose "functional requirements for decision support systems that improve the five processes," and then performed a simple case study to demonstrate the usefulness of their paradigm (Weber & Konsynski, 1987).

Hazel Taylor included problem resolution strategies in the proposed risk management categories "control, negotiation, research, and monitoring" (Taylor, 2006). Taylor's research methodology involved surveys and interviews, and the results included little on the effectiveness of problem management. Srivastav performed a series of survey studies on problem management techniques employed based on age (Srivastav, 2007a) and public sector executives (Srivastav, 2007b). The empirical studies do little for problem management as a whole and focus more on individual problem management strategies, as well as health and stress side-effects for risk managers. Terry Bahill introduced the concept of Diogenes, a process for anticipating unintended yet predictable consequences for the design of new systems (Bahill, 2012).

As discussed in this author's article (Perry et al., 2016), "the trend with all of these articles appears to be developing and presenting a model or process, and then following up with research to support it. The research above focuses on risk management and an extension of risk management: when the likelihood of a risk reaches 100% the risk becomes a problem." The *Systems Engineering Handbook* (Haskins, 2011) does not account for problem management techniques, which is where the SEPMP (Olson et al., 2012) can provide a paradigm for consideration.

2.5 Framework and Comparative Analysis

Several models have been proposed for risk management, and a few specifically focus on problem management, including Porter's Five Forces Model (Rice, 2010), Taylor's IT Problems Model (Taylor, 2006), and Weber & Konsynski's Decision Support Systems (DSS) Model (Weber & Konsynski, 1987).

The SE Problem Management Model is the basis of this research, and the factors chosen are specified in the model. The other project problem models, Porter's Five Forces Model, Taylor's IT Problems Model, and Weber and Konsynski's DSS model, each represents a subset of the variables suggested by Olson, as shown in Table 2-1.

The Five Forces Model, originally developed for competitive advantage analysis (Rice, 2010), is suggested as a model for effective risk and problem management. The model is based on five risk forces: internal organization, industry, information, infrastructure, and influences. The model provides for analysis of the impact of problems, identification of problems through risk analysis, categorization and monitoring of problems, and using a defined tool for tracking and reporting purposes (Rice, 2010). Unfortunately, the model does not account for much else, and only determines success of the project through cost and completion criteria; it is nonetheless significant because of the relationship between risk and problems.

Table 2-1: Problem Management Models

Factors	Sub factors	Variables	SE Problem Management Model	Porter's Five Forces Model	Taylor's IT Problems Model	Weber & Konsynski's DSS Model
Problem Management	Planning	Resources	✓		✓	
		Tools	✓	✓	✓	✓
	Identification	Risks	✓	✓		
		Emergent	✓		✓	✓
	Analysis	Impact	✓	✓		✓
		Timeliness	✓			
	Handling	Design	✓		✓	
		Implement	✓			✓
	Monitoring	Reporting	✓	✓	✓	✓
		Validation	✓		✓	✓
	Closure	Close Problem	✓		✓	
		Lessons Learned/KM	✓			
Project Success	Technical	Validation	✓			
		Verification	✓			
	Schedule	Key Events	✓		✓	
		Completion	✓	✓	✓	✓
	Cost	Budget	✓	✓	✓	✓
	Safety	Project	✓			
		Product	✓			
	Environmental	Regulation	✓			
		Community	✓			
	Programmatic	Events	✓			
		People	✓		✓	

In 2006, Taylor introduced a model for managing IT-related problems (Taylor, 2006). This model involved a set of strategies based on the common themes of control, negotiation, research, and monitoring. From these themes, Taylor provides mechanisms for planning using both resources and tools, identification of emergent problems, the design of a handling strategy for individual problems, problem monitoring, and problem closure (Taylor, 2006). In addition to budget and completion schedules, Taylor's model also measures project success by key event measurement and success of associated personnel. The Taylor model is rather robust compared to some of the other models, but its focus on IT problems limits the scope, practicality, and applicability to general project problems.

The Decision Support Systems model for problem management focuses on finding problems, problem representation, information surveillance (i.e. research and knowledge management), solution generation, and evaluation (Weber & Konsynski, 1987). These principles correlate to identification of emergent problems, impact analysis, use of management tools, implementation of handling mechanisms, and problem monitoring. Like the Five Forces Model, the DSS model is limited to two simple measures of success. The DSS model is rudimentary by modern standards, but it was one of the first systems engineering-related models for managing problems.

"The Systems Engineering (SE) Problem Management model provides a solution for problem management that addresses planning, identification, analysis, handling, monitoring, and closure of problems. The SE model also suggests measures of project success by ensuring that technical, schedule, cost, safety, environmental, and programmatic needs are met" (Olson et al., 2012; Perry et al., 2016). This analysis is based on the SE model, and the next section provides information on the individual components of the model. The problem management process consists of planning, identification, analysis, handling, monitoring, and closure, and each of these actions are critical steps in the life of a problem being managed. The study evaluates effective problem management based on indicators suggested in the SEPMP.

2.6 Summary and Conclusions

The literature reviewed focuses on several central themes. First, a brief history of risk management shows early research and development of the concepts of risk and uncertainty. The role of risk management in systems engineering has evolved to the point where risk is often considered a primary component of systems engineering, and it is represented in the *Systems Engineering Handbook*. Several examples of risk management process improvement articles show how research can be used to improve or validate an existing process. Finally, articles are shown that cover problem management. These articles provide a comparative view of the research on problem management.

Problem Management and Problem Solving are each documented in books, reports, government guidelines, and journal articles. However, problem solving is often presented as a teachable skill, whereas problem management is an organizational responsibility that requires many facets of the SEPMP, including problem solving. The US Department of Defense has issued a guideline for risk management that extends risk management to issues when the possibility of occurrence becomes a certainty, but the guideline recommends dropping the likelihood measure and focusing solely on consequence.

Many articles that propose a framework or process do so without empirical evidence. It is the responsibility of the subsequent research to establish the validity of the model and confidence for its users. This analysis provides an initial examination of the SEPMP process parameters and how they relate to effective problem management and which elements are most efficacious. The research will uncover opportunities to improve the process or increase the confidence in the competency of the process as originally presented.

These are the conclusions drawn from the literature review:

- Risk management is a well-documented objective in systems engineering research and theory.
- There are many types of research methods applied in expanding the knowledge base of risk management.
- There is a synergy that exists between systems thinking and effective risk management.
- Many quality management systems contain tools for problem solving and management.
- There is a difference between problem solving and problem management.
- Problem management is an organizational responsibility.
- Problem solving requires effective root cause analysis, and many tools are available to support this.
- The SEPMP is a potential systems engineering tool for, and there is a significant opportunity for, additional research in problem management in general, and the SEPMP specifically.
- This research needs to evolve from the realms where Risk Management, Systems Engineering, and Quality Management overlap, as shown in Figure 2-2.

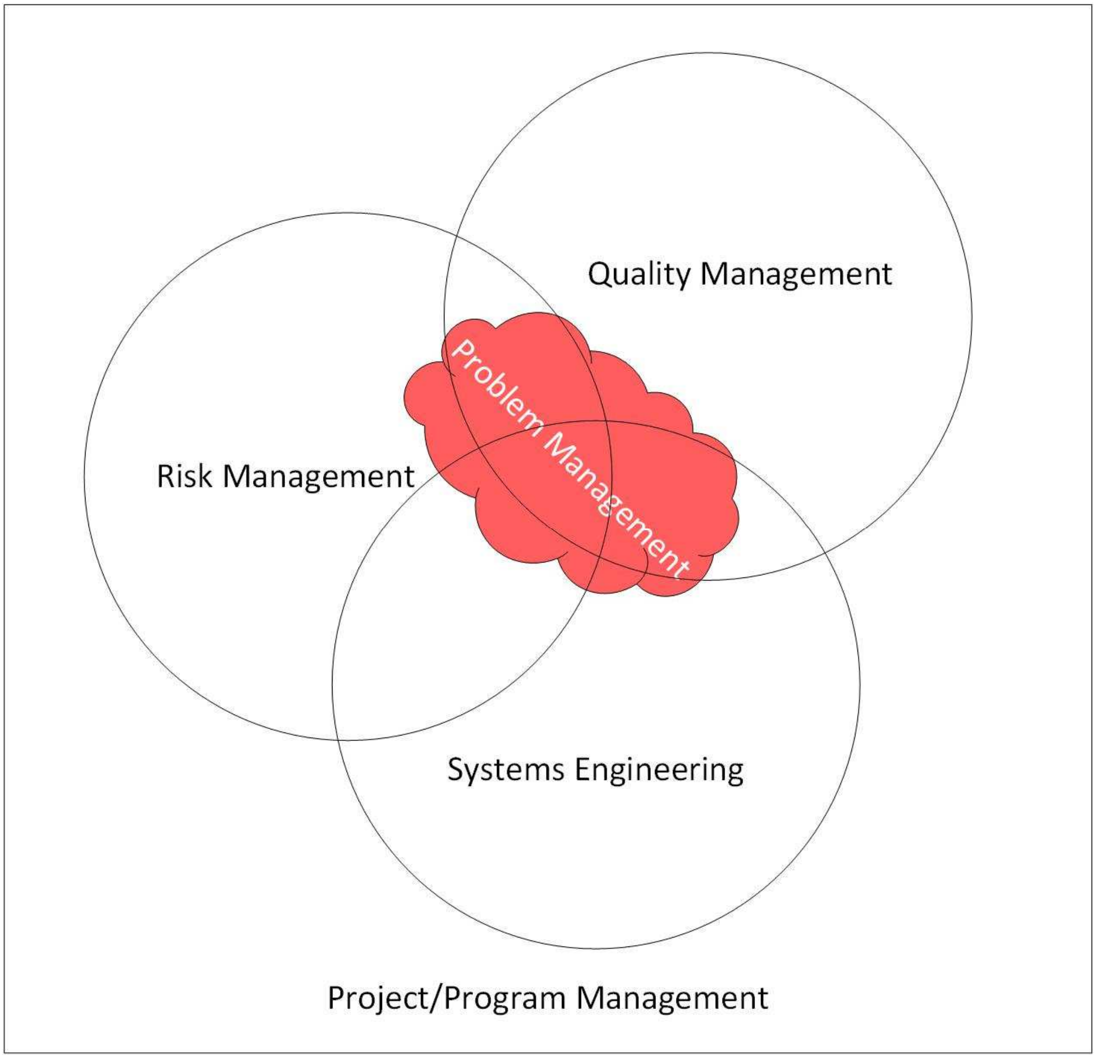

Figure 2-2: Problem Management Research Nexus

Chapter 3. Research Problem

The SEPMP has been proposed, incorporating elements of the INCOSE risk management process, with the expressed goal of identifying problems as early as possible (Olson et al., 2012) This process contains several activities and approaches for identifying, tracking, and managing problems to ensure the success of a project. The goal of this research is to study the application of the SEPMP using a regression analysis of existing problem management results, and evaluate the credibility of the model (Perry et al., 2016).

The analysis will evaluate various parameters of the problem management process, such as the inputs, controls, enablers, activities, and outputs. The inputs include identified problems, realized risks, and unplanned events (Olson et al., 2012). The controls include: applicable laws and regulations; government and industry standards; contracts and agreements; project procedures; plans and standards directives; corporate code of ethics; and systems engineering processes (Olson et al., 2012). Enablers will include organization/enterprise policies, procedures, plans, standards, and infrastructure, and project infrastructure (Olson et al., 2012).

However, special attention must be paid to the outputs, which are: a project problem management plan; a problem inventory; a problem report; and a problem management knowledge transfer (Perry et al., 2016). The activities include: planning problem management; managing the problem inventory; analyzing problems; resolving problems; and executing the problem management process (Olson et al., 2012). These represent the bulk of the effort, and ultimately reflect what the process will be and how it will be evaluated.

The goals of the study are to establish a record of use of the problem management process and report on the value of the process. The analysis will demonstrate whether relationships exist between the independent variables of the SEPMP and the dependent variables modelling effective problem management. The value of the research is derived from applying the problem management process, and the resulting recommendations for improvements, to the process or confirmation of the value of the process (Perry et al., 2016).

The scope of the research is limited to a set of problems, managed to completion, in a large industrial manufacturing organization that employs risk management and other systems engineering activities in accordance with the INCOSE *Systems Engineering Handbook* guidelines (Perry et al., 2016). The problems were identified and completed over a 39-month period, occurring on many different programs with some affecting multiple programs.

3.1 Assumptions

In order to proceed with this research effort, several assumptions will need to be made. First, the problems identified are expected to have negative consequences. Positive consequences are the result of realized opportunities or unexpected benefits; the focus of this research is the use of the problem management process to address the issues of problems with negative consequences.

The problems contained in the data set occurred on multiple types of projects and programs, and the entire lifecycle of the product from design to retirement is represented. While the problems are specific to the organization in which they occurred, the organization is exceptionally complex such that no less than sixteen common industrial functional areas are represented in the set. A further assumption is that the breadth and diversity of the types of problems included in this set warrants that the results of this analysis can be extended to other industries, programs, and complex systems that experience problems.

Next, the model specifies timeliness as the time available until the project is terminated (Olson et al., 2012). The impact of these problems varies from a mere nuisance level to a pending catastrophe, but for each impact, large or small, there comes a point at which the program cannot proceed until the problem is addressed, at which point, the opportunity cost of dealing with the problem is so exorbitantly high it places the future of the program and company in jeopardy (Perry et al., 2016). However, the actual decision to declare program failure may not occur at this time, depending on the current business climate and the health of the program and company. This date has been identified for each of the problems, and is the reference point against which timeliness is measured (Perry et al., 2016).

The measured tenets of the SEPMP used to communicate and categorize problems, Impact and Timeliness (Olson et al., 2012), along with several additional variables, are evaluated using correlation and a multiple regression analysis. This research addresses the pertinent measurement aspects of the process for problems over the period of three years, and will either confirm the asserted value of the process or make recommendations based on the analysis results (Perry et al., 2016). The integrity of any sensitive proprietary data will be given the utmost respect, and the analysis will note any discrepancies as a result. The process will be evaluated without the benefit of developing a custom procedure tailored to the subject organization, providing a detailed look at the process and the results garnered.

3.2 Conceptual Model

Risk management has been recently linked to problem management (Olson et al., 2012). Olson attempts to standardize a process for the management of problems based on the risk management process as detailed in the INCOSE *Systems Engineering Handbook* (Olson et al., 2012), and considers the implications to the project's earned value management system. The management of problems is obviously critical to a project's success, and systems engineering is ideally suited to manage the process, much like the risk management process (Perry et al., 2016). The effect of a problem on a project could be minor or could result in imminent failure. The SEPMP provides guidelines and rationale for many aspects of problem management, and many considerations for the measurement of project success, and these are used to develop the conceptual model shown in Figure 3-1. Each of these factors and variables will be examined in this analysis of the SEPMP.

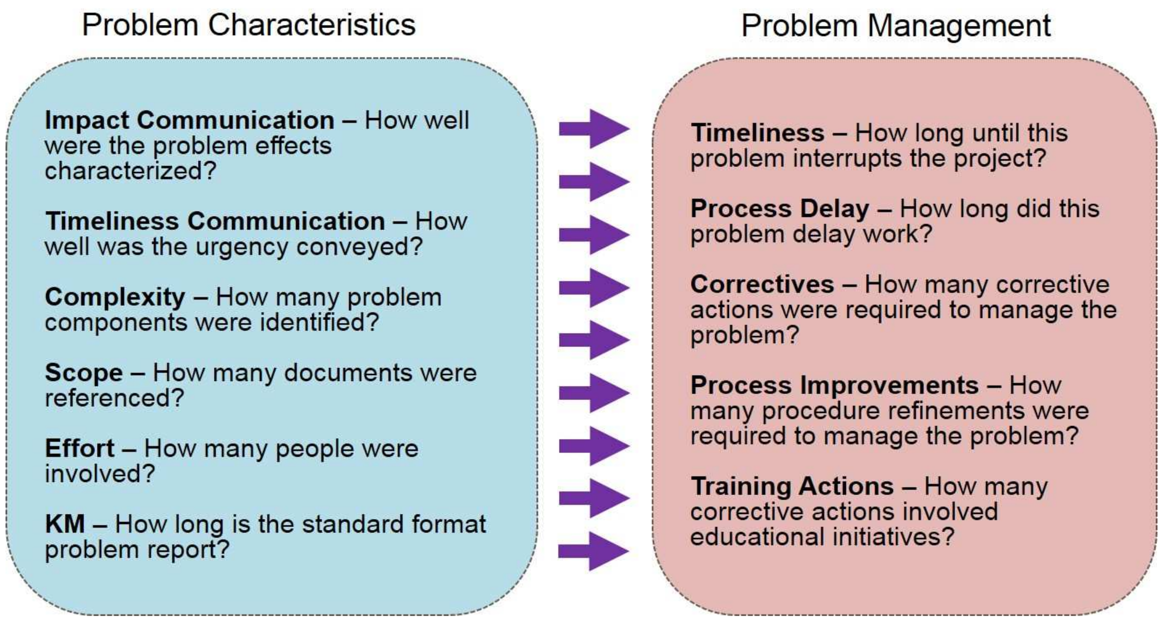

Figure 3-1: Problem Characteristics and Problem Management

3.3 Research Problem Summary

This chapter highlights the problem this dissertation attempts to address, namely, to evaluate the problem management constructs identified in the SEPMP, but not the problem solving techniques identified. The researcher proposes a regression analysis using a convenience sample of existing industrial manufacturing problem management results, and qualifies that sensitive proprietary information will be protected and any discrepancies in the data as a result will be acknowledged. The study assumes the problems had undesirable consequences, and that the failure to address the issues was unacceptable. Finally, the conceptual model used in the development of the research methodology is presented, suggesting that the problem characteristics identified may be related to effective problem management, which is recognized as important to the success of the subject program or project.

Chapter 4. Methodology

4.1 Sample and Data Collection

The sample consists of 314 problems managed and resolved over a 39-month period between December 2010 and February 2014 in a large, heavy industrial manufacturing company. The problems were identified through independent inspection and audit practices completed on-site as a part of the ongoing ISO 9001-compliant quality program, and managed to completion. The database used to track and manage the problems was restricted to a finite group of trained users, which reduced variability due to data entry. All problems were managed according to documented standards and subject to independent approval prior to designation as complete. A table of the data for all independent, root dependent, and regression variables used in the analysis is included in Appendix A.

The programs experiencing the problems include multi-year design and construction contracts, long term repair and re-build projects, and moderate length on-site customer service jobs. Each type of program includes multiple functional departments working simultaneously on multiple systems. The impact of each problem ranged from minor, such as a records retention procedure violation, to catastrophic, such as a widespread systemic safety issue. However, all problems were significant enough to warrant attention and management, and, if ignored, would each independently halt all progress on the program at a per-day delay cost so exorbitantly high as to be designated as a program failure. It is important to note that these are not risks – each item has been identified as a problem with existing effects, and with a finite time before the problem derails at least the program, and potentially other programs, if not the entire organization.

Figure 4-1 shows a summary of the process used by the researcher in collecting the data for this study. The software program SAP contains the records from the problem management system used in the subject organization. A general reporting function in the SAP module was used to develop a list of all the problems in the categories specified above. The list was exported into a spreadsheet, and separated into two files. The first file contained the record number for all problems in the list, and the second file contained all of the metadata available in the reporting function, including the information for the dependent variables of Timeliness and Process Delay. The second file was archived and not accessed until later in the collection process.

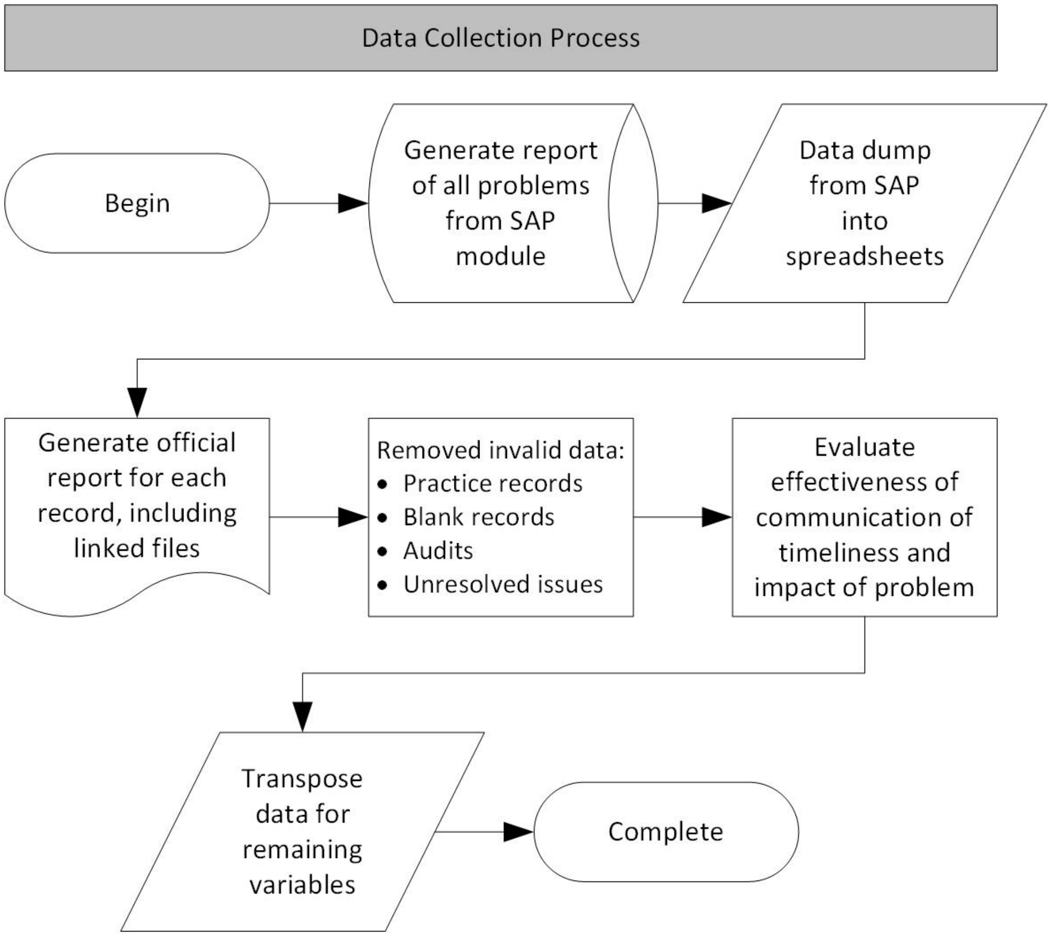

Figure 4-1: Data Collection Process

For each problem record in the first spreadsheet file, the researcher generated the official problem report in the standardized format, which is an automated process within SAP. Files linked to the problem in SAP were added to the back of the standardized report. Each problem report was reviewed to ensure the record was valid. Fourteen records were determined to not be valid problem reports, and are not included in the sample. The logic for making this assessment is captured in Table 4-1 below.

Table 4-1: Records Removed from Sample

Records Removed	Reason	Logic
6	Practice records	Not a valid problem - Practice records are sometimes used to train employees on the complicated rules for data entry in the SAP module
4	Blank records	Not a valid problem - Blank records were initiated, perhaps mistakenly, but no data existed in the record
3	Audits	Potentially valid problems, but they do not meet the criteria established - Audit findings were mistakenly entered into the wrong SAP module
1	Unable to access	Unknown conditions prevented accessing this record - there was no available information in the metadata or the standardized record

The author is a designated company problem expert, proficient in the use of the problem management tool and familiar with each program represented by the problems in the sample. The author evaluated the reports and scored the two subjective independent variables using the coding guidelines in Table 4-2. Additional guidelines unique to each subjective variable were developed and used in order to eliminate bias. These are specified in Section 4.2, and bias is also discussed in Section 4.5.

Table 4-2: Impact and Timeliness Communication Effectiveness

Score	Communication Effectiveness	Description
10	90-99%	Larger
9	80-89%	is
8	70-79%	Better
7	60-69%	
6	50-59%	
5	40-49%	
4	30-39%	
3	20-29%	
2	10-19%	
1	0-9%	

The data for the independent variables of Complexity, Scope, Effort and KM were counted from the standardized reports as documented in Section 4.2 below. The data for the dependent variables of Corrective Actions, Training Actions, and Process Improvements were counted from the standardized report as described in Section 4.3.1 below. At this point, the two spreadsheet files were combined to complete the data collection process. The steps taken to calculate the Interim Dependent Variables and Combined Regression Dependent Variable are described in Sections 4.3.2 and 4.3.3 below, respectively.

4.2 Research Model and Data Coding – Independent Variables

The independent variables of Impact Communication and Timeliness Communication represent the core functionality of the SEPMP model (Olson et al., 2012). Better communication of Impact and Timeliness correspond to the model requirement to showcase and track Impact and Timeliness in a Risk Management-style matrix. If higher values for the communication variables correspond to more effective problem management, then this will demonstrate the importance of employing a matrix to track and communicate these problem characteristics and provide support for validation of the SEPMP model.

The remaining independent variables (see Figure 4-2) are used to suggest a potential range of situations in which the SEPMP model may be effective as a systems engineering tool. If there is a strong correlation with any of these variables and effective problem management, this may suggest that effectiveness of the SEPMP is affected by certain types of problems. Each of the independent variables are described below:

- Impact Communication (X1) – This is a subjective description of the quality with which each problem's impact was communicated while being managed. Over a period of five months, the author, a designated company problem expert, rated the communication effectiveness for the impact of each problem and assigned a score from 1 to 10 using the interval guidelines established in Table 4-2. To ensure a consistent rating, these additional guidelines were used to evaluate and score this variable:
    - Ineffective Communication (0-19%, Score 1-2) – Impact mentioned little or none.
    - Minimal Communication (20-39%, Score 3-4) – Impact discussed passively. Little to no use of references, visual aids, or multiple perspectives.
    - Moderate Communication (40-59%, Score 5-6) – Impact discussed directly. Occasional use of references, visual aids, or multiple perspectives.
    - Effective Communication (60-79%, Score 7-8) – Impact discussed directly, effectively, and repeatedly. Moderate use of references, visual aids, or multiple perspectives.
    - Exceptional Communication (80-99%, Score 9-10) – Impact discussed in complete detail. Effective use of references, visual aids, systems thinking, and responses to questions or additional discussion. Involves multiple perspectives.

- Timeliness Communication (X2) – This is a subjective description of the quality with which each problem's timeliness was communicated while being managed. Over a period of five months, the author, a designated company problem expert, rated the communication effectiveness for the timeliness of each problem and assigned a score from 1 to 10 using the interval guidelines established in Table 4-2. To ensure a consistent rating, these additional guidelines were used to evaluate and score this variable:
    - Ineffective Communication (0-19%, Score 1-2) – Key Event or deadline mentioned little or none.
    - Minimal Communication (20-39%, Score 3-4) – Key Event or deadline referenced passively. No urgency detected.
    - Moderate Communication (40-59%, Score 5-6) – Key Event or deadline discussed specifically, including some sense of urgency.
    - Effective Communication (60-79%, Score 7-8) – Key Event or deadline specifically discussed and schedule or POAM used. May discuss ripple schedule effects.
    - Exceptional Communication (80-99%, Score 9-10) – Key Event, schedule, deadline, POAM or other tools used effectively throughout the entire process. Visual aids, references, systems thinking and ripple effects prominent.
- Complexity (X3) – This is an objective measure of the number of independent problem statements. When the problem is identified, problem statement(s) are written to capture essential information as succinctly as possible to specifically

define the issue. More complex problems have more facets or angles and generally affect more individual components or subsystems. This may also indicate systemic issues with multiple instances having been documented. An example problem statement is: "Preventative maintenance records for pump 'A' are not available to support system certification."

- Scope (X4) – This is an objective measure of the number of items referenced in the problem statement(s). The references may be product drawings, requirements statements, specifications, purchase orders, official or unofficial correspondence, or other documents. A larger scope implies that a problem has more far-reaching implications and may be more difficult to resolve.
- Effort (X5) – This is an objective measure of the number of individuals officially involved in the problem. Each of the people counted are responsible for some aspect of managing the problem, including investigation, reporting, or being assigned a corrective action. While the actual number of people that will work to support the individuals designated on the problem report is likely to be considerably higher, this is a consistent indication of the effort required to manage the problem.
- Knowledge Management (X6) – This is an objective measure of the number of pages in the standard format report. This shows the amount of information captured in the problem management tool and is a quantitative estimate of knowledge management for the problem.

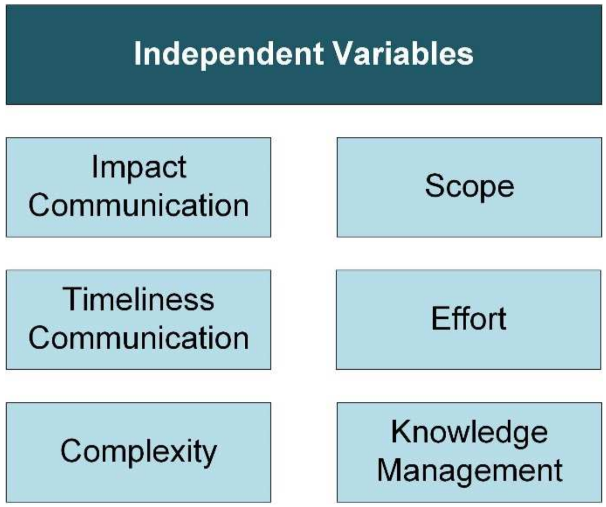

Figure 4-2: Independent Variables

The subjective variables for Impact and Timeliness Communication are defined on an interval scale to support the selected analyses. These items are all unidirectional from low to high, and personal interpretation is not problematic because a single person evaluated these items and coded the percentage of effectiveness onto the established scale in Table 4-2, and the intervals of the scale are consistent and substantively meaningful throughout the range (Casacci & Pareto, 2015). Also, Kolmogorov-Smirnov and Shapiro-Wilks tests on the two interval scaled items failed to reject normality. All of this supports the use of the interval scale items in the Pearson correlation and regression analyses (Cariou, 2006; Harwell & Gatti, 2001; Su & Wang, 2014).

4.3 Research Model – Dependent Variables

The dependent variables fall into three categories: Root Dependent Variables, Interim Dependent Variables, and the Combined Regression Dependent Variable.

4.3.1 Root Dependent Variables

The Root Dependent Variables (Figure 4-3) of Timeliness, Process Delay, Corrective Actions, Training Actions, and Process Improvements are manipulated and combined to produce the single dependent variable Effective Problem Management, which is used in the regression analysis.

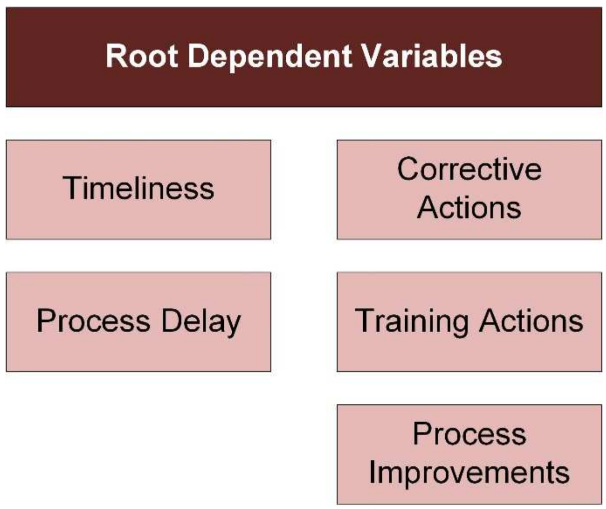

Figure 4-3: Root Dependent Variables

- Timeliness (Z1) – This is an objective measure of the number of days from the time the problem is identified until the deadline or key event. The deadline varies depending on the phase of the program, but in all cases is established as the point at which the program is scheduled to enter the next phase and at which unresolved problems would prohibit the program from doing so.
- Process Delay (Z2) – This is an objective count of the number of days lost on the affected process after the problem was identified and before work could resume. This is important because it shows an absolute measure of lost schedule time.

- Corrective Actions (Z3) – This is an objective measure of the number of actions implemented to resolve the problem. The actions may include steps that isolate a process or otherwise restore safety, correct defects, bound problems or other investigative actions, provide training, implement process improvements, or update technical work documents. In all cases, the actions were sufficiently and independently important enough as to require commitment management for completion tracking.
- Training Actions (Z4) – This is an objective count of the number of actions that contribute to the management of the problem by solving an identified need for additional process, product, or safety training. An example training action is: "Add requirements for configuration management of preventative maintenance records to mechanics training."
- Process Improvements (Z5) – This is an objective count of the number of actions that improve processes and update work documents that were identified and implemented as a result of the problem. An example of a process improvement is: "Develop database to maintain and configuration manage preventative maintenance records."

4.3.2 Interim Dependent Variables

Inefficient Time Use, Efficient Time Use, Solving Actions, and Percent Solving Actions are Interim Dependent Variables (see Figure 4-4) used to show the manipulation and combination of the observed data into the regression variable.

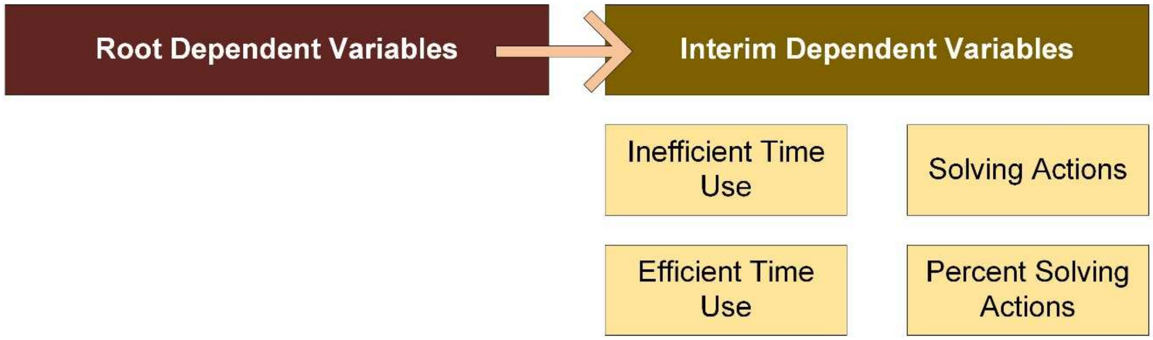

Figure 4-4: Interim Dependent Variables

- Inefficient Time Use (Z6) – This is a calculated by normalizing Process Delay based on the Timeliness. This answers the question, "What percentage of the available time before the deadline was lost to the problem?" A higher percentage indicates poor problem management.

Equation 4-1: Inefficient Time Use

$$Z6 = \frac{Z2}{Z1}$$

- Efficient Time Use (Z7) – This is calculated by subtracting Inefficient Time Use from 100%. The result is a percentage with a maximum of 100%, where a higher percentage shows less wasted time and more effective management of the problem.

Equation 4-2: Efficient Time Use

$$Z7 = 1 - Z6 = 1 - \frac{Z2}{Z1}$$

- Solving Actions (Z8) – This is calculated by adding the number of training actions to the number of process improvements. These are the action types that contribute to solving the problem and preventing recurrence, as opposed to actions for investigating and bounding problems, restoring systems, correcting defects, or resuming work under a non-permanent solution.

Equation 4-3: Solving Actions

$$Z8 = Z4 + Z5$$

- Percent Solving Actions (Z9) – This is a calculation of the Solving Actions divided by the total number of Corrective Actions. The result is a percentage with a maximum of 100% where a higher percentage indicates more effective problem management.

Equation 4-4: Percent Solving Actions

$$Z9 = \frac{Z8}{Z3} = \frac{Z4 + Z5}{Z3}$$

4.3.3 Regression Dependent Variable

The Root and Interim Dependent Variables are combined into the Regression Dependent Variable (see Figure 4-5).

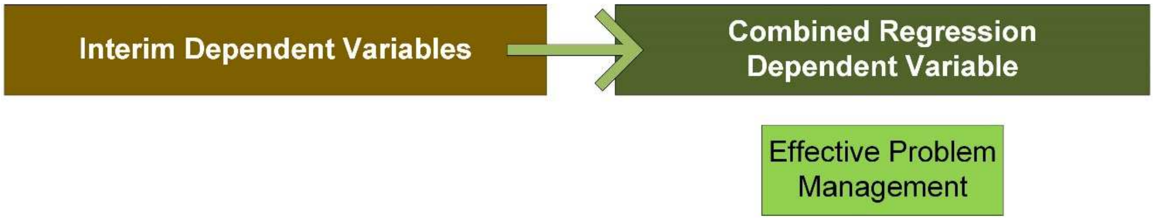

Figure 4-5: Combined Regression Dependent Variable

- Effective Problem Management (Y) – The combined dependent variable is calculated by adding Efficient Time Use and Percent Solving Actions. The variable has a maximum value of 200% and weights each component equally. The formula for Effective Problem Management is:

Equation 4-5: Effective Problem Management

$$Y\ (EPM) = \left[\left(100\% - \frac{Z2}{Z1}\right) + \left(\frac{Z4\ +\ Z5}{Z3}\right)\right] * 100$$

4.4 Research Hypotheses

Each of the six independent variables were examined for potential correlation with Effective Problem Management. The following research hypotheses were developed for this study:

4.4.1 Impact Communication

H_1 – There is a moderate positive correlation between the effective communication of the impact of a problem and effective problem management.

4.4.2 Timeliness Communication

H_2 – There is a moderate positive correlation between the effective communication of the timeliness of a problem and effective problem management.

4.4.3 Complexity

H_3 – There is a moderate positive correlation between the complexity of a problem and effective problem management.

4.4.4 Scope

H_4 – There is a moderate positive correlation between the scope of a problem and effective problem management.

4.4.5 Effort

H_5 – There is a moderate positive correlation between the human capital effort spent on a problem and effective problem management.

4.4.6 Knowledge Management

H_6 – There is a moderate positive correlation between the knowledge management of a problem and effective problem management.

For the communication variables, supporting the research hypotheses will support the value of the SEPMP model. For the remaining variables, supporting the research hypotheses may indicate relationships outside the model that may need to be considered in order to further develop the SEPMP model.

4.5 Research Planning to Eliminate Bias

Several measures were enacted with the goal of eliminating bias from the research contained in this dissertation:

- Selection Bias – The sample used in this study was not a random sample. All of the available records for the problem types specified in Section 4.1 were included, with the exception of the records determined to be invalid as identified above.
- Data Snooping Bias – A process was employed in which separate electronic files were used to isolate the dependent variable data from the researcher evaluating the subjective independent variables of Impact Communication and Timeliness Communication. Also, the outcome variables are all objective. The intended blinding was effective at maintaining a zero awareness state for the researcher with respect to the outcome variables.
- Funding Bias – There was no financial sponsor for this study. However, it should be noted that the researcher did receive funding for the course tuition from his employer in the form of tuition reimbursement. Accountability and review of the requirements for approving tuition reimbursement and the associated processes were strictly enforced and managed by a third party subcontractor.

- Reporting Bias – Every effort has been made by the author to report the results of the research as they occurred. Interpretation of these results is by nature subjective, but the results themselves are presented in their entirety.
- Exclusion Bias – This research was designed so as to include every relevant problem in the available collection. Items were excluded only when they were deemed to be invalid as described in Section 4.1.
- Confirmation Bias – The study was designed using existing problem records as data available from a standardized repository. The subjective effort for collecting data for two independent variables was documented and controlled using the methods discussed in Section 4.2. Equal respect was paid to each of the six research hypotheses when reviewing the results.

4.6 Methodology Summary

This study was designed to evaluate the SEPMP using records from a sample of 314 completed industrial manufacturing problems. The problems exist on multiple programs involving many functional departments, and ranged in severity from minor to critical, but all required attention in order to prevent program failure. They were also clarified as problems instead of risks. The process used to collect data was explained, including the steps taken to ensure the problems were presented for analysis consistently, and the determination that fourteen records were eliminated from the sample because of one of four different reasons.

The independent variables were each explained, followed by the dependent variables, which were broken into three categories. Five root dependent variables representing objective data collected from the problem database were identified. Then, four interim dependent variables were defined, each a calculation using one or more of the root dependent variables. The interim dependent variables were then manipulated into the Combined Regression Dependent Variable, Effective Problem Management, which is the outcome of the model. Six research hypotheses were presented, and the methods employed to eliminate bias were discussed.

Chapter 5. Data Analysis and Results

5.1 Descriptive Statistics

Data describing the six independent variables, five root dependent variables, and regression dependent variable, is shown in Table 5-1. Appendix B contains excerpts from the Minitab session. Also, Figure 5-1 shows histograms of the independent variables.

Table 5-1: Descriptive Statistics

Variable	N	Mean	St. Dev.	Min	Q1	Median	Q3	Max
Impact Communication	314	5.443	2.147	1	4	5	7	10
Timeliness Communication	314	4.930	2.126	1	3	5	6	10
Complexity	314	2.433	2.243	1	1	1	3	14
Scope	314	2.971	2.031	0	2	3	4	12
Effort	314	5.678	2.990	1	4	5	7	34
Knowledge Management	314	7.038	3.318	3	5	6	8	25
Timeliness	314	121.83	117.35	9	44	78	162	854
Corrective Actions	314	5.799	4.504	1	3	4	7	28
Process Delay	314	50.86	65.87	0	14	31	60	510
Training Actions	314	1.787	2.207	0	0	1	2	14
Process Improvements	314	1.083	1.812	0	0	0	2	14
Effective Problem Management	314	94.95	56.17	-158.88	56.03	98.19	140.55	200.00

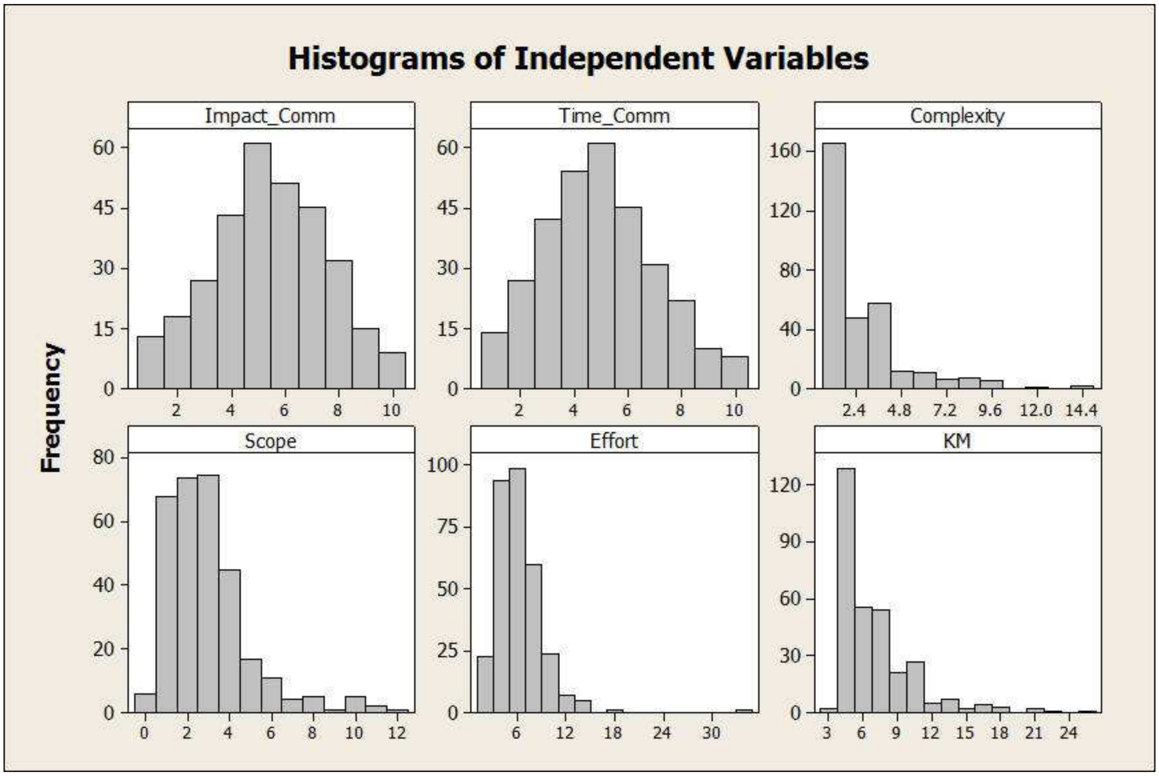

Figure 5-1: Histograms of Independent Variables

5.2 Pearson Correlations – The Relationships between the Independent Variables and EPM

Pearson correlation analysis was performed between all independent variables and the derived dependent variable of Effective Problem Management (see Appendix B for excerpts from the Minitab session). In order to demonstrate that a significant relationship exists between the independent variables and the dependent variable, a threshold of 0.01 was selected for α. Relationships were identified for Impact Communication and Timeliness Communication, and both were significant at $\alpha = 0.000$. Thus the research hypotheses H_1 and H_2 are supported, as shown in Table 5-2. No significant relationships were identified for Complexity, Scope, Effort, or KM. As a result, the research hypotheses H_3-H_6 fail to be supported.

However, assuming a less stringent threshold of 0.05 for α, weak positive correlations for Scope and Effort would have been identified. For problems where additional people (Effort) are working to solve the issue, more effective problem management would seem a reasonable expectation. However, a stronger correlation would also be preferred, which would indicate better value for the cost of the extra effort. For problems with more far-reaching implications (Scope), a positive correlation, even a weak one, seems counterintuitive.

Table 5-2: Pearson Correlations Relative to Effective Problem Management

Effective Problem Management	Impact Comm.	Timeliness Comm.	Complexity	Scope	Effort	KM
Research Hypothesis	H_1	H_2	H_3	H_4	H_5	H_6
Pearson Correlation	0.375	0.528	0.050	0.115	0.119	0.064
p-value	0.000	0.000	0.380	0.041	0.035	0.259

5.3 Regression Analysis

A stepwise regression analysis was conducted to further evaluate the relationships between the independent and dependent variables. After each step, the least significant variable was removed and the analysis repeated with the remaining variables. Appendix B contains excerpts of the Minitab sessions for the regression analysis. The general multiple regression equation is:

Equation 5-1: General Multiple Regression Equation

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon$$

Y represents the dependent variable, Effective Problem Management,

X represents the independent variables,

β are the regression coefficients, and

ε is the random error term.

The results are shown in Table 5-3. Impact Communication and Timeliness Communication remained significant at $\alpha = 0.000$ through the five steps of the regression, at which point all remaining variables were deemed significant and the removals ceased. Complexity, Scope, Effort, and KM never reach significance. Therefore, this supports the same two research hypotheses (H_1 and H_2) as indicated in the Pearson Correlations analysis, and the failure to support the remaining hypotheses (H_3-H_6).

For each step, the coefficients for both communication variables are several times higher than the coefficients for any of the other variables. This is a good indicator that the communication variables are more important to the model than are the rest of the variables.

The F statistic increases at each step and is always significant at $\alpha = 0.000$. This indicates that the regression equation has some validity and the independent variables are not random as compared to Effective Problem Management. The consistently low R square value suggests that this is not a great predictive model, and significant portions of the variance remain unexplained. However, as the purpose of this analysis is to explore relationships, this is not surprising, nor is it cause for concern. Additionally, problems by their nature are complicated and difficult to predict, more so when they exist in a complex system involving human behavior.

Table 5-3: Regression Results

Stage #	R-Square (adj.)	F	p-values	Variables	Coefficient (β)	SE Coefficient	t-values	p-values
1	31.5%	25.04	0.000	Constant	-3.85	10.18	-0.38	0.706
				Impact Comm.	5.294	1.343	3.94	0.000
				Timeliness Comm.	11.958	1.331	8.98	0.000
				Complexity	1.223	1.846	0.66	0.508
				Scope	2.302	1.371	1.68	0.094
				Effort	0.344	0.980	0.35	0.726
				KM	-0.105	1.368	-0.08	0.939
2	31.8%	30.14	0.000	Constant	-4.105	9.608	-0.43	0.669
				Impact Comm.	5.288	1.338	3.95	0.000
				Timeliness Comm.	11.967	1.324	9.04	0.000
				Complexity	1.116	1.210	0.92	0.357
				Scope	2.274	1.318	1.72	0.086
				Effort	0.318	0.917	0.35	0.729
3	32.0%	37.75	0.000	Constant	-3.103	9.150	-0.34	0.735
				Impact Comm.	5.377	1.311	4.10	0.000
				Timeliness Comm.	11.977	1.322	9.06	0.000
				Complexity	1.194	1.187	1.01	0.315
				Scope	2.299	1.314	1.75	0.081
4	32.0%	50.00	0.000	Constant	-0.684	8.828	-0.08	0.938
				Impact Comm.	5.368	1.311	4.09	0.000
				Timeliness Comm.	11.942	1.321	9.04	0.000
				Scope	2.536	1.293	1.96	0.051
5	31.3%	72.41	0.000	Constant	5.961	8.189	0.73	0.467
				Impact Comm.	5.549	1.314	4.22	0.000
				Timeliness Comm.	11.924	1.327	8.98	0.000

The final stage multiple regression equation is:

Equation 5-2: Stage 5 Multiple Regression Equation

$$EPM = 5.961 + 5.549\, X_1 + 11.924\, X_2 + \varepsilon$$

X_1 represents Impact Communication,

X_2 represents Timeliness Communication,

ε is the random error term.

5.4 Residuals

The residual plots were evaluated to determine whether the remaining error present in the model is random or attributable to some other unknown factor. Evaluating the residuals for the two significant independent variables in the regression indicates several interesting observations, as shown in Figures 5-2 through 5-6. The Normal Probability Plots appear to be a straight line, except for four obvious outliers, suggesting that the data is approximately normally distributed. The outliers comprise less than 1.5% of the data set and were not removed from the analysis. The 'Histogram of the Residuals' plots resemble a bell and further support this conclusion. The 'Residuals Versus the Fitted Values' plots appear to be randomly scattered about zero, which is a good indication that the error terms have a mean of approximately zero. Also, the random patterns suggest that the variance in error is approximately constant, and not significantly influenced by an unnamed variable. Finally, the charts for 'Residuals Versus the Order of the Data' appear to have a generally consistent spread above and below zero. This implies that the error observed over time is random as well.

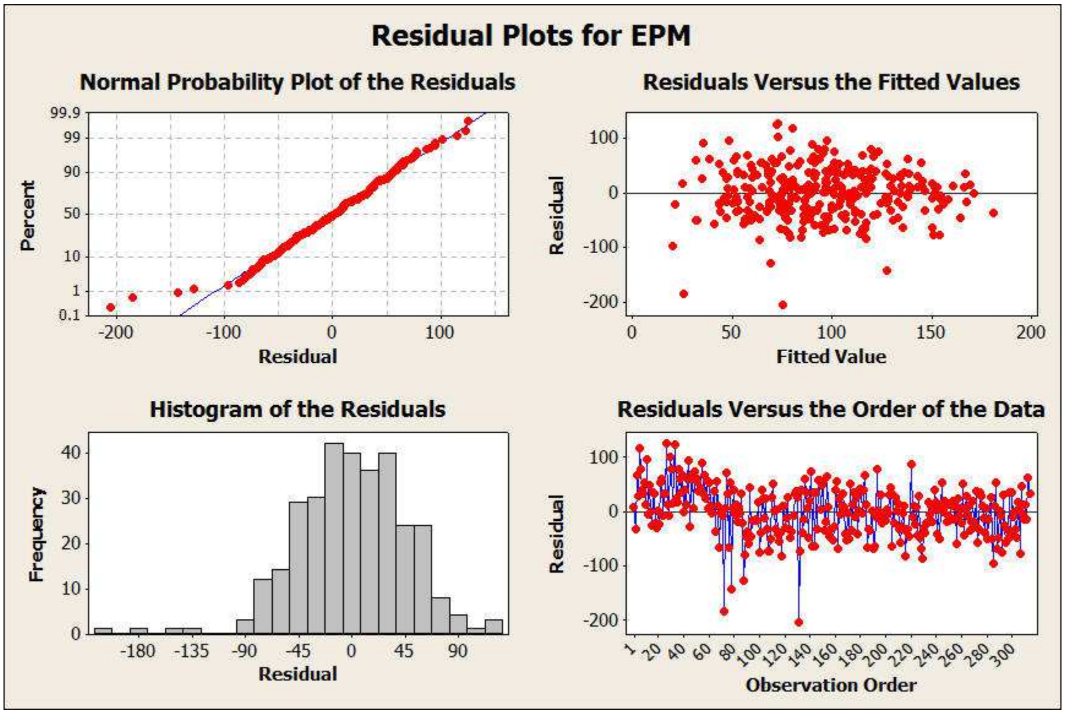

Figure 5-2: Regression Stage 1 Residuals

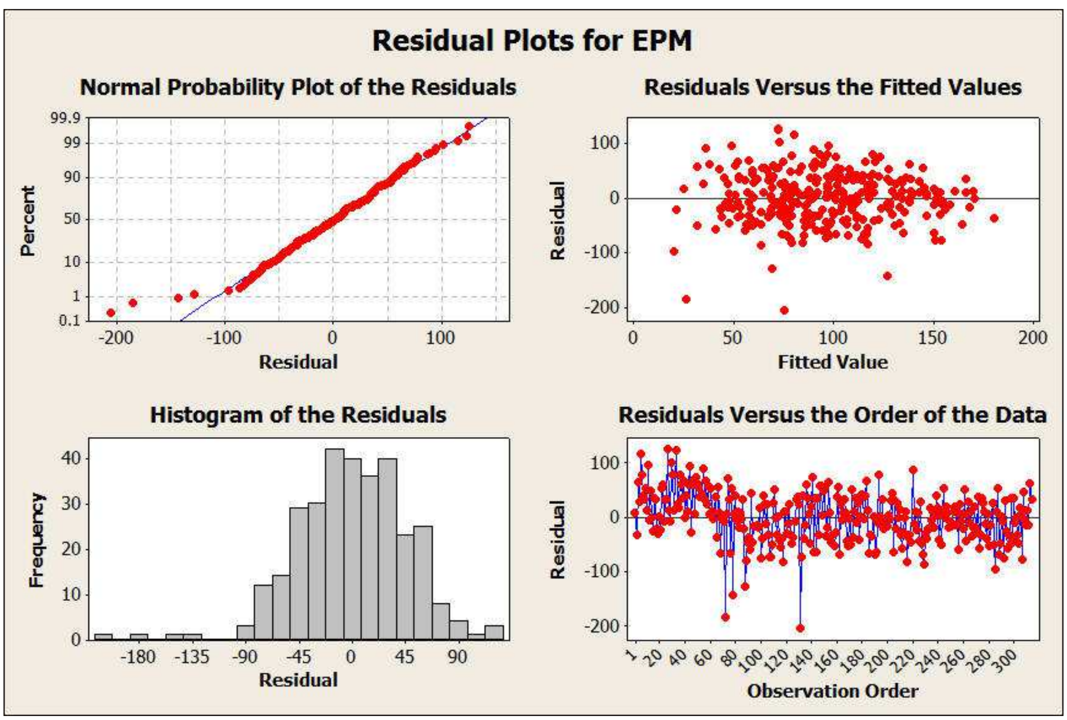

Figure 5-3: Regression Stage 2 Residuals

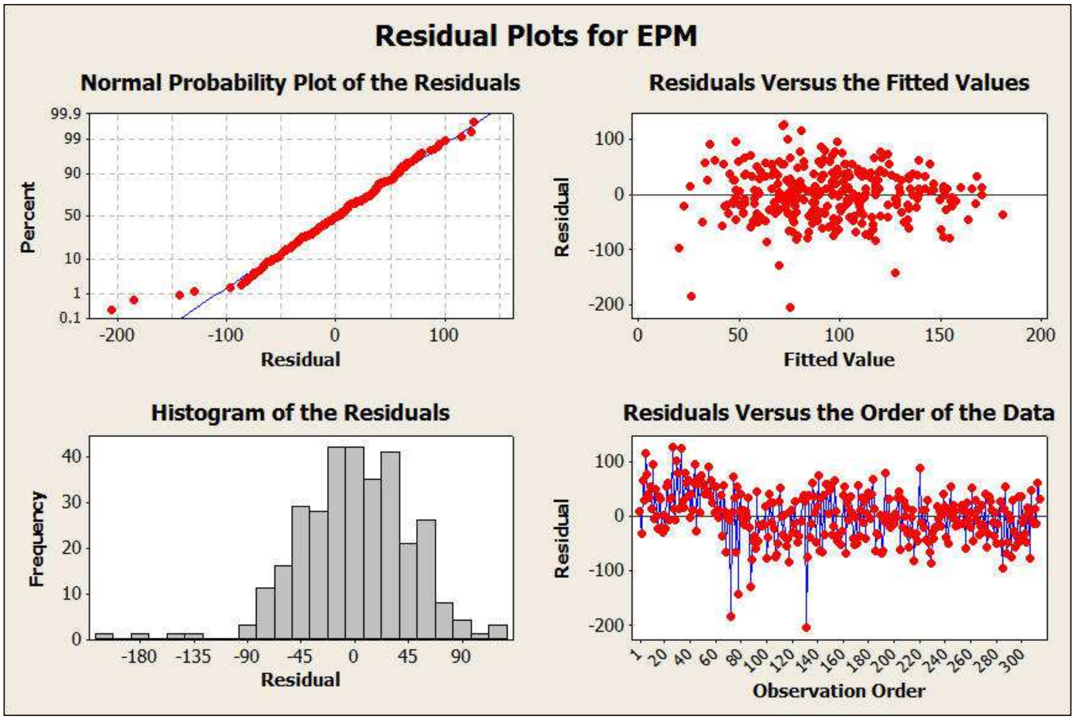

Figure 5-4: Regression Stage 3 Residuals

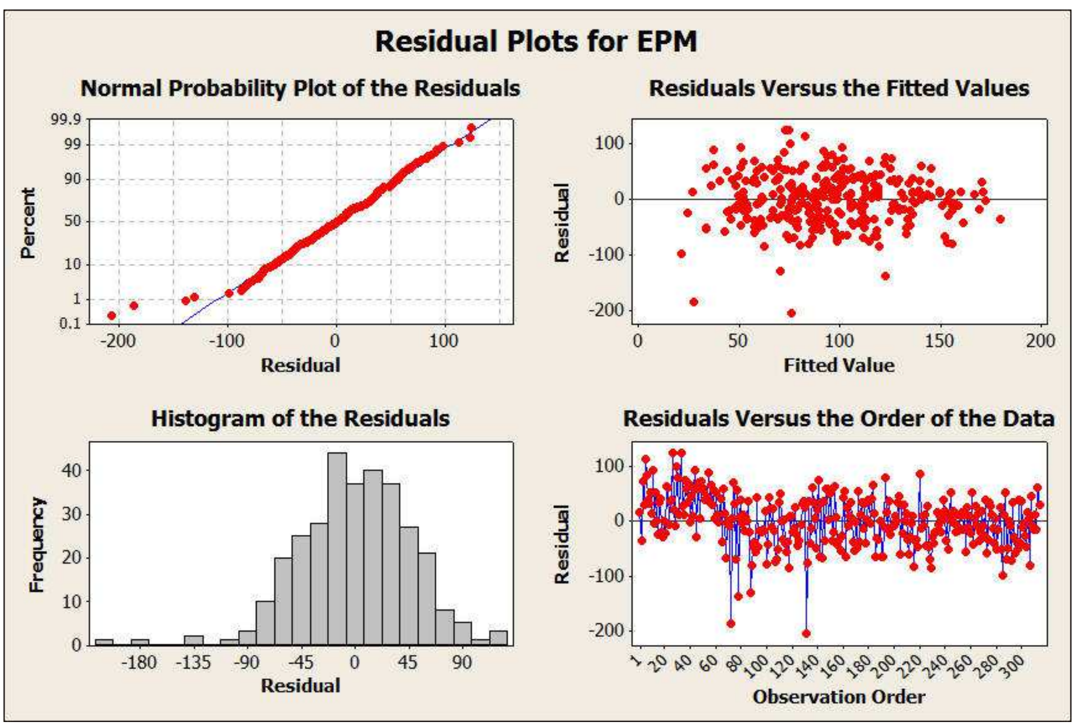

Figure 5-5: Regression Stage 4 Residuals

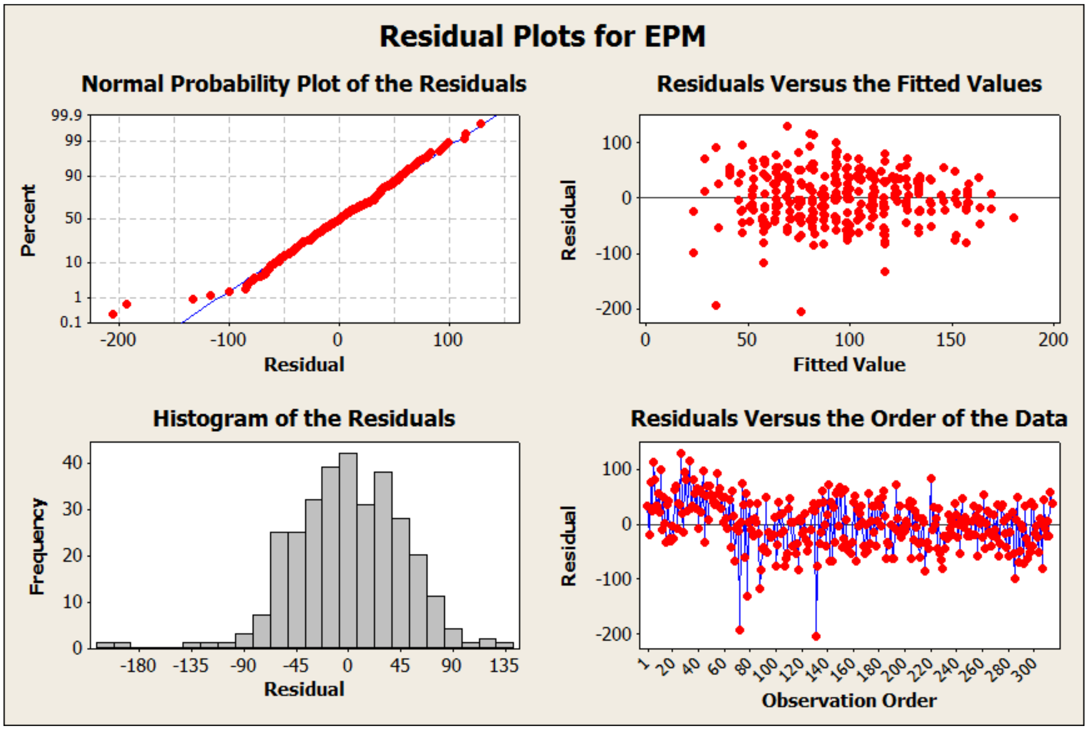

Figure 5-6: Regressions Stage 5 Residuals

5.5 Discussion

Evidence supporting hypotheses H_1 and H_2 in turn supports the SEPMP model's requirement to measure, track, and report the Impact and Timeliness of a problem. While the correlation is weak to moderate, it is quite significant. However, the model used in the analysis is incomplete, and further work needs to be done to ensure that this model is ready to be implemented and advertised as a systems engineering tool.

The failure to support the research hypotheses H_3-H_6 shows no concerns with the model due to Complexity, Scope, Effort, or Knowledge Management. In other words, there is no evidence that would demand altering the SEPMP model to accommodate these variables. If the research hypothesis H_3 was supported, for example, it would be important to recommend the model be altered to take into account problems with different levels of complexity, or that the model may work better for large problems, or small problems, etc. Since this is the first study delving into the validity of the SEPMP model, this is a great opening salvo, but it certainly should not be the final word.

Likewise, there is insufficient evidence that the SEPMP model is complete. These results suggest that the model may work equally well regardless of the Complexity of or Effort required for a given problem, but more substantiation is needed to completely rule out these variables. It is also important to realize that this study examined the variables identified in the SEPMP, and four additional problem characteristics, but there are countless other variables that should be evaluated for possible inclusion in the model. For example, future research models may evaluate existing principles such as the "rule of ten," which specifies that defects cost ten times more to address when identified at the next phase of production (Anderson, 2014).

5.6 Additional Findings

The analysis required a large data set including many variables. The data collected for the preceding analysis will be further examined using Pearson Correlations to explore other relationships not suggested by the SEPMP. Then, the author performed additional quantitative analysis on the original data collected, extending beyond the primary conceptual model. Two-sample t-tests were used to compare the EPMs from the subsets determined by the top and bottom quartiles of each independent variable. The results of these analyses are presented here along with interpretation.

5.6.1 Pearson Correlations – The Relationships between the IVs and Root DVs

The first additional quantitative analyses performed were Pearson correlations on the independent variables and the root dependent variables. The independent and root dependent variables were selected because they are representative of the data collected by a problem management organization, and insights garnered here may contribute to improvements in knowledge management or identification of systemic issues. Table 5-4 shows the results of this analysis, and significant correlations are highlighted in yellow.

Table 5-4: Pearson Correlations for Independent and Root Dependent Variables

Root Dependent Variables	Impact Comm.	Timeliness Comm.	Complexity	Scope	Effort	KM
Timeliness						
Pearson Correlation	-0.014	-0.230	0.241	0.162	0.144	0.357
p-value	0.810	0.000	0.000	0.004	0.011	0.000
Corrective Actions						
Pearson Correlation	0.294	0.086	0.475	0.145	0.500	0.601
p-value	0.000	0.130	0.000	0.010	0.000	0.000
Process Delay						
Pearson Correlation	-0.154	-0.405	0.155	0.019	0.075	0.258
p-value	0.006	0.000	0.006	0.744	0.186	0.000
Training Actions						
Pearson Correlation	0.317	0.303	0.180	0.086	0.390	0.215
p-value	0.000	0.000	0.001	0.127	0.000	0.000
Process Improvements						
Pearson Correlation	0.234	0.065	0.411	0.120	0.201	0.536
p-value	0.000	0.248	0.000	0.033	0.000	0.000

There were several moderate to strong correlations above 0.4, including:

- Corrective Actions and Complexity (0.475) – This may seem self-evident, but it's worth highlighting that more complex problems tend to involve more corrective actions.
- Corrective Actions and Effort (0.500) – More corrective actions involves more effort to actually perform the work necessary to complete the action.
- Corrective Actions and Knowledge Management (0.601) – Corrective actions taken lend themselves to documentation, which in turn contributes to knowledge management, as defined in this paradigm.
- Process Delay and Timeliness (-0.405) – This is an especially interesting discovery. When there is more time available prior to project failure (Timeliness), the author would expect more process delay, especially based on Parkinson's Law, which is the adage that "*work expands so as to fill the time available for its completion*" (Parkinson, 1955). Instead, the moderate negative correlation implies otherwise.
- Process Improvements and Complexity (0.411) – Again, this seems self-evident, similar to the relation between Corrective Actions and Complexity above.
- Process Improvements and Knowledge Management (0.536) – This correlation is encouraging because it is expected that processes and procedures in a complex technical organization are the tools for managing and

communicating technical requirements. However, in the author's experience, many problems indicate this is not always practiced.

5.6.2 Independent Variables – Top Quartile versus Bottom Quartile

Next, the author determined the subsets containing the top and bottom quartile scores for each independent variable and looked at the EPM for each of those subsets. Then the top and bottom quartile subset EPMs for each independent variable were compared using a two sample t-test to determine whether there is a difference. In each case, the top and bottom quartiles are mutually exclusive, so the independence requirement is met.

5.6.2.1 Impact Communication

Table 5-5 contains the results of the two sample t-test for top quartile Impact Communication (Impact Communication rated at 7 or higher) and bottom quartile Impact Communication (Impact Communication rated at 4 or lower). The p-value of 0.000 indicates there is a significant difference between the EPMs for the populations. This supports the findings about Impact Communication in the regression analysis.

Table 5-5: Top Quartile vs Bottom Quartile - Impact Communication

Top Quartile Impact Communications (>=7)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Impact_Comm	101	7.8812	0.9725	7	7	8	8	10
EPM	101	120.78	44.25	16.67	86.45	129.58	153.01	200
Bottom Quartile Impact Communications (<=4)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Impact_Comm	101	2.99	1.063	1	2	3	4	4
EPM	101	74.06	58.77	-158.88	39.24	81.06	117.85	195.92
Two-Sample T-Test and CI								
Sample	N	Mean	StDev	SE Mean				
Top Quartile	101	120.8	44.3	4.4				
Bottom Quartile	101	74.1	58.8	5.8				
Difference = mu (1) - mu (2)								
Estimate for difference: 46.72								
95% CI for difference: (32.2784, 61.1616)								
T-Test of difference = 0 (vs not =):			T-Value =	6.38	p-Value =	0.000	DF =	185

5.6.2.2 Timeliness Communication

Table 5-6 contains the results of the two sample t-test for top quartile Timeliness Communication (rated 6 or higher) and bottom quartile Timeliness Communication (rated 3 or lower). The p-value of 0.000 indicates there is a significant difference between the EPMs for the populations. This supports the findings about Timeliness Communication in the regression analysis.

Table 5-6: Top Quartile vs Bottom Quartile - Timeliness Communication

Top Quartile Timeliness Communications (>=6)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Time_Comm	116	7.181	1.234	6	6	7	8	10
EPM	116	125.7	42.46	-15.77	98.19	133.57	154.71	200
Bottom Quartile Timeliness Communications (<=3)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Time_Comm	83	2.3373	0.7535	1	2	3	3	3
EPM	83	60.85	59.28	-158.88	21.43	59.86	101.85	198.84
Two-Sample T-Test and CI								
Sample	N	Mean	StDev	SE Mean				
Top Quartile	116	125.7	42.5	3.9				
Bottom Quartile	83	59.3	59.3	6.5				
Difference = mu (1) - mu (2)								
Estimate for difference: 66.42								
95% CI for difference: (51.3778, 81.4622)								
T-Test of difference = 0 (vs not =):			T-Value =	8.73	p-Value =	0.000	DF =	139

5.6.2.3 Complexity

Table 5-7 contains the results of the two sample t-test for top quartile Complexity (3 or higher) and bottom quartile Complexity (exactly 1). The p-value of 0.116 indicates there is no significant difference between the EPMs for the population. This resembles the results for Complexity in the regression analysis, in that there is no significant difference in problem management effectiveness between highly complex and less complex issues.

Table 5-7: Top Quartile vs Bottom Quartile - Complexity

Top Quartile Complexity (>=3)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Complexity	101	4.98	2.392	3	3	4	6	14
EPM	101	102.85	49.96	-59.68	71.52	113.81	144.34	183.05
Bottom Quartile Complexity (=1)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Complexity	165	1	0	1	1	1	1	1
EPM	165	92.15	59.25	-158.88	50	95.24	138.82	200
Two-Sample T-Test and CI								
Sample	N	Mean	StDev	SE Mean				
Top Quartile	101	102.9	50	5				
Bottom Quartile	165	92.2	59.3	4.6				
Difference = mu (1) - mu (2)								
Estimate for difference: 10.7								
95% CI for difference: (-2.6595, 24.0595)								
T-Test of difference = 0 (vs not =):			T-Value =	1.58	p-Value =	0.116	DF =	238

5.6.2.4 Scope

Table 5-8 contains the results of the two sample t-test for top quartile Scope (Scope 4 or greater) and bottom quartile Scope (2 or lower). The p-value of 0.575 indicates there is no significant difference between the EPMs for the population. These results support the findings about Scope in the regression analysis.

Table 5-8: Top Quartile vs Bottom Quartile - Scope

Top Quartile Scope (>=4)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Scope	91	5.407	2.011	4	4	5	6	12
EPM	91	99.02	55.17	-59.68	58.89	100	143.07	200
Bottom Quartile Scope (<=2)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Scope	148	1.4595	0.5759	0	1	1.5	2	2
EPM	148	94.82	57.52	-158.88	55.16	98.24	139.04	200
Two-Sample T-Test and CI								
Sample	N	Mean	StDev	SE Mean				
Top Quartile	91	99	55.2	5.8				
Bottom Quartile	148	94.8	57.5	4.7				
Difference = mu (1) - mu (2)								
Estimate for difference: 4.2								
95% CI for difference: (-10.53212, 18.93212)								
T-Test of difference = 0 (vs not =):			T-Value =	0.56	p-Value =	0.575	DF =	196

5.6.2.5 Effort

Table 5-9 contains the results of the two sample t-test for top quartile Effort (7 or greater) and bottom quartile Effort (4 or lower). The p-value of 0.003 indicates there is a significant difference between the EPMs for the population. These results do not coincide with the findings about Effort in the regression analysis. The different results may be an indication to re-evaluate Effort in future research. For example, while it may seem logical that more people working on a problem lends to better management of the problem, at what point do the cost of the extra people outweigh the value of the extra effort?

Also, the author considers more granular measurements for effort, such as man-hours or money spent on human resources, would be better information to capture in order to perform a more comprehensive analysis on problem management, and most certainly for adequate budget forecasting when bidding future projects.

Table 5-9: Top Quartile vs Bottom Quartile - Effort

Top Quartile Effort (>=7)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Effort	98	8.847	3.206	7	7	8	9.25	34
EPM	98	108.26	47.35	3.26	71.25	118.51	145.57	200
Bottom Quartile Effort (<=4)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Effort	117	3.2308	0.8649	1	3	3	4	4
EPM	117	85.56	63.32	-158.88	40.26	87.63	133.57	200
Two-Sample T-Test and CI								
Sample	N	Mean	StDev	SE Mean				
Top Quartile	98	108.3	47.4	4.8				
Bottom Quartile	117	85.6	63.3	5.9				
Difference = mu (1) - mu (2)								
Estimate for difference: 22.7								
95% CI for difference: (7.7977, 37.6023)								
T-Test of difference = 0 (vs not =):			T-Value =	3.00	p-Value =	0.003	DF =	210

5.6.2.6 KM

Table 5-10 contains the results of the two sample t-test for top quartile KM (8 or greater) and bottom quartile KM (5 or lower). The p-Value of 0.153 indicates there is no significant difference between the EPMs for the population. This supports the findings about KM in the regression analysis.

Table 5-10: Top Quartile vs Bottom Quartile - KM

Top Quartile KM (>=8)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
KM	101	10.752	3.457	8	8	10	11.5	25
EPM	101	102.17	52.17	-59.68	61.92	115.08	143.77	183.05
Bottom Quartile KM (<=5)								
Variable	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
KM	131	4.626	0.5164	3	4	5	5	5
EPM	131	92.01	55.27	-76.74	54.85	93.46	133.33	200
Two-Sample T-Test and CI								
Sample	N	Mean	StDev	SE Mean				
Top Quartile	101	102.2	52.2	5.2				
Bottom Quartile	131	92	55.3	4.8				
Difference = mu (1) - mu (2)								
Estimate for difference: 10.16								
95% CI for difference: (-3.8128, 24.1328)								
T-Test of difference = 0 (vs not =):			T-Value =	1.43	p-Value =	0.153	DF =	220

5.6.3 Summary of Additional Findings

The additional quantitative findings produced some interesting if largely unsurprising results. The significant Pearson Correlations between the independent and root dependent variables were plentiful, but nearly all seemed reasonable. However, the significant inverse relationship between Timeliness and Process delay seems to dispute at least the author's experience.

Two sample t-tests were performed on the top and bottom quartile subsets of each independent variable. These largely supported the regression findings, although a difference in EPMs was noted on the top and bottom quartile samples for Effort, which did not match the regression results. This may suggest Effort should be more closely examined in future research on the SEPMP.

Chapter 6. Case Study – Problem Management in a Complex Industrial Manufacturing Organization

The regression analysis provided an overview of the relationships present in the independent and dependent variables, and specifically addressed the research hypotheses. However, a case study analysis was also performed. The purpose of the case study is to review and evaluate some of the circumstances and experiences surrounding problem management in a complex industrial manufacturing organization, and to review and evaluate specific individual problems in order to qualitatively assess the effectiveness of the problem management system. These will contribute to the recommendations for improving and effectively implementing the SEPMP.

6.1 Qualitative Observations of Problem Management Realities

The observations presented in this section are subjective comments on the reality of problem management at a large industrial manufacturing organization. The author is a quality manager in the organization and is responsible for overseeing some of the problem management mechanisms in place, with substantial experience as a senior engineer in quality and systems engineering roles. These observations are related to the organizational problem management competency, and additional recommendations for the SEPMP and its implementation will be based in part on these observations.

6.1.1 Problem Management Mechanisms

In this industrial manufacturer's industry, complexity is abundant. As a quality manager, the author interacts with no less than ten different problem management mechanisms on a daily basis. These include:

- Agenda Items – These are high level problems where concern has been expressed by the customer's leadership, or by this company's leadership in anticipation of the concern that may be raised by the customer's leadership.
- Quality Item Matrix – These are low to mid-level problems shared between this company and one of its teaming partners.
- Preventive and Corrective Action Board – This is an upper management team responsible for embracing and addressing cross functional problems of a significant or systemic nature.
- Significant Items – A separate process for managing, approaching, and solving problems from any of the other mechanisms that may be expected to require extra attention.
- Unplanned Events – This is the standard process for simple to severe, self-identified, and self-investigated problems throughout the entire company.
- Significant Defect Reports – These are moderate to high impact problems identified through the internal audit and assessment organization.
- Corrective Action Requests – CARs are problems identified by the customer with a full range of significance levels from minor to critical. These form the basis of

the problem set used in the primary analysis in the study performed in support of this dissertation.

- Material Investigations – Problems characterized by concerns over the quality and installation of defective or questionable material.
- Brew List – A separate problem management tool, often employed for material investigations, but also a catch-all for any problem that does not adequately fit the profile of one of the other mechanisms.
- Engineering Events – The standard process for engineering-specific problems where internal engineering quality control oversight is required.
- Incomplete Work List – This is the tool used by each program to manage open work and known problems. However, the information within contains references to multiple other problem management mechanisms.

There are countless other mechanisms that exist in pockets throughout the company, including some in the programs, facilities, safety, and human resources divisions. In addition, for nearly every mechanism, there is little to no consistency in the way problems, corrections, communication, awareness, complexity, liability, cost, schedule, quality, or KM is handled.

6.1.2 Problem Management Responsibility

In the past two years, the responsibility for managing Corrective Action Requests has evolved from a distributed model to a centralized model. Before fall 2014, and for all of the CARs included in the sample used in this study, CARs were managed individually by program, and the effectiveness varied widely from one program to another. The consistency of the responses across programs suffered, and the single customer oversight authority received conflicting responses for similar problems across multiple programs, which in turn created more potential issues and cost the company in customer confidence. Additionally, there was less success in identifying widespread, systemic issues, and no consistent mechanism for elevating the concerns when systemic issues were identified. Since the transition, the overall quality of the responses has improved, as well as the response time, but a lack of resources has delayed further improvements in reducing the backlog of these problems.

Problem management involves a constant struggle between strategic and tactical objectives. The tactical response to a problem addresses the issue using specific resources to achieve specific goals. The strategic response addresses the issue to prevent recurrence or otherwise improve the operating and long term goals of the organization. In many cases, a balance of both is ideal, and the problem management authority should consider each when managing problems.

The current program management paradigm in place utilizes a matrix-based organization preferred by the customer. These project-based trade management organizations allow the focus to be at the whim of the program manager, whether it is schedule, cost, quality, or other driving force, instead of on the technical expertise of an independent trade management-based organization. This makes addressing problems substantially more difficult, and the functional area representatives involved are less accountable to the requirements behind the issues.

6.1.3 Problem Categories

The SEPMP identifies 5 categories of problems (Olson et al., 2012):

- Technical
- Cost
- Schedule
- Safety/Environmental
- Programmatic

The last category, Programmatic, seems to include everything that does not fit into one of the other categories. The SEPMP also acknowledges that each problem will likely be characterized as belonging to more than one category. In practice, and while reviewing the individual problem reports for this analysis, the author found this to be true. Additionally, categories such as Quality, Legal, or Employee Engagement were recognized as viable options distinct from the five original categories, even understanding there is overlap for nearly every problem. Additionally, there are Environmental issues that are more related to Technical than Safety (such as chemical storage or paint application).

To provide an understanding (again, subjectively) of the problems in the sample analyzed, the author developed a Venn diagram (Figure 6-1) to document the perception of the multiple categories and the level of duplication or overlap that exists when characterizing these problems. As the diagram illustrates, there are a couple of near absolute truths for these problems – 1) every problem has a cost component, and 2) nearly every problem has a schedule component.

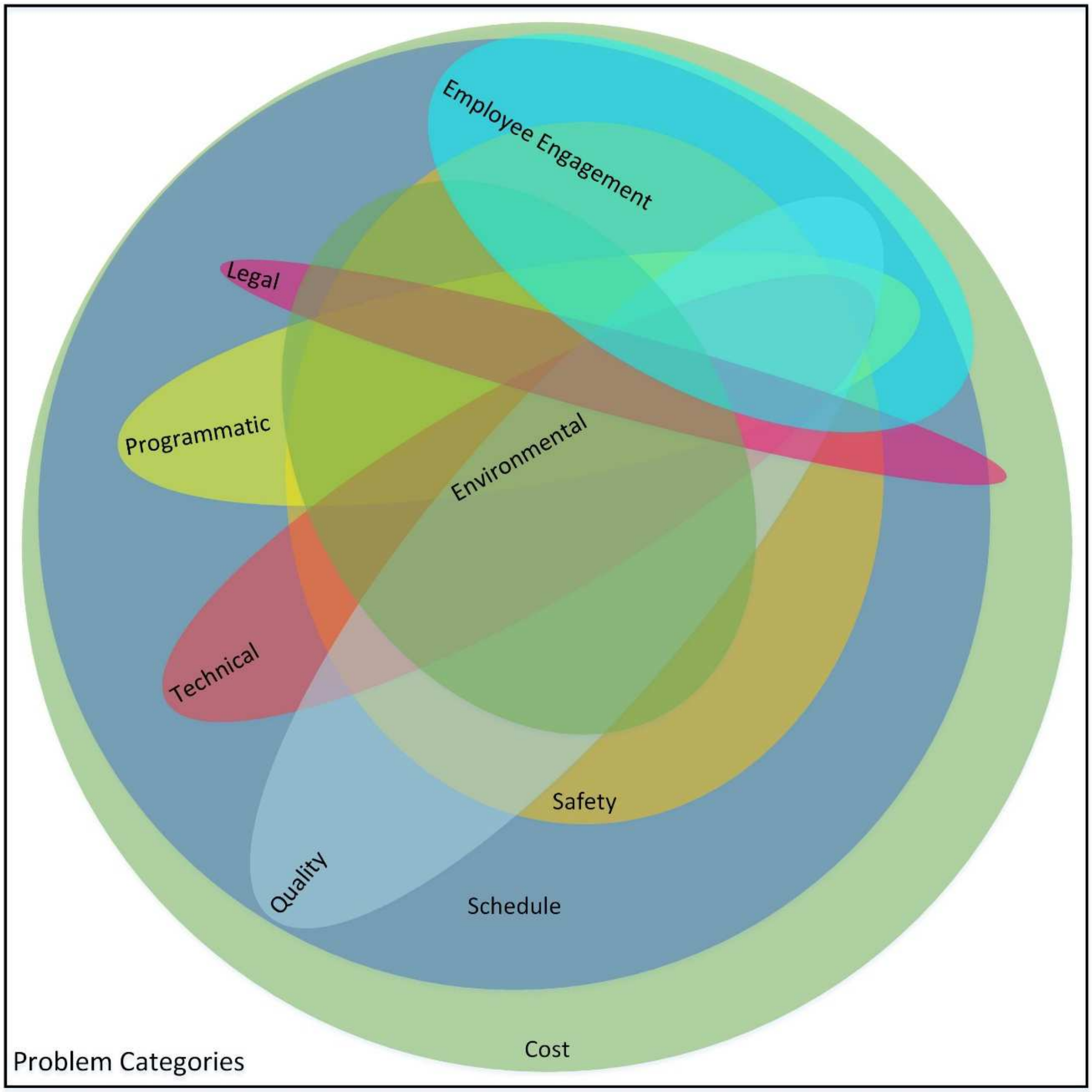

Figure 6-1: Problem Category Venn Diagram

6.1.4 Work Model

Several divisions within this company use a work model approach to problem solving based on the nuclear work model (Devgun, 2013). The basic work model has been embellished for use in this company and Figure 6-2 shows the essential components of the model. Problem investigators are often asked to consider the model as they perform their investigations.

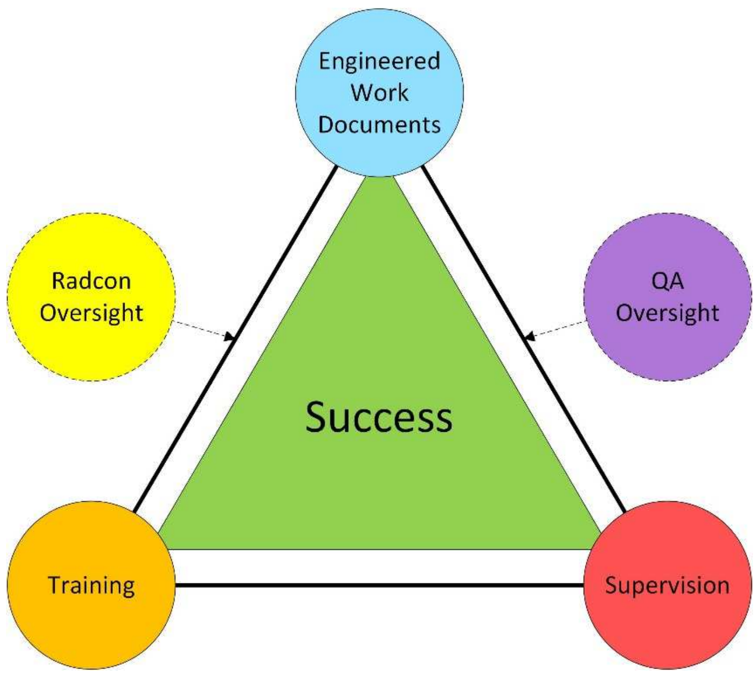

Figure 6-2: Nuclear Work Model

When a problem or failure occurs, the work model can help the investigator perform the necessary root cause analysis to ensure the appropriate actions are taken. The model suggests there are three components necessary to have success in an organizational operation – 1) adequate training, 2) engineered work documents, drawings, or instructions, and 3) appropriate supervision. To some extent, a weakness in one area can be acceptably compensated for by excess in one or both of the other areas. Regardless, quality assurance and radiological control oversight (or other technical oversight organization for non-nuclear work) helps to ensure the model and the corresponding efforts are in place to provide the opportunity for success.

6.1.5 Problem Severity Level

One characteristic of many of the problem management mechanisms is the use of Problem Severity Level designations to quickly recognize the seriousness of a specific problem within a mechanism designed for multiple levels of problems. A common pictorial representation of this phenomena in the author's organization is shown in Figure 6-3.

In this diagram, the larger triangle on the left shows the breakdown of problems by percentage of occurrence that fall into each severity level, with the most severe occurring the least often. The goal of a responsible problem management organization is to continuously improve their process by identifying future red issues from the information available on current yellow and green problems. In the model below, the red issues are eliminated, so the more critical level two issues are then treated as red issues, and the percentage of the green problems grows accordingly.

Unfortunately, the mechanisms in place are not always conducive to identifying the next critical issue. The knowledge management is anemic compared to the necessary effort to reliably accomplish this type of improvement on a regular basis. Few mechanisms plan for this capability.

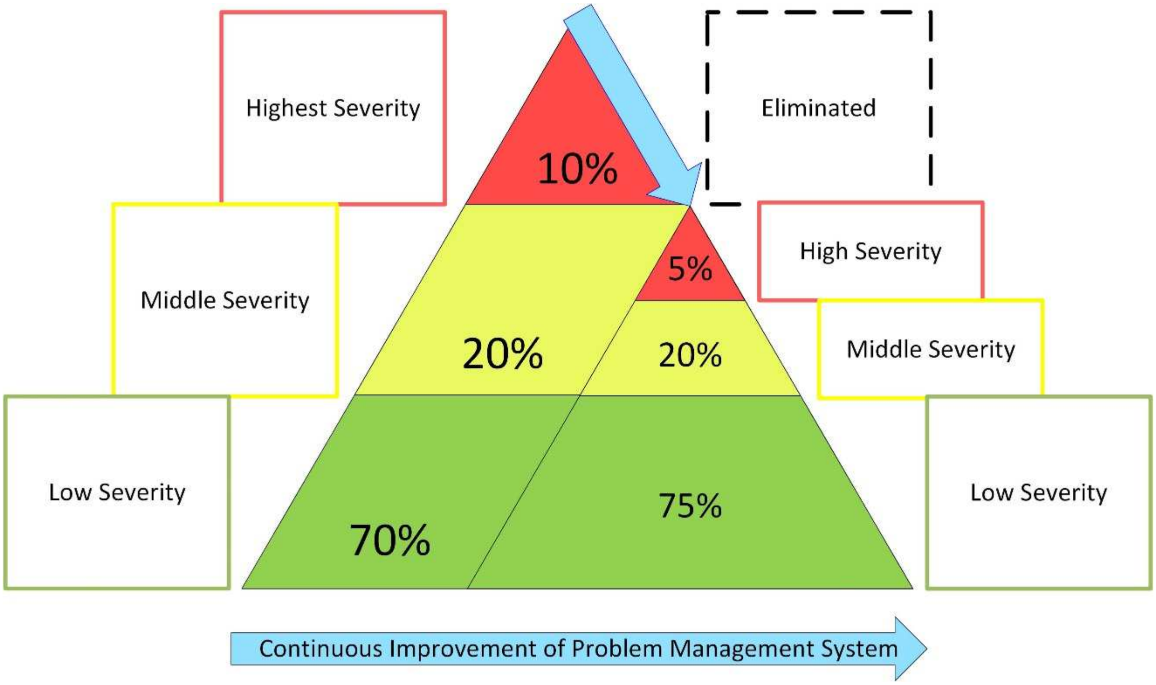

Figure 6-3: Problem Severity Levels

6.1.6 Yellow Line / Red Line Philosophy

Another idea being embraced in some areas of the author's company is the concept of Yellow Lines and Red Lines to promote self-detection and self-correction of problems.

- The yellow line is a boundary that is crossed when an internal or external oversight organization identifies an issue and makes a local functional area aware of the problem. On one level, it is the responsibility of the oversight organization to identify these issues. However, and more importantly, it is the responsibility of the functional area to identify and correct its own issues without information from the oversight organization.
- The red line is a boundary that is crossed when the internal or external oversight organization has to help the local functional area identify and

correct problems. This is a more severe failure because the functional area missed its responsibility to identify but also could not fix the issue once it was identified. This implies the current organization is inadequate to accomplish its purpose, and is working without a safety net.

6.2 Individual Problems

Four problems from the data sample were selected based on various conditions detailed below, in order to gain an understanding of the types of problems, the nature of the problem management system's representation of the problem, and the efficacy of the primary study's characterization of the problems.

The case study model used to evaluate these problems in detail is based on the Convergence of Evidence practices identified by Robert Yin for case-study research (Yin, 2009). Figure 6-4 shows the evidence that was available and used to determine the facts of the problems. The case studies themselves have been sanitized as necessary to remove technical or proprietary details not needed to understand the issue or the role of problem management in addressing the issue.

Convergence of Evidence

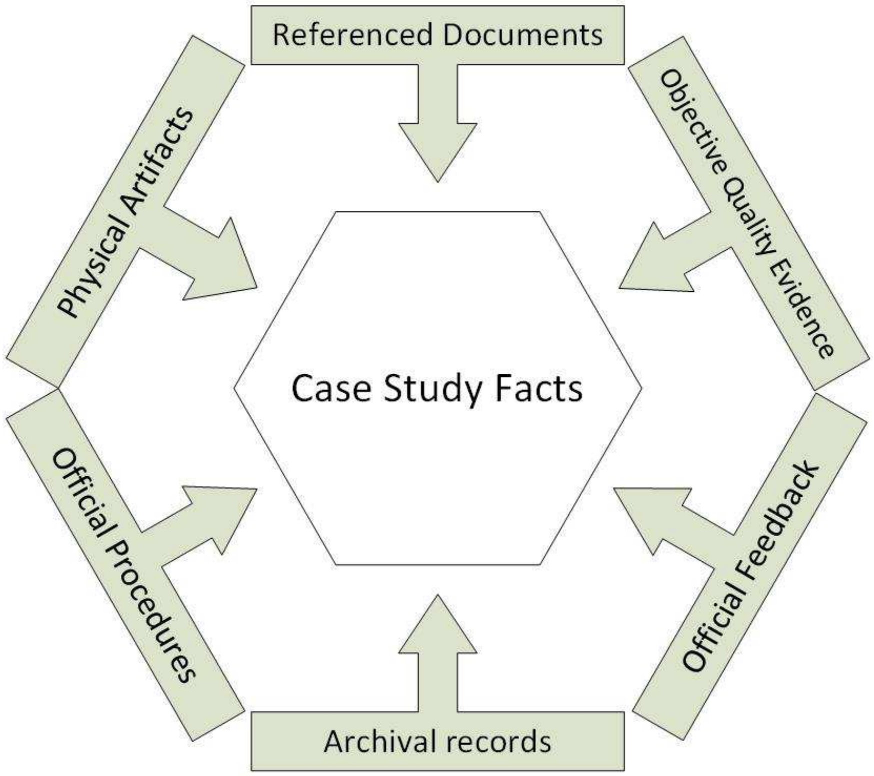

Figure 6-4: Convergence of Evidence

6.2.1 Problem 72

The author selected Problem 72 to be subjected to an in-depth analysis because of its revelatory status as the lowest calculated EPM from the entire sample (-158.88). This score was achieved by combining a process delay of 510 days (also an extreme), a timeliness of 197 days, and zero solving actions. The issue within is a somewhat complex supply chain management failure.

Figure 5-10 shows the stakeholder relationships contributing to the problem. The manufacturer (M) receives a complex, highly specialized mechanical assembly from the

Vendor (V), who receives some components of the assembly from the Subcontracted Supplier (SS). The Customer Oversight Authority (COA) has access to and performs regular audits of all the facilities in use by M, V, and SS. M was responsible for oversight of V, but also responsible for indirect oversight of SS. COA noted that V had not relayed appropriate technical requirement information to SS, which called into question V's control of Objective Quality Evidence. As a result, SS experienced instances of inadequate record certifications, with required signatures missing. The calibration system in use at SS was inadequate for the tolerances specified by the technical requirements, and the sampling methodology was also not appropriate. Finally, SS experienced calibration issues (beyond the system used) and quality defects in workmanship.

The actions taken by V involved a long-term, detailed bounding investigation where the findings at SS were evaluated. V discovered (or admitted) it had been taking on the responsibility of addressing these and similar issues with the components supplied by SS, and assembly lead times suffered as a result. In this case, the delivery for the mechanical assembly was delayed almost a year while the investigation cleared the concern for the delivery (and subsequent use) of the assembly. No urgency was communicated regarding the date the assembly was needed by the construction program, which was 197 days after the problem was identified. Very little information about the problem was relayed in the primary records, which potentially contributed to the duration of the bounding actions.

No solving actions were reported because V was taking on the responsibility to correct SS deficiencies. With one of the root causes being identified as V's poor communication of the technical requirements, the chain of poor communication about the problem, and the events leading to the problem, calls into question the missed opportunity to address communication as a cause. The delay of the assembly shipment of over ten months likely had many ripple effects on the project plan for the entire program. In this case, the model used for EPM accurately reflected a problem management failure, but the uniqueness and complexity of the problem cannot be fully appreciated without a more thorough review of the facts.

This issue contained facets with many overlapping problem categories. There is a technical component, but also quality issues. Schedule delay was a key byproduct of the failure, and delay nearly always inflates costs. Safety is always a concern when complex machinery technical information is not accurate, and depending on the severity of the issue and the willingness of the four identified stakeholders to address it, there may be a legal component to the problem category.

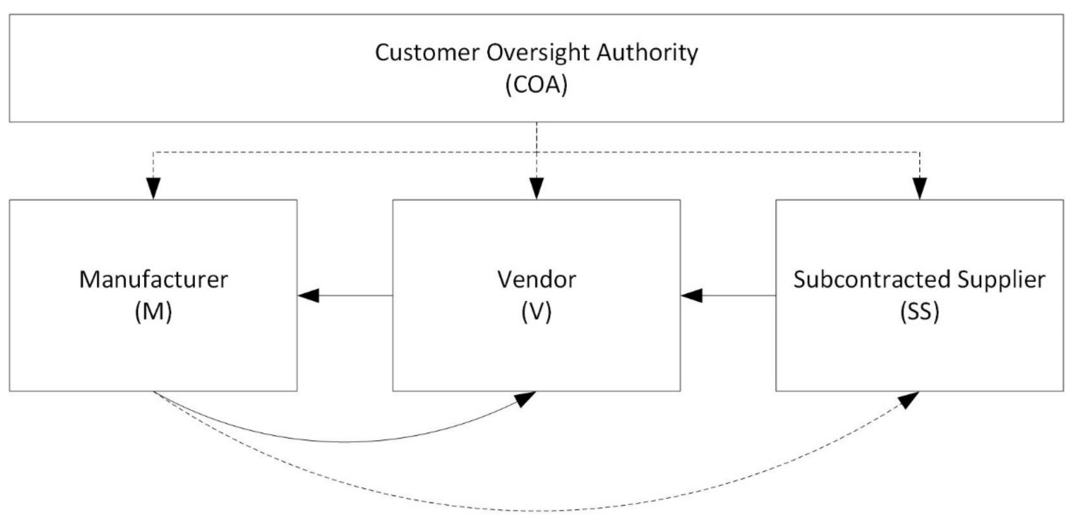

Figure 6-5: Problem 72 Stakeholders

6.2.2 Problem #78

Problem 78 was selected for an in-depth analysis because of its calculated EPM was well below the first quartile (-0.032), despite having average impact and timeliness communication results (5 and 7, respectively). This EPM score was a result of a process delay of 49 days, a timeliness of 197 days, and one solving action. The subject is a construction process and performance issue. The problem is primarily a construction issue – welded materials did not match the drawing, but also had a quality component, with inadequate surface conditions noted.

The problem report notes inadequate supervision, failure to work to a technical document, and insufficient training, all of which are reminiscent of the work model identified in Section 6.1.4. Insufficient training and inadequate supervision are two of the three corners of the work model. There is no evidence to suggest the technical work document itself was incorrect, although there was an interpretation question on one of the findings that was eventually rescinded. Still, in any process, in can be difficult to overcome failures on two of the corners.

The process delay that contributed to the poor EPM result was ultimately caused by the time necessary to correct the defects identified, with almost two weeks of schedule lost. One of the referenced documents indicated this issue had previously occurred, which prompts the question of whether a potentially systemic issue was not identified at the previous occurrence, and whether or not it was identified in problem 78. Unfortunately, the records do not indicate capturing this issue, but a cursory review of later problems uncovered additional findings of a similar nature. Again, this problem can be categorized in many ways. There are quality, cost, schedule, and programmatic components identified. The schedule delay, recurrence, and work model challenges indicate the low EPM is accurate.

6.2.3 Problem #5

Problem 5 was analyzed in detail because of its distinguished EPM (195.92) and exceptionally low process delay. This EPM score was calculated from a process delay of 2 days, a timeliness of 49 days, and a single solving action. This is specifically interesting because Impact Communication was in the first quartile and Timeliness Communication was at the median score. The issue within appears to be less complex than many of the problems in the sample – a key standard procedure for operational validation on one of the company's primary programs was found to contain passages that were in conflict with customer technical requirement documents.

Median Timeliness Communication, and a somewhat simple problem with which the functional area management accepts and agrees, overcome substandard impact communication to allow for a two day turnaround, barely chipping away at the 49 days of schedule remaining. The only action documented was a change to the affected procedure, which qualifies it as a solving action. What is not obvious from the data collected is the story behind what is not included in the report.

There was no bounding action performed. Additional investigative actions may have decreased the EPM score, but actually increased the effectiveness of the problem management. The specific issues cited in the problem were only applicable to the specific procedure and the specific technical requirement on which the procedure is based. This may be why the functional area manager did not challenge the issue or take more time to investigate and resolve it.

However, additional bounding in a general sense, or more accurately, looking for other procedures not meeting their own specific functional requirements, would have been a long process in a complex organization containing thousands of procedures, even if a sampling method would have been used (and it often is used). Doing so would have delayed the solution, perhaps even approaching or exceeding the 49 day Timeliness limit, and added more non-solving actions, both of which drastically reducing the EPM score, but creating a more thorough and effective instance of problem management. With existing processes in place for regular procedure reviews, additional actions were deemed excessive in this case. Any problem management process needs to consider the opportunity cost of managing problems and make decisions according to the business strategies in place. This is also a justification for improving the Impact Communication practices, if for no other reason than to make the best business decision using all available information to support the decision. This problem appears to be primarily technical, but even the short delay affected the cost and the schedule.

6.2.4 Problem #172

Problem 172 is the last of the four problems being subjected to an in-depth analysis, and the author chose it because the Communications scores were both top quartile. The EPM score (172.86) was achieved by combining a process delay of 19 days, a timeliness of 70 days, and nine corrective actions, all of which were solving actions. The problem is a series of welding process violations. While the specific issues identified are not terribly complex, the visibility of the process and the amount of work done on the process is substantial for this company. Thorough and effective communication is critical for complex problems, but also for more straightforward issues to prevent them from escalating into widespread systemic issues. That's exactly what happened in this instance. The problem categories for this issue include technical, programmatic, schedule, and cost components.

Failure to communicate the facts could have allowed this issue to turn into something much more substantial – similar issues in the past have started simple and grown because of lack of attention. This is an example of successfully avoiding this trap.

6.3 Conclusions and Implications of the Case Study Analysis

The qualitative observations discussed above reviewed the many types of problem management mechanisms in place in the author's company, and addressed the strengths and weaknesses of several examples to illustrate that there is not a consistent experience among the many different mechanisms.

Several operating models for problem management functions were discussed, including distributed versus centralized responsibilities, strategic versus tactical approaches, and project-focused versus trade-focused management structures, and how they affect problem management.

The multiple categories of problems from the study sample were evaluated, and a Venn diagram was presented to suggest the complexity of the subject. The work model used in many problem investigations was discussed, as were Problem Severity Levels as a tool for continuous improvement of problem management practices. Finally the Red Line /Yellow Line Philosophy was reviewed.

The information available was sufficient to provide information to support the case study goal, which is a deeper understand of the problem, the problem management mechanism, and its effectiveness in capturing the truth of the problem. This investigation implies that problem solving can be used effectively as a skill, but this is not absolute across the complex organization. However, the feedback and analysis indicates problem management is disjointed and inconsistently applied across the organization.

The individual problems also provided insight into problem solving and problem management in the organization. In one case, the extreme scores in the primary study alone did not sufficiently explain the nature of the issue, and the deep dive was necessary to understand the problem and the difficulty in resolving the problem (especially since multiple vendors were involved), but the scores and low overall rating were fair given the criteria of the study.

A second case showed that the most prudent path for effectively managing a problem, if it had been followed and recommended actions were taken, may have made the EPM score lower than it was based on the actions completed. This seems to be an unusual scenario, but may also encourage the next researchers evaluating the SEPMP to consider a more robust measure of effectiveness.

Using the information obtained from the SAP reporting function is helpful when performing a study like this, but the key takeaways from the case study analysis are that the details are important and that knowledge management is most effective when it captures more than just the numbers, but also the story. The story is what can be used to identify systemic issues, prevent larger problems in the future, and effectively manage problems. The apparent issue is ensuring that the information is easy to obtain and use. Data mining can be time consuming when the salient details are obscured in rhetoric.

Chapter 7. Conclusions, Recommendations, and Future Research

7.1 Conclusions

This study is the first attempt to validate the proposed SEPMP model. Significant relationships were identified, and they were obtained using a novel approach to measuring the characteristics of the model and determining effective problem management. The convenience sample used was sufficient to establish a foundation of research on the subject, and to demonstrate the potential for additional results in the future that may drive acceptance of this model as a Systems Engineering tool.

The failure to establish a relationship between Effective Problem Management and the additional variables tested does nothing to eliminate them from concern, but it does suggest the model may be on the right track. As the research surrounding the SEPMP grows, these variables should be considered until other research models can conclusively exclude them. Also, additional variables must be explored to further refine the SEPMP, such as problem cost, problem management cost, problem category, and recurrence.

7.2 Recommendations for Enhancing the SEPMP

There is an incredible opportunity for complex organizations to be able to consolidate multiple official processes and unofficial practices into a single system, designed for the task of managing a wide array of problems. This is the essence of engineering a system, and of field of systems engineering. There is now some empirical evidence to support the SEPMP. Based on this research, the additional findings, the case study, and the author's experience in performing the review of the data for this study and in applied problem management, the section contains recommendations for improving the SEPMP model in the following ways.

7.2.1 Problem Solving and Problem Management

In the case study, the author identified multiple mechanisms for problem management within the subject organization, with varying effectiveness with respect to program management. However, the problems evaluated were eventually addressed effectively. Problem solving can be achieved with the tools in place, but the inconsistency of problem management techniques challenged the effectiveness of the organization. The SEPMP should make Problem Solving and Problem Management modular, and approach each as a function of the other. Problem solving is a skill as well as a technique, and many organizations already have a method and the required training system in place to succeed, but struggle in how problems are managed, such as identified in the case study. The novelty of the SEPMP is truly the use of a risk-style matrix to facilitate problem management. Making these concepts modular will facilitate implementation of the SEPMP as a problem management tool, without over committing limited resources to a problem solving skill for which there are multiple turn-key solutions available, such as Apollo or Think Reliability.

In fact, the ISO 9000 standard ("ISO 9000 - Quality management," 2016) prescribes a Quality Management System to include mechanisms for addressing non-conformity. This details the traditional problem solving actions, including:

- RCA
- Bounding
- Correction of Defect
- Correction of Cause
- Reviewing Corrective Actions for Effectiveness

Problem management involves the process through which problem solving, problem notification and reporting, action tracking, corrective action effectiveness, and all of the supporting actions are managed, as well as managing the process or processes for problem solving, and also doing so in a way that best benefits the organization. The SEPMP meets some of these objectives by incorporating the problem matrix paradigm as a means to improve the communication, reporting, and understanding of problem status.

7.2.2 Knowledge Management and Identification of Systemic Issues

The case study evaluation of the four problems identified a wealth of information not available in the standard SAP reporting function. Data mining efforts supporting the identification of systemic issues often rely on these standard reports. Strengthen the role of the knowledge management within the SEPMP to ensure the identification of systemic issues. The organization must instill faith in its stakeholders that the problem management process will continually strive for effective knowledge management, and that mechanisms are in place to self-identify and elevate systemic issues.

Lower level recurring issues must be evaluated and considered for elevation to a higher status. Below is an example of how this would work.-Whenever a trend of similar problems exceeds the established thresholds or other triggers, the stakeholder must declare an Area of Concern. The investigator creates a spreadsheet with all of the known findings, causes, and corrective actions taken. The investigator then evaluates other data streams (such as the other problem management mechanisms in Section 6.1.1) for similar problems and compiles all of the findings on the spreadsheet. With the completed spreadsheet, the investigator develops a white paper on the subject and submits it to a Preventive and Corrective Action Board, recommending a more detailed cross functional assessment at a higher level in the company. The PCAB team represents senior management from all functional areas of the organization, and they evaluate and respond with one of several possible outcomes, including:

- No issue – the problem team keeps the issue on a watch list until the trend subsides or elevates.
- PCAB issue – the PCAB agrees takes on the investigation from a global perspective.
- Request more information – the PCAB will enlist the help of the internal audit and assessment team to perform additional audits or assessments as necessary to make a recommendation on the subject.

There are many potential triggers indicating widespread or systemic problems (WSSP). This includes any of the following possible problem thresholds:

- Repeating (historical instead of current)
- Special Cause - Above and beyond a normal cause
- Smaller Corrective Actions failed
- Occurs in multiple platforms, projects, or programs
- Defect rate for a process hits a trigger percentage
- Customer identifies it as a WSSP
- Risk exists for the problem to lead to a bigger problem

7.2.3 Make the SEPMP Scalable

Many of the problem management mechanisms identified in the case study exist to address different levels of problems. As a complex organization such as the one in the case study transitions to fewer problem management mechanisms during the conversion to SEPMP, the scalability of the process must be considered to account for varying Problem Severity Levels. As an example from the case study, problems of a significant level may be evaluated by the PCAB. Eventually, lower level problems must be evaluated by a correspondingly lower level audience, to maximize the effectiveness of the various stakeholders and teams involved. Depending on the size and complexity of the organization, it may not be appropriate for the company president to preside over a low level problem review. The correct levels of review need to be established in the SEPMP charter process, creating a scalable but consistent process for all problems, with the goals of efficiency from fewer mechanisms, consistency from the charter of the SEPMP, and effectiveness at preventing larger level problems by appropriate reviewing, elevating, and managing the known issues.

7.2.4 Feedback Loop to Risk Management

The most recent revision to ISO 9001, rev E (ISO, 2015), added a mandate for risk-based thinking. The SEPMP was established before this new revision, but based on the ISO recommendation, The SEPMP is a problem management process built on the success of the risk management process, so logic follows that risk-based thinking should be an easy extension of the SEPMP. The author recommends embracing the mandate and establishing a feedback loop to the risk management process for managed problems and also where there is concern for escalation from existing problems to a more serious situation. Figure 7-1 demonstrates the concept.

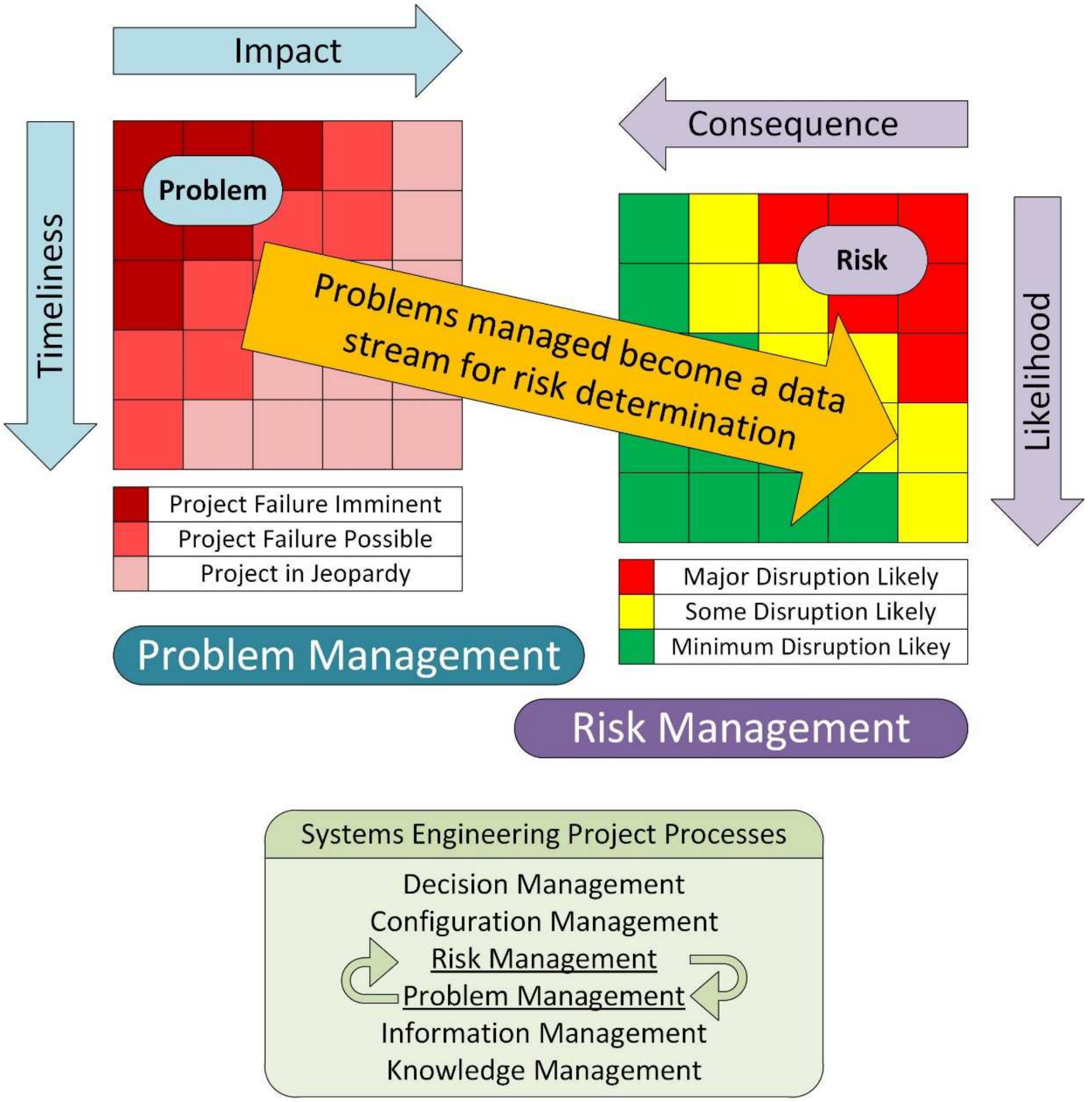

Figure 7-1: Feedback Loop to Risk Management

7.2.5 Commit to Continuous Improvement of the SEPMP Itself

With multiple problem management mechanisms identified in the subject organization, and multiple models, paradigms, and philosophies in use, the effectiveness of each becomes difficult to quantify, much less improve. To address this concern, another recommendation for enhancing the SEPMP is to strive for quick implementation and system improvement from the inception of the process. The implementing team should develop and employ a Problem Management Capability and Maturity Model similar to the concepts presented by K.T. Yeo and Yingtao Ren (Yeo & Ren, 2009). Using the Yeo & Ren model as a template, and tweaking it to better suit problem management, the problem management model could resemble Tables 7-1 and 7-2.

Table 7-1: PM-CMM Maturity Levels

Maturity Level	1. Ad-Hoc	2. Initial	3. Defined	4. Managed	5. Optimizing

Table 7-2: PM-CMM Key Capability Areas

Category	**Key Capability Area**
Organization	Organizational Culture
	Stakeholder Support and Buy-in
	Leadership
	Organization Structure and Support
Process	Problem Identification and Validation
	Problem Reporting and Knowledge Management
	Problem Investigation
	Corrective Action Effectiveness
	SEPMP Process Integration
Technology	Technology and Tools

7.2.6 Impact Granularity

With the large overlap in the practical categorization of problem types, as specified in Section 6.1.3, the implemented SEPMP should consider increasing the granularity of the Impact portion of the problem matrix to allow for individual impact ratings on all of the impact types, with perhaps the highest one deciding the problem's location in the problem matrix.

7.3 Areas for Future Research

The next empirical research effort should offer other measures for Effective Problem Management, and case studies should be employed to provide qualitative evaluations of the SEPMP. Furthermore, looking at the modularization of the SEPMP into solving and management components may help to clarify this idea. Research into problem solving is needed to establish primary requirements for problem solving techniques when used in various complex systems. Additionally, there are many areas where problem management needs to be evaluated.

The role of problem management in the system life cycle must be explored, and the suggested refinements to the model, including feedback loops and Capability Maturity Models for continuous improvement of the system or program, should be evaluated concurrently and independently where possible. Future research may also consider the use of systems thinking during investigation and analysis. Additional research should expand the variables assessed, and take into account other variables, such as:

- Types of Impacts (e.g., technical, cost, schedule, or safety)
- Cost of Problem
- Cost to Manage Problem (Administration)
- Cost to Investigate Problems
- Widespread Systemic Problems

- Likelihood of Recurrence
- Likelihood of Detection
- Problem Severity Level
- Centralized versus Distributed Management
- Strategic versus Tactical approaches to problem management
- Matrix organizations and program management responsibility for problem management versus trade management responsibility

Finally, each of the recommended enhancements will need to be evaluated through research. This is the beginning of research into the SEPMP; every research proposal has the potential to be valid, necessary, and groundbreaking. As the body of research for the SEPMP expands, and if the SEPMP is to become an accepted methodology, it is imperative that future research addresses quantitative risk analysis and mirrors research in that field where possible. Another area in dire need of research would include the use of predictive analytics to identify problems. All of this will determine the role of problem management in the system's life cycle and may exhibit the value of problem management as a systems engineering process.

7.4 SEPMP and the Future of Systems Engineering

There is considerable effort and cost associated with establishing a problem management process, with high stakes for failure (Perry et al., 2016). Efforts are underway in the organization from which this data was obtained that may lead to case studies and other empirical research. Future research will benefit from lessons learned in problem management, increased data collection and analysis, and additional metrics employed.

Challenges and maximizing value are recurring themes in the Systems Engineering Vision 2025 (Hartmann, 2014), and these ideas imply that problems will continue to occur, and that organizations must manage problems in a cost effective manner. Additionally, the SE Vision 2025 predicts the future of Systems Engineering as an environment dependent on methods and tools designed to accommodate increasing complexity (Hartmann, 2014). In the authors' opinion, increased system complexity precipitates a need for effective problem management. The SEPMP is worthy of the additional consideration and research necessary for the tool to be added to the system engineer's tool box to meet this need.

References

Anderson, D. M. (2014). *Design for Manufacturability: How to Use Concurrent Engineering to Rapidly Develop Low-Cost, High-Quality Products for Lean Production* (First ed.): Productivity Press; Boca Raton, FL.

Anthony Cox, L. (2008). What's Wrong with Risk Matrices? *Risk Analysis, 28*(2), 497-512. doi: 10.1111/j.1539-6924.2008.01030.x

Arrow, J. (2008). Knowledge-Based Proactive Project Risk Management. *AACE International Transactions*, 1-9.

Bahill, A. T. (2012). Diogenes, a process for identifying unintended consequences. *Systems Engineering, 15*(3), 287-306. doi: 10.1002/sys.20208

Baldassarre, M., Caivano, D., Pino, F., Piattini, M., & Visaggio, G. (2012). Harmonization of ISO/IEC 9001:2000 and CMMI-DEV: from a theoretical comparison to a real case application. *Software Quality Journal, 20*(2), 309-335. doi: 10.1007/s11219-011-9154-7

Baldwin, K. J. (2015). *Department of Defense Risk, Issue, and Opportunity Management Guide for Defense Acquisition Programs*. Washington, DC: Department of Defense.

Ball, D. J., & Watt, J. (2013). Further Thoughts on the Utility of Risk Matrices. *Risk Analysis, 33*(11), 2068-2078. doi: 10.1111/risa.12057

Berkeley, D., Humphreys, P. C., & Thomas, R. D. (1991). Project risk action management. *Construction Management & Economics, 9*(1), 3.

Bhatia, M. S., & Awasthi, A. (2014). Investigating Effectiveness of Quality Management Systems. *IIE Annual Conference. Proceedings*, 1594-1603.

Bristow, M., Fang, L., & Hipel, K. W. (2012). System of Systems Engineering and Risk Management of Extreme Events: Concepts and Case Study. *Risk Analysis, 32*(11), 1935-1955. doi: 10.1111/j.1539-6924.2012.01867.x

Bryant, J. (1989). *Problem Management: A Guide for Producers and Players*. New York, NY: Wiley.

Cariou, V. (2006). Extension of multivariate regression trees to interval data. Application to electricity load profiling. *Computational Statistics, 21*(2), 325-341. doi: http://dx.doi.org/10.1007/s00180-006-0266-7

Casacci, S., & Pareto, A. (2015). Methods for quantifying ordinal variables: a comparative study. *Quality & Quantity, 49*(5), 1859-1872. doi: 10.1007/s11135-014-0063-2

Chang, R. Y., & Kelly, P. K. (1993). *Step-By-Step Problem Solving*. San Francisco: Jossey-Bass Pfeiffer.

Devgun, J. (2013). *Managing Nuclear Projects - A comprehensive management resurce* (Vol. 60). Oxford: Woodhead Publishing.

Dey, P. K. (2002). Project Risk Management: A Combined Analytic Hierarchy Process and Decision Tree Approach. *Cost Engineering, 44*(3), 13.

Duijm, N. J. (2015). Recommendations on the use and design of risk matrices. *SAFETY SCIENCE, 76*(Journal Article), 21-31. doi: 10.1016/j.ssci.2015.02.014

Edwards, P. J., & Bowen, P. A. (1998). Risk and risk management in construction: a review and future directions for research. *Engineering Construction & Architectural Management (Blackwell Publishing Limited), 5*(4), 339.

Gahin, F. S. (1971). Review of the Literature on Risk Management. *Journal of Risk & Insurance, 38*(2), 309.
Galley, M. (2007). Six Common Errors when Solving Problems (pp. 1-6). Houston, TX: Think Reliability.
Galley, M. (2008). Basic Elements of a Comprehensive Investigation (pp. 1-5). Houston, TX: Think Reliability.
Gano, D. L. (1999). *Apollo Root Cause Analysis - A New Way of Thinking*. Yakima, WA: Apollonian Publications.
Grossi, L., Calvo-Manzano, J. A., & San Feliu, T. (2014). High-maturity levels: achieving CMMI ML-5 in a consultancy company. *Journal of Software: Evolution and Process, 26*(9), 808-817. doi: 10.1002/smr.1666
Guglielmo, G., M. (2009). ITIL Problem Management Tool Guide. Washington, DC: Fermi National Accelerator Laboratory.
Haimes, Y. Y. (2012). Systems-Based Guiding Principles for Risk Modeling, Planning, Assessment, Management, and Communication. *Risk Analysis, 32*(9), 1451-1467. doi: 10.1111/j.1539-6924.2012.01809.x
Hall, M. G. (2014). *Problem Management: An Implementation Guide for the Real World*. Swindon, UK: BCS, The Chartered Institute for IT.
Hartmann, R. (2014). A World in Motion - Systems Engineering Vision 2025. www.incose.org.
Harwell, M. R., & Gatti, G. G. (2001). Rescaling ordinal data to interval data in educational research. *Review of Educational Research, 71*(1), 105-131.
Haskins, C. (2011). *Systems Engineering Handbook - A Guide for System Life Cycle Processes and Activities, Version 3.2.2*: INCOSE.
Hatfield, A. J., & Hipel, K. W. (2002). Risk and Systems Theory. *Risk Analysis: An International Journal, 22*(6), 1043-1057.
Hessami, A. G. (1999). Risk management: A systems paradigm. *Systems Engineering, 2*(3), 156-167. doi: 10.1002/(sici)1520-6858(1999)2:3<156::aid-sys3>3.0.co;2-h
ISO 9000 - Quality management. (2016). *International Standards Organization* Retrieved June 10, 2016, from http://www.iso.org/iso/home/standards/management-standards/iso_9000.htm
ISO. (2015). ISO 9001 Quality Management Systems - Requirements *Risk-based Thinking*. Switzerland.
Kabachinski, J. (2011). Have You Heard of ITIL? It's Time You Did. *Biomedical Instrumentation & Technology, 45*(1), 59-62.
Kaliprasad, M. (2006). Proactive Risk Management. *Cost Engineering, 48*(12), 26-36.
Khraiwesh, M. (2012). Risk Management Measures in CMMI. *International Journal of Software Engineering & Applications, 3*(1), 149-163. doi: 10.5121/ijsea.2012.3111
Kujawski, E., & Angelis, D. (2010). Monitoring risk response actions for effective project risk management. *Systems Engineering, 13*(4), 353-368. doi: 10.1002/sys.20154
Lock, R. (2012). Developing a methodology to support the evolution of System of Systems using risk analysis. *Systems Engineering, 15*(1), 62-73. doi: 10.1002/sys.20194

Olson, B. A., Mazzuchi, T. A., Sarkani, S., & Forsberg, K. (2012). Problem management process, filling the gap in the systems engineering processes between the risk and opportunity processes. *Systems Engineering, 15*(3), 275-286. doi: 10.1002/sys.20209

Park, J., Seager, T. P., Rao, P. S. C., Convertino, M., & Linkov, I. (2013). Integrating Risk and Resilience Approaches to Catastrophe Management in Engineering Systems. *Risk Analysis, 33*(3), 356-367. doi: 10.1111/j.1539-6924.2012.01885.x

Parkinson, C. N. (1955, Nov 19, 1955). Parkinson's Law. *The Economist*.

Pennock, M. J., & Haimes, Y. Y. (2002). Principles and guidelines for project risk management. *Systems Engineering, 5*(2), 89-108. doi: 10.1002/sys.10009

Perry, D. A., Olson, B., Blessner, P., & Blackburn, T. D. (2016). Evaluating the Systems Engineering Problem Management Process for Industrial Manufacturing Problems. *Systems Engineering*, n/a-n/a. doi: 10.1002/sys.21340

Rice, J. F. (2010). Adaptation of Porter's Five Forces Model to risk management. *Defense AR Journal, 17*(3), 375-388.

Sage, A. P., and Rouse, W. B. (2009). *Handbook of Systems Engineering and Management* (Second ed.). Hoboken, NJ: John Wiley & Sons, Inc.

Smith, E. D., Siefert, W. T., & Drain, D. (2009). Risk matrix input data biases. *Systems Engineering, 12*(4), 344-360. doi: 10.1002/sys.20126

Soomro, T. R., and Hesson, Mihyar. (2012). Supporting Best Practices and Standards for Information Technology Infrastucture Library. *Journal of Computer Science, 8*(2), 272-276.

Sproull, B. (2001). *Process Problem Solving*. Portlan, OR: Productivity Press.

Srivastav, A. K. (2007a). Problem Management Across Age Groups: An Empirical Study. *ICFAI Journal of Management Research, 6*(10), 71-81.

Srivastav, A. K. (2007b). Problem Management in Public Sector: An Empirical Study. *South Asian Journal of Management, 14*(1), 38-52.

Su, Z.-g., & Wang, P.-h. (2014). Regression analysis of belief functions on interval-valued variables: comparative studies. *Soft Computing, 18*(1), 51-70. doi: 10.1007/s00500-013-1033-7

Taylor, H. (2006). Risk Management and Problem Resolution Strategies for IT Projects: Prescription and Practice. *Project Management Journal, 37*(5), 49-63.

UCISA. (2016). ITIL - A Guide to Problem Management Retrieved 6/30/2016, from https://www.ucisa.ac.uk/~/media/Files/members/activities/ITIL/service_operation/problem_management/ITIL_a%20guide%20to%20problem%20management%20pdf.ashx

Walker, G. (2001). *IT Problem Management*. Upper Saddle River, NJ: Prentice Hall.

Weber, E. S., & Konsynski, B. R. (1987). Problem Management: Neglected Elements in Decision Support Systems. *Journal of Management Information Systems, 4*(3), 64-81.

Yeo, K. T., & Ren, Y. (2009). Risk management capability maturity model for complex product systems (CoPS) projects. *Systems Engineering, 12*(4), 275-294. doi: 10.1002/sys.20123

Yin, R. K. (2009). *Case Study Research; Design and Methods* (Fourth ed.). Thousand Oaks, CA: SAGE, Inc.

Appendix A – Data

Independent Variables						Root Dependent Variables					Outcome DV
Impact_Comm	Time_Comm	Complexity	Scope	Effort	KM	Timeliness	Corrective_Actions	Process_Delay	Training_Actions	Process_Improvements	EPM
8	6	10	10	8	25	854	20	8	6	5	154.0632
7	6	1	10	2	4	83	1	2	0	0	97.5904
4	3	8	5	5	13	148	4	14	1	1	140.5405
4	3	3	1	4	4	127	3	15	0	0	88.1890
3	5	1	3	2	4	49	1	2	0	1	195.9184
6	3	9	2	4	14	178	19	21	6	7	156.6233
5	6	1	1	9	6	100	17	8	8	0	139.0588
5	5	1	3	6	6	91	11	10	4	0	125.3746
2	2	1	4	7	3	157	1	7	0	0	95.5414
7	3	3	6	6	4	269	8	30	1	0	101.3476
5	5	1	6	2	4	334	1	24	0	1	192.8144
7	6	3	1	7	7	63	7	14	2	0	106.3492
3	5	4	2	7	10	88	7	10	3	0	131.4935
7	6	4	3	5	10	63	8	13	3	0	116.8651
5	4	1	0	8	5	59	6	60	3	0	48.3051
5	3	2	3	6	7	74	10	12	2	0	103.7838
7	5	10	4	4	18	206	28	88	11	14	146.5673
6	5	2	1	7	7	46	6	28	2	0	72.4638
4	5	3	2	3	8	41	4	18	0	0	56.0976
5	5	2	1	3	5	27	3	3	0	0	88.8889
7	5	3	1	4	6	50	6	20	1	0	76.6667
3	5	9	3	6	4	256	2	14	1	0	144.5313
2	1	4	6	5	4	432	3	6	0	0	98.6111
9	6	3	3	8	7	50	13	13	6	0	120.1538
7	5	6	4	5	10	302	10	24	4	1	142.0530
1	4	7	2	2	5	106	2	5	0	0	95.2830
5	3	1	5	6	4	172	1	2	1	0	198.8372
4	7	8	3	4	5	37	2	7	1	0	131.0811
4	7	1	1	3	4	41	2	1	0	0	97.5610
7	3	1	1	2	4	247	4	2	2	1	174.1903
5	5	4	4	3	9	349	4	0	2	1	175.0000

Impact_Comm	Time_Comm	Complexity	Scope	Effort	KM	Timeliness	Corrective_Actions	Process_Delay	Training_Actions	Process_Improvements	EPM
6	10	3	8	4	15	59	4	10	1	3	183.0508
7	3	1	0	8	5	572	1	21	0	1	196.3287
5	7	4	3	9	11	47	9	8	3	1	144.4444
6	8	1	11	3	8	57	8	12	5	2	166.4474
5	7	1	5	3	5	42	2	1	1	1	197.6190
6	5	1	2	4	9	660	5	36	2	1	154.5455
10	6	1	1	9	6	47	11	1	6	1	161.5087
5	7	4	2	2	9	322	6	4	0	5	182.0911
6	10	1	1	3	5	64	4	0	1	1	150.0000
5	4	8	10	3	16	93	19	4	3	6	143.0673
7	7	2	8	5	10	42	2	0	0	1	150.0000
5	5	1	2	5	5	162	2	2	0	1	148.7654
1	3	1	4	5	8	203	6	14	1	2	143.1034
7	4	1	2	4	6	35	12	14	0	0	60.0000
8	4	1	1	2	4	35	2	0	1	0	150.0000
5	2	1	3	11	9	214	8	51	1	3	126.1682
3	3	1	4	3	5	43	2	15	0	0	65.1163
7	7	1	2	4	5	43	1	1	1	0	197.6744
8	8	1	1	3	4	62	3	0	0	3	200.0000
9	8	1	1	8	6	57	13	0	12	1	200.0000
9	1	1	4	13	9	207	11	40	0	3	107.9491
6	7	3	1	5	6	60	4	10	2	1	158.3333
7	5	1	1	11	10	144	11	31	2	5	142.1086
3	1	1	4	7	11	760	6	58	1	1	125.7018
7	3	1	12	17	14	182	22	50	14	0	136.1638
4	2	3	3	2	6	158	5	35	0	2	117.8481
7	4	6	3	9	11	70	8	12	2	1	120.3571
2	2	1	0	1	3	519	1	54	0	0	89.5954
4	5	2	2	6	7	62	2	6	0	0	90.3226
4	4	1	2	5	5	117	3	9	1	0	125.6410
5	5	4	2	3	8	184	7	21	0	1	102.8727
7	6	3	1	6	7	55	8	23	4	0	108.1818
3	2	6	4	4	10	184	6	17	0	0	90.7609
5	4	1	2	4	4	39	2	43	1	0	39.7436
3	3	4	4	10	12	538	4	164	0	2	119.5167

Impact_Comm	Time_Comm	Complexity	Scope	Effort	KM	Timeliness	Corrective_Actions	Process_Delay	Training_Actions	Process_Improvements	EPM
4	2	7	3	4	18	328	14	277	0	7	65.5488
5	7	1	3	8	6	20	6	20	3	0	50.0000
4	4	1	1	4	4	35	3	35	2	0	66.6667
7	4	4	1	6	9	99	4	37	0	1	87.6263
4	3	1	1	4	4	36	2	36	1	0	50.0000
3	1	1	0	4	6	197	1	510	0	0	-158.8832
4	2	1	3	6	6	120	5	101	0	2	55.8333
5	5	1	5	4	6	34	2	11	1	1	167.6471
2	4	1	4	10	6	111	1	0	0	0	100.0000
5	3	1	6	4	5	61	1	56	0	0	8.1967
5	6	3	3	11	9	221	8	4	3	2	160.6900
5	7	7	5	6	9	37	6	49	1	0	-15.7658
7	4	1	2	8	5	91	5	77	2	2	95.3846
8	5	2	3	2	5	75	2	39	0	2	148.0000
6	6	2	1	5	8	125	5	0	0	0	100.0000
8	7	1	2	6	6	49	7	29	7	0	140.8163
5	4	1	2	8	5	57	9	61	6	0	59.6491
6	5	1	5	5	6	131	4	118	1	3	109.9237
7	2	5	4	10	10	274	9	230	1	4	71.6139
6	6	5	3	7	8	65	5	8	3	0	147.6923
4	3	4	4	7	9	118	6	122	1	2	46.6102
5	2	3	8	4	8	62	4	99	0	0	-59.6774
6	4	2	2	7	8	92	2	89	0	0	3.2609
1	3	1	4	1	6	97	4	95	0	0	2.0619
5	5	1	2	6	4	56	2	55	1	0	51.7857
5	4	7	5	6	12	394	8	371	2	0	30.8376
9	5	3	5	5	7	135	5	22	0	4	163.7037
7	8	1	1	4	7	106	9	72	3	2	87.6310
4	2	1	4	6	8	498	3	485	0	1	35.9438
7	8	1	1	3	5	29	5	13	3	0	115.1724
6	8	1	1	5	5	82	5	22	0	2	113.1707
8	10	1	3	7	8	40	10	0	5	0	150.0000
5	4	1	1	7	5	104	2	111	0	2	93.2692
9	8	1	4	5	5	25	8	22	5	0	74.5000
7	5	1	5	4	6	34	3	34	2	0	66.6667

Impact_Comm	Time_Comm	Complexity	Scope	Effort	KM	Timeliness	Corrective_Actions	Process_Delay	Training_Actions	Process_Improvements	EPM
4	7	4	2	5	8	75	11	2	6	0	151.8788
6	4	1	1	5	5	97	2	93	1	1	104.1237
10	8	1	1	8	8	119	21	22	5	7	138.6555
8	6	1	2	4	7	162	2	96	0	2	140.7407
9	6	8	5	34	18	235	26	76	7	5	113.8134
5	7	2	2	3	5	28	4	31	2	0	39.2857
7	5	4	6	14	13	87	16	73	4	0	41.0920
5	4	1	2	7	5	36	4	35	1	0	27.7778
5	1	8	1	6	12	122	14	93	3	4	73.7705
4	3	2	1	6	8	239	8	97	2	2	109.4142
5	5	3	4	5	15	257	4	203	0	3	96.0117
5	4	2	0	4	7	29	5	29	0	2	40.0000
4	7	3	3	2	9	155	7	23	1	1	113.7327
3	5	2	4	8	6	41	8	33	2	0	44.5122
7	6	1	4	7	6	168	6	148	1	2	61.9048
6	6	5	4	2	8	76	4	19	0	0	75.0000
5	7	1	4	2	5	122	1	81	0	0	33.6066
4	3	2	4	3	6	357	2	90	0	0	74.7899
8	6	1	2	8	6	397	8	37	2	1	128.1801
6	4	12	4	7	21	237	19	234	0	13	69.6869
6	4	3	3	3	7	139	3	129	0	2	73.8609
2	3	1	1	5	5	142	3	134	1	1	72.3005
6	4	8	2	4	13	95	16	99	4	6	58.2895
4	6	5	1	5	11	181	10	163	0	4	49.9448
6	6	3	3	7	7	34	4	34	2	1	75.0000
7	8	3	2	5	8	160	6	6	2	0	129.5833
8	1	2	1	4	7	328	2	39	0	0	88.1098
6	5	1	4	5	6	386	6	50	2	1	137.0466
1	2	1	3	6	5	298	13	303	3	5	59.8606
4	4	2	3	5	6	43	4	131	0	3	-129.6512
6	5	1	3	2	5	18	3	20	1	0	22.2222
6	6	1	3	5	5	41	2	1	1	0	147.5610
5	4	3	5	7	7	151	4	156	1	1	46.6887
8	5	2	3	7	8	70	6	27	2	0	94.7619
5	3	3	3	5	8	297	4	60	2	0	129.7980

Impact_Comm	Time_Comm	Complexity	Scope	Effort	KM	Timeliness	Corrective_Actions	Process_Delay	Training_Actions	Process_Improvements	EPM
2	2	2	5	4	6	132	2	91	1	0	81.0606
5	4	1	1	5	5	59	4	56	2	1	80.0847
7	3	2	7	7	11	191	10	151	0	2	40.9424
4	6	4	1	5	7	110	5	49	2	1	115.4545
7	5	2	2	5	6	322	5	15	1	3	175.3416
7	9	1	3	6	5	53	5	29	1	1	85.2830
7	4	2	6	4	5	184	3	1	1	0	132.7899
5	7	1	3	4	4	17	2	17	1	0	50.0000
5	5	1	1	9	6	64	3	27	2	0	124.4792
7	4	1	4	5	5	45	4	41	0	2	58.8889
2	3	1	2	8	6	165	1	151	1	0	108.4848
5	4	3	3	11	7	169	7	28	3	1	140.5748
4	4	1	1	2	5	40	4	31	1	1	72.5000
3	3	6	10	4	12	240	5	33	0	2	126.2500
2	4	3	3	4	12	96	4	29	1	1	119.7917
6	1	1	1	4	6	174	12	172	0	1	9.4828
6	8	1	1	3	6	75	8	12	1	1	109.0000
5	5	1	3	3	5	232	3	24	2	0	156.3218
8	3	1	4	6	5	300	2	19	0	0	93.6667
7	10	4	2	10	10	44	6	7	0	2	117.4242
1	5	1	2	3	5	50	1	33	0	0	34.0000
4	5	1	3	3	5	29	3	29	1	0	33.3333
5	6	2	1	7	5	44	4	34	1	1	72.7273
10	5	6	2	9	17	89	10	35	4	6	160.6742
7	5	3	2	3	9	209	6	22	0	4	156.1404
4	4	5	2	5	11	62	10	63	0	1	8.3871
6	5	3	4	7	9	76	7	46	1	5	125.1880
5	1	1	5	4	11	201	3	184	1	0	41.7910
8	7	2	7	9	10	68	12	27	2	9	151.9608
7	8	1	3	7	5	23	7	3	5	1	172.6708
4	2	1	2	4	5	79	3	62	1	0	54.8523
5	2	5	3	8	10	175	10	178	2	0	18.2857
3	3	1	3	4	5	28	5	27	0	0	3.5714
6	4	3	3	9	9	53	8	41	3	2	85.1415
1	4	2	3	4	7	32	2	29	0	0	9.3750

Impact_Comm	Time_Comm	Complexity	Scope	Effort	KM	Timeliness	Corrective_Actions	Process_Delay	Training_Actions	Process_Improvements	EPM
2	9	2	3	13	6	209	11	5	6	3	179.4258
8	2	2	4	4	6	79	2	88	0	1	38.6076
6	6	1	1	5	5	55	3	28	2	0	115.7576
2	3	2	3	4	5	204	1	27	0	0	86.7647
6	1	1	2	3	6	238	4	154	0	0	35.2941
2	8	7	3	7	11	41	5	6	0	3	145.3659
6	4	3	3	5	7	86	6	89	2	1	46.5116
5	8	1	4	9	6	421	6	0	1	1	133.3333
5	2	1	5	3	4	54	1	53	1	0	101.8519
9	7	2	2	7	6	70	9	19	9	0	172.8571
8	2	2	4	3	7	134	3	128	0	2	71.1443
5	6	3	7	5	6	230	6	27	3	1	154.9275
9	6	1	1	6	4	105	2	14	2	0	186.6667
8	9	3	4	8	8	43	4	1	2	1	172.6744
6	5	1	4	12	10	258	17	228	2	2	35.1573
6	3	2	3	10	7	39	16	42	4	4	42.3077
3	4	4	1	4	8	28	4	26	1	0	32.1429
4	3	1	2	5	5	43	3	45	2	0	62.0155
2	7	6	4	4	10	34	3	21	0	0	38.2353
7	6	1	4	5	6	218	10	170	0	3	52.0183
5	4	1	4	6	6	62	7	35	2	0	72.1198
6	5	1	1	8	9	291	2	83	0	2	171.4777
8	4	14	1	5	16	313	19	76	4	2	107.2978
4	5	1	3	4	4	35	1	10	0	0	71.4286
10	6	6	2	6	6	206	9	25	6	1	165.6419
1	1	1	3	1	5	57	1	57	0	0	0.0000
5	6	1	3	8	5	149	4	47	1	0	93.4564
4	8	4	4	3	11	98	4	7	0	1	117.8571
2	4	8	1	12	22	161	7	77	0	0	52.1739
6	5	6	2	6	9	66	4	63	1	3	104.5455
4	6	4	2	10	5	70	5	30	1	1	97.1429
5	6	4	2	9	9	204	5	46	1	2	137.4510
9	4	1	2	9	5	54	6	30	5	1	144.4444
8	7	3	3	10	8	42	6	26	0	2	71.4286
6	8	1	7	8	6	128	2	34	1	1	173.4375

Impact_Comm	Time_Comm	Complexity	Scope	Effort	KM	Timeliness	Corrective_Actions	Process_Delay	Training_Actions	Process_Improvements	EPM
7	6	1	1	4	5	38	3	30	1	1	87.7193
8	7	4	1	8	11	176	10	23	4	3	156.9318
8	8	1	1	5	4	127	6	14	3	0	138.9764
2	1	1	2	3	4	190	3	113	0	0	40.5263
5	5	1	3	6	5	52	3	39	0	1	58.3333
5	2	1	3	5	5	293	2	301	0	0	-2.7304
4	4	1	1	3	4	69	3	63	1	0	42.0290
8	9	2	9	7	6	168	5	19	2	2	168.6905
6	4	1	1	3	4	47	3	36	2	0	90.0709
3	5	1	2	6	5	99	4	102	0	0	-3.0303
10	10	3	3	6	4	109	22	36	13	4	144.2452
4	7	1	3	9	5	39	4	18	1	0	78.8462
4	4	1	4	5	4	36	2	43	1	0	30.5556
3	6	1	2	3	4	145	1	33	0	1	177.2414
5	10	2	4	3	6	47	5	8	3	0	142.9787
7	6	3	11	5	7	153	7	39	3	2	145.9384
5	4	14	6	13	21	351	19	236	7	2	80.1320
2	8	2	3	10	7	30	10	20	8	1	123.3333
8	4	2	3	4	6	84	3	40	0	0	52.3810
4	4	2	3	5	5	99	3	29	1	0	104.0404
5	3	3	0	7	10	76	4	84	0	1	14.4737
1	6	1	4	6	6	170	2	141	0	0	17.0588
5	2	4	5	5	8	35	7	43	0	0	-22.8571
6	9	2	6	8	8	63	9	13	4	0	123.8095
9	6	2	2	3	6	66	4	61	2	1	82.5758
10	8	2	3	7	7	141	10	50	3	4	134.5390
3	5	2	1	6	6	105	2	46	0	0	56.1900
7	3	1	3	6	5	42	4	33	3	0	96.4290
5	4	1	3	4	4	159	5	73	1	0	74.0880
8	9	1	2	5	5	50	3	2	2	0	162.6670
4	2	1	3	3	4	65	4	61	1	0	31.1540
3	6	1	2	6	4	147	3	105	1	1	95.2380
5	3	1	3	5	4	27	1	25	1	0	107.4070
6	5	3	2	6	8	126	6	65	0	4	115.0790
7	5	6	8	9	10	71	7	55	2	2	79.6780

Impact_Comm	Time_Comm	Complexity	Scope	Effort	KM	Timeliness	Corrective_Actions	Process_Delay	Training_Actions	Process_Improvements	EPM
9	8	1	1	13	7	295	11	40	3	4	150.0770
1	2	1	2	4	5	58	6	79	1	0	-19.5400
7	9	4	2	6	9	127	3	8	2	0	160.3670
8	5	1	1	8	6	280	11	19	3	4	156.8510
9	7	2	2	1	4	173	2	28	0	1	133.8150
7	5	1	1	5	5	35	2	29	2	0	117.1430
6	6	1	1	6	6	39	8	19	2	3	113.7820
7	7	1	2	6	4	35	5	26	4	0	105.7140
3	3	1	1	3	4	39	3	35	1	0	43.5900
2	3	1	1	5	6	67	1	47	0	0	29.8510
8	10	1	2	8	5	25	5	1	4	0	176.0000
10	6	1	10	4	9	70	3	1	2	0	165.2380
3	3	1	1	5	5	33	7	30	1	1	37.6620
8	7	6	4	7	9	102	6	36	3	2	148.0390
5	5	5	2	7	8	77	6	63	1	0	34.8480
3	4	3	5	5	7	52	5	21	2	0	99.6150
6	5	1	8	7	11	111	13	34	2	2	100.1390
6	5	5	3	3	8	68	10	36	6	0	107.0590
3	2	1	2	6	5	42	7	45	2	0	21.4290
4	3	2	4	8	5	70	8	14	3	0	117.5000
6	5	5	2	3	11	185	10	159	2	2	54.0540
8	6	1	2	6	5	54	3	24	0	2	122.2220
3	6	1	2	6	5	57	4	32	3	0	118.8600
8	3	1	1	7	5	99	9	51	2	0	70.7070
4	7	5	5	7	13	172	4	34	1	1	130.2330
7	1	1	2	4	5	30	5	31	1	0	16.6670
1	3	1	2	3	6	27	4	27	1	0	25.0000
3	4	1	3	5	5	190	2	23	0	0	87.8950
4	2	9	2	10	16	219	8	213	1	2	40.2400
8	7	1	4	10	5	69	5	35	3	0	109.2750
4	6	1	2	7	4	105	3	33	1	1	135.2380
8	4	1	3	7	4	43	4	37	1	0	38.9530
7	1	1	2	8	5	81	4	85	1	0	20.0620
3	8	1	1	5	4	46	4	1	2	0	147.8260
9	6	3	6	7	8	94	6	36	2	4	161.7020

Impact_Comm	Time_Comm	Complexity	Scope	Effort	KM	Timeliness	Corrective_Actions	Process_Delay	Training_Actions	Process_Improvements	EPM
10	7	2	1	7	5	74	5	8	2	1	149.1890
7	10	1	1	7	5	21	10	5	7	0	146.1900
6	2	1	2	6	5	23	4	24	1	0	20.6520
3	4	2	6	5	8	42	3	35	2	0	83.3330
5	7	1	1	6	5	32	4	29	2	0	59.3750
6	3	1	3	5	5	45	2	41	1	0	58.8890
2	5	1	2	6	5	31	6	21	4	0	98.9250
1	2	1	2	4	4	26	1	31	0	0	-19.2310
1	1	1	2	4	5	43	2	76	0	0	-76.7440
6	5	1	2	12	8	91	13	15	3	0	106.5930
6	3	1	2	6	5	125	3	11	0	1	124.5330
6	5	2	3	6	6	105	3	109	1	0	29.5240
5	2	2	3	4	6	158	6	145	0	0	8.2280
6	5	1	3	4	4	45	1	1	0	0	97.7780
3	4	2	3	5	6	60	5	47	2	0	61.6670
6	3	6	3	5	13	85	6	82	0	0	3.5290
2	9	5	3	5	7	101	3	9	2	0	157.7560
4	3	1	4	2	6	121	3	116	1	0	37.4660
1	3	1	1	1	4	48	2	56	0	0	-16.6670
6	2	1	2	2	5	27	4	27	1	0	25.0000
8	7	1	3	3	4	34	4	15	1	0	80.8820
4	5	5	3	4	9	27	7	16	6	0	126.4550
9	4	2	4	7	6	80	3	82	2	0	64.1670
7	5	3	2	8	9	87	16	21	10	0	138.3620
5	7	1	1	4	4	27	1	27	1	0	100.0000
6	6	1	3	4	6	53	6	23	3	0	106.6040
3	4	7	4	9	10	87	14	90	7	0	46.5520
8	5	2	2	6	6	46	8	42	4	0	58.6960
4	8	1	1	3	5	69	1	46	0	1	133.3330
4	5	1	2	2	4	70	3	31	0	1	89.0480
10	8	1	3	5	4	41	2	10	0	0	75.6100
6	6	1	3	4	5	40	5	2	3	0	155.0000
8	9	1	3	3	5	58	5	18	3	1	148.9660
5	4	1	1	4	5	35	7	34	1	3	60.0000
4	5	1	1	5	5	32	4	34	4	0	93.7500

Impact_Comm	Time_Comm	Complexity	Scope	Effort	KM	Timeliness	Corrective_Actions	Process_Delay	Training_Actions	Process_Improvements	EPM
6	6	1	1	4	5	28	7	19	2	2	89.2860
3	6	2	2	3	5	9	4	2	3	0	152.7780
9	9	1	6	2	4	14	1	0	1	0	200.0000

Appendix B – Minitab Session Examples

Descriptive Statistics: Impact_Comm, Time_Comm, Complexity, References, ...

Variable	N	Mean	StDev	Minimum	Q1	Median
Impact_Comm	314	5.443	2.147	1.000	4.000	5.000
Time_Comm	314	4.930	2.126	1.000	3.000	5.000
Complexity	314	2.433	2.243	1.000	1.000	1.000
References	314	2.971	2.031	0.000000000	2.000	3.000
Effort	314	5.678	2.990	1.000	4.000	5.000
KM	314	7.038	3.318	3.000	5.000	6.000
Timeliness	314	121.83	117.35	9.00	44.00	78.00
Corrective_Actio	314	5.799	4.504	1.000	3.000	4.000
Process_Delay	314	50.86	65.87	0.000000000	14.00	31.00
Training_Actions	314	1.787	2.207	0.000000000	0.000000000	1.000
Process_Improvem	314	1.083	1.812	0.000000000	0.000000000	0.000000000
EPM	314	94.95	56.17	-158.88	56.03	98.19

Variable	Q3	Maximum
Impact_Comm	7.000	10.000
Time_Comm	6.000	10.000
Complexity	3.000	14.000
References	4.000	12.000
Effort	7.000	34.000
KM	8.000	25.000
Timeliness	162.00	854.00
Corrective_Actio	7.000	28.000
Process_Delay	60.00	510.00
Training_Actions	2.000	14.000
Process_Improvem	2.000	14.000
EPM	140.55	200.00

Correlations: Impact_Comm, Time_Comm, Complexity, References, Effort, KM, EPM

	Impact_Comm	Time_Comm	Complexity	References	Effort
Time_Comm	0.361				
	0.000				
Complexity	-0.004	-0.026			
	0.942	0.641			
References	0.073	0.020	0.179		
	0.200	0.730	0.001		
Effort	0.214	0.092	0.191	0.102	
	0.000	0.102	0.001	0.071	
KM	0.077	-0.034	0.762	0.313	0.375
	0.174	0.542	0.000	0.000	0.000
EPM	0.375	0.528	0.050	0.115	0.119
	0.000	0.000	0.380	0.041	0.035

	KM
EPM	0.064
	0.259

Cell Contents: Pearson correlation
P-Value

Regression Analysis: EPM versus Impact_Comm, Time_Comm, ...

The regression equation is
EPM = - 3.9 + 5.29 Impact_Comm + 12.0 Time_Comm + 1.22 Complexity
      + 2.30 References + 0.344 Effort - 0.10 KM

Predictor	Coef	SE Coef	T	P
Constant	-3.85	10.18	-0.38	0.706
Impact_Comm	5.294	1.343	3.94	0.000
Time_Comm	11.958	1.331	8.98	0.000
Complexity	1.223	1.846	0.66	0.508
References	2.302	1.371	1.68	0.094
Effort	0.3441	0.9797	0.35	0.726
KM	-0.105	1.368	-0.08	0.939

S = 46.4769   R-Sq = 32.9%   R-Sq(adj) = 31.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	324499	54083	25.04	0.000
Residual Error	307	663151	2160		
Total	313	987650			

Source	DF	Seq SS
Impact_Comm	1	138891
Time_Comm	1	174907
Complexity	1	3861
References	1	6568
Effort	1	259
KM	1	13

Unusual Observations

Obs	Impact_Comm	EPM	Fit	SE Fit	Residual	St Resid
1	8.0	154.06	145.63	16.21	8.43	0.19 X
5	3.0	195.92	80.22	5.18	115.70	2.51R
11	5.0	192.81	97.71	6.55	95.10	2.07R
22	3.0	144.53	91.38	15.91	53.15	1.22 X
27	5.0	198.84	72.87	5.96	125.97	2.73R
28	4.0	131.08	118.57	12.85	12.51	0.28 X
30	7.0	174.19	72.87	6.43	101.32	2.20R
32	6.0	183.05	169.38	13.59	13.67	0.31 X
33	7.0	196.33	72.53	6.69	123.80	2.69R
35	6.0	166.45	150.31	12.38	16.13	0.36 X
44	1.0	143.10	48.63	7.45	94.47	2.06R
56	7.0	136.16	102.31	16.74	33.85	0.78 X
72	3.0	-158.88	25.96	7.14	-184.84	-4.02R
78	5.0	-15.77	127.51	8.20	-143.28	-3.13R
88	5.0	-59.68	69.16	8.26	-128.84	-2.82R
106	9.0	113.81	146.65	25.33	-32.84	-0.84 X
121	6.0	69.69	99.84	12.61	-30.15	-0.67 X
131	4.0	-129.65	75.60	3.32	-205.25	-4.43R
194	8.0	107.30	105.80	16.03	1.50	0.03 X
200	2.0	52.17	68.48	15.58	-16.31	-0.37 X
223	5.0	80.13	103.66	14.51	-23.52	-0.53 X
285	1.0	-76.74	20.08	7.04	-96.82	-2.11R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: EPM versus Impact_Comm, Time_Comm, ...

The regression equation is
EPM = - 4.11 + 5.29 Impact_Comm + 12.0 Time_Comm + 1.12 Complexity
+ 2.27 References + 0.318 Effort

Predictor	Coef	SE Coef	T	P
Constant	-4.105	9.608	-0.43	0.669
Impact_Comm	5.288	1.338	3.95	0.000
Time_Comm	11.967	1.324	9.04	0.000
Complexity	1.116	1.210	0.92	0.357
References	2.274	1.318	1.72	0.086
Effort	0.3181	0.9175	0.35	0.729

S = 46.4018   R-Sq = 32.9%   R-Sq(adj) = 31.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	5	324486	64897	30.14	0.000
Residual Error	308	663164	2153		
Total	313	987650			

Source	DF	Seq SS
Impact_Comm	1	138891
Time_Comm	1	174907
Complexity	1	3861
References	1	6568
Effort	1	259

Unusual Observations

Obs	Impact_Comm	EPM	Fit	SE Fit	Residual	St Resid
1	8.0	154.06	146.44	12.28	7.62	0.17 X
5	3.0	195.92	80.16	5.12	115.75	2.51R
11	5.0	192.81	97.56	6.23	95.25	2.07R
27	5.0	198.84	72.63	5.01	126.21	2.74R
30	7.0	174.19	72.83	6.40	101.36	2.21R
33	7.0	196.33	72.47	6.62	123.86	2.70R
35	6.0	166.45	150.43	12.26	16.01	0.36 X
41	5.0	143.07	102.82	11.51	40.25	0.90 X
44	1.0	143.10	48.88	6.66	94.22	2.05R
56	7.0	136.16	102.62	16.23	33.55	0.77 X
72	3.0	-158.88	26.11	6.85	-185.00	-4.03R
78	5.0	-15.77	127.19	6.99	-142.96	-3.12R
88	5.0	-59.68	69.08	8.18	-128.75	-2.82R
106	9.0	113.81	146.40	25.07	-32.58	-0.83 X
121	6.0	69.69	100.20	11.65	-30.52	-0.68 X
131	4.0	-129.65	75.56	3.26	-205.21	-4.43R
172	2.0	179.43	127.36	11.47	52.07	1.16 X
194	8.0	107.30	105.55	15.68	1.74	0.04 X
223	5.0	80.13	103.60	14.47	-23.47	-0.53 X
253	10.0	165.24	145.70	11.55	19.54	0.43 X
285	1.0	-76.74	20.08	7.03	-96.83	-2.11R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: EPM versus Impact_Comm, Time_Comm, ...

The regression equation is
EPM = - 3.10 + 5.38 Impact_Comm + 12.0 Time_Comm + 1.19 Complexity
+ 2.30 References

Predictor	Coef	SE Coef	T	P
Constant	-3.103	9.150	-0.34	0.735
Impact_Comm	5.377	1.311	4.10	0.000
Time_Comm	11.977	1.322	9.06	0.000
Complexity	1.194	1.187	1.01	0.315
References	2.299	1.314	1.75	0.081

S = 46.3357   R-Sq = 32.8%   R-Sq(adj) = 32.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	324228	81057	37.75	0.000
Residual Error	309	663423	2147		
Total	313	987650			

Source	DF	Seq SS
Impact_Comm	1	138891
Time_Comm	1	174907
Complexity	1	3861
References	1	6568

Unusual Observations

Obs	Impact_Comm	EPM	Fit	SE Fit	Residual	St Resid
1	8.0	154.06	146.71	12.24	7.36	0.16 X
5	3.0	195.92	81.00	4.51	114.91	2.49R
11	5.0	192.81	98.66	5.36	94.16	2.05R
27	5.0	198.84	72.40	4.97	126.43	2.74R
30	7.0	174.19	73.96	5.50	100.23	2.18R
33	7.0	196.33	71.66	6.19	124.67	2.71R
35	6.0	166.45	151.46	11.88	14.99	0.33 X
41	5.0	143.07	104.23	10.75	38.83	0.86 X
44	1.0	143.10	48.60	6.60	94.51	2.06R
56	7.0	136.16	99.25	13.00	36.91	0.83 X
72	3.0	-158.88	26.20	6.84	-185.08	-4.04R
78	5.0	-15.77	127.47	6.94	-143.24	-3.13R
88	5.0	-59.68	69.71	7.96	-129.39	-2.83R
121	6.0	69.69	100.59	11.58	-30.90	-0.69 X
131	4.0	-129.65	75.60	3.25	-205.25	-4.44R
150	3.0	126.25	79.11	10.50	47.14	1.04 X
194	8.0	107.30	106.83	15.22	0.46	0.01 X
222	7.0	145.94	135.27	10.83	10.67	0.24 X
223	5.0	80.13	102.20	13.87	-22.07	-0.50 X
253	10.0	165.24	146.72	11.15	18.52	0.41 X
285	1.0	-76.74	20.04	7.02	-96.79	-2.11R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

Regression Analysis: EPM versus Impact_Comm, Time_Comm, References

```
The regression equation is
EPM = - 0.68 + 5.37 Impact_Comm + 11.9 Time_Comm + 2.54 References

Predictor      Coef  SE Coef      T      P
Constant     -0.684    8.828  -0.08  0.938
Impact_Comm   5.368    1.311   4.09  0.000
Time_Comm    11.942    1.321   9.04  0.000
References    2.536    1.293   1.96  0.051

S = 46.3365   R-Sq = 32.6%   R-Sq(adj) = 32.0%

Analysis of Variance

Source           DF      SS      MS      F      P
Regression        3  322057  107352  50.00  0.000
Residual Error  310  665593    2147
Total           313  987650

Source       DF  Seq SS
Impact_Comm   1  138891
Time_Comm     1  174907
References    1    8259

Unusual Observations

Obs  Impact_Comm      EPM     Fit  SE Fit  Residual  St Resid
  1          8.0   154.06  139.28    9.76     14.78      0.33 X
  2          7.0    97.59  133.91    9.55    -36.32     -0.80 X
  5          3.0   195.92   82.74    4.16    113.18      2.45R
 27          5.0   198.84   74.67    4.43    124.17      2.69R
 30          7.0   174.19   75.26    5.35     98.93      2.15R
 32          6.0   183.05  171.24    9.54     11.81      0.26 X
 33          7.0   196.33   72.72    6.10    123.61      2.69R
 35          6.0   166.45  154.96   11.36     11.48      0.26 X
 41          5.0   143.07   99.29    9.56     43.78      0.97 X
 44          1.0   143.10   50.66    6.27     92.45      2.01R
 56          7.0   136.16  103.16   12.40     33.01      0.74 X
 72          3.0  -158.88   27.36    6.74   -186.25     -4.06R
 78          5.0   -15.77  122.44    4.80   -138.20     -3.00R
 88          5.0   -59.68   70.33    7.94   -130.01     -2.85R
131          4.0  -129.65   76.17    3.20   -205.82     -4.45R
150          3.0   126.25   76.61   10.20     49.64      1.10 X
214          8.0   168.69  172.57    9.58     -3.88     -0.09 X
222          7.0   145.94  136.45   10.77      9.49      0.21 X
253         10.0   165.24  150.02   10.66     15.22      0.34 X
285          1.0   -76.74   21.70    6.82    -98.44     -2.15R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.
```

Regression Analysis: EPM versus Impact_Comm, Time_Comm

The regression equation is
EPM = 5.96 + 5.55 Impact_Comm + 11.9 Time_Comm

Predictor	Coef	SE Coef	T	P
Constant	5.961	8.189	0.73	0.467
Impact_Comm	5.549	1.314	4.22	0.000
Time_Comm	11.924	1.327	8.98	0.000

S = 46.5481   R-Sq = 31.8%   R-Sq(adj) = 31.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	313799	156899	72.41	0.000
Residual Error	311	673852	2167		
Total	313	987650			

Source	DF	Seq SS
Impact_Comm	1	138891
Time_Comm	1	174907

Unusual Observations

Obs	Impact_Comm	EPM	Fit	SE Fit	Residual	St Resid
5	3.0	195.92	82.23	4.17	113.69	2.45R
11	5.0	192.81	93.32	2.70	99.49	2.14R
27	5.0	198.84	69.48	3.57	129.36	2.79R
30	7.0	174.19	80.57	4.63	93.62	2.02R
33	7.0	196.33	80.57	4.63	115.75	2.50R
44	1.0	143.10	47.28	6.06	95.82	2.08R
52	9.0	107.95	67.83	8.58	40.12	0.88 X
72	3.0	-158.88	34.53	5.68	-193.41	-4.19R
78	5.0	-15.77	117.17	3.99	-132.94	-2.87R
88	5.0	-59.68	57.55	4.55	-117.23	-2.53R
131	4.0	-129.65	75.85	3.21	-205.50	-4.43R
172	2.0	179.43	124.37	8.61	55.05	1.20 X
285	1.0	-76.74	23.43	6.80	-100.18	-2.18R
293	2.0	157.76	124.37	8.61	33.38	0.73 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.