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# Reliability Centered Maintenance: A Case Study of Railway Transit Maintenance to Achieve Optimal Performance, MTI Report 10-06

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# Reliability Centered Maintenance: A Case Study of Railway Transit Maintenance to Achieve Optimal Performance



MTI Report 10-06



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MTI Report 10-06

**RELIABILITY CENTERED MAINTENANCE:  
A CASE STUDY OF RAILWAY TRANSIT  
MAINTENANCE TO ACHIEVE OPTIMAL  
PERFORMANCE**

Felix A. Marten, Jr., DBA

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## EXECUTIVE SUMMARY

This qualitative case study identified the types of obstacles and patterns experienced by a single heavy rail transit agency located in North America that embedded a Reliability Centered Maintenance (RCM) process. The outcome of the RCM process also examined the impact of RCM on availability, reliability, and safety of rolling stock. This qualitative study interviewed managers (10 cases), and non-managers (10 cases) at the transit agency to obtain data. The data may serve to help rail transit leaders determine future strategic directions that would improve the heavy rail transit industry. Despite the RCM record in other fields, it has infrequently been used in heavy rail transit agencies.

The research method for the first portion of this qualitative case study was to collect data from subjects by administering an open-ended, in-depth personal interview, of managers and non-managers. The second portion of the study explored how the RCM process affected rolling stock availability, reliability, and safety.

The study used data derived from project documents and reports (such as progress reports, email, and other forms of documentation) to answer questions about the phenomena. The exploration and identification of the patterns and obstacles are important because organizational leaders in other heavy rail transit systems may use this knowledge to assist in embedding the process more smoothly, efficiently, and effectively to obtain the desired end results.

Based on the analysis of data, seven themes emerged in regard to obstacles experienced by maintenance employees during the implementation of the RCM process at the single heavy rail transit agency. The first theme related to the problems with the predicted implementation time. The second theme was the effective communication methods used. The third theme was the influence of organizational culture on RCM implementation. The fourth theme was the effect of RCM processes on employees. The fifth theme was the most challenging aspects of implementing RCM. The sixth theme was the most significant obstacles of implementing RCM. The seventh theme was the impact of RCM on rolling stock.

The analysis revealed that there was very mixed results regarding the impact of RCM on the rolling stock. Some of the participants indicated that there was an increase in safety and reliability, whereas others indicated that there was a decrease in those aspects. However, the analysis revealed that the participants indicated that there had been a significant increase in rolling stock availability since pre-RCM.



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## INTRODUCTION

Multinational leaders, managers, and employees of heavy rail transit agencies have faced new challenges in the 21<sup>st</sup> century related to innovation, technology, quality assurance movements, and downsizing initiatives (Newstrom and Davis 2002). One such innovation that has made use of technology to drive quality management is Reliability-Centered Maintenance (RCM) (Backlund and Akersten 2003; Campbell and Reyes-Picknell 2006; Hansson, Backlund, and Lycke 2002). RCM is a process that identifies the maintenance requirements of physical assets (plant, rolling stock, and buildings) and productivity to complement the operational goals of the organization (Campbell and Reyes-Picknell). This ultimately results in optimal performance of the equipment as reported by Campbell and Reyes-Picknell.

Campbell and Reyes-Picknell (2006) reported that RCM must progress through three iterative steps before significant results are achieved. First, the RCM process must examine the function of the asset and understand the productivity goals of the asset. Second, various methods by which an asset can fail should be explored, including the impact of failure on other systems and subsystems. Third, depending on what is learned during the previous steps, RCM develops mitigation strategies that can be implemented against potential failures. When the RCM process has been used in other industries, the maintenance process increased equipment efficiency, reliability, and safety, and lowered maintenance costs (Backlund and Akersten 2003; Delzell and Pithan 1996; Fleming 2006; Toomey 2006). Creecy (2003) reported that some organizations have realized up to \$147 million per year in RCM-related maintenance cost savings.

Despite the RCM record in other fields, it has infrequently been used in heavy rail transit agencies. The focus of this qualitative case study was to interview 20 employees—one group in management (10 cases), and the other in non-management positions (10 cases)—of an East Coast United States heavy rail transit agency who have had at least one year of work experience with an RCM maintenance system to identify types of obstacles and patterns experienced embedding an RCM maintenance program. The outcome of the RCM process also sought to identify the impact on maintenance of the rolling stock (known as the revenue vehicles carrying passengers or a train) with regard to availability, reliability, and safety. This data may serve to help rail transit leaders determine future strategic directions that would improve this industry.

This chapter includes an overview of the case study, the general and specific problem studied, the purpose statement, the significance of the study, the significance of the study to leadership, the nature of the study, the research questions, and the conceptual framework that guided the case study. It also includes definitions of key terms, assumptions, limitations, delimitations, and a section summary. The summary recaps significant points of the study regarding the implementing of an RCM process in a heavy railway transit agency.

## BACKGROUND OF THE PROBLEM

According to the American Public Transportation Association (APTA) (2007), heavy rail transit agencies in 2005 spent more than \$5.2 billion dollars on maintaining rolling stock,



which represents a substantial amount of their operating budget. Heavy rail transit agencies depend on their fleet of rolling stock to move their patrons from point-A to point-B. The lack of a properly maintained fleet could create service problems that result in a change in leadership at the affected agency. A sustainable inability to provide transit service could even force the agency to seek bankruptcy protection. In order for heavy rail transit agencies to sustain their existence, transit leaders, may want to explore if an RCM-based maintenance process in a non-RCM-based maintenance organization is an option.

The demand for public transportation in the 21<sup>st</sup> century is estimated to increase based on a number of factors, including: (a) growing population, (b) increases in cost of fuel for personal vehicles, (c) increases in traffic congestion, (d) environmental concerns and the green revolution, (e) urban growth, and (f) increasing employment (APTA 2006; *Capital Corridor* 2007; Celik and Yankaya 2006). These factors can influence decisions made by a heavy rail transit board of directors. The government and the public both realize the economic importance of rapid transit agencies (APTA). Rapid transit agencies are established to provide transportation services to the general public, and are governed by a board of directors.

The board of directors of heavy rail transit agencies is accountable to several governing bodies, including county, state, and federal governments. The board of directors oversees the operation of the transit agency, and their stakeholders and constituencies hold them accountable for their business decisions. According to *Capital Corridor* (2007), the government supports mass transit, primarily because it offers an efficient carbon footprint over personal vehicles, thus reducing the amount of global warming gases emitted by individual vehicles. Public transportation is supported because heavy rail transit systems are more efficient to operate and cost less per passenger mile than traveling by personal vehicle (*Capital Corridor* 2007).

Compared to the initial stagecoach transit system, heavy rail transit systems of the 21<sup>st</sup> century are considerably more complex, efficient, and effective (Middleton 2006). These innovations are attributed to the advances in complex solid-state technology and the Information Age (Wolinsky 2006). Middleton (2006) noted that the more sophisticated and complex the transit vehicles (also known as rolling stock) design becomes, the more maintenance the rolling stock requires to remain efficient and reliable.

Increased rolling stock complexity increases the likelihood that failures will be experienced; frequent maintenance inspections are deemed necessary to avoid recurrent failures (Hansson et al. 2002; Tsang 2002). Non-operational rolling stock is difficult to remove from service because of the disruption to schedule when it fails on mainline (Lustig 2005). Mainline failures cause system-wide delays and customer dissatisfaction with the transit agency (BART 2006a). The goal of the maintenance department is to eliminate or correct any known problem on the rolling stock, (e.g., brake problem, propulsion, or HVAC) or any mechanical failure that would keep the train from moving on its own propulsion. Rolling stock absent of any mechanical or electrical failures are considered revenue ready vehicles (operational rolling stock) ready for revenue service.

Heavy rail transit agencies are heavily invested in rolling stock, which consists of heavy,

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complex, and expensive machinery. Due to the nature of such machinery, agencies need to consider various methods of maintenance. Backlund and Akersten (2003) documented that organizations that had implemented an RCM-based maintenance process realized an increase in rolling stock availability, reliability, and safety.

## RCM Principles

Moubray (as cited in Mostafa 2004) defined RCM “as a process used to determine the maintenance requirements of any physical asset in its operating context, and [to] determine what must be done to ensure that the equipment continues to fulfill its function” (109). Backlund and Akersten (2003) noted that the RCM process combined several well-known risk analysis tools and techniques, including failure modes and effect analysis, as well as decision-tree analysis to identify problematic areas. Wheeler (2007) stated that the RCM process is more than just a way of performing maintenance. Wheeler noted “in a nut shell, it’s a way at looking at system performance in terms of the impact of a failure and then mitigating those results by design, detection, or effective *maintenance*” (38).

According to Backlund and Akersten (2003), different terms have been used in the literature to refer to RCM-based maintenance. Researchers have used the terms *RCM process*, *RCM technique*, and *RCM method* interchangeably. According to Backlund and Akersten (2003), RCM is a process to maintain or improve reliability, availability, and safety, as well as control the cost of maintenance by reducing the amount of maintenance required.

Tsang (2002) reported that maintenance plays a vital role in any organization using machinery and should be incorporated into an organizations’ business model. Backlund and Akersten (2003) and Hansson et al. (2002) reported that for an efficient and successful implementation of the RCM process, organizations might need to review their current business processes.

Several transit agency directors have challenged railway managers to seek alternative methods to the existing maintenance processes to optimize rolling stock reliability, improve availability, and reduce maintenance costs (BART 2006a). Managers of heavy rail transit agencies are looking for a method of optimizing the performance of maintenance programs and availability of rolling stock while reducing maintenance costs.

One potential process that managers explored was RCM, in which RCM uses statistical analysis tools to optimize the performance of the equipment (Backlund and Akersten 2003; Fleming 2006; Hanson and Backlund 2003; Pintelon et al. 1999; Schein, 2004). The absence of a published study regarding implementing an RCM process in heavy rail transit agency may be limiting understanding of how the process functions and why it may be successfully applied to heavy rail transit agencies. Exploring the embedding of the RCM process and its outcome in one heavy rail transit agency may contribute to the adoption of an RCM process at other transit agencies. Adoption of an RCM process may allow heavy rail transit agencies to optimize performance, increase reliability, availability, and improve the safety of the rolling stock at a reasonable economic cost (BART 2006a).

## STATEMENT OF THE PROBLEM

The general problem that is addressed in this study relates to a number of failures (ranging from a quantity of 5, and as many as 15 or more) of rolling stock that are experienced by heavy rail transit and the organizational need to cope with them (BART 2006a). For example, San Francisco Bay Area Rapid Transit (BART) reported that heavy rail transit agencies experience frequent and long service delays almost daily. These delays are often greater than 5 minutes and frequently occur during peak revenue hours. Since the inception of rolling stock, leaders in the heavy rail transit industry have operated the rolling stock until it failed.

Operational failures not only impact the customers' satisfaction level and increase maintenance cost (BART 2006a; Forker, Vickery, and Droge 1996), but also deter patrons from relying on public transportation (Murthy, Atrens, and Eccleston 2002). According to BART, a decrease in ridership results in a loss of fare-box revenue, which is essential for maintaining and operating an urban railway transit system. A cycle of rolling stock maintenance failures due to poor maintenance practices leads to a loss of revenue for the transit agency.

The specific problem is the lack of sufficient knowledge about the obstacles and patterns experienced by heavy rail transit agencies when implementing an RCM process and the outcome of RCM with regard to rolling stock availability, reliability and safety.

One specific way of coping with rolling stock failures can be through the advantages offered by an RCM process. A lack of knowledge makes it more challenging for leaders of heavy rail transit agencies to address the barriers to a smooth transition implementing the RCM process. The gap in the literature regarding traditional challenges highlights the need for studies that examine RCM transitional experiences. The result of this study may influence leaders on strategies that would contribute to minimizing or avoiding potential obstacles (including lack of management support and understanding, lack of training, partial implementation, and well-defined goals) experienced by other heavy rail transit agencies during the RCM embedding process. Transit agencies struggle to keep their rolling stock revenue ready, they can minimize and avoid potential obstacles by seeking to locate maintenance strategies that can optimize rolling stock performance.

The focus of this qualitative case study was to interview 20 employees—one group in management (10 cases), and the other in non-management positions (10 cases)—of an East Coast United States rail transit agency who have at least one year of work experience with the use and implementation of an RCM-based program. QSR-NVivo 8 software was used to perform content analysis of interviews and project documentation (e.g., project progress reports, memorandums, project reports, and email) to identify themes and trends of obstacles and patterns experienced implementing and using an RCM-based program. This data may serve to help leaders of rail transit systems determine future strategic and profitable directions of this industry.

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## **PURPOSE OF THE STUDY**

The purpose of this qualitative case study was to identify themes of obstacles experienced by maintenance employees during the implementation of the RCM process at a single heavy rail transit agency. One part of the case study focused on two groups of heavy rail transit maintenance employees in North America, one group in management (10 cases) and the other group in non-management positions (10 cases). The other part of the case study explored the outcome of the RCM process to determine the impact that the RCM process has had on the rolling stock with regard to change in availability, reliability, and safety. This single case study used an embedded design in which more than one unit of analysis was examined. The units of analysis will include in-depth personal interviews for the first part of the study, and project documentation (e.g., project progress reports, memorandums, project reports, and email) for the second part of the study.

A case study research design was appropriate because it allows the identification of events to help describe the RCM implementation obstacles and patterns, including any changes in rolling stock availability, reliability, and safety. The gathering of information may help to develop an in-depth understanding of the phenomenon. Multiple data collection methods were used to triangulate on the topic under study. These multiple data collection methods included in-depth telephone interviews and project documentation review (project progress reports, memorandums, project reports, and email).

QSR-NVivo 8 software was used to do a content analysis of the interview data and project documentation (e.g., project progress reports, memorandums, project reports, and email). The exploration of the interview data may identify themes, patterns, and keywords using the QSR-NVivo 8 software. Content analysis was used for the written documentation. The selected employees who were considered are subject matter experts (SME) in their field. The participants of the study were full-time employees who have been with the organization longer than one year and have been involved with the implementation and use of RCM.

## **SIGNIFICANCE OF THE STUDY TO LEADERSHIP**

The first part of the study sought to uncover information about the obstacles that were experienced by the heavy rail transit agency when implementing the RCM strategy. Data from this study could provide new insights into changes on the availability, reliability, and safety of the rolling stock fleet as a result of applying an RCM strategy. The experiences of implementing an RCM process using the shared perceptions of one agency may serve to inform the management of other agencies regarding how to deal with patterns and obstacles.

The exploration and identification of the patterns and obstacles was important because organizational leaders in other heavy rail transit systems may use this knowledge to assist in embedding the process more smoothly, efficiently, and effectively to obtain the desired end results. By examining and exploring patterns associated with the embedding of an RCM process at a heavy rail transit agency, the findings could provide information that may help other heavy rail transit properties reduce the stress associated with implementing the same or a similar maintenance strategy. The data may provide leaders with a point

of departure for heavy rail transit agencies looking for a more predictable solution. The data may assist transit agency leaders avoid organizational resistance to change while implementing an innovative RCM maintenance strategy.

## **NATURE OF THE STUDY**

The purpose of the qualitative two-part case study was (a) to explore and gain a holistic understanding of the obstacles encountered while embedding an RCM process at a single heavy rail transit agency; and (b) to explore if applying the RCM process changed the availability, reliability, and safety of the rolling stock. By exploring the implementation of the RCM process, other transit agencies will be better able to strategically design and implement a similar RCM-based maintenance process. The heavy rail transit agency used for this case study was selected because of its availability to be studied. This heavy rail transit agency was one of the first to incorporate RCM into their maintenance practice. On its ships, the U.S. Navy uses the RCM process to analyze the fleet's maintenance requirement. As a result the Navy has witnessed significant benefits in equipment availability, reliability, and safety on board its fleet.

A qualitative research method was chosen over a quantitative or mixed method for this study. Creswell (2005) described a qualitative study as the ability to ask participants broad questions to collect data that will be in the form of stories and experiences. Qualitative researchers pose questions that gauge the experiences of the participants (Creswell). The respondents' ability to express personal views in their own words is an important component of qualitative research. A qualitative method is appropriate for this study because it provides a deeper understanding of the RCM implementation and use by individuals who have been involved in the process. Qualitative research is an appropriate research method when there is a need to study and understand an unknown (Yin 2003).

Quantitative research was not selected because it focuses on exacting measurements into such areas as business research, consumer behavior, extent of understandings, knowledge, attitudes, and opinions, providing conclusions about how many, who, and when (Creswell 2005). Quantitative research does not meet the need of this study to identify themes leading to an understanding of the outcome.

In this qualitative case study the participants were asked to describe the complex nature (Yin 2003) of embedding an RCM process in order to obtain a holistic perspective on the types of obstacles experienced by the different groups during the embedding of the RCM process in a natural setting and the outcome of the RCM process. A qualitative method is chosen over other research methods because the study will explore obstacles, patterns, and themes that may identify the reasons heavy rail transit agencies do not implement RCM-based programs.

Yin (2003) reported case studies are an appropriate method to use when seeking to understand social and human challenges. Leedy and Ormrod (2005) noted that researchers typically use qualitative designs to answer questions about a complex natural phenomenon, often with the purpose of describing and understanding the phenomenon from the participants' perspectives. This case study collected data by conducting in-



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depth interviews and by exploring project documentation, such as progress and project reports, memorandums, and other forms of documentation, to answer questions about the phenomena.

The study sought to identify (a) the types of obstacles and patterns that will be necessary for the agency to overcome during the embedding of the RCM program or any obstacles that have not been resolved; and (b) establish changes in rolling stock availability, reliability, and safety since the implementation of the RCM process. This was achieved through the review of qualitative data obtained from personal interviews and through the review of project documentation (e.g., project progress reports, memorandums, project reports, and email). The goal of the research was to evaluate the efficacy of the RCM maintenance program, not to predict the outcome of the program on the equipment.

## RESEARCH QUESTIONS

The following two research questions guided this qualitative case study.

- Research Question 1: What were the major obstacles encountered implementing the RCM process?
- Research Question 2: What has been the impact on the rolling stock since the implementation of the RCM process with regard to rolling stock availability, reliability, and safety?

## CONCEPTUAL FRAMEWORK

As organizations move into the 21<sup>st</sup> century, multinational leaders, railway managers, and railway maintenance employees face new and challenging issues such as innovation, technology, quality movement, and downsizing (Newstrom and Davis 2002). Newstrom and Davis (2002) noted that organizations must be flexible and willing to recognize and accept change to remain competitive. Chowdhury (2003) reported:

Organizations must create (a) a constant learning environment that embraces positive challenges, (b) a fearless environment where people can collaborate with one another, (c) a diversified environment where people think differently and value each other's thinking, (d) new ways of looking at old problems and opportunities and a strong sense of urgency, and (e) a culture that effectively leverages talent.  
(1)

Chowdhury (2003) noted that organizations must examine new ways of resolving old problems, which becomes an important strategy for the sustainability of organizations. For example, an examination of existing maintenance techniques and the introduction of new techniques might help uncover a viable solution to an existing problem, and a newly proposed maintenance solution that can trigger a paradigm shift for the maintenance process in the organization. According to Newstrom and Davis (2002), a paradigm is a model, a pattern, or "framework of possible explanations about how things work" (33). Underlying paradigm shifts are powerful guides that form and guide managers' behavior

and later become integral elements in transforming an organization's current business model (Newstrom and Davis 2002). The paradigm shift may influence how a transit agency performs maintenance on the rolling stock.

Paradigm shifts tend to influence managers' perceptions of an organization's business model and can assist in resolving old problems with new approaches (Newstrom and Davis 2002). According to Newstrom and Davis, organizations require a paradigm shift to resolve old problems with tools previously developed for and used in other industries. The RCM process was developed and has been used in the airline industry since the 1960s; its application could be considered a maintenance paradigm shift for the heavy rail transit industry.

## **Management Theory**

Management Theory was selected for this qualitative case study. Fredrick W. Taylor first introduced management Theory in 1911. The RCM process is grounded in the work of Fredrick W. Taylor, a scientific management theorist. Taylor believed that minimizing unnecessary steps could result in efficient productivity. According to Wren (2004), Taylor utilized time motion study to analyze and minimize the number of redundant steps, thus increasing productivity and efficiency.

Management theory consists of applying quantitative management techniques to resolve management and organizational challenges (Bowditch and Buono 2005). This may require that organizations evaluate their strategic perspectives, combined with planning and forecasting to reach the organizational goals. Today, management science has expanded to include management practices, such as Just-In-Time (JIT), Six Sigma, Total Quality Management (TQM), and Continuous Improvement (CI) programs (Bowditch and Buono 2005). The same scientific management concepts will be applied to the RCM process. Organizations today continue to seek scientific principles to improve how organizations become effective and efficient.

## **DEFINITION OF TERMS**

Defining terms serves to convey an understanding of each term's specific meaning. The following terms are defined with a brief discussion of their intended meaning.

*Computerized Maintenance Management System (CMMS):* A CMMS is an application that runs on a computer. The user can schedule future maintenance work, view what work has been performed, and track equipment performance. The application allows the user the flexibility to run reports at will (Wilmeth and Usrey 2000).

*Failure Mode, Effects, and Criticality Analysis (FMECA):* Failure mode, effects, and criticality analysis is an analytical tool for evaluating products and processes that can be used to prevent failure or malfunction (Moubray 1997).

*Heavy rail:* Heavy rail consists of an electric railway with the capability of carrying a high capacity of passengers at high speeds and with rapid acceleration in a separate right of

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way (APTA 2006). Heavy rail is also known as metro, subway, rapid transit, or rapid rail.

*Light rail:* Light rail vehicles are also known as streetcars, tramways, or trolleys. These transit vehicles are lightweight passenger rail cars driven on a non-dedicated right of way. Light rail draws electric power from an overhead power line via a trolley or a pantograph (APTA 2006).

*Mean Time Between Failures (MTBF):* The mean time between failures is the arithmetic average of the time between physical hardware and or software failure (Wu, Liu, Ding, and Liu 2004).

*Reliability Centered Maintenance (RCM):* The process of Reliability Centered Maintenance helps determine the maintenance requirements of any asset and helps conduct analysis to ensure the asset continues to perform the task without loss of function. Reliability Centered Maintenance combines several well-known risk-analysis tools and techniques that can identify failure modes, along with decision trees to identify problematic areas (Backlund and Akersten 2003; Delzell and Pithan 1996; Fleming 2006; Toomey 2006). In this study, the term RCM process is used when referring to a series of maintenance actions or operations conducted to obtain a desired goal or objective.

*Rolling stock:* Rolling stock consists of the revenue vehicles or cars used for providing transit service for passengers. Rolling stock includes the chassis and the control logic for each of the cars (APTA 2006).

*Run-to-failure:* Run-to-failure is a form of maintenance that allows the component to fail without affecting the safety of the asset. Run-to-failure requires removal of the asset from service to correct the failure (Mostafa 2004).

*Total Productive Maintenance (TPM):* Total productive maintenance is a means to improve the performance and condition of projects or manufacturing plants with the assistance of repetitive maintenance activities (Sharma, Kumar, and Kumar 2005).

*Unscheduled maintenance:* Unscheduled maintenance consists of any maintenance actions initiated by the governing property because of malfunction of the equipment (APTA 2006).

*Wayside:* Wayside is equipment located along the track and not located in a remote location such as a control room (APTA 2006).

## **ASSUMPTIONS**

Assumptions are concepts that are accepted as truths or “statements about the nature of things that are not observable or testable” (Neuman 2003, 49). The following assumptions are not in any specific order of importance. This study identified five assumptions that were made for this qualitative case study. The first assumption was that participants understood the confidentiality and anonymity provided to them and would respond openly and candidly. The second assumption was that the participants of the heavy rail transit RCM process



recall accurately what, how, and why certain events were obstacles in the implementation of the RCM process. The third assumption was that the participants had a positive attitude towards the heavy rail transit RCM implementation process. The fourth assumption was that the RCM process at the heavy rail transit agency was successful. A successful RCM process may be verified by reviewing maintenance records or by examining if there was an increase in rolling stock availability or reliability. The fifth assumption was that the obstacles experienced during the embedding process at this agency could be successfully mitigated at other heavy rail transit agencies.

## **LIMITATIONS**

Creswell (2005) described limitations as “potential weaknesses or problems with the study that are identified by the researcher” (253). The qualitative case study had several limitations. One limitation was that this study focused on a single heavy rail transit agency. There were a number of employees at this transit agency, the sample of participants was small compared to the relative number of employees. Another limitation of the case study pertained to the participant population, which consists only of maintenance department managers and non-managers as opposed to engineering, transportation and finance. Another limitation was geographical. Because of the geographical distance of the chosen transit agency from the researcher’s home, the researcher conducted interviews by telephone. The digital voice recorded telephone interviews eliminated face-to-face contact, which would have allowed collecting body language as an additional source of data. The use of multiple sources of data, which included written agency documentation and personal interviews, helped to minimize potential bias.

## **DELIMITATIONS**

In a research study, delimitations were used to narrow the scope of the study or to list what is not included or intended in the study (Creswell 2005). This study contained several delimitations. The study involved a single heavy rail transit agency. Only a few RCM heavy rail transit agencies exist. The study did not examine more than the one that indicated a willingness to participate. Within this single transit agency, the study focused only on the maintenance department and excluded other departments or higher-level executives within the transit agency. The only department that participated in the study was the maintenance department, known as the Rolling Stock and Shop (RS&S). Another delimitation of the case study was that it included only a single department that had been using the RCM process for longer than one year. The final delimitation was that the study consisted of only two groups of heavy rail transit maintenance employees, one group in management positions (10 cases) and one group in non-management positions (10 cases), which represented only a fraction of the employees who work in the RS&S maintenance department.

## **SUMMARY**

Multinational leaders, managers, and employees of heavy rail transit agencies face new challenges in the 21<sup>st</sup> century related to innovation, technology, quality assurance movements, and downsizing initiatives (Newstrom and Davis 2002). One such innovation

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that makes use of technology to drive quality management is RCM (Backlund and Akersten 2003; Campbell and Reyes-Picknell 2006; Hansson et al. 2002). The RCM process has been shown to reduce the cost of maintaining equipment in other industries (Backlund and Akersten 2003; Delzell and Pithan 1996; Fleming 2006; Toomey 2006) and appears to have the same ability to reduce maintenance on rolling stock in the heavy transit industry. A few instances exist where the RCM process has been implemented in the heavy transit industry (Cotaina, Matos, Chabrol, Djeapragache, Prete, and Carretero 2000). By understanding the embedding of an RCM process, managers at other transit agencies may be able to implement a similar program to reduce mainline system failures, increase rolling stock availability and reliability, and extend the life cycle of the rolling stock until funding can be identified for procurement of new rolling stock.

This qualitative case study sought to explore and identify the types of obstacles and patterns experienced by heavy rail transit maintenance employees who have implemented RCM and have at least one year of experience with the use and implementation of this system. This study collected, analyzed, and interpreted detailed information to produce an in-depth understanding of the obstacles and outcomes of the RCM process at the particular heavy rail transit agency in North America.

An understanding of the types of obstacles and pattern of implementing an RCM process at an existing heavy rail transit system may help other transit agencies develop a support system that can guide other transit agencies to implement a similar RCM-based maintenance program. This might offer management at heavy rail transit systems insight to the challenges they face implementing a maintenance program that may have an impact on the availability, reliability, profitability, and safety.

The qualitative case study expands the existing body of knowledge in the literature, exploring obstacles that heavy rail transit agencies face while embedding an RCM-based maintenance program, and by exploring and identifying patterns of difficulties during the implementation of the program. The qualitative case study also expands the existing body of knowledge in the literature by determining the impact an RCM-based maintenance program has on the rolling stock with regard to availability, reliability, and safety. Leaders of heavy rail transit may use results of this study to become aware of the various obstacles and patterns potentially encountered when implementing an RCM-based maintenance program.

The resulting research data can be utilized to overcome the barriers of implementing such a program. The results created knowledge of availability, reliability, and safety of rolling stock and the maintenance strategy for optimal availability, reliability, and safety of rolling stock through the RCM process. The RCM process may enhance the maintenance process of the organization and realizes a better understanding of the Return on Investment (ROI).

### **Organization of this Study**

The next chapter presents a review of the literature that guided the case study. The literature review includes an examination of the importance of the RCM process in other

industries, and provides evidence indicating that the RCM process might serve heavy rail transit agencies as well as it has served the airline industry, the power generation industry (e.g., fossil and nuclear), and the automotive manufacturing industry. The next chapter, Methodology, describes the research methods used in compiling this study. The following chapter, “Presentation and Analysis of Data,” answers the two reserach questions, “What were the major obstacles encountered implementing the RCM process?” and “What has been the impact on the rolling stock since the implementation of the RCM process with regard to rolling stock availability, reliability, and safety?” The study concludes with a chapter titled “Conclusions and Recommendations.” Appendices include milestones in United States trainsit history, a list of transit organizations in North America, and materials used in obtaining the data used in this report.

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## REVIEW OF THE LITERATURE

The purpose of this qualitative case study was to identify themes of obstacles experienced by maintenance employees during the implementation of the RCM process at a single heavy rail transit agency. One part of the case study focused on two groups of heavy rail transit maintenance employees in North America, one group in management (10 cases) and the other group in non-management positions (10 cases). The other part of the case study explored the outcome of the RCM process to determine the impact that the RCM process had on the rolling stock with regard to change in availability, reliability, and safety.

This chapter is a review of the literature that guided the case study illustrating successful and failed implementations of RCM processes that have been documented in other industries; none of the literature researched discussed the implementation of an RCM process in the heavy rail transit industry. Examination of the importance of the RCM process in other industries provides evidence indicating that the RCM process may serve heavy rail transit agency as well as it has served the airline, power generation (e.g. fossil and nuclear), and automotive manufacturing industries.

According to Backlund and Akersten (2003), a number of obstacles are experienced during the implementation of an RCM process. The aim or goal was to provide leaders at heavy rail transit agencies with the knowledge to avoid same or similar obstacles that were experienced in other industries, allowing for a smoother transition. The second goal of the study was to review the outcome of the RCM process to identify the impact of RCM on availability, reliability, and safety of rolling stock.

Hansson et al. (2002) noted that companies in the transportation, aviation and power plant industry realized that, in order to remain competitive, maintenance must be performed. This will ultimately improve the efficiency and safety of the equipment. The quality and frequency of maintenance plays a significant role because it affects the performance of the equipment (Backlund and Akersten 2003; Hansson et al. 2002). Hansson et al. identified in the same case study that organizational livelihood depends on the performance of equipment.

Equipment performance can be tracked with a computerized maintenance management system. When the equipment is off line or in a state of disrepair, the organization is losing revenue (Murthy et al. 2002; Wu 2004). Murthy et al. (2002) reported that the loss of revenue in an open-cut mining operation caused by non-operational equipment could be as high as \$500,000 to \$1,000,000 per day. In an airline operation, the loss of revenue from a Boeing 747 plane being out of service could reach \$500,000 per day (Murthy et al. 2002). Smith and Hinchcliffe (2004), noted that organizations should perform frequent maintenance in order to ensure the equipment is performing optimally. Equipment not properly maintained will experience failure during critical moments, such as when approaching a deadline or during a time of high volume. According to BART (2006b), mainline failure or unreliable forms of transportation can persuade patrons to find alternative forms of transportation driving away patrons, resulting in a reduction of revenue. Public transit agencies have a legal liability of ensuring that maintenance is performed to ensure that safety is not compromised, and meets oversight regulatory needs (BART 2006b).

Companies in the aviation, automotive, fossil, and nuclear power industries that have implemented an RCM process have operated more efficiently, effectively, and with increased equipment reliability (Hansson et al. 2002; Smith and Hinchcliffe 2004; Moubray 1997; Pintelon, Nagarur, and Van Puyvelde 1999). Because transit agencies rely heavily on high quality preventative maintenance to minimize equipment failure, the successful use of RCM in the transit industry appears to be worthy of case study.

The authors reported that many successful RCM implementations have been documented; several failed RCM implementations have been documented. Many implementations failed because they were poorly implemented, or not fully supported by upper management (Backlund and Akersten 2003; Hansson et al. 2002). In the study by Backlund and Akersten, (2003) the authors discussed the importance of making the RCM process a long-term goal of the organization, with full support and buy-in from senior and middle management. The study reported organizations that failed to have full support of senior and middle management failed to successfully implement an RCM process. Backlund and Akersten (2003) reported that management and employee buy-in is relatively important, the more people involved in the process, the greater the challenge to involve more people.

The relatively frequent failure of RCM implementation is viewed as problematic and a weakness of RCM, often leading management and individuals to look for other maintenance strategies that have less vulnerability (Hansson et al. 2002). Hansson et al. (2002) identified that RCM implementation requires the commitment from the entire organization. RCM needs to be an integral part of the fabric of the organization, meaning that the RCM process should be incorporated in the strategic plan of the organization in order to be supported by staff and management (Backlund and Akersten 2003; Fleming 2006).

## **Documentation**

The purpose of this section is to examine relevant literature regarding the phenomena of managing an RCM implementation in order to examine the obstacles and patterns experienced by heavy rail transit agencies. The literature review includes current research in RCM implementation in industries other than transportation, as well as background information on relevant maintenance processes. The characteristics of successful RCM implementation identified in the research literature are examined to determine if similar experiences were encountered by the transportation industry in an effort to increase equipment availability, efficiency, and offer both a reduction of unplanned maintenance and cost savings. Several title searches were conducted to find germane information on the following topics: (a) the economic importance of rapid transit both historically and currently, (b) transit deterioration due to a lack of maintenance, (c) transit maintenance strategies (e.g., strengths and weaknesses), (d) overview of RCM, (e), computerized maintenance management systems, and (f) impact of organizational culture changes as a result of RCM.

The literature research findings were obtained from title searches, journals, refereed journal articles, books, case studies and research documents. The University of Phoenix's online library collection was utilized including EBSCOhost, ProQuest, ProQuest Digital

Dissertation, and Thomson Gale PowerSearch (see Appendix J). Literature was obtained from the Harmer E. Davis transportation library located at the University of California, Berkeley campus. The research identifies a dearth of information dealing with embedding an RCM process in a rapid transit environment. This gap in the literature served as the foundation for the case study such that the body of knowledge regarding the introduction of RCM serves as a strategic means to optimize the operation by the leadership at heavy rail transit agencies.

## **URBAN TRANSPORTATION IN NORTH AMERICA**

The history of rapid transit began with the first transit system, which consisted of stagecoaches pulled by horses. Over time, horses were replaced with other motive sources such as pneumatic, steam, cable, and electricity. Middleton (2003), a rapid transit historian, reported that the first urban transit system in North America appeared in New York City in 1827, consisting of horse-drawn stagecoaches.

By 1832, the New York City stagecoaches were replaced by horse-drawn streetcars. The congestion on the street from the horse-drawn streetcars, pedestrians, and private stagecoaches, became a concern for the growing city (Iles 2005). Middleton reported that in 1867, an innovator named Alfred Beach proposed to resolve the congestion problem on New York City streets with a pneumatic subway, which he subsequently designed and built. His pneumatic subway used air to power the trains under street level, avoiding the use of conventional steam engines. Beach's innovation used 10-foot fans located at each end of the subway to propel the train along the subway line.

Middleton (2003) went on to report that in 1866, William Hemstreet built a transit system that was elevated 30 feet above the busy streets of New York City. The elevated railway transit system operated for the next two decades. Middleton posited that since the introduction and subsequent abandonment of the pneumatic subway in 1870, other innovators proposed, designed, and built different configurations of railway transit systems.

Schwarz (1998) reported that San Francisco, California was the first city to successfully implement a street railway system powered by a cable running underneath the city streets. Andrew Hallidie, the owner of the cable car railway, placed it into service on September 1, 1873. The cable car line traversed six-tenths of a mile and ran between Kearney Street and Jones Street, known as the Clay Street line (Schwarz 1998). According to Schwarz, the cable cars were popular and practical until the advent of the electric powered streetcars. With the advent of the electric streetcar, cable cars continued to fill a niche in the city's transit scheme, while electric cars offered service to much of the rest of the city.

Semsel (2001) reported that owners Edward Bentley and Walter Knight, of the East Cleveland Street Railway, were the first to commission an electric powered railway. The electric system carried its first passenger on a one-mile route along Garden Street in Cleveland in 1884. This electric powered railway was capable of operating at speeds up to 25 mph. Due to several technical problems the electric vehicles were removed from service, and horse drawn vehicles were reinstated within less than 7 years (Semel 2001).



In 1889, Eben M. Boynton created the Boynton Bicycle Railway, which developed the concept of a steam-powered locomotive monorail train. This bicycle railway ran on a single running rail, giving birth to the monorail. While the idea of the steam-powered locomotive monorail did not catch on, this did not discourage inventor Eben M. Boynton from developing another locomotive concept. By 1894, Boynton had developed the Boynton Electric Bicycle Railway. This electric powered train was able to travel at speeds up to 100 mph on a 2-mile test track in Long Island New York (Middleton 2003). The train operated on the 2-mile test track for 2 years and was later abandoned.

In 1901, the popularity of the monorail design influenced the development of a 9.3 mile suspended monorail rapid transit system in Germany (Middleton 2003). According to Middleton, by 1910, New York City had developed a monorail transit system capable of reaching 50 mph. Middleton goes on to report that these innovative monorail successes influenced the construction of additional European rapid transit lines. In 1921, the Russian government constructed a 20-mile monorail. A similar design in 1929 was developed in Glasgow, Scotland, which operated using a steam diesel-electric propulsion system (Middleton 2003).

Since the 1900s, several transit designs have used subway, elevated tracks, and at-grade guideways. Designs incorporated pneumatic, steam, complex cable, and electricity to propel the trains. While each of the propulsion systems offer advantages and disadvantages, pneumatic and steam solutions have been largely abandoned, while cable remains suitable for limited situations.

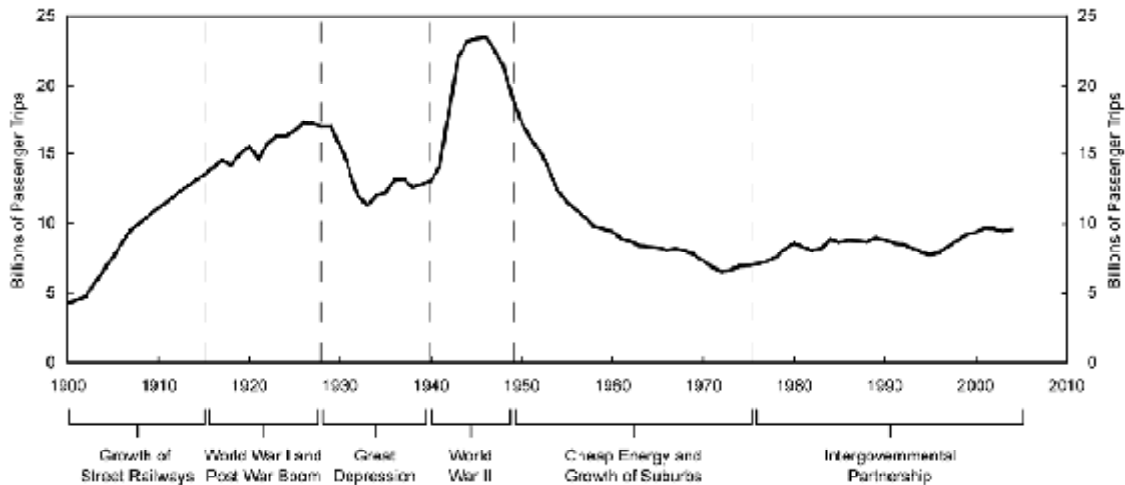
Since the introduction of Beach's rapid transit system, many forms of underground (e.g., subway) and elevated railway transit systems have been constructed. After 1900, railway rapid transit increased in popularity and eventually replaced the horse- and mule-drawn carriages. Appendix A illustrates additional milestones of the U.S. public transportation history.

## **PUBLIC TRANSPORTATION RIDERSHIP TRENDS**

Heavy rail transit systems have grown in popularity for several reasons (APTA 2006). Patrons rely on public railway transit systems primarily because of the increasingly high cost of automobile fuel, traffic congestion, escalating property costs, and environmental concerns, as well as the systems' convenience and efficiency (APTA 2006; *Capital Corridor* 2007; Celik and Yankaya 2006). The public transportation ridership trend illustrated in Figure 1 clearly illustrates the trends and importance of transit to the United States since the early 1900s (APTA 2006).

According to APTA (2006), various social and economic factors have affected the popularity of public transportation. In the beginning of the 20<sup>th</sup> century, ridership grew at a steady rate until the Great Depression (see Figure 1). Between 1929 and 1939 ridership declined (APTA), which was directly attributed to the loss of jobs and lack of money. The patron ridership increased again during World War II, when public transport became the main mode of transportation in many urban areas. Ridership peaked in 1946 with more than 23.4 billion trips reported on trains, buses, and trolleys. The increase in ridership in

the early 1940s was directly attributed to the large increase in the workforce supporting the war, the rationing of fuel, and a shortage of automobiles, which were scrapped for their metal to support the war effort (Kirk 1995).



**Figure 1. Billions of Passenger Trips in the United States from 1900 to Present**  
(Copyright 2003 by APTA. Permission to reproduce by APTA [Appendix I]).

APTA (2006) reported that following World War II, public transport experienced a decline in ridership due to low-density suburban housing and the availability of individual cars with cheap gas and more highways. By 1960, public transportation ridership had declined to 9.3 billion trips, and the number continued to fall, reaching 6.5 billion trips by 1972 (APTA). Ridership then increased and reached 9.6 billion trips by 2004. This increase resulted from a strong economy and better relations with patrons, as well as government support for public transportation and the passing of a funding resolution bill in 1991, making public transportation more economical than other modes (APTA 2006).

### The Economic Importance of Rapid Transit

According to the American Public Transportation Association (APTA) report (2006), rapid transit plays a vital role to the economy, both historically and presently. The APTA report, noted that the public transportation industry was a \$27 billion industry. Over the last several years transit agencies have been partnering with both private and public sectors. The joint business partnership has worked well for transit agencies and the private sector. According to APTA, capital investments in public transportation spark an economic chain reaction generating hundreds, if not thousands, of jobs. In 2004, more than \$13.2 billion tax dollars were spent on capital expenses to procure rolling stock, facilities guide ways, stations, administrative buildings, and other expenses, of which 28.7 percent was spent on actual heavy rail (APTA).

Investing in public transportation has a positive effect on the local economy (APTA 2006). Public transportation investments stimulate the economy by generating business sales; for example, every \$10 million in capital investment in public transportation can result in \$30 million in business sales, and the creation of 310 additional jobs (APTA 2006). The 14 heavy rail rapid transit agencies in North America employ more than 47,000



employees nationwide (see Appendix B) (*Public Transportation Fact Book 2006*). Public transportation stations attract and promote development, often creating transit villages, which encourage the use of public transportation, and discourage the use of a private vehicle (APTA).

Several transit agencies have embraced transit-oriented development (TOD), which often leads to new jobs and an increased revenue base (APTA 2006). TODs are private-public partnership developments near and around stations. They typically consist of residential and commercial property (APTA 2006). These high-density residential properties are known as transit villages. The individuals who reside in transit villages adjacent to rail stations are more likely to use public transportation, and rely less on personal motor vehicles (APTA 2006). Transit agencies who offer efficient, reliable, and safe service are more likely to attract these patrons, resulting in revenue for maintenance and operation of the system.

### **Importance of Rapid Transit**

The rising costs of property in metropolitan cities have forced individuals to relocate to the suburbs in order to find greater value in real estate. With the relocation of families to the suburbs, more individuals rely on commuter rail or rapid transit as a means to commute to work. Empirical data revealed when new transit lines are brought to suppressed areas, property value increases (APTA 2006). A number of other factors may influence individuals to consider heavy rail transit as their primary form of transportation.

Economic factors include the rising cost of parking, major roadwork or repair, serving the needs of economically disadvantaged individuals who cannot afford to procure a motor vehicle, insurance premiums, and car maintenance. This includes both the young and mature populations who do not operate a motor vehicle. As individuals continue to move to the suburbs, many come to depend on public transportation due to environmental concerns or because they belong to the aging population (APTA 2006). Since many patrons rely on heavy rail transit as their primary form of transportation, the transit system needs to function optimally, reliably, and economically.

The increase in demand requires longer or additional trains for frequent service. Increasing train length or frequency of service on any line requires that trains be more reliable to minimize any failure during revenue service. The added service translates into higher maintenance costs that must be controlled. Maintenance must optimally and efficiently be performed in order to minimize failure during revenue service.

According to Holmgren (2005) and Backlund and Akersten (2003), implementing the RCM process is a means of optimizing equipment functionality and reducing maintenance inefficiencies and cost. Holmgren suggested that RCM could extend the life cycle of the equipment while increasing its reliability, availability, and safety. The benefits provided by an RCM process can be directly applied to the heavy rail transit industry. Not maintaining equipment properly can generate safety issues (Backlund and Akersten 2003; Holmgren 2005; Murthy et al. 2002). According to a study by Holmgren (2005), between the years of 1988 and 2000 there were 666 train derailments and collisions caused by a lack of properly maintained equipment.

The RCM process reduces the frequency of maintenance, thus reducing operating and maintenance costs (Backlund and Akersten 2003; Toomey 2006). The RCM process evaluates and ensures that the functionality of assets is maintained through analysis of the assets and designs against known failures. According to Toomey (2006), Trans-Alta Utilities witnessed that RCM offered significant “advantages by focusing on systems failures” (2).

Toomey (2006) reported that RCM was first used as an analysis tool for identifying failures, access to equipment history and preventative maintenance records. RCM quickly became a tool for identifying repeated failures. Managers viewed RCM as an optimization strategy and a tool for continued improvement (Backlund and Akersten 2003; Holmgren 2005; Murthy et al. 2002). The Trans-Alta utility company identified additional advantages of an RCM program: (a) “identified design shortcomings and operational problems, (b) justified manpower resources utilization and reallocation, (c) defined a clear set of PM tasks tied to failure causes, and (d) served as a learning and bridging tool” (Toomey 2006, 3).

Organizations can take advantage of RCM during the re-engineering phase of a plant. Plants are re-engineered to introduce latest state-of-the-art machinery and technology to optimize plant performance. According to Creecy (2006), NOVA Gas Transmission Ltd. accomplished this goal within three years after implementing an RCM program. As a result, they witnessed significant cost savings in maintenance. NOVA saved \$1 million in an RCM process for the pipeline alone, and another \$980,000 in an RCM process for leak detectors, cathodic protection, and station valves (Toomey 2006). Creecy (2003) reported that some organizations have realized up to \$147 million per year in RCM related savings in maintenance costs.

RCM-based maintenance may be an excellent solution for the heavy rail transit agencies. The process of RCM results in an extension of the life cycle of the rolling stock and an increase in reliability, availability, and safety (Holmes 2005; Murthy et al. 2002). The RCM process results in an increase in effectiveness, which is an alternative solution for transit agencies. This translates in operations’ cost savings over the life cycle of the product (Backlund and Akersten 2003; Murthy et al. 2002). Implementing the RCM process involves working closely with technical and management teams (Murthy et al. 2002).

Management and staff members of the organization need to commit to the RCM process, resulting in a modification in the culture of the organization (Backlund and Akersten 2003). According to the study by Backlund and Akersten (2003), organizations that share the vision of the RCM maintenance program have been more successful than those who were not totally committed. This change in maintenance philosophy is a culture change and may require the introduction of a change management team to assist everyone in adjusting to the cultural changes brought about by the implementation of an RCM process. Backlund and Akersten (2003) and Toomey (2006), noted that an RCM process has a better chance of succeeding if the organization’s employees offer their full support, involvement, commitment, and open communication in the implementation of the RCM process. Several industries have successfully applied the RCM process, very few heavy rail transit agencies have managed to do so.

Capturing the experiences of heavy rail maintenance employees during the implementation of the RCM process in heavy rail transit environments helps the transit agency comprehend how to overcome the obstacles. Those who have experience with the process may be able to articulate and explain why the RCM process can be used to optimize equipment reliability, facilitate a reduction in cost of conducting business, and extend the life cycle of equipment with planned maintenance (Holmes 2005; Murthy et al. 2002). The literature reported several successful RCM processes in the power generation and airline industries (Backlund and Akersten 2003; Delzell and Pithan 1996; Fleming 2006; Toomey 2006). Conversely, the literature contained little information on the successful management and implementation of the RCM process in heavy rail transit agencies in North America. None of the literature located discusses the introduction of RCM in the transportation industry.

### **Population in the U.S. and Public Transportation**

According to APTA (2006), in the coming decade a number of factors will cause public transportation ridership to increase. One such factor is the growth of urban areas. According to Smith (2003), the population in the United States is doubling every 35 years. According to Kincannon (2006), California remains the most heavily populated with 35.9 million people, followed by Texas with 22.5 million and New York with 19.2 million. At the current trend, Florida, California, and Texas will account for 46 percent of the total U.S. population sometime between 2000 and 2030. As the population continues to grow in these metropolitan cities, individuals are moving further out to smaller towns, often commuting to work via heavy rail (Rogers 2006). More individuals are commuting to work and rely on public transportation to escape traffic congestion.

An indication that more individuals are becoming dependent on heavy rail transit for transportation is the aging population. A report by APTA (2006), asserted that over the next 25 years baby boomers will reach their 60s, 70s, and beyond. According to APTA, senior citizens prefer to take public transportation rather than drive their personal vehicle. The numbers of patrons that rely on public transportation fluctuate; the fare collected at the fare box plays a vital economic role in paying for the operations and maintenance of public transportation. The 2006 annual report published by APTA stated that during fiscal year 2004, more than 2.7 billion trips were taken on rapid transit (*Public Transportation Fact Book* 2006). According to the *Public Transportation Fact Book*, 83 percent of trips were by those who were between 19 and 65 years old. These trips occurred on 14 heavy rail rapid transit agencies throughout North America (Appendix B).

### **Property Value and Public Transportation**

Several studies reported that rail transit promotes an increase in property values of both residential and commercial property within close proximity of a passenger station (Celik and Yankaya 2006; Trian 2006). Celik and Yankaya reported that development planners need to consider this relationship when envisioning future developments; the presence of a station can, in fact, transform economically suppressed areas.

APTA (2006) reported that from a city planning point of view, public transportation is much more efficient than traveling by automobile. Each year, public transportation saves more

than 885 million gallons of gasoline (equivalent to the consumption of 45 million barrels of oil), which is the quantity of foreign oil that is imported in to the U.S. in a month. According to an APTA report, a full rail car removes 200 vehicles from the road, thus reducing traffic congestion. A decrease in automobile traffic results in a decrease in greenhouse gas emissions (Balsas 2001; Smith, 2003). According to Balsas (2001), “continued automobile usage causes serious environmental and social problems” (316).

The United States continues to deplete natural resources at an alarming rate, which may result in exhausting the fossil fuel resources used for making gasoline (Smith 2003; Turpin 2008). The nation has felt the financial strain associated with the rise in fuel; gas prices have experienced an exorbitant rise in cost over the last few years, not to mention the affect of the byproducts on our environment (Smith 2003; Turpin 2008). Secondary factors are associated with motor vehicles, such as global warming, fumes, traffic congestion, traffic accidents, and noise pollution (Smith 2003; Jenks 2003). Studies suggested that public transportation travel is more than twice as efficient compared to traveling by motor vehicle (APTA 2006; *Capital Corridor* 2007).

Traveling by rapid transit results in fewer accidents than traveling by motor vehicle (*Capital Corridor* 2007). Communities need to consider the impact of rapid transit use rather than that of personal vehicles, the potential rise in traffic safety, and other savings associated with health-related issues (Smith 2003). According to the American Automobile Association (AAA), the average cost of driving an automobile is 44 to 62 cents per mile, excluding parking and bridge tolls, compared to 21 cents per mile (*Capital Corridor* 2007). The cost can be further reduced to 11 cents per mile with discounted multi-ridetickets as stated by the Capital Corridor.

Some health-related issues are associated with the high level of pollutants for individuals who have respiratory or heart-related concerns (Rockhold 2005). According to Rockhold, automobiles are responsible for about the 33 percent of air pollution. This air pollution creates smog and the acid rain that affects our ecosystem (Rockhold 2005). The author asserts that society does not fully understand the magnitude of the emissions released by automobiles. For example, an automobile that gets 25 mpg generates 11,640 pounds of carbon dioxide (CO<sub>2</sub>) per year, a gas that is assumed to be responsible for global warming. Another advantage<sup>2</sup> of traveling by rapid transit is the ability to run on clean electricity, which reduces emissions and conserves hydrocarbon fuels (Smith 2003).

Phillips (2007) reported that coal is the energy source responsible for half of the electricity generated in the United States. Forty years ago, coal energy plants were far from being environmentally friendly; today the coal generation power plants can reduce some pollutants by more than 90 percent. This reduction has been achieved with the development and deployment of CO<sub>2</sub> capture and storage technologies (Phillips 2007). In other parts of the world, some nations have taken advantage of more clean power. In Switzerland, trains run on electricity; 97 percent of their power is generated from renewable hydropower. In France, 77 percent of their trains run on electricity generated by nuclear power (Smith 2003).

## Public Transportation Fleet

According to the *Public Transportation Fact Book* (2006), public transportation fleets consist of various forms of transit vehicles, amounting to about 144,000 active vehicles that include buses, subways, rail, trolleys, ferryboats, and paratransit services. Rail modes (e.g., railway) include heavy rail, light rail, commuter rail, automated guideways transit, incline plane, cable car, monorail, and aerial tramway (Appendix B). The focus of the case study is exclusively on heavy rail or railway transit.

Railway transit vehicles make up 18 percent of the public transportation fleet. Rapid transit has a number of different aliases. In the United States rapid transit systems aliases include the following: urban public transit, mass rapid transit, electric subway, metro, or railway. Iles (2005) describes a rapid transit system as a means of mass transportation offering a uniquely fast service compared to other forms of transit, with an average speed greater than 31 mph (e.g., 50 KPH), running on an exclusive or dedicated right-of-way (e.g., grade separation).

Rapid transit systems fall into the categories of light rail or heavy rail, and both operate on a high-frequency schedule (Iles 2005). According to the *Public Transportation Fact Book* (2006), a light-rail car is a vehicle powered by electricity, with power usually distributed by overhead lines, and it operates on a non-exclusive right-of-way. Light rail is referred to as streetcar, tramway, or trolley. Heavy rail is an electric railway with the capability of carrying a high capacity of passengers at high speeds and with rapid acceleration on a separate right-of-way (APTA 2006). Heavy rail is referred to as metro, subway, rapid transit, or rapid rail

According to *Public Transportation Fact Book* (2006), commuter rail is an electric or diesel propelled railway. This form of rail primarily is found utilizing locomotives and self-propelled railroad cars for making short trips, or between central city and adjacent suburbs. Commuter rail is referred to as metropolitan rail, regional rail, or suburban rail (*Public Transportation Fact Book* 2006).

Another mode of railway transit is called a monorail or people mover. Monorails operate on a fully automated guideway and contain no operator on board (*Public Transportation Fact Book* 2006). This form of transit operates on a loop or shuttle route within the central business district, an airport, and at Disneyland parks.

According to *Public Transportation Fact Book* (2006), another mode of rail transit is the incline plane. Few remain in operation today. Incline planes typically are used on short distances on the side of a mountain and are operated up and down with a cable. Another less popular mode of transit is the cable car that is operated with a cable (Appendix B). Cable cars are electric, individually operated, and attached to a cable located beneath the street surface (*Public Transportation Fact Book* 2006). Only one cable car system exists in the world; it operates in San Francisco, California.

Another mode of railway transit is the aerial tramway. The aerial tramway is an electric system consisting of a network of cables connected to the powerless passenger vehicles.



Only two transit operations exist: in New York, and at Mountain Village in Colorado. All others are in ski areas or tourist sites (*Public Transportation Fact Book 2006*). An example of a heavy rail fully automated rapid transit system is located in the San Francisco Bay Area, California, and is known as BART.

### **San Francisco Bay Area Rapid Transit District**

The San Francisco Bay Area Rapid Transit District (BART) provides service to passengers in the San Francisco Bay Area. The service lines run through the urban and suburban areas of San Francisco, Contra Costa, Alameda, and San Mateo Counties. Including 43 passenger stations distributed on 104 miles of double track. Service patterns are largely dictated by the topography of the region. Lines run along the east and west sides of the San Francisco Bay, under the bay, and then traverse the hills and valleys of the East Bay. The system radiates from the Oakland wye (e.g. a triangle of railroad track), which is located under downtown Oakland. Lines running west from the Wye travel under San Francisco Bay, through downtown San Francisco, and they terminate at Daly City, Millbrae, or the San Francisco International Airport. Other lines radiate from the Oakland wye and terminate in Richmond, Pittsburg/Bay Point, Dublin, or Fremont.

A second wye is located on the San Francisco Peninsula between San Bruno Station, Millbrae Station, and the San Francisco International Airport station. Not only in the two wye do merges and diverges occur, they are also found at two other locations in Alameda County. A merge/diverge for three service lines is located between Bay Fair Station, Castro Valley Station, and Hayward Station. Other merge/diverge occurrences exist for three service lines located between MacArthur Station, Rockridge Station, and Ashby Station. Approximately one-third of the system is underground, one-third is aerial, and one-third is at grade. The transportation system has been in service for more than 40 years and much of the equipment is reaching the end of its life cycle (Holmes 2005; Murthy et al. 2002).

### **DETERIORATION DUE TO A LACK OF MAINTENANCE**

Transit agencies continuously look for various methods of saving operating costs. One particular area that is often considered for cutbacks is in the area of maintenance. Organizations often view maintenance as an expense and not as a profit center (Campbell and Reyes-Picknell 2006). According to Holmgren (2005), equipment maintenance is necessary for several reasons. First, it ensures dependability of the equipment. Second, it reduces potential problems because of equipment failure, such as a derailment or collision that might injure or kill passengers. Finally, low-cost maintenance that is performed incorrectly can result in an accident, just as if no maintenance had been performed (Holmgren 2005). This is an important factor because accidents cost organizations a great deal of money, create ill will with the public, and develop a poor reputation, resulting in revenue loss (Holmgren 2005).

According to the Federal Railroad Administration (FRA) which tracks data regarding railway accidents in North America, rail accidents across the nation have been increasing (Kean 2005). As indicated by Kean in 2004, more than 3,100 accidents were recorded, which was up from 2002 with 2,700 rail accidents. Kean (2005) suggested that, although

several accidents were related to operator error and rule violation, many accidents were attributed to equipment failure due to a lack of maintenance, improper maintenance, or equipment malfunction (Holmgren 2005). An increase in equipment failures or accidents should result in less usage of the transit system.

Normal operations of equipment, whether rolling stock or located on the wayside (track way), sustain normal wear and tear. Equipment degradation inevitably occurs, rendering equipment performance to become impaired. Intervening corrective maintenance is necessary to restore the equipment from excessive wear and tear, dirt build up, and corrosion (Holmgren 2005). Equipment failures in the passenger station usually cause only minor patron frustrations, but do not result in catastrophic failure; if switches and track failure occur on the wayside or on the vehicle, the result can be catastrophic failure, causing injuries or even deaths.

On June 22, 2009, the Washington Metro experienced the worst accident it has experienced in the history of heavy rail transit in this nation. One metro train slammed into the rear of another metro train waiting to enter into the station. The accident that resulted in nine fatalities and 80 passengers were injured. The key component under investigation is equipment that failed to detect the presence of a train on the track (Urbina and Emery 2009). Could the incorporation of an RCM-based maintenance strategy have avoided such a catastrophic accident?

Holmgren (2005) suggested that management must make sure that maintenance strategies and business objectives and goals are in line with the maintenance program to ensure the maintenance of vital equipment. According to Kube (2005), due to deferred maintenance, some railroad infrastructures are in shambles and have experienced frequent derailment caused by the poorly maintained tracks and infrastructure.

Accidents occur when maintenance procedures are performed on the infrastructure but deviate from the recommended procedures of the equipment manufacturer. When maintenance is performed on the infrastructure consistent with recommendations listed by the manufacturer, the equipment generally performs and operates as designed (Holmgren 2005). According to Holmgren, this can often assist in identifying premature equipment failure (Holmgren 2005). Holmgren reported that on October 1999, a derailment and collision occurred and, as a result, 31 people died and 227 were taken to hospital. In October 2000, due to rail failure caused by a lack of maintenance, four people were killed. Maintenance strategies are not to be taken lightly; they can be detrimental to patrons and the community, taking days and weeks to restore service.

## **MAINTENANCE AS A FORM OF STRATEGY**

According to Murthy et al. (2002), almost all modern industrial societies rely on technology in order to produce goods and services. Businesses (transportation, mining, computer, technology, and health) require equipment to deliver their final product. According to Murthy et al., (2002), equipment assets play a vital role for business success. As a result of technological advances, equipment has increased in productivity and efficiency (Campbell and Reyes-Picknell 2006; Murthy et al. 2002).

Campbell and Reyes-Picknell (2006) and Murthy et al. (2002) reported that the equipment is getting more complex and expensive. When equipment fails to perform, businesses realize heavy losses. The authors reported equipment degrades with age usage and becomes non-operational, and that degradation can be controlled or reduced through the use of proper operating practices and proper preventative maintenance actions (e.g. RCM process).

### **What is Considered Maintenance?**

According to Campbell and Reyes-Picknell (2006), maintenance “is an activity carried out to retain an item in, or restore it to, any acceptable condition for use or to meet its functional standard” (331). Studies have shown that equipment not properly maintained costs more to restore than equipment that undergoes periodic maintenance. The authors reported that “there is a link between planned maintenance and reduced cost” (84), and reported that work that is planned is easier and cheaper to perform than unplanned work. According to Campbell and Reyes-Picknell, unplanned running repair work costs 50 percent more than planned and scheduled work and emergency work will cost three times as much.

### **Maintenance Strategies**

Over the last decade, transit agencies have pursued several maintenance strategies. These strategies have evolved to deal with the complexity and sophistication of the equipment. Sharma, Kumar, and Kumar (2005) reviewed the five strategies. These maintenance strategies focus on different aspects of the equipment to make sure performance is optimal and not compromised.

One such maintenance strategy, according to Sharma et al. (2005), is called Breakdown Maintenance (BDM). This type of reactive maintenance is also known as Frequency-Based Maintenance (FBM). This type of maintenance is conducted on a periodic basis. The authors indicate that BDM maintenance is conducted to restore the functionality of the equipment; no action is taken to comprehend what caused the failure, or what possible actions could be taken to minimize future failures. This form of maintenance strategy is often called action-oriented maintenance or fire fighting maintenance strategy.

The second maintenance strategy described by Sharma et al. (2005) is called Preventative Maintenance (PM). Preventative maintenance is a maintenance strategy that reduces the frequency and sporadic failure by performing planned repairs, replacement, overhauling, lubricating, cleaning and inspecting at specific time intervals. The intent of the PM strategy is to minimize the probability of equipment failure prematurely by conducting maintenance before the failure of the equipment. Sharma et al. (2005) reported that this form of maintenance would be more effective with the support of a computerized system, such as a Computerized Maintenance Management System (CMMS). A CMMS generally is not incorporated as part of the maintenance strategy. This form of maintenance is effective, but the maintenance process does possess inherent risk; it lacks the use of a data collection and risk assessment tools used by RCM to assist in identifying potential problematic areas.



The third maintenance strategy is called predictive or Conditions-Based Maintenance (CBM). This form of maintenance defined by Sharma et al. (2005) suggests that maintenance is performed with the assistance of diagnostic tools, on a timely schedule—daily, weekly, or monthly. CBM maintenance can be performed with the aid of vibration-based tools and diagnostic equipment. The diagnostics equipment measures physical conditions such as temperature, vibration, noise, corrosion, and other telltale signs, which may lead to premature equipment failure.

The author reported that CBM maintenance is considered a more prominent maintenance program designed for mechanical industries, which monitors the performance of rotating or reciprocating equipment. This form of maintenance is effective in the mechanical industry; this maintenance strategy does possess an inherent risk. This form of maintenance lacks the use of a data collection and risk assessment tools used by RCM to assist in identifying potential problematic areas. CBM requires the maintainers receive specialized training that requires additional time, cost, and resources without necessarily receiving the cost savings proposed by RCM.

The fourth maintenance strategy is identified as Total Productive Maintenance (TPM). This maintenance philosophy requires active participation by all in the organization, including management. Sharma et al. (2005) suggested that the TPM priorities here are to eliminate or minimize the following: loss due to downtime, loss due to setup and adjustments, speed loss, speed reduction, defect loss, and reduced yields. This form of maintenance focuses on increasing the overall equipment effectiveness (OEE). According to Sharma et al. (2005), this is an excellent indicator of how well TPM is working. According to the author although TPM has been effective and offers advantages over the other maintenance strategies, it does possess an inherent weakness. According to Ben-Daya (2000) and Jonsson (1997), TPM lacks the necessary component for implementing an effective preventative maintenance program that keeps the equipment running optimally.

The fifth and final maintenance strategy reviewed by Sharma et al., (2005) was Reliability Centered Maintenance. The authors reported that this maintenance strategy focuses on optimizing preventative and predictive maintenance, which results in an increase in equipment effectiveness while minimizing maintenance cost. The RCM strategy focuses on maintaining system function rather than both restoring equipment functionality and restoring equipment to an ideal condition (Sharma et al. 2005; Worledge, 1993). According to Ben-Daya (2000), RCM plays a significant role in developing preventative maintenance programs to ensure that equipment continues to function at a high level of overall effectiveness.

RCM is clearly effective over the other maintenance strategies. However, RCM is often mistakenly viewed as abandoning periodic maintenance. Many experts do not necessarily agree with this perspective. According to Campbell and Reyes-Picknell (2006), this perspective exists because RCM provides for the safe minimum amount of proactive maintenance. RCM preserves preventative maintenance and incorporates Condition-Based Maintenance, and where appropriate, Run-to-Fault Maintenance (Fleming 2006).

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## Measuring Operational Optimization and Benchmarking

According to Jones (2004) and Newstrom and Davis (2002), organizations need to benchmark their operations against industry competitors. Vitasek (2006) and Whitlock and Rubin (2006) suggested that benchmarking involves comparing the operation of one's own plant and comparing the findings to the competitor. The data can be used to generate performance reports, which can be used to identify areas that may need adjusting in order to achieve optimal performance in the organization (Whitlock and Rubin 2006). Performance reports can assist management in identifying assets, which continue to run optimally, or to identify assets that are not running optimally and may need service or replacing (McPherson 2005). Ultimately, this translates into an optimal financial position for the operation of the organization.

Railway transit managers need to have the tools in place to measure if the proposed maintenance program is effective and operating efficiently (Garg and Deshmukh 2006). The vast amount of data that is produced and available with the implementation of the RCM program can be tracked and compared against industry standards. This can be tracked with the implementation of a performance measurement system. A performance tracking system can be achieved with the implementation of a CMMS (Garg and Deshmukh 2006; Labib 2005; Wilmeth and Usrey 2000; Worledge 1993).

Garg and Deshmukh reported that one of the features of a CCMS is to track equipment performance, which can be used to identify the optimal and efficient operation of any piece of equipment. A CMMS has become an important aspect of organizations to keep detailed information of equipment performance metrics and to track critical aspects of maintenance programs such as an RCM program (Garg and Deshmukh 2005).

## Overview of Reliability Centered Maintenance

David H. Worledge (1993) articulated that RCM was first proposed by airline and major airplane manufacturers in the late 1960s when the aircraft industry introduced a new generation of wide-bodied passenger jets. According to Worledge (1993), the aircraft industry feared the introduction of technological advances along with the enormous size of these jets would make the new planes uneconomical to maintain. The traditional methods used to maintain the previous airlines would become too expensive to perform on the new generation of aircrafts.

Due to external pressure and concerns from the Federal Aviation Administration (FAA), traditional methods of maintenance would be overlooked due to the uneconomical cost of using these methods of maintenance. Major airlines responded by proposing RCM as a maintenance strategy (Worledge 1993). Several years after the implementation of RCM in the airline industry, empirical data revealed that aircraft reliability and availability actually improved, while the cost of maintenance remained virtually constant (Worledge 1993). An early version of RCM was used in a Naval ship design project, which resulted in substantial fleet availability improvements where fewer vessels were required to replace the antiquated fleet. According to Campbell and Reyes-Picknell (2006), this alone resulted in capital cost savings of nearly \$2 billion.

## **Reliability Centered Maintenance Process**

The RCM process (also known as a proactive approach) focuses on four particular key elements that (a) preserve system functions, (b) identify failure modes that can impact system function, (c) prioritize system function needs, and (d) select applicable and effective preventative maintenance tasks (Backlund and Akersten 2003). According to a General Accounting Office (GAO) report by Fleming (2006), RCM techniques are more effective than other maintenance processes and techniques. Primarily, RCM techniques are effective because they involve (a) continued periodic maintenance that includes inspections, repairs, and performance checks; (b) conditioned-based maintenance that can assist in preventing equipment failure; and (c) run-to-fault maintenance (Fleming 2006). Equipment that is allowed to run-to-fault, this equipment can run to failure without causing safety concerns. Fleming reported that this form of failure is considered non-salient and is similar to a burnt out light bulb.

## **Nuclear Power Plant**

According to Worledge (1993), in order to minimize damage, lost production, and other losses under control, Periodic Preventative Maintenance (PM) may need to be performed in order to decrease failure. In 1990, the Utility Data Institute database identified that nuclear power plants averaged maintenance costs of more than \$37 million per 1000 MW (Worledge 1993). The nuclear industry turned to RCM to reduce the cost of maintenance and to increase reliability of the plants. The implementation of RCM in 72 power plants resulted in maintenance man-hour savings amounting to more than \$5,000 per system.

## **Utilities Company**

According to Wilmeth and Usrey (2000), in 1991, the Puget Sound Power & Light Company was motivated to find an alternative maintenance strategy after management made budget cuts. Subsequently, management decided to turn to the RCM process as the alternative maintenance strategy. In 1991, the utility company implemented an RCM process to the substation equipment, transformers, voltage regulators, and transmissions and line maintenance (Wilmeth and Usrey 2000). By 1995, the utility company reported that planned maintenance had been substantially reduced; several of the required planned maintenance procedures along with the circuit breakers maintenance were reduced (Wilmeth and Usrey 2000). The authors noted that not only did Puget Sound Power & Light Company feel that their liability decreased with regard to equipment failure, but as a result of RCM, they were now able to focus their attention on the operations aspect of the organization.

According to Wilmeth and Usrey (2000), the British Columbia Hydro and Power Authority have been applying RCM principles since 1995. Since then, they have received an annual savings of 20 percent to 50 percent on job site hours on circuit breakers and 15 percent on transformers. These savings in labor hours accumulate over time, yielding a substantial savings for the organization.

Wilmeth and Usrey (2000) believed the CMMS contributed to the success of their RCM program. They mentioned that a Texas energy company (TXU) evaluated the RCM process in 1994. When TXU engaged in the RCM process, they elected to do so without the use of a CMMS to assist with data record keeping. CMMS can contribute to the success of the RCM program, especially since the CMMS is used to track vital information such as maintenance records and the preventative Maintenance (PM) schedule, as well as conduct performance analysis. Since that first year, TXU has implemented a CMMS yielding larger cost saving. TXU is in the process of adding an RCM process to the existing maintenance procedures in the plant and expect an additional 10 percent to 15 percent savings (Wilmeth and Usrey 2000).

## **RELIABILITY CENTERED MAINTENANCE IMPLEMENTATION OBSTACLES**

According to Backlund and Akersten (2003), several organizations that have implemented an RCM program experienced a number of obstacles. Backlund and Akersten noted that some obstacles that organizations faced during the embedding of an RCM-based maintenance program included a lack of management support, information, and communication. The authors reported that identifying obstacles early in the implementation process is vital to overcoming the obstacles.

The authors reported that in order to implement an RCM program with the least amount of resistance, management and employees must be committed to a long-term approach rather than a quick introduction of an RCM program (Backlund and Akersten 2003). Commitment includes the full support by executive management, middle management, and employees at all levels of the organization (Ahuja and Khamba 2008). Backlund and Akersten (2003) reported that management should be aware of what is required to fully implement RCM; this includes the aim and goal of the RCM program, and the necessary resources required to fully embed the program.

Backlund and Akersten (2003) reported that a number of failed RCM implementations occurred. The authors noted that many implementations were designed to fail from the beginning, since the program was being introduced during a time when the organizations lacked the resources to fully commit to the implementation. With a lack of support from executive management, the RCM program tends to simply fade away (Backlund and Akersten). Backlund and Akersten also noted that if management does not have a clear comprehension of the program or an understanding of what the RCM program can do for the organization, management simply withdraws from the program. Management must be fully aware of the benefits of the RCM program and what it means to the performance of the equipment (Backlund and Akersten).

In the study conducted by Backlund and Akersten (2003), the following obstacles were identified during the planning, preparation and analysis phase. The obstacles include (a) lack of a computerized maintenance management system; (b) lack of a computer system; (c) lack of a plant register; (d) unavailability of documentation and information; (e) problematic routines, roles, and responsibilities; (f) communication problems; (g) lack of overarching maintenance management strategy; and (h) incomplete goal setting, and benefits identification and measurement.

## **Computerized Maintenance Management System**

According to Fernandez, Labib, Walmsley, and Petty (2003), information is an essential resource, which can be leveraged by management to determine if the organization's objectives are being met. Fernandez et al. (2003) suggested that maintenance information can be used to gain knowledge about the status of the equipment and the information can be utilized to measure the overall performance of the assets. According to Fernandez et al. information systems were no longer being used to supply management with information about the operation of the organization. The author suggested that CMMS are computerized systems that are specifically developed along with software applications to monitor the work, as well as report how assets are working (Fernandez et al. 2003).

CMMS software is a tool that can be used with any of the above five maintenance strategies, offering management tools to make decisions about maintenance strategies. Labib (2005) suggested that several factors were a driving force behind CMMS. The onset of such a requirement is driven by the mere fact that record keeping in an RCM program is paramount, which can be the difference between success and failure.

Labib (2005) stated that CMMS is a set of computer based software programs used to control resources and work activities, as well as monitor conditions of equipment located in the plant. The ability to have information readily available on equipment in real time is critical for management to make decisions (Fernandez et al. 2003; Labib 2005). Maintenance planners can effectively use the CMMS tools to schedule work based upon information made available on the system, track maintenance costs, and develop an accurate budget.

A CMMS can be used to retain equipment performance and compare against previously defined metrics. This can assist management to easily identify bad actors or frequently ineffective pieces of equipment. Maintenance and equipment historical records can assist management in gaining an insight into how well the facility is functioning (Fernandez et al. 2003; Labib 2005). This is an important indicator of the effectiveness and efficiency of the maintenance program. Organizations that have implemented a CMMS with an RCM program, have found that the systems do complement one another and perform more effectively (Smith 2004).

Without a system that tracks vital maintenance records and information, it becomes challenging to measure the effectiveness of an RCM program; the lack of a CMMS can influence an RCM program from operating efficiently and effectively. With a CMMS, all employees in the organization can track equipment performance and compare the data to similar equipment on the property (Fernandez et al. 2003; Labib 2005). The CMMS may be used to track the asset management to realize how well the equipment performs against the ROI (Gahbauer 2007).

With a CMMS system, workers may easily identify when the last service was conducted as well as the next scheduled date for service, allowing planners to schedule work accordingly. With safety on the mind of many, federal and state regulatory agencies require transit agencies to remain compliant with scheduled maintenance. These transit



agencies are often required to provide a copy of their service records, or the information may be requested during an accident investigation or a safety audit (Fernandez et al. 2003; Labib 2005). A CMMS offers management and employees the ability to generate customized reports that satisfy the needs of regulatory bodies.

Labib (2005) suggested that organizations that implement a CMMS into their maintenance center often achieve world-class maintenance. He stated that such a tool offers a number of functions and supports for various maintenance programs, such as Reliability Centered Maintenance (RCM), Condition-Based Maintenance (CBM), and Total Productive Maintenance (TPM). A CMMS has the capability of tracking spare parts and inventory levels with automatic order replenishment. This system facilitates inter-departmental communication, provides historical information about equipment, schedules preventative maintenance, and provides senior management with the health status of the plant. CMMS has the ability to run statistical analysis to assist in locating problematic assets (Labib, 2005). Labib asserts that companies that have implemented a CMMS into their business process have witnessed substantial savings in their maintenance program. According to Campbell and Reyes-Picknell (2006), using “data management clearly has a direct impact on maintenance output” (208). The authors’ purport that equipment effectiveness can jump from 50 percent to 85 percent, reliability can rise from 20 percent, workforce productivity can increase 20 to 30 percent, and material usage can be reduced 20 to 50 percent.

### **Impact of Organizational Culture Changes as a Result of RCM**

According to Jones (2004) and Proctor and Doukakis (2003), organizations have to experience change and deal with transformation if the organization shall continue to prosper and exist. Organizations have to continuously develop and assess their strategic plan. Railway transit agency management, along with the support of the board of directors, must craft a business plan that will outline how to compete in its environment (Ahuja and Khamba 2008; Jones 2004). According to Jones (2004) and Newstrom and Davis (2002), comprehending the impact of change on an organization can minimize the effects and impact on the organization.

### **CHANGE MANAGEMENT**

According to Jones (2004) and Proctor and Doukakis (2003), organizations have to experience change and deal with transformation if the organization shall continue to prosper and exist. This means that organizations have to continuously develop and assess their strategic plan. Railway transit agency management, along with the support of the board of directors, must craft a business plan, which will outline how to compete in its environment (Jones 2004). According to Jones (2004) and Newstrom and Davis (2002), comprehending and understanding the impact of change on an organization can minimize the effects and impact on the organization. Change agents can facilitate successful change in the organization (Newstrom and Davis 2002). Newstrom and Davis noted that change agents are “people whose roles are to stimulate, facilitate, and coordinate change within a system while remaining independent of it” (476).

## **Organizational Behavior to Change**

According to Newstrom and Davis (2002), change is considered to be any form of alteration occurring at the place of work that causes an individual to change the way work is conducted. Newstrom and Davis claimed that “changes may be planned or unplanned, catastrophic, or evolutionary, positive, negative, strong or weak, slow or rapid and stimulated either internally or externally” (337). Jones (2004) defined organizational change as “the process by which organizations move from their present state to some desired state to some desired future to increase their effectiveness” (301). According to Bowditch and Buono (2005), employees can adequately prepare to deal with the resistance of change in a constructive manner if the effects of change are understood.

## **Cultural Changes**

According to McGreevy (2003), employees exhibited a number of behavioral changes influencing cultural changes in the organization. Key talents may disappear if downsizing is an issue, minimizing the effects of downsizing. The organization may experience morale problems by the employees surviving the downsizing. After a downsizing phase, it takes time before the employees begin to gain the trust of management, fearing that they may be next to be cut from the workforce. The author reported that the added workload resulted in employees being unmotivated because of the additional workload. According to McGreevy, individuals need to recognize the world encounters changes and organizations need to be flexible and adaptable in order to remain competitive.

## **Management’s Role**

According to Jones (2004), organizational change is considered a normal course of action to be considered by management. This can occur at any of the four different levels: human resource, functional resource, technological, and organizational capabilities. Jones suggested the latter areas are interdependent; change in any one region will most likely trigger a change in the other areas.

Railway transit agency management and employees, as well as the board of directors, recognize that change is being driven not by the latest fad, but rather by external factors such as recently adopted executive orders or federal regulations. Failure to comply with the executive order or federal regulations can jeopardize the funding source, resulting in loss of funding due to failure to comply with the executive orders.

Management plays a key role in initiating and implementing change successfully (Newstrom and Davis 2002). According to Jones (2004), management has to articulate and communicate to its employees the strategic changes being implemented and why the changes are necessary. Employees can exhibit behavioral changes that can influence a negative cultural change in the organization. This may result in key employees leaving the organization due to the fear of losing their job, or a lack of information or the benefits of the change (Proctor and Doukakis 2003). Often organizations may experience morale problems by the employees surviving the downsizing (McGreevy 2003). Employees will need to recognize the world has changed and the organization needs to be flexible and adaptable to remain competitive (Meredith 2007).

Railway transit agency management and employees have to accept the fact that organizational change is a normal course of being in business and that its effects can influence the human resource, functional resource, technological, and organizational capabilities (Jones, 2004; Newstrom and Davis, 2002). A change in any one region will cause the other areas to trigger a change (Harrington and Tjan 2008).

## **CONCLUSION**

The review of the literature revealed that organizations that implement an RCM-based maintenance program encounter a number of challenges and obstacles (Backlund and Akersten 2003). Hansson et al. (2002) noted that companies in the transportation, aviation and power plant industry realized that in order to remain competitive, maintenance must be performed. The quality and frequency of maintenance plays a significant role because it affects the performance of the equipment (Backlund and Akersten 2003; Hansson et al. 2002).

Backlund and Akersten (2003) discussed the importance of making the RCM process a long-term goal of the organization. Hansson et al. (2002) identified that RCM implementation requires the commitment from the entire organization. RCM needs to be an integral part of the fabric of the organization (Backlund and Akersten 2003; Fleming 2006). Management and staff members of the organization need to commit to the RCM process, resulting in a modification in the culture of the organization (Backlund and Akersten 2003).

Campbell and Reyes-Picknell (2006) and Murthy et al. (2002) reported that the equipment is getting more complex and expensive. When equipment fails to perform, businesses realize heavy losses. The authors reported that the degradation can be controlled or reduced through the use of proper operating practices and proper preventative maintenance actions (e.g. RCM process).

Studies have shown that equipment not properly maintained costs more to restore than equipment that undergoes periodic maintenance. According to Campbell and Reyes-Picknell, unplanned running repair work costs 50 percent more than planned and scheduled work and emergency work will cost three times as much.

The authors reported that in order to implement an RCM program with the least amount of resistance, management and employees must be committed to a long-term approach rather than a quick introduction of an RCM program (Backlund and Akersten 2003). Commitment includes the full support by executive management, middle management, and employees at all levels of the organization (Ahuja and Khamba 2008).

According to Jones (2004) and Proctor and Doukakis (2003), organizations have to experience change and deal with transformation if the organization shall continue to prosper and exist. Organizations have to continuously develop and assess their strategic plan (Jones).



## SUMMARY

This chapter reviewed the literature that guides the case study. The literature review examined the importance of RCM in other industries and evidence indicating that it may serve heavy railway transit agencies as well as it has served the airline industry, power generation (e.g., fossil and nuclear), and automotive manufacturing industries. The following topics were reviewed: (a) the historic and current economic importance of rapid transit; (b) the reliability of RCM in the airline; (c) the power generation; (d) automotive industries; (e) transit deterioration due to a lack of maintenance; (f) current transit maintenance strategies other than RCM; (g) RCM implementation obstacles; and (h) a computerized maintenance management system (CMMS).

Hansson et al. (2002) noted that companies in the transportation, aviation and power plant industries realize that in order to remain competitive they must perform maintenance. Hansson et al. identified in the same case study that organizational livelihood depends on the performance of equipment. When the equipment is off line or in a state of disrepair, the organization is losing revenue (Murthy et al. 2002; Wu 2004).

If patrons rely on heavy rail transit as their primary form of transportation, the transit system will need to function optimally, reliably, and economically. The added service translates into higher maintenance costs that must be controlled. Maintenance must be performed optimally and efficiently (Pintelon, Nagarur, and Van Puyvelde 1999) in order to minimize failure during revenue service.

According to Backlund and Akersten (2003), and Holmgren (2005), implementing the RCM process is a means of optimizing equipment functionality and reducing maintenance inefficiencies and cost. Holmgren (2005) suggested that RCM could extend the life cycle of the equipment while increasing its reliability, availability, and safety. Not maintaining equipment properly can generate safety issues (Backlund and Akersten 2003; Holmgren 2005; Murthy et al. 2002).

The RCM process reduces the frequency of maintenance while reducing operating and maintenance costs (Backlund and Akersten 2003; Pintelon, Nagarur, and Van Puyvelde 1999; Toomey 2006). Managers viewed RCM as an optimization strategy and a tool for continued improvement (Backlund and Akersten 2003; Holmgren 2005; Murthy et al. 2002). Many successful RCM implementations are documented, several failed RCM implementations have been documented, because they were poorly implemented, or not fully supported by upper management (Backlund and Akersten 2003; Hansson et al. 2002).

This change in maintenance philosophy is a culture change and may require the introduction of a change management team to assist everyone in adjusting to the cultural changes brought about by the implementation of an RCM process. Backlund and Akersten (2003) noted that an RCM process has a better chance of succeeding if the organization employees offer their full support, involvement, commitment, and open communication (Backlund and Akersten 2003; Toomey 2006) in the implementation of the RCM process.

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Over the last decade, transit agencies have pursued several maintenance strategies looking for an optimal and effective maintenance strategy (Sharma et al. 2005; Pintelon, Nagarur, and Van Puyvelde 1999). RCM techniques are effective because they involve: (a) continued periodic maintenance that includes inspections, repairs, and performance checks; (b) Conditioned-Based Maintenance that can assist in preventing equipment failure; and (c) Run-to-Fault Maintenance (Fleming 2006). As a result, the major airline and nuclear power plant industry responded by embedding RCM as a maintenance strategy (Worledge 1993). Garg and Deshmukh (2005), Sharma et al. (2005), and Smith (2004) reported that this form of maintenance would be more effective when complimented with the support of a computerized system, such as a Computerized Maintenance Management System (CMMS).

According to Backlund and Akersten (2003), several organizations that have implemented RCM programs experienced a number of obstacles. Backlund and Akersten (2003) and Hansson et al. (2002) noted that some obstacles organizations faced during the embedding of an RCM-based maintenance program included a lack of management support, information, and communication. The next chapter provides details of the research methodology, including the design of the case study, the population and sample, data sources and data.



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## METHODOLOGY

The purpose of this qualitative case study was to identify themes of obstacles experienced by maintenance employees during the implementation of the RCM process at a single heavy rail transit agency. One part of the case study focused on two groups of heavy rail transit maintenance employees in North America, one group in management (10 cases) and the other group in non-management positions (10 cases). The other part of the case study explored the outcome of the RCM process to determine the impact that the RCM process had on the rolling stock with regard to change in availability, reliability, and safety.

This chapter provides an overview of the research method used in this study. The primary focus is to describe the method and explain the data collection process. Discussion includes the design appropriateness, population, sampling, the instrument chosen for the study, validity, and reliability, and the planned data analysis process.

This qualitative case study consists of two parts. First, the study identified the types of obstacles and patterns experienced by two groups of heavy rail transit maintenance employees at an Eastern U.S. heavy rail transit agency that have embedded and used the RCM process for at least one year. One group of employees held management positions (10 cases) and the other group of employees were in non-management positions (10 cases). Second, the study explored whether the RCM process affected rolling stock with regard to a change in availability, reliability, and safety. The data collection for the study consisted of in-depth personal interviews and the second part consisted of project documentation and progress reports.

Once the interview questions were formulated, a pilot study was performed to determine if any of the interview questions needed to be rewritten or clarified. The pilot study is explained further in this chapter. Once the semi-structured questions were refined, the 10 cases in management, and the other 10 cases in non-management positions were interviewed and their responses were digitally recorded. In a qualitative case study, the researcher captures and records the events and later interprets them to identify themes and patterns (Patton 2002). A qualitative method was selected over other research primarily because the study explored patterns and themes regarding obstacles embedding an RCM program in an existing heavy rail system.

### RESEARCH DESIGN

The focus of this qualitative case study was to interview management positions (10 cases) and non-management positions (10 cases) of an East Coast U.S. rail transit agency that have had at least one year of work experience with the use and implementation of a RCM maintenance system. The case study design was selected and explored the experience of individuals who were able to describe the types of barriers and patterns experienced during the implementation. The study also explored the potential impact the RCM program had on the availability, reliability, and safety of rolling stock.

In the first part of the study, the two groups, which consisted of management and non-management employees, were interviewed. In the second part of the study, a review of

project documentation was conducted. The interview data obtained from the two groups (non-management maintenance employees and managers) was expected to provide a perspective of the nature of the RCM embedding process. A review was made of the data obtained from management and non-management maintenance employees with regard to the obstacles experienced during the embedding of the RCM process. Each participant group could offer a different opinion and outcome based upon the individual's experience of the implementation process. Project documentation was reviewed to explore any outcome changes as a result of the RCM process. The data obtained from the interview and written documentation was expected to validate, corroborate, or refute the emerging findings.

Neuman (2003) described a case study as research in which one studies a few people or cases in great detail during a defined time. Case studies capture information about behavior in unique ways. The focus is on one individual or one group of subjects which enables the researcher to perform a very close inspection and allows for detailed data collection. Several different techniques can be used to gather the data, including personal observations, interviews, or project records. According to Neuman, case studies are the best method for obtaining a rich account of behavior. Strengths of a case study identified by Neuman include:

1. Allows in-depth examination of subject
2. Deals with the real world
3. Easy to understand by non-researchers
4. Able to focus on data-rich subjects

Because this study sought to understand why or how obstacles were overcome during the implementation of the RCM process, a case study was deemed the appropriate research design. The qualitative case study research method was appropriate because the study involved interviews with a specific group of people. According to Creswell (2005), the use of the case study design helps to fulfill the goal of the study by exploring the experiences of individuals who can describe a trend through explaining and relaying their experiences. Creswell reported that a case study allows for in-depth data collection of a bounded system (in this case the RCM process) to more fully understand the case and draw conclusions from interviews and project documentation (e.g., project progress reports, memorandums, project reports, and email).

The strength of case studies is increased when a variety of evidence, including documents, artifacts, and interviews, are examined to objectively and purposefully assess the case (Creswell 2005; Neuman 2003). During the process, the researcher observed for themes and patterns to emerge that may help guide the research process. Yin (2003) reported that case studies are desirable when the researcher wants to understand complex social phenomena. Yin reported, "case studies allow the investigator to retain a holistic and meaningful characteristic of real-life events" (2). Case studies can assist in identifying program strengths and weaknesses, which can be used to assess or render judgment, facilitate improvement, or generate knowledge (Leedy and Ormrod 2005; Patton 2002).

The researcher explored the use and implementation of an RCM maintenance system. This occurred by examining and gaining an in-depth understanding of the managers' intent, design, and implementation. This step consisted of collecting data to explore obstacles, patterns, and themes in order to have a better understanding of how the participants of the agency perceived and carried out the implementation process. Data for this phase was collected through in-depth interviews. The final step consisted of evaluating the impact the RCM process had on rolling stock availability, reliability, and safety. This phase of the study was performed with the support and examination of written project documentation (e.g., project progress reports, memorandums, project reports, and email). The interviews and outcome answered the two research questions that guided this study:

- Research Question 1: What were any major obstacles encountered implementing the RCM process?
- Research Question 2: What has been the impact on the rolling stock since the implementation of the RCM process with regard to rolling stock availability, reliability, and safety?

The second part of the data collection involved content analysis of letters, memoranda, email, and progress reports. Content analysis research, which has existed for over 100 years, identifies themes in text (Neuman 2003) by examining the content of texts including government documents, books, essays, speeches, interviews, and informal conversation dialogue (Creswell 2005). Examination of the repetition of words and phrases in text creates inferences. Researchers in the U.S. government, marketing professionals, and social scientists use content analysis to identify trends and themes. Content analysis, was used as a technique to gather and analyze the content of text, quantifies and tallies the presence of the concept chosen for examination (Leedy and Ormrod 2005). Qualitative coding characteristics representing variables convert into numbers for relational and thematic analyses.

Yin (2003) reported that a “research design is a logical plan for getting from here to there, where here may be defined as the initial set of questions to be answered, and there is some set of conclusions (answers) about these questions” (20). According to Leedy and Ormrod (2005), a qualitative case study is used when the researcher is going to study a program in-depth for a specific period. Leedy and Ormrod noted that a case study design is used to answer questions about an event, program, or an activity that is not well understood. Yin (2003) purported that, in a qualitative case study, the researcher was the primary instrument for data collecting and analysis. According to Creswell (2005), the nature of the research problem determines the choice of methodology. Leedy and Ormrod (2005) reported that a qualitative design is often selected as the preferred specific design when the researcher wants to study a phenomenon in a natural setting with all its complexities.

The researcher examined extensive data and information available from interviews and published documents, including annual reports and historical documents. The review of the published documents revealed or identified obstacles that were overcome, and some obstacles that were not overcome during the embedding process of the RCM maintenance program. The researcher examined the data to determine if the RCM process had an

impact on the rolling stock with regard to availability, reliability, and safety. According to Yin (2003), a case study “is appropriate when *how* or *why* questions are being proposed, or when the investigator has little or no control over events, and when the focus is on a contemporary phenomenon within some real life context” (1).

According to Yin (2003), a case study is defined as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident” (13). Leedy and Ormrod (2005) reported “in a case study, a particular individual, program, or event is studied in depth for a defined period of time” (135). Leedy and Ormrod reported that the strength of case studies is realized through the extensive collection of data on individuals, program, and events. The data may consist of the following: (a) observation, (b) interviews, (c) documents, (d) past records, (e) and audiovisual materials (Leedy and Ormrod 2005; Yin 2003). This qualitative case explored the experiences of maintenance employees in-depth while focusing on the obstacle of embedding an RCM process and the impact the process may have on rolling stock.

The case study design was appropriate for the study because the researcher had access to a heavy rail transit agency that had expressed a willingness to be studied, and the employees were willing to report on the real life experiences selected for this research. The results of this study may allow academicians and practitioners the knowledge to more smoothly implement similar programs, while enabling them to better understand expected outcomes with regard to rolling stock. The case study design included in-depth interviews and review of project documentation (e.g., project progress reports, memorandums, project reports, and email) that may lend insight to new ideas, and identify or discover opportunities and challenges that were not previously found in the literature. The case study design was appropriate for the qualitative case study because it contributed to the researcher’s knowledge and to an understanding of the phenomenon (Leedy and Ormrod 2005; Yin 2003) of obstacles encountered during the implementation of an RCM process and the outcome at a heavy rail transit agency.

According to Leedy and Ormrod (2005), the case study design focuses on developing an in-depth understanding of the obstacles and outcome of an event or process by examining multiple data collection methods and triangulating the data. The use of data from multiple data collection methods in triangulating the data eliminates researcher bias and makes the study findings more reliable, accurate and convincing. The intent of examining several data collection methods may reveal the nature of the phenomenon of embedding an RCM process in an existing transit agency, as well as the outcome the process had on transit vehicles.

A case study was chosen over other qualitative designs because it represented the most appropriate design to accomplish the goals of the qualitative design. The goals were to use a qualitative case study with multiple data collection methods, which included in-depth interviews and project documentation, to gather information to explore patterns, trends, and types of obstacles transit agencies face during the embedding of an RCM process. This case study used open-ended questions and review of project documentation to answer the research questions.



An ethnography design was considered, but it was deemed inappropriate for the study because an ethnography design seeks to explore the culture within a group (Leedy and Ormrod 2005). This study explored the obstacles that were encountered during the embedding of the RCM process and the outcome of the process, rather than the culture within the group. Creswell (2005) reported that an ethnography design is considered a procedure for “describing, analyzing, and interpreting a cultural group’s shared patterns of behavior, beliefs, and language that develop over time” (53). Creswell (2005) reported that the “ethnographer typically spends considerable time ‘in the field’ interviewing, observing, and gathering documents about the group in order to understand their culture-sharing behaviors, beliefs, and language” (436). An ethnography design was considered inappropriate for the study.

A phenomenological design was considered, but was deemed inappropriate for the study because a phenomenological design examines a person’s experience of the meaning of an event or experience to that person, as opposed to the event itself as it exists to that individual (Leedy and Ormrod 2005). This study explored the obstacles and outcomes of an RCM process during the embedding process, rather than the experience of the individual. The data collection consisted of personal interviews through the examination of archival project documents (Creswell 2005). The case study design supported obtaining a richer and more detailed understanding of the obstacles and outcomes that are encountered during the RCM embedding process. A phenomenological design was considered inappropriate for the study.

A grounded theory design was considered, but was deemed inappropriate for the study because a grounded theory design uses data to develop a theory (Leedy and Ormrod 2005). Creswell (2005) reported that a grounded theory “is a systematic, qualitative procedure used to generate a theory that explains, at a broad conceptual level, a process, an action, or interaction about a substantive topic” (396). A grounded theory design was considered inappropriate because grounded theory typically examines a process, which later allows the researcher to develop a theory (Leedy and Ormrod 2005). Creswell reported that “Grounded theory *generates* a theory when existing theories do not address your problem or the participants that you plan to study” (396). A grounded theory design was considered inappropriate for the study.

A qualitative case study was selected over other research designs because the study explored patterns and themes while examining the experience of the two groups of heavy rail transit maintenance employees in North America: one group of managers (10 cases) and the other group of non-managers (10 cases); railway transit employees who were involved with the successful embedding of the RCM process. A case study is appropriate when the “literature reveals little information about the phenomenon of study and you need to learn more from participants through exploration” (Creswell 2005, 45). In this case study the aim of the study was not to explain the implementation process of embedding the RCM process, but rather in gaining a deeper understanding to determine the obstacles when embedding an RCM process and the outcome to examine the perceived effects on the rolling stock equipment with regard to availability, reliability, and safety.



A case study was chosen over other qualitative designs because it was deemed to be the most appropriate to accomplish the goals of the qualitative case study. Leedy and Ormrod (2005) reported that case studies seek to explore trends, patterns, and themes, in particular the ones that complement a successful implementation of an RCM process at the heavy rail transit agency. A case study was appropriate for this study because exploring what is required to overcome the obstacles during the embedding of the RCM process had not been explored. The outcome of the RCM process was explored to understand the impact to rolling stock availability, reliability, and safety.

## **METHODOLOGY JUSTIFICATION**

A qualitative methodology was selected over quantitative to address the research questions in this study. Neuman (2003) indicated quantitative research condenses data, reduces the number of variables, and comes from precise measurements, whereas qualitative research enhances data, addresses themes and generalizations, and comes from documents, surveys, interviews, and transcripts. Quantitative and qualitative research overlap, but the most striking difference appears in data analysis. Quantitative analysis occurs by using statistics and qualitative analysis extracts themes and generalizations and organizes the data into a coherent and understandable presentation (Neuman 2003). The study extracted themes and generalizations using Neuman's qualitative meaning of content analysis using QSR-NVivo 8 software.

## **POPULATION**

According to Leedy and Ormrod (2005) a population is a group of individuals with characteristics that differentiates them from other groups. The focus of this qualitative case study was to interview the managers (10 cases) and non-managers (10 cases) of an East Coast United States heavy rail transit agency who have had at least one year of work experience with the use and implementation of a RCM maintenance system. QSR-NVivo 8 software was used to do a content analysis of interviews and corporate data in order to identify themes and trends of obstacles and patterns experienced while implementing and using a RCM maintenance program. This population was selected because they represented the two different classifications of employees that may offer varying perspectives. One group consisted of management or non-represented positions, while the other group of maintenance employees was represented by a local Union. The two representations of classification offered a unique perspective to the obstacles encountered during the embedding of the RCM process. The population included maintenance employees in various positions, with the participants in positions ranging from supervisors, to mechanics, maintainers, and project sponsors.

## **SAMPLING**

All employees working in the rolling stock maintenance department within the East Coast heavy rail transit agency were contacted and invited to participate in the study. From the pool of those who responded to a corporate announcement, the first 10 managers (which included supervisors, superintendents, and assistant superintendents) and the first 10 maintenance employees (which included electronic technicians, mechanics, and lead

mechanics) that responded as volunteers were selected to participate in the study. Eligible participants must have had at least one year of work experience in implementation and use of RCM. Purposeful sampling was used to identify the research participants. Purposeful sampling allows a researcher to gather a group of respondents with experiences and information needed to understand the phenomenon being studied (Creswell 2005).

The RCM process at this agency was phased in with a focus on rolling stock. According to Backlund and Akersten (2003) their study revealed that a phased in approach is the preferred method rather than a full-scale implementation. A phased in approach provides a better control of the implementation process (Backlund and Akersten 2003). The case study design allowed the researcher to explore the participants' perspective of obstacles and patterns of embedding an RCM process in a heavy railway agency and the change it had on rolling stock availability, reliability, and safety.

This heavy railway agency was selected for several reasons. First, the agency had implemented its RCM process within the last five years, and many of the same staff members remained an integral part of the RCM implementation team. Second, the original project sponsors remained on the design and implementation team since inception of the program in the transit agency. Lastly, the stakeholders (management) of the agency welcomed information that may offer a holistic view of what worked and what needed further refinement and adjustment based upon the participants' perceptions and what it takes to achieve an optimal ROI.

## **INFORMED AND ORGANIZATION CONSENT**

The organization signed the Organizational Informed Consent Form, which is located in Appendix D. The participants were informed both orally and in writing about participating in this case study. Prior to the interview they were reminded that they were volunteering to be part of this study, they would remain anonymous, and could opt out at any time. A unique identifier was used to ensure the anonymity of the participants during data collection and data analysis. The volunteers were required to sign a consent form; a copy is located in Appendix C. According to Creswell (2005) "it is important to protect the privacy and confidentiality of individuals who participate in the study" (151). Only participants who signed the informed consent form were allowed to participate in the study.

## **CONFIDENTIALITY**

First, the organization signed the Organizational Informed Consent Form (see Appendix D). The participants were informed both orally and in writing about participating in this case study. Prior to the interview they were reminded that they were volunteering to be part of this study, they would remain anonymous and could opt out at any time. A unique identifier was used to ensure the anonymity of the participants during data collection and data analysis. The volunteers were required to sign a consent form (see Appendix C). Only participants who signed the informed consent form were allowed to participate in the study.

The researcher encouraged openness and honesty by ensuring the participants' responses would be confidential and secured, away from the view of other people. Confidentiality was explained on the consent form (Appendix C), which was signed prior to the interviews. The consent form guaranteed that individual responses would be assigned a unique identifier to ensure anonymity from other participants and by managers. The following identifier was used to ensure the anonymity of the participants during data collection and data analysis: a 3-digit alphanumeric character identifying the month, followed by a 6-digit number, which was comprised of two digits for the date and 4-digits for the year, separated by a dash; the subsequent 2-digit number identified the order of the interview, and a 3-letter character identifying the participants position in the organization. For example, MAR102008-01PSP identified that on March 10, 2008, the first interview performed was with a project sponsor. The following position identifiers were used for the respective individuals: supervisor (SUP), mechanic (MCH), electronic technician (ET), program director (PDR), master mechanic (MSM), and project sponsor (PSP) (See Appendix H for a complete list of participant identifiers).

The following safety precautions were used: The code with the unique identifier was placed in a locked and secured location, with access available only to the researcher. The names of the employers remained anonymous and undisclosed in the case study. The recordings of the interviews were transcribed and stored in a locked safety deposit box, along with the digital voice recording file for a period of 3 years, after which the information will be destroyed.

## **GEOGRAPHIC LOCATION**

The participants of this case study were located in the North America, where metropolitan cities rely heavily on mass transit for people commuting to work, school, and local businesses. The participants were contacted via email and by telephone to schedule the appropriate time for the in-depth interview. Due to geographical and logistical constraints, all management positions (10 cases) and non-management positions (10 cases) interviews were conducted via telephone.

## **DATA COLLECTION**

According to Yin (2003), "Data for case studies can be obtained from many sources of evidence" (83). Yin stated that some commonly used sources of evidence in case studies include but are not limited to documentation, archival records, interviews, direct observation, and participant observation. Patton (2002) wrote that "qualitative findings grow out of three kinds of data: (1) in-depth open-ended interviews, (2) direct observation, and (3) written documentation" (4).

Yin (2003) explained, "the use of multiple sources of evidence in case studies allows an investigator to address a broader range of historical, attitudinal, and behavioral issues" (98). The most important aspect of using multiple sources is that the research can converge on the data. Yin explained, "case studies are more likely to be convincing and accurate if it is based on several different sources of information" (98). For consistency, the data collection protocol and interview protocol (Appendix G) guided the data collection process.

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## THE DATA COLLECTION PROCESS

Leedy and Ormrod (2005) discussed how the researcher's only perception of the truth could be obtained by investigating several layers of the truth to identify revealing facts. To explore these layers of truth, the researcher interviewed management (10 cases) and non-management positions (10 cases) via telephone. The interview followed a one-on-one semi-structured format and allowed the researcher to ask clarifying questions to the participant.

The first part of the study used 11 semi-structured interview questions for the 10 participants in non-management positions, and 11 semi-structured questions for the 10 participants in management positions. These questions are located in Appendix E and F. The interview consisted of a series of open-ended questions to obtain demographic data, knowledge of the participant's lived program experience, and perceptions of the RCM process implementation and outcome. According to Patton (2002), open-ended questions support the emergence of themes and patterns by examining the words of the participants used to describe their feelings, beliefs, and thoughts about the RCM process implementation.

The second part of the study relied on secondary data. This provided a behind-the-scenes look at the implementation of the RCM program, which may not ordinarily be available. Information available in documents prompted the researcher to ask appropriate questions during the interview, especially if the documents had not provided insight about the RCM program. With full cooperation of the transit agency, the executive managers agreed to share relevant documentation that lent insight into the implementation process. The organization signed the Organizational Informed Consent Form (see Appendix D).

Data in this qualitative case study was collected, analyzed, and triangulated to (a) obtain an in-depth understanding of the participants' perspective on the types of obstacles and patterns that were necessary for the agency to overcome during the embedding of the RCM program or any that were not overcome, and (b) establish changes in rolling stock availability, reliability, and safety since the implementation of the RCM process. The purpose of triangulating the data was to compare the results from the interview and the project documentation in terms of trends, themes, and patterns. Triangulation also served to validate the findings from the various analyses (Creswell 2005; Leedy and Ormrod 2002).

Triangulation consisted of an integration of the resulting data from personal interviews, relevant project documents, as well as the literature (Patton 2002). Relevant documentation included the use of letters, memoranda, progress reports, and other communiqués concerning the implementation and outcome; thus, these data were requested from the transit agency. The researcher requested design and implementation documents to understand both the objectives and the evolution of the RCM process. Content analysis and the qualitative software tool, QSR-NVivo 8, were used to automatically group words, phrases, or texts into categories (Creswell 2005; Leedy and Ormrod 2002). This procedure revealed the identification of themes and patterns found in the transcripts.

The content of the narrative transcripts consisted of the participants' words, thoughts, or themes that would be communicated during the digital voice recorded interviews. Key words and phrases were identified and coded that corresponded to a specific category. The results from the QSR-NVivo 8 software, content analysis, and perceptions of the project documentation were examined to assist in creating themes and validating the accuracy of the research findings. The transcribed text data from the interview was analyzed using content analysis by parsing the data a number of times and repeating the analysis to identify common themes in the experiences of heavy rail maintenance employees.

The interviews were scheduled to last between 30 minutes and about 1 hour. They were conducted by telephone in a quiet environment where the participants were digitally recorded. The telephone interview process included a brief introduction describing the case study, answering any questions the participant may have had, reviewing the signed informal consent form with the participant, establishing rapport, and then, proceeding with the one-on-one interview.

In accordance to the Collaborative Institutional Training Initiative (CITI) requirements, none of the following participants were part of the study: (a) under the age of 18, (b) pregnant, (c) mentally handicapped, (d) or in prison. This process included re-contacting the participant to seek clarifying information, if necessary. By investigating relevant documentation, including project status reports, program records, progress reports, and memoranda describing the program implementation process and outcome, the researcher was able to converge on the data.

## **INSTRUMENTATION**

The researcher was the primary instrument for data collection and analysis for the first part of this qualitative case study. The in-depth interview questions were open-ended to allow the participants to elaborate on their experience. The interview schedule contained two sets of questions for the different groups (Appendices E and F). Each set of questions was designed to solicit and reconstruct the lived experiences by management and non-management employees. The semi-structured open-ended questions were designed such that the participants could elaborate on their personal experiences and the researcher could ask clarifying probing questions to explore the meaning of particular responses.

The researcher requested that the participants be free from distraction and able to commit to reserving up to 1 hour of uninterrupted time. The interview was performed in an area where the participant was comfortable and could participate in the interview without any interruptions. Due to the geographical location, it was not possible to conduct a face-to-face interview with management positions (10 cases) and non-management positions (10 cases). Each interview was conducted by telephone, during work hours. The interview was digitally recorded with an Olympus DS-40 digital voice recorder, so that it could be transcribed and reviewed by the participant for accuracy prior to it being entered into a database for analyses.

The interview schedules for management and non-management employees are located in Appendices E and F. The interview questions contained in the schedule were designed



to explore and identify obstacles that were experienced by maintenance employees during the implementation of the RCM process. The interview schedules created an open dialogue and explored the perceived effect of the obstacles of embedding an RCM process and the outcome on rolling stock.

The interview questions included demographic questions regarding the participant's name, education level, and years of employment. The following questions were also asked: What factors influence the incorporation of an RCM program in to the organization strategy? What was the most challenging aspect of the RCM implementation? What kinds of obstacles were encountered during the implementation of the RCM process? Which were the biggest barriers? How did the organization overcome these barriers? If not overcome, what was done? What was the difference between the plan for implementation and the actual full implementation? For a comprehensive list of the questions refer to Appendix E and F.

## **PILOT STUDY**

Prior to conducting the telephone interviews with management positions (10 cases) and non-management positions (10 cases), the researcher performed a pilot study on an additional three maintenance employees of the same organization to determine if any of the questions needed to be rewritten or clarified. A pilot study improves the internal validity of the study (Leedy and Ormrod 2005). The following section discusses the importance of validity. Once the semi-structured questions were refined, the management positions (10 cases) and non-management positions (10 cases) were interviewed and their responses were digitally recorded.

Leedy and Ormrod (2005) purport that piloting the interview questions can promote rigor and an effective interview process, as well as yield in-depth descriptive data. Despite the best intentions, the researcher may develop interview questions that render ambiguous, misleading answers and result in useless data (Leedy and Ormrod 2005). The researcher can save a great deal of time by piloting the questions to make sure they will be clear and in a logical sequence (Yin 2003).

A pilot allows the data analysis processes to be tested to identify any areas that may require further adjustments. The researcher pilot tested the interview questions on three maintenance employees employed at the heavy rail transit agency. The results of the pilot study were excluded from the results of the management positions (10 cases) and non-management positions (10 cases).

## **VALIDITY**

Leedy and Ormrod (2005) identified internal validity as the accuracy, credibility, and meaningfulness of the research, so that the investigator is able to draw meaningful and defensible conclusions about the data. This qualitative study collected data from multiple sources so that the investigator could converge on the data to identify the phenomenon (Leedy and Ormrod 2005). Triangulated data can be analyzed to identify common themes and patterns to support the validity of the findings (Yin 2002).

## Internal Validity

Leedy and Ormrod (2005) suggested that certain precautions be taken to ensure internal validity. For the qualitative case study, the following precautions can be taken: (a) a controlled laboratory experiment, where the experiment is performed in a laboratory and the settings and conditions are regulated; (b) a double-blind experiment, “where two or more different methods are being compared, neither the participants in the study nor the people administering the methods... know what the researcher’s hypothesis is or which method” (98); (c) an unobtrusive measure, where individuals are being observed and documented without their knowledge; and (d) triangulation, where multiple sources of data are collected and examined with the hopes the data will converge to support a particular theory (Leedy and Ormrod 2005). The pilot test will reveal if the interview questions may need further refinement to answer the research questions.

This qualitative case study consisted of multiple data sources, allowing the researcher to triangulate and converge on the data to identify common themes and patterns to provide support of the findings (Creswell 2005; Leedy and Ormrod 2005; Yin 2003). Creswell reported that threats to internal validity are problems that threaten the researcher’s ability to draw correct conclusions because of the experiment procedures or the experiences of the participants.

## External Validity

Creswell (2005) described that the intent of qualitative research is not to generalize the findings but rather to gain an in-depth understanding of the phenomenon. Leedy and Ormrod (2005) described external validity as “the extent to which its results apply to situations beyond the study itself” (99). Creswell suggested the following strategies for qualitative case studies when attempting to draw correct influences about the data. Some of the threats to external validity included (a) interaction of selection and treatment, an inability to generalize beyond the participants in the study; (b) interaction of setting and treatment, an inability to generalize from the setting and where the experiment was conducted to another setting; and (c) interaction of history and treatment, where the researcher attempts to generalize findings from past and future situations (293–294).

In this qualitative case study, the process and procedures were described to demonstrate the participant’s data converged against the secondary data. The collection, analysis, and convergence of the multi-source data allowed for an in-depth understanding of the perceptions of the railway maintenance employees regarding the successful implementation of the RCM process. The researcher analyzed the experiences of the management positions (10 cases) and non-management positions (10 cases) that played a vital role in the implementation of the RCM process at the heavy railway transit agency.

The aim of this study was to understand the embedding of the successful RCM process to identify specific types of obstacles that were encountered. The outcome of the RCM process was also explored to identify the impact on maintenance of the rolling stock with regard to change in availability, reliability, and safety. The study results may be transferred to rapid transit agencies throughout North America, and possibly to other settings, wherever railway transit exists.



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## DATA ANALYSIS

Creswell (2005) described data analysis as “taking the data apart to determine individuals’ responses and then putting it together to summarize it” (10). At the completion of each telephone interview, the participant’s digital voice recording was reviewed, and the responses to the questions were evaluated (Patton 2002). Patton suggested that “post interview time is a critical time of reflection and elaboration” (384), allowing time to review the data to make sure that they will be useful, reliable, and authentic (Patton 2002). The raw interview data was transcribed and reviewed for accuracy against the digital voice recording files. The transcribed responses were delivered to the participants for their review, and upon the participants’ concurrence, the data was coded to reveal trends, patterns, and themes.

The data analysis offered an illustration of the evolution process or steps encountered that manifested in the successful implementation of the RCM process at the transit agency. By understanding the program’s objectives, design decisions, and other development objectives, insight was revealed by exploring project documents, progress reports, and other forms of documentation. The researcher relied on the stories and memory of the participants to trace the history of how the pieces of hardware or areas were selected to be candidates for the RCM process evaluation. Reviewing project documentation revealed the criterion for selecting the specific areas in the railway to introduce the RCM process.

The research concentrated on the obstacles that were encountered during the implementation of the RCM process at an existing heavy railway transit agency. The perceptions of transit employees revealed through their lived experiences the characteristics that manifested in the successful implementation of the RCM process at their agency. This was achieved through the telephone interview data. The data was collected, transcribed, and reviewed by the participant for their concurrence. Then the data was coded and input into a qualitative analysis program (QSR-NVivo 8). According to QSR International, NVivo 8 software can handle very rich information, including deep levels of analysis on both small and large volumes of data (QSR International [QSR-I] 2009). The application software NVivo 8 “removes many of the manual tasks associated with qualitative analysis, like classifying, sorting and arranging information, allowing the researcher more time to explore patterns, trends, themes and ultimately arrive at answers to questions” (QSR-I 2009, 4). According to QSR-I (2009), qualitative research software helps individuals to manage, shape and make sense of unstructured information. An analysis with QSR-NVivo 8 was performed on the data, and the results revealed trends, patterns, and themes.

## SUMMARY

In this chapter, design appropriateness, population, sampling, the instrument chosen for the study, validity, and reliability, and the data analysis process were discussed. This qualitative case study consisted of two parts. First, the study identified the types of obstacles and patterns experienced by two groups of heavy rail transit maintenance employees at a North America heavy rail transit agency that has embedded an RCM process. One group of employees were in management positions (10 cases) and the other group of employees were in non-management positions (10 cases). Second, the study explored if the RCM process affected rolling stock with regard to a change in availability, reliability, and safety.

Data collection for the first part of the study consisted of personal interviews and the second part consisted of project documentation and reports.

The case study explored the experience of individuals who could describe the types of barriers and patterns experienced during the embedding of the RCM process and explored potential impact the program had on rolling stock. The strength of case studies is increased when a variety of evidence, including documents, artifacts, and interviews, is examined to objectively and purposefully assess the case (Creswell 2005; Neuman 2003).

The case study design was appropriate for the study because the researcher had access to a heavy rail transit agency that expressed a willingness to be studied, and its employees were willing to report on the real life experiences selected for this research. The case study design was appropriate for the qualitative case study because it contributed to the researcher's knowledge and to an understanding of the phenomenon (Leedy and Ormrod 2005; Yin 2003) of obstacles encountered during the implementation of an RCM process and the outcome at a heavy rail transit agency. The use of data from multiple data collection methods for triangulating the data eliminated researcher bias and made the study findings more reliable, accurate and convincing. The intent of examining several data collection methods revealed the nature of the phenomenon of embedding an RCM process in an existing transit agency and the outcome the process has on transit vehicles.

Leedy and Ormrod (2005) reported that piloting the interview questions can promote rigor and an effective interview process, as well as yield in-depth descriptive data. Despite the best intentions of the researcher, the researcher may develop interview questions that render ambiguous, misleading answers and result in useless data (Leedy and Ormrod 2005). To explore these layers of truth, the researcher interviewed management positions (10 cases), and non-management positions (10 cases) via telephone.

The first part of the study used 11 semi-structured interview questions for the 10 participants in non-management positions, and 11 semi-structured questions for the 10 participants in management positions. The interview consisted of a series of open-ended questions to obtain demographic data, knowledge of the participant's lived program experience, and perceptions of the RCM obstacles the organization had to overcome, and outcome with regard to rolling stock availability, reliability, and safety. The transcribed text data from the interview was analyzed using content analysis by parsing through the data a number of times and repeating the analysis to identify common themes in the experiences of heavy rail maintenance employees. An analysis with QSR-NVivo software was performed on the data, and the results revealed trends, patterns, and themes.

The next chapter provides the findings from the research. This includes the data collected from the heavy rail maintenance employee management positions (10 cases) and non-management positions (10 cases). The data reveals obstacles and effectiveness of the RCM process in the heavy railway transit environment. The results reveal if there is an impact on rolling stock availability, reliability, and safety as a result of the RCM implementation.

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## PRESENTATION AND ANALYSIS OF DATA

The purpose of this qualitative case study was to identify obstacles experienced by maintenance employees during the implementation of the RCM process at a single heavy rail transit agency. One part of the case study focused on two groups of heavy rail transit maintenance employees in the North America, one group in management (10 cases) and the other group in non-management positions (10 cases). The other part of the case study explored the outcome of the RCM process to determine the impact the RCM process had on rolling stock with regard to change in availability, reliability, and safety. This single case study used an embedded design in which more than one unit of analysis was examined. For purposes of the study, the units of analysis included in-depth personal interviews for the first part of the study, and project documentation (e.g., memoranda and review of project documents and reports) for the second part of the study.

A case study research design was appropriate because it allowed for the identification of events to help describe the RCM implementation obstacles and patterns, including any changes in rolling stock availability, reliability, and safety. The gathering of information assisted to develop an in-depth understanding of the phenomenon. Multiple data collection methods were used to triangulate to identify the obstacles experienced by maintenance employees during the implementation of the RCM process. These multiple data collection methods included in-depth telephone interviews and project documentation reviews (e.g., memoranda and review of project documents and reports).

The telephone interview process included a brief introduction describing the case study, answering any questions the participant may have had, reviewing the signed informal consent form with the participant, establishing rapport, and then, proceeding with the one-on-one interview. The interview was digitally recorded with an Olympus DS-40 digital voice recorder, so that it could be transcribed and reviewed by the participants for accuracy prior to it being entered into the QSR-NVivo 8 software for analysis.

The QSR-NVivo 8 software was used to do a content analysis of the interview data and project documents. The participants of the study were full-time employees who had been with the organization longer than one year and had been involved with the implementation and use of RCM. The selected employees were considered SME in their field.

This chapter presents the results of the qualitative case study. This section will describe the following: (a) research questions, (b) sample, (c) pilot study, (d) data collection and analysis procedures, (e) results and findings, (f) themes, (g) content analysis of project documentation, and (h) summary.

### RESEARCH QUESTIONS

Data were collected and analyzed to address the central research questions:

- Research Question 1: What were the major obstacles encountered implementing the RCM process?

- Research Question 2: What has been the impact on the rolling stock since the implementation of the RCM process with regard to rolling stock availability, reliability, and safety?

## **SAMPLE**

The sample was composed of 20 rail transit maintenance employees (10 in management positions and 10 in non-management positions) in the North America. Employees who are in management positions pertain to individuals who are in a position that provides guidance and makes decisions for subordinate employees. Employees who are in non-management positions are employees who are subordinates.

The purpose of the in-depth personal interviews was to identify the types of obstacles and patterns experienced by two groups of heavy rail transit maintenance employees at a North America heavy rail transit agency that has embedded an RCM process. The second part of the study explored whether the RCM process affected rolling stock with regard to a change in availability, reliability, and safety. Data collected for the first part of the study consisted of personal interviews and the second part consisted of a review of project documents and reports (Creswell 2005; Neuman 2003). The purpose of this study was to gain a richer and more detailed understanding of the experiences of heavy rail maintenance workers embedding an RCM process including the outcome of the maintenance program.

## **PILOT STUDY**

The personal interview questions were administered to a pilot group of three maintenance workers to ensure that the questions were clear and precise. The pilot sample consisted of two cases in management positions and one case in a non-management position. The pilot interview questions were conducted following research approval from the Academic Review Board and the Institution Review Board. Three maintenance workers were randomly selected to participate in the pilot test. All maintenance workers' names that met the minimum sampling criteria were placed in a bowl, and three names were randomly selected to participate.

An Olympus DS-40 digital voice recorder was used to capture the responses of the pilot study. The feedback from the pilot study was critical to improve and revise any of the interview questions and to test-drive the administrative procedures. The feedback from the respondents was used to validate the interview questions for both groups of maintenance workers (10 cases in management positions and the other 10 cases in non-management positions). The pilot study revealed that the interview questions were clear to the three participants and did not require any of the open-ended interview questions to be modified. Following pilot testing, the data-gathering phase lasted approximately four weeks. Prior to the start of the interview process, the consent form was reviewed and any questions were answered. The interview session began by requesting the pilot participants to state their name, followed by the time and date at the beginning of the interview.

The three pilot participants identified that it was efficient and effective to receive an electronic copy of the interview questions and consent form prior to the interview session. Receiving an email copy of the interview questions one hour before the interview gave the interviewees an opportunity to recall scenarios to discuss during the in-depth interview process. The pilot study revealed that the interviewer and interviewee had to remain vigilant of the time difference between the east coast and the west coast. Prior to the start of the interview process, two pilot participants reminded the interviewer of their lunchtime and about the quitting time.

## **DATA COLLECTION PROCESS**

The qualitative case study identified and described the patterns and areas for improvement by identifying the types of obstacles and patterns experienced by 20 heavy rail maintenance workers (10 cases in management and the other 10 cases in non-management positions). The interview data obtained from the two groups (managers and non-management maintenance employees) was expected to provide a perspective on the nature of the RCM embedding process. The second part of the study explored whether the RCM process affected rolling stock with regard to a change in availability, reliability, and safety. Data collected for the first part of the study consisted of personal interviews and the second part consisted of review of project documentation and reports. The in-depth semi-structured interviews were conducted via telephone with the sample of 20 heavy rail maintenance workers. Nineteen interviews were conducted on the telephone at the heavy rail transit agency, during work hours, behind closed doors. One interview was completed after work hours, due to the busy schedule of the participant.

A content analysis was performed on project documentation (e.g., project progress reports, memorandums, project reports, and email) exploring the outcome of the effect on rolling stock. Content analysis is a detailed and systematic examination of the content (Krippendorff 1980). This content analysis is used to determine the frequency of words or concepts within the body of material, and used to identify patterns or themes. The text is analyzed to determine the meanings and relationships of key words or phrases defined by the researcher. A researcher may then analyze the phrases and key words to make inferences about the messages within the texts (Krippendorff). For example, there were key words and phrases that were defined and coded to represent the most significant obstacles with the implementation of RCM. The key words and phrases were “lack of computers skills, getting support from union, acquiring of necessary parts, purchasing of tools, and getting support from labor.” The in-depth telephone interviews were later analyzed for the frequency in the response from the participants.

The gathering of information helped to develop an in-depth understanding of this RCM study phenomenon. An in-depth understanding consisted of reviewing the participants' telephone interviews to gain a better understanding of the lived experiences by the participants. The lived experience and perspective offered an insight to the obstacles and challenges that were experienced during the embedding of the RCM process.



## DATA ANALYSIS

Content analysis is a form of analyzing data from multiple texts into smaller content areas according to specific coding procedures (Krippendorff 1980). Content analysis has been applied to many forms of communication such as books, newspapers, films, and television. These domains include forms of communication. According to Holsti (1969), content analysis is “any technique for making inferences by objectively and systematically identifying specified characteristics of messages” (14). Content analysis allows researchers the ability to examine multiple data sources in a systematic manner in order to identify themes and/or patterns (Weber 1990). Researchers have asserted it is useful for exploring individual and group perspectives on a variety of important research topics (Stemler 2001). As such, content analysis is frequently used in qualitative research designs.

Originally, content analysis was designed to analyze content in communications (Holsti 1969). Content analysis was developed from the context of a communication paradigm that focused on the specific purpose, communication element, and question of content within a given text. The analysis was used to address three areas of concern. First, the content analysis was used to make inferences about the antecedents of communication. Second, the content analysis was used to describe and make inferences about the characteristics of a particular communication. Third, the content analysis was used to make inferences about the effects of a communication (Holsti 1969).

Content analysis was based on the assumption that particular words and phrases could be measured in communication by measuring word frequencies (Krippendorff 1980). In addition, it was assumed that by doing so, there would be words that were used frequently in comparison to other words and these words could be grouped according to categories. The subsequent categories were thought to depict the overall meaning that was attempting to be conveyed which resulted in the development of patterns and themes presented in the communication (Krippendorff 1980).

However, although word frequency count is a common practice in content analysis in qualitative research, there are other factors that must be taken into account when analyzing data through this method (Stemler 2001). It is important to search for synonyms to frequently cited words. The use of synonyms may add to the weight of a particular category. Also, there are many instances in which a particular word has more than one meaning. This issue must be taken into account in order to make sure that word frequency counts are not overestimated. Researchers concerned with this line of inquiry suggest that word frequency counts should begin with identifying words of potential interest, and then conduct a search for a “key word” in order to analyze word consistency and usage. Software may be used that can examine the context in which words of interest are used in sentences. However, the most meaningful interpretations of data occur when words within the text are coded according to specific rules (Stemler 2001).

Coding is defined as the process of analyzing the data for themes, ideas, and categories with labels to make it easier to identify patterns and make comparisons (Ryan and Bernard 2003). Codes can be based on themes, ideas, concepts, terms, keywords, or phrases.



Each code is given a name to indicate the idea or concept that is underlying the category. Any part of the data that is found to be related to the topic is given the appropriate label. If there is a theme found that does not fit with a code that is already in place, then a new code is developed (Ryan and Bernard 2003).

There are two ways in which data can be coded (Ryan and Bernard 2003). The two ways that data can be coded are emergent coding and a priori coding. A priori is the most common form of coding. A priori coding is when the researcher is concerned with pre-existing ideas regarding theory or ideas. The themes of concern are established and defined prior to looking at the data. Codes can be developed from a variety of sources. These include, but are not limited to, previous research or theory, research questions that the researcher is concerned with, or topics from an interview. A priori coding allows for modifications to be made to coding if necessary (Ryan and Bernard 2003). Emergent coding is not based on any pre-existing ideas or theories (Strauss and Corbin 1990). It allows for the codes to emerge from the data itself.

In emergent coding, there are two researchers that independently view the initial data set and create a list of common themes that they view as emerging. Once this list has been formed, the researchers examine each other's list to see if there are any similarities in the common themes that each has identified. Next, the researchers form a list that is a consolidation of the previous lists that is comprised of the common themes. If there is a 95 percent agreement among the researchers, then the code is determined to be reliable and is used in the subsequent analysis (Strauss and Corbin 1990).

According to Stemler (2001), the three types of coding units used are as follows:

1. Sampling units: These vary depending on how the researcher creates meaning. They can either be words, sentences, or paragraphs.
2. Context units: These can be either independent or attached. They can overlap and be numerous. They set limits on what kind of data can be recorded. Typically, defining context units is quite arbitrary.
3. Recording units: These are not limited. They are independent and coded separately.

There are six questions that are examined in content analysis (Krippendorff 1980). The six questions are as follows: (1) Which data is analyzed?; (2) How are they defined?; (3) What is the population from which they are drawn?; (4) What is the context relative to the analyzed data?; (5) What are the boundaries of the analysis?; and (6) What is the target of the inferences? An accurate content analysis must effectively answer such questions. Many times, there are issues that arise when conducting a content analysis, which makes answering these questions difficult. For example, a document that is needed for analysis may be missing or may not be able to be coded according to the specified criteria (GAO 1996). These problems must be addressed in addition to the questions concerned with content analysis.

Another important issue that must be addressed in any content analysis is the reliability of the analysis (Ryan and Bernard 2003; Stemler 2001). It is crucial that an analysis is reliable in order to make meaningful interpretations from the data and to draw inferences

as well as suggestions regarding the patterns and themes that emerge (Stemler 2001). In order to demonstrate reliability, the same coder should get the same results when the coding process is repeated. Additionally, the same themes should become evident when the data is coded by different people. Hence, there are techniques that have been developed to measure the reliability as an effort to increase the reliability of the analysis (Ryan and Bernard 2003).

One of the ways to measure reliability is to assess the percent of agreement among the coders (Stemler 2001). The procedure involves adding up the number of cases that were coded the same way by the two raters and then dividing by the total number of cases. Typically, Cohen's Kappa is used to measure this agreement as it takes into account those instances where agreement occurs by chance. A coding system is viewed as being reliable the closer it gets to 1 and is viewed as being unreliable the closer it gets to 0. All three assumptions must be met in order to use Cohen's Kappa in analysis (Stemler 2001).

In addition to reliability, validity is also of concern. An analysis can only be inferred to be meaningful if the results that are demonstrated are related to other measures of the similar construct (O'Donoghue and Punch 2003). In qualitative research, validity is established through the use of the triangulation of data. Triangulation of data is designed to increase the validity by combining several research methods. Triangulation stems from the idea that if different methods of assessment lead to the same results, the likelihood is increasing that the results gathered are accurate and measuring what they are intending to measure (O'Donoghue and Punch 2003).

The current study yielded itself to content analysis due to the primary research questions. A priori coding was utilized and Krippendorff's six steps were used in analyzing the data gathered from the interviews. The utilization of priori coding allowed data to be triangulated for the most meaningful and comprehensive interpretation. Prior to the analysis of data, participant responses were coded according to whether they were a manager or a non-manager. This coded process of the data allowed for additional comparison to identify differences between managers, non-manager participants, and project documentation (e.g., project progress reports, memorandums, project reports, and email).

## **RESULTS AND FINDINGS**

The following section describes the results and findings of the research study. This section contains demographic information about the participants, both in tabular and narrative form.

### **Demographic Information**

The demographic information collected consisted of the following five characteristics: (a) age; (b) gender; (c) education level; (d) number of years on the job; and (e) ethnicity. The intent behind the demographic questions was to correlate the data collected from the in-depth interviews with other sources of information to explore the possibly of contextual factors that may influence the participants' perception of the phenomenon. The demographic

information was collected after the participant signed the consent form and any questions the participant had were addressed. After all of the participants' questions were answered, the in-depth interview questions commenced. The demographic information pertaining to the 20 heavy rail maintenance workers (10 cases in management and the other 10 cases in non-management positions) who were interviewed is presented in Table 1.

**Table 1. Demographic Characteristics**

Participant	Age	Gender	Education	Number of Years on Job (range)	Ethnicity
1	60–65	Male	B.S	4–6	White
2	54–59	Male	B.S	7–9	White
3	48–53	Male	Masters	30–32	White
4	48–53	Male	B.S	10–12	White
5	48–53	Male	B.S	4–6	White
6	30–35	Male	B.S	4–6	White
7	36–41	Male	Associates	7–9	White
8	42–47	Male	Some college	10–12	White
9	42–47	Male	B.S and M.A	4–6	Hispanic
10	42–47	Male	Some college	10–12	White
11	54–59	Male	Trade School	33+	White
12	36–41	Male	Some college	10–12	White
13	36–41	Male	Trade school	10–12	White
14	54–59	Male	Associates	10–12	White
15	54–59	Male	Some College	33+	White
16	60–65	Male	High School	33+	White
17	48–53	Male	Trade School	30–32	White
18	48–53	Male	High School	1–3	White
19	40–53	Male	Some College	27–29	White
20	36–41	Male	Some College	4–6	White

## Themes

This section contains the description of the seven themes that emerged from the data analysis. The seven themes emerged from the participants' transcripts upon analysis of key words, and project documentation, which were then analyzed and coded in the QSR-NVivo 8 software.

### *Theme 1: Problems with the Predicted Implementation Time*

Theme 1 addressed the problems with the predicted implementation time. The most frequently reported invariant constituent was that creating the framework took time. Seventy-five percent ( $n = 15$ ) of the participants reported that creating the framework necessary

for the implementation would take time. For example, participant 1 indicated that they “took all the lessons learned from our first implementation efforts and developed what we call the implementation framework.” In addition, it was reported that this implementation was “time consuming.” Table 2 summarizes the invariant constituents that constitute this theme.

**Table 2. Problems with the Predicted Implementation Time**

Invariant Constituents	# of Participants to Offer this Experience	% of Participants to Offer this Experience
Creating framework took time	15	75%
No problems	3	15%
Continuing effort	2	10%

Other participants indicated that there was not a problem with the implementation time. Specifically, 15 percent ( $n = 3$ ) of the participants reported not having any problems. Participant 6 indicated that there was not a problem and that “it took a year.” Similarly, participant 7 reported that “it was pretty much on time.” Ten percent ( $n = 2$ ) of the participants described the implementation as a continuing effort. For example, participant 3 described the implementation as, “the initial implementation, perhaps, was completed, but like I said, it’s a living program that continues on.”

There were other invariant constituents that were only mentioned once. These included reporting that implementation time varied by fleet, the organization’s implementation process should have progressed at a slower pace, underestimated training time, slowed down, and one participant indicated that he had left during the implementation phase.

### *Theme 2: Effective Communication Methods Used*

Theme 2 identifies the effective communication methods that were used. The most frequently reported invariant constituent was direct communication. Ninety percent ( $n = 18$ ) of the participants indicated using some form of direct communication. Many of the individuals reported having “face-to-face” meetings or conversations with leaders. Others described communicating with “the spokesperson.” Table 3 summarizes the invariant constituents that constitute this theme.

The second most frequently reported invariant constituent was viewing PowerPoint presentations on RCM implementation. Sixty-five percent ( $n = 13$ ) of the participants described watching a PowerPoint presentation. Fifty percent ( $n = 10$ ) of the participants reported communicating about RCM implementation in meetings. For example, participant 10 described how there were “one-on-one meetings with the crew.” Participant 12 also described such meetings. In addition, 10 percent ( $n = 2$ ) of the participants reported participating in data presentations and seminars/training courses on RCM. Participant 18 indicated that the data presented was “impressive” and indicated that he felt “impressed with it.”

**Table 3. Effective Communication Methods Used**

Invariant Constituents	# of Participants to Offer this Experience	% of Participants to Offer this Experience
Direct communication	18	90%
PowerPoint presentation	13	65%
Presenting in meetings	10	50%
Data presentations	2	10%
Seminars/training course	2	10%

*Theme 3: Influence of Organizational Culture on RCM Implementation*

Theme three focuses on the influence that the organizational culture had on RCM implementation. The majority of the participants indicated some form of general difficulties related to cultural change in implementing RCM. Eighty-five percent ( $n = 17$ ) of the participants described general difficulties regarding cultural change. Participant 9 described these changes by reporting that “the human aspect is to stay in your comfort zone, and once you’re asking for a change, there’s a different methodology used” and a “cultural intervention” will be needed. Participant 8 indicated that “some guys” are not “receptive to change” and this presents difficulties in implementation. Others described similar difficulties in “changing culture” and the “pushback” that resulted from doing so. Table 4 summarizes the invariant constituents that constitute this theme.

**Table 4. Influence of Organizational Culture on RCM Implementation**

Invariant Constituents	# of Participants to Offer this Experience	% of Participants to Offer this Experience
General difficulties of culture change	17	85%
Having inclusion of all workers	2	10%

The second most frequently reported invariant constituent regarding the influence of organizational culture on RCM implementation was having the inclusion of all workers. Ten percent ( $n = 2$ ) of the participants described the need to include all workers. For example, participant 12 reported that in regard to including all workers, “getting them involved in the decision making process and in the implementation was key.” Participant 10 also indicated that getting all of the workers involved was “key” to successful implementation.

There were other invariant constituents that were only reported once. These included change management plan needed, communicating the importance to stakeholders, and reluctance for step-by-step procedures.

*Theme 4: Effect of RCM Process on Employees*

Theme 4 was identified as the effect of the RCM process on employees pertaining to how standardized procedures would effect their daily work experiences. The effects of the

RCM process on employees introduced concerns of a new standardized procedure, work responsibilities, and work demands. Table 5 summarizes the invariant constituents that constitute this theme. In general, the theme “effect of RCM process on employees” was concerned with the direct impact that employees would experience as the RCM process was embedded in an existing agency. Employees experienced standardize procedures as a major effect on the employees responsible for maintainability of the rolling stock. Although several participants were concerned with the responsibility and accountability shifting to the employees, many were in agreement to identify that RCM offered an opportunity to standardize its maintenance procedures.

**Table 5. Effect of RCM Process on Employees**

Invariant Constituents	# of Participants to Offer this Experience	% of Participants to Offer this Experience
Standardized procedures	14	70%
Shift of responsibilities	10	50%
More demands from employees	2	10%

The most frequently reported invariant constituents were standardized procedures (70 percent,  $n = 14$ ), shifts of responsibilities (50 percent,  $n = 10$ ), and more demands from employees (10 percent,  $n = 2$ ). For example, participant 17 described it as an “extension of corporate policy.” Similarly, another participant described it as a “logical extension of corporate policy.”

*Theme 5: Most Challenging Aspects of Implementing RCM*

Theme 5 identified the most challenging aspects of RCM implementation. The most frequently reported invariant constituent was cultural change. Eighty percent ( $n = 16$ ) of the participants described ways that RCM implementation influenced the culture. Maintenance workers reported that one of the difficulties in changing how maintenance is performed since it has been performed the same ways for years. For example, participant 6 indicated that “routine maintenance tasks are critical” and that records must be kept that show “discrepancies that are found on equipment.” Similarly, participant 5 described the difficulties in “changing mentality” in regard to the culture within the organization and reported that this was the “most significant barrier.” Table 6 describes the invariant constituents that constitute this theme.

**Table 6. Most Challenging Aspects of Implementing RCM**

Invariant Constituents	# of Participants to Offer this Experience	% of Participants to Offer this Experience
Culture change	16	80%
Review of procedures	7	35%



The second most occurring invariant constituent was the review of procedures. Thirty-five percent ( $n = 7$ ) of the participants described the challenges that were present in the review of procedures due to the implementation of RCM. For example, participant 2 described the “inevitable conflict between operations and maintenance” in regard to reviewing procedures. He went on to describe “that people take short cuts” and “don’t have time to perform it correctly.” Participant 7 reported that since the implementation of RCM that it has allowed the agency to review and document maintenance procedures that were not documented. This ensured the maintenance worker performed the same set of processes and procedures to ensure that maintenance was conducted as recommended by the manufacturer.

There were many other invariant constituents reported, however, they were only reported once. These included conflict between operations and maintenance, having adequate time, variation in employee learning curves, accurate records, accountability, using previous employees, and no big challenges.

#### *Theme 6: The Most Significant Obstacles of Implementing RCM*

Theme 6 focused on identifying the most significant obstacles of implementing RCM. The most frequently reported invariant constituent was the lack of computer skills. Seventy-five percent ( $n = 15$ ) of the participants indicated that the lack of computer skills was the most significant challenge to implementing RCM. To address the lack of computer skills, many participants did not possess adequate computer usage skills and required remedial training on the use of computers. Participant 8 described how an “RCM trainer came on each shift and did a computer generated shots on the screen” and the trainer “walked them through.”

The second most frequently reported invariant constituent was the lack of union support. Sixty percent ( $n = 12$ ) of the participants indicated that unions represented the most significant challenge to implementing RCM. Participants indicated that unions offer “very little support” and tend to think RCM implementation is “about reducing jobs or reducing overtime.” Thirty percent ( $n = 7$ ) of the participants described the difficulties within the organization in attaining labor support. For example, participant 1 indicated, “that labor can potentially be a great barrier, but you have to understand what their concerns are” and they have “to be addressed.” Participant 3 described that there is “skepticism on the part of the crafts personnel that someone is going to come in and tell them how to do their work.” Table 7 describes the invariant constituents that constitute this theme.

Twenty-five percent ( $n = 5$ ) of the participants indicated that the dangers of slipping back into old processes and purchasing of tooling were the most significant obstacles. In regard to slipping back into old processes, participant 2 indicated that “you always have a few people that think that it is going to go away and that things are going to go back to the way things used to be.” Participant 16 reported that the “resistance to this change” was the most significant barrier because it was different “than the way things had always been done for 25 years.” Fifteen percent ( $n = 3$ ) of the participants indicated that purchasing of tooling was the most significant obstacles. In addition, participant 1 described that the “parts support and the availability of tools and the manner in which the work was assigned were all barriers.”

**Table 7. Biggest Obstacles of Implementing RCM**

Invariant Constituents	# of Participants to Offer this Experience	% of Participants to Offer this Experience
Lack of computer skills	15	75%
Unions	12	60%
Getting support from labor	7	35%
Danger of slipping back to old processes	5	25%
Purchasing of tooling	3	15%

*Theme 7: Impact of RCM on Rolling Stock*

Theme 7 is the impact of RCM on rolling stock. Eighty-five percent ( $n = 17$ ) of the participants indicated that availability of rolling stock increased. Participant 6 reported a “10 percent increase in availability.” Sixteen of the other participants also reported that “availability increased.” Table 8 describes the invariant constituents that constitute this theme.

**Table 8. Impact of RCM on Rolling Stock**

Invariant Constituents	# of Participants to Offer this Experience	% of Participants to Offer this Experience
Availability increased	17	85%
Reliability increased	13	65%
Emphasis on safety	4	20%
Lack of change in safety and reliability	3	15%
Reliability decreased	2	10%

There were significant mixed results regarding the impact of RCM on reliability and safety. Some participants indicated that reliability had increased; others indicated that it had decreased. In addition, there were participants who indicated the emphasis on safety and reliability did not change. For example, 65 percent ( $n = 13$ ) of the participants indicated that reliability had increased and 10 percent ( $n = 2$ ) indicated that reliability had decreased. Participant 8 indicated that reliability increased and reported that “the reliability of this train set has gone up.” Participant 10 described how “reliability has gotten better since the pre-RCM time.” Participant 6 indicated that reliability had decreased and reported that this was a “result of a smaller time window for repairs.” Twenty percent ( $n = 4$ ) of the participants indicated that RCM had an emphasis on safety. Participant 9 indicated that safety has increased and reported that this was a “result of reviewing and updating of maintenance procedures.” Furthermore, 15 percent ( $n = 3$ ) of the participants reported that there were not any changes in safety and reliability in regard to the RCM implementation.

### *Content Analysis of Project Documentation*

Content analysis of project documentation (e.g., project progress reports, memorandums, project reports, and email) was conducted from three sets of data sources. One set of data source included project documentation; the second set included the interview of the 10 cases in management positions. The third set included the 10 cases in non-management positions. The content of all three data sets were compared to identify if there were any similarities or differences between project documentation and from the two different groups of maintenance workers' in-depth telephone interviews.

The objective of the comparison between project documentation and the two maintenance worker group's in-depth telephone interviews was to analyze whether the RCM maintenance based program influenced a change in rolling stock availability, reliability, and safety. The content and triangulated analysis revealed that rolling stock availability and rolling stock reliability had moderately increased post RCM implementation. The findings revealed by Backlund and Akersten (2003) and Holmgren (2005), also identified that the post-RCM implementation had an increase in equipment availability and reliability.

The perception from project sponsors and management identified that rolling stock operated longer periods without the need for maintenance. This inferred that rolling stock was more reliable since the implementation of RCM. Although the content analysis and triangulated analysis revealed that the rolling stock availability and reliability had definitely increased, there was insignificant or little evidence that rolling stock safety had increased or decreased since post implementation of RCM as identified in the research by Backlund and Akersten (2003) and Holmgren (2005).

### **SUMMARY**

The purpose of the current qualitative case study was to identify obstacles experienced by maintenance employees during the implementation of the RCM process at a single heavy rail transit agency. In addition, the outcome of the RCM process was explored to determine the impact of which the RCM process had on the rolling stock with regard to change in availability, reliability, and safety. Based on the analysis of the data, there were mixed results regarding the impact of RCM on the rolling stock. Some of the participants indicated that there was an increase in all three variables, whereas other participants indicated that there was a decrease. These results were not influenced by whether an employee was in a management position or a non-management position.

Based on the analysis of data, seven themes emerged in regard to obstacles experienced by maintenance employees during the implementation of the RCM process at a single heavy rail transit agency. The first theme elicited problems with the predicted implementation time. The second theme elicited the effective communication methods used. The third theme elicited the influence of organizational culture on RCM implementation. The fourth theme elicited the effect of RCM processes on employees. The fifth theme elicited the most challenging aspects of implementing RCM. The sixth theme elicited the most significant obstacles of implementing RCM. The seventh theme elicited the impact of RCM on rolling stock.

Content analysis of project documentation (e.g., project progress reports, memorandums, project reports, and email) was conducted from three sets of data source. One set of data source included projects documentation; the other set of data source included the interview of the 10 cases in management positions. The third data set included the 10 cases in non-management positions. The content analysis and triangulation analysis revealed that rolling stock availability increased post RCM implementation. The content analysis also revealed that rolling stock reliability had a moderate increase. However, there were mixed perceptions by maintenance employees regarding safety.

This analysis yielded valuable insight regarding the perceptions of RCM implementation from the perspectives of both managers and non-managers. Participants indicated that the implementation of RCM took a significant amount of time and that the majority of the communication regarding implementation occurred directly. The cultural climate within the organization had an influence on the RCM implementation. Two of the most significant obstacles involved the lack of computer skills and lack of union support. These findings have important implications for theory as well as future research and practice. These will be described in detail in the next chapter.

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## CONCLUSIONS AND RECOMMENDATIONS

The conclusions presented in the previous chapter articulate the themes identified in the chapter “Presentation and Analysis of Data,” and the outcome of the RCM process with regard to rolling stock. This section will bring together and address the themes and outcome of the RCM process to the research questions that guided the study. The specific problem that the study addressed is the lack of sufficient knowledge about the obstacles and patterns experienced by heavy rail transit agencies when implementing an RCM process and the outcome of RCM with regard to rolling stock.

A purposive sample of 20 maintenance workers was selected for their experiences during the RCM implementation. A semi-structured interview was captured on an Olympus digital voice recorder to gather data about the most significant obstacles of the RCM implementation. The identified lack of sufficient RCM implementation knowledge about the types of obstacles and patterns were addressed to prevent future implementation barriers of the RCM process at the heavy rail transit agency.

The findings suggest that the sample of 20 maintenance workers (10 in management positions and the other 10 in non-management positions) appeared to have experienced similar obstacles and challenges encountered in other industries as identified by Backlund and Akersten (2003) and Holmgren (2005). A triangulated analysis explored the RCM process outcome to determine the impact on the rolling stock with regard to change in availability, reliability, and safety. The researchers’ Backlund and Akersten (2003) and Holmgren (2005), findings also revealed that the RCM process outcome had an influence with similar results in areas of availability and reliability. According to Backlund and Akersten, “RCM can, among other things, improve system availability and reliability, reduce the amount of preventative and unplanned corrective maintenance, and increase safety.” Backlund and Akersten (2003) reported the latter elements are important factors for organizations to sustain in a competitive environment.

The study identified themes and patterns, which will influence leaders on strategies that would contribute to minimizing or avoiding potential obstacles experienced by other heavy rail transit agencies during the RCM embedding process. Therefore, the obstacles led to the following questions that structured much of this qualitative case study: (1) What were the major obstacles encountered implementing the RCM process? (2) What has been the impact on the rolling stock since the implementation of the RCM process with regard to rolling stock availability, reliability, and safety? To understand the real-life experiences of the maintenance employees, research data was collected by administering open-ended questions and by performing content analysis of project documents (e.g., project progress reports, memorandums, project reports, and email).

In “Presentation and Analysis of Data,” questions through the analysis of raw data imparted in “Methodology” are addressed. First, two specific research questions are addressed in sequence through analyzing the seven themes identified. (1) What were the major obstacles encountered implementing the RCM process? (2) What has been the impact on the rolling stock since the implementation of the RCM process with regard to rolling stock availability, reliability, and safety? Second, the implications of this study are presented,

followed by recommendations for future research.

In conclusion, the objective of this chapter is to integrate the findings and the emerging themes identified in the literature review. The findings of the study will fill in the literature gap for transit leaders on strategies that would contribute to minimizing or avoiding potential obstacles and barriers that were experienced during the RCM embedding process. The findings of the RCM process on rolling stock with regard to availability, reliability, and safety also are discussed. The findings will articulate to heavy rail transit leaders determine whether the RCM process can be considered an optimal solution to increase the performance for rolling stock.

## **OVERVIEW**

The discussion in this chapter contains a summary of the previous four sections, a discussion of the significance of the study to leadership, the significance of the themes as defined in the analysis, the content analysis of project documentation and the interviews of the heavy rail maintenance employees, paradigm shift in heavy rail maintenance philosophy, implications, the recommendations for further study, the summary and conclusions.

## **SIGNIFICANCE TO LEADERSHIP**

The findings in this study will assist political, federal government, and heavy rail transit leaders in understanding and making decisions about the challenges and obstacles of implementing an RCM-based maintenance program for rolling stock in mass transit systems in America. Chowdhury (2003) explained that organizations without the proper leadership cannot successfully achieve change in the organization. In order to achieve the successful implementation, the program or plan must be clearly articulated and communicated to the staff, with clear and concise goals and objectives, and vision (Erwin 2009). Political leaders, federal government, and heavy rail transit leaders can strategically plan for mass transit RCM implementation with reduced challenges by using data contained in this study.

The study could be used to develop a strategy to reduce the amount of maintenance required while enhancing rolling stock reliability. An improved strategy to enhance rolling stock reliability is particularly important to provide optimal service with out reducing revenue service, and when board members suggest doing more with less funding. Approximately 55 percent of the operating and maintenance department proceeds come from passenger revenue, parking revenue, and advertising the remaining 45 percent are generated from sales tax, and property tax (BART 2006a). In the Bay Area and in the nation the weak economy from 2006 to 2009 has experienced very little or no growth, which has impacted tax proceeds (BART 2006a).

Government funds, which historically were provided by the federal government to pay for capital improvements in transit properties, have been cut from 2006 to present. Additional challenges have been experienced by transit properties as a result of a decline in ridership, a slow growth in the economy that has resulted in an increase in the unemployment rate, which translates into fewer patrons relying on public transportation (BART 2006b). Several



years of funding cuts, along with a slow economy, equate to reduced funding available to public transportation for operation and maintenance. In the past, maintenance costs were mostly supported by a combination of revenue from sales tax proceeds, state and federal transportation subsidies, and fare box revenues. In the current economic period, maintenance cost expenses continue to be supported by the same funding sources, but offer less revenue due to less ridership and a slow growth in the economy. The heavy rail transit leaders may utilize the savings from the more reliable equipment and from the reduced maintenance, saving as an additional funding source.

The literature presented by Jones (2004) underscored the importance of organizational change and that organizations must accept that this is a normal course of action to be considered by leadership. Change in any organization is centered on the human resources, functional resources, technological, and organizational capabilities. Jones (2004) suggested that heavy rail transit leadership may need to understand that the following areas are interdependent and change in any one area will likely trigger a change in the other areas. It is suggested that leadership respond accordingly; otherwise, decisions rendered may negatively affect the organization.

In a dynamic transit organization, leaders must constantly evolve through flexibility and adaptability to remain competitive and deal with organizational change (Chowdhury 2003). Leaders play a vital role in initiating and implementing change successfully in the organization (Newstrom and Davis 2002). Heavy rail transit leadership may need to accept the fact that organizational change is considered part of conducting business and the impact organizational change may have on human resources, functional resources, technological, and organizational capabilities. Typically, changes in one area will cause other areas to realize change, as well. Heavy rail transit leaders need to understand and recognize that change is often driven not by the latest fad, but by external factors such as newly adopted executive orders, or changes in local, state or federal legislations.

## **FINDINGS AND INTERPRETATIONS**

This section presents the data from the research questions, and identifies obstacles experienced by maintenance employees and the impact the RCM process had on rolling stock. The analysis is based on the existing conceptual frameworks of the authors discussed in the literature review. The findings in this study suggested that similar obstacles and patterns are prevalent and existed in the RCM implementation at the heavy rail transit agency as it was experienced by other industries as identified by Backlund and Akersten (2003) and Holmgren (2005). Seven themes and patterns emerged from the data to address one of the research questions. The other research question was addressed by the content analysis. The findings were supported by the themes and research questions, which were sequentially introduced to the participants. The questions that guided this study were: (1) What were the major obstacles encountered implementing the RCM process? and (2) What has been the impact on the rolling stock since the implementation of the RCM process with regard to rolling stock availability, reliability, and safety?

### *Theme 1: Problems with the Predicted Implementation Time*

Theme 1 addressed problems with the predicted implementation time. Based on the statement from participants, the most frequently reported invariant constituent was that creating the framework took time. Seventy-five percent (15 out of 20) of the participants reported that creating the framework necessary for the implementation would take time. One participant described that they “took all the lessons learned from the first implementation efforts and developed what we call the implementation framework.” In addition, it was reported that RCM implementation was “time consuming.”

However, 15 percent of participants (3 out of 20) indicated that there was not a problem with the implementation time. Other statements on the implementation time include training time was underestimated, the organization should have slowed down, and one participant indicated that he had left during the implementation phase. There was no significant difference of statements on RCM implementation time between manager and non-manager participants.

### *Theme 2: Effective Communication Methods Use*

According to Backlund and Akersten (2003), effective communication is critical to the successful implementation of an RCM implementation. Several failed RCM implementations have been attributed to poor communication between technical staff, middle management, operators, and maintenance personnel. Theme 2 identified effective communication methods used to communicate with maintenance workers. According to the communication method statement, participants of this study expressed a variety of methods used as effective communication methods. Those communication methods included direct communication, viewing PowerPoint presentations, meeting presentations, participating in data presentations, and seminars/training courses course attendance. The most frequently reported invariant constituent was direct communication. Ninety percent (18 out of 20) of the participants indicated using some form of direct communication. Many of the individuals reported having “face-to-face” meetings or conversations with leaders. Other participants described communicating with “the project spokesperson.”

### *Theme 3: Influence of Organizational Culture on RCM Implementation*

Theme 3 focused on the influence that the organizational culture had on RCM implementation. The majority of the participants indicated some form of general difficulties related to cultural change in implementing RCM. Eighty-five percent (17 out of 20) of the participants described general difficulties regarding cultural change. One participant reported that “the human aspect is to stay in your comfort zone, and once you’re asking for a change, there’s a different methodology used” and a “cultural intervention” is needed. Another participant indicated that “some guys” are not “receptive to change” and this presents difficulties in implementation. Other participants described similar difficulties in “changing culture” and the “pushback” that resulted from doing so. The importance of cultural change should start at the executive level and then push down to the rank and file. According to Murthy, Atrens, and Eccleston (2002), a cultural change in maintenance philosophy must be created so that all functional units in the organization understand the importance of RCM process.

The second most frequently reported invariant constituent regarding the influence of organizational culture on RCM implementation involved the inclusion of all workers. Ten percent (2 of 20) of the participants described the need to include all workers. For example, one participant reported that in regard to the inclusion of all workers, “getting them involved in the decision making process and in the implementation was key.” Another participant also indicated that getting all of the workers involved was “key” to successful implementation.

Other invariant constituents were only reported once included: (1) change management plan needed, (2) communicating the importance to stakeholders, and (3) reluctance for step-by-step procedures. There was no difference on statements about the influence organizational culture has on RCM implementation.

#### *Theme 4: Effect of RCM Process on Employees*

Theme 4 was identified as the effect of the RCM process on employees. The participants interviewed described various affects the RCM process had on employees. Seventy percent (14 out of 20) of the participants reported that they adopted standardized procedures. Employees experienced standardize procedures as a major effect on the employees responsible for maintainability of the rolling stock. Fifty percent (10 out of 20) reported changes in shifts of responsibilities, and 10 percent (2 out of 20) reported more demands from employees. Several participants expressed a concern that the responsibility and accountability shifted to the employees and many were in agreement to identify that RCM offered an opportunity to standardize its maintenance procedures.

#### *Theme 5: Most Challenging Aspects of Implementing RCM*

Theme 5 focused on the most challenging aspects of RCM implementation. The most frequently reported invariant constituent was culture change. Eighty percent (16 out of 20) of the participants described ways that RCM implementation influenced the culture. For example, one participant indicated that “routine maintenance tasks are critical” and that records must be kept that show “discrepancies that are found on equipment.” Another participant reported the difficulties in “changing mentality” in regard to the culture within the organization, and reported that this was the “most significant barrier.” Many challenged aspects of the RCM implementation included the review of procedures, conflict between operations and maintenance, having adequate time, variation in employee learning curves, accurate records, and accountability.

#### *Theme 6: The Most Significant Obstacles of Implementing RCM*

Theme 6 focused on the most significant obstacles of implementing RCM. The most frequently reported invariant constituent was limited computer skills among the maintenance workers. Seventy-five percent (15 out of 20) of the participants indicated that the lack of computer skills was the most significant challenge to implementing RCM. Many of the maintenance workers did not own a computer and were not familiar with the basics of computer hardware (e.g. mouse) and software (e.g. Windows Operating System). Some maintenance workers were familiar with computers but only were versed at retrieving

email. Prior to the implementation of RCM, computers were not required to complete their responsibilities at work.

The second most frequently reported invariant constituent was unions and the lack of getting support from labor. Sixty percent (12 out of 20) of the participants indicated that unions represented the most significant challenge to implementing RCM. Participants indicated that unions offer “very little support” and tend to think RCM implementation is “about reducing jobs or reducing overtime.”

Thirty-five percent (7 out of 20) of the participants reported difficulties within the organization in attaining labor support. For example, one participant indicated, “that labor can potentially be a great barrier, but you have to understand what their concerns are” and they have “to be addressed.” Another participant described skepticism on the part of the crafts personnel that someone is going to come in and tell them how to do their work.” Twenty-five percent of participants (5 out of 20) described obstacles in implementing RCM as dangers of slipping back into the old processes, and 15 percent (3 out of 20) were concerned with the lack of purchasing of tooling. For example, one participant indicated, “you always have a few people that think that it’s going to go away and that things are going to go back to the way things used to be.” One participant reported that the “resistance to this change” was the most significant barrier because it was different “than the way things had always been done for 25 years.”

#### *Theme 7: Impact of RCM on Rolling Stock*

Theme 7 is related to the impact RCM had on rolling stock. The results regarding the impact of RCM on reliability and safety were mixed. While some participants indicated that reliability had increased, others indicated that it had decreased. The results revealed that, 85 percent (16 out of 20) of the participants indicated that availability increased. One participant reported a “10 percent increase in availability.” Another 15 participants also reported, “that availability increased.”

There were participants who indicated that safety and reliability did not change. For example, 65 percent (13 out of 20) of the participants indicated that reliability had increased, while 10 percent (2 out of 20) indicated that reliability had decreased. One participant reported that reliability increased and reported that “the reliability of this train set has gone up.” Another participant described how “reliability has gotten better since the pre-RCM time.” Twenty percent (4 out of 20) of the participants indicated that RCM had an emphasis on safety.

Based on the analysis of the data, seven themes emerged in regard to the obstacles and patterns experienced by maintenance employees during the implementation of the RCM process, as well as the impact an RCM process has on the rolling stock with regard to change in availability, reliability, and safety.

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### *Content Analysis of Project Documentation*

Content analysis of project documentation was conducted from three sets of data sources. One set of data included project documentation (e.g., project progress reports, memorandums, project reports, and email). The second set of data included the interviews of the 10 cases in management position. The third set consisted of the 10 cases in non-management positions.

The content analysis revealed that rolling stock availability increased and moderately increased in reliability post RCM implementation. Although the content analysis revealed that the rolling stock availability and reliability had definitely increased. However, there was insignificant or little evidence that rolling stock safety had increased or decreased since post implementation of RCM.

### *Paradigm Shift in Heavy Rail Maintenance Philosophy*

The current study revealed that the leadership of heavy rail transit agency have to identify new maintenance methods of addressing the old maintenance paradigm. The old maintenance philosophy consisted of running the rolling stock until failure. This reflection of less than frequent periodic maintenance to the rolling stock resulted in less than optimal performance of the rolling stock. Changes in maintenance methods are beyond the control of heavy rail transit leadership; these changes are often manifested or precipitated by technological developments, lack of funding, environmental laws, changing laws, and regulations (Soderholm, Holmgren, and Klefsjo 2007). The change in maintenance philosophy calls for a new maintenance method or strategy, which offers, reduced maintenance costs, increases equipment availability, and increase safety, and reliability. The RCM process should be considered a new maintenance strategy called RCM-based maintenance (Soderholm, Holmgren, and Klefsjo 2007). Soderholm, Holmgren, and Klefsjo argued that maintenance not only reduces risk to the organization, but also makes the organization less vulnerable to problems, which can also be viewed as adding value to the organization.

The implementation of RCM-based maintenance poses several challenges and obstacles for the leadership. Newstrom and Davis (2002) articulated the importance of understanding the opposition a group undergoes during the process; however, understanding these challenges and obstacles in advance allows the leadership to respond accordingly to resistance to change. Heavy rail transit leaders need to be aware of the challenges of incorporating a new maintenance strategy. Heavy rail transit leaders also need to recognize that employees that undergo a new maintenance philosophy ultimately cause the organization to experience performance transformation. Performance transformations can be difficult for an organization to endure without the buy-in and support of both employees and management (Erwin 2009).

According to Erwin, there are valuable strategies that organizational leaders will have to develop and incorporate to prepare employees for organizational change which included: (a) understanding the urgency for moving to an RCM-based maintenance philosophy; (b) incorporating RCM into the fabric of the organization; (c) creating a vision; (d) communicating



the vision; (e) empowering individuals to remove obstacles; (f) creating and celebrating short-term wins; (g) consolidating improvements and creating more change; and (h) institutionalizing new approaches (Erwin 2009).

The analysis of the data identified seven valuable themes in regard to the obstacles experienced by maintenance employees during the implementation of the RCM process. The impact the RCM process has on the rolling stock with regard to change in availability, reliability, and safety was also explored. The content analysis revealed that the rolling stock availability and reliability had definitely increased. However, there was insignificant or little evidence that rolling stock safety had increased or decreased since post implementation of RCM. The information has important implications for theory as well as future research, which will be discussed in the next section.

## **IMPLICATIONS**

The qualitative research findings may be used to expand the body of research in the heavy rail industry and be compared with findings from past research on RCM implementation in other fields. The findings in this study may assist political, federal government, and heavy rail transit leaders in understanding and making decisions about the challenges and obstacles of implementing an RCM-based maintenance program for rolling stock in mass transit systems in America. The findings can also aide transit leaders to identify problematic areas, which were experienced by this heavy rail transit agency in order to minimize, or eliminate similar resistance at other heavy rail transit agencies. Chowdhury (2003) explained that organizations without proper leadership cannot successfully achieve change in the organization. In order to achieve the successful implementations of a program or a plan, the program or plan must be clearly articulated and communicated to the staff, with clear, concise goals, objectives and vision (Erwin 2009). Political leaders, federal government, and heavy rail transit leaders need resources contained in this study to structure a strategic plan for mass transit agencies in America.

The study could be used to develop strategies to reduce the amount of maintenance required while enhancing rolling stock reliability, especially for heavy rail transit leaders who have been challenged by board members to do more with less funding. Approximately 55 percent of the operating and maintenance proceeds come from passengers' revenue, parking revenue, and advertising; the remaining 45 percent are generated from sales tax, and property tax (BART 2006a). The weak economy of the nation and the Bay Area has affected tax proceeds. Over the last few years, the nation's and Bay Area's economy has seen very little or no growth (BART 2006a). The weak economic situation increases the need to develop strategies to reduce the amount of maintenance costs.

This study and its implications can extend beyond the specific topic of study and could relate to other transit agencies with characteristics similar to the one studied in the research. The results of the study may also be generalizable to other industries that have a need to incorporate an effective maintenance strategy.



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## RECOMMENDATIONS

Further research into this topic may contribute to the body of research that would assist transit leaders in the heavy rail transportation industry to ascertain the barriers of implementing an RCM-based maintenance program. The explored and identified challenges learned from the RCM implementation process strategies have provided a richer and more detailed understanding of the obstacles encountered and the success factors, which were identified by transit leaders when incorporating the RCM program into an existing agency.

Additional research might be conducted to review the introduction of an RCM-based program at a light rail transit agency and in the bus industry. Further research may also be conducted on whether the experiences of the heavy rail transit workers are representative of a specific gender or ethnic groups. The study did not include representation of maintenance workers in other ethnic groups other than Caucasian and Hispanic. Further research may be conducted on women working in the heavy rail transit industry to explore and understand their experiences. Further research should also be conducted on whether an RCM-based maintenance program brings critical maintenance skills and computers skills to provide an effective and comprehensive maintenance program.

RCM implementation obstacles identified include a number of challenges during the implementation such as lack of commitment and upper management support, lack of training, cultural resistance to changes, failure to allow the program to effectively evolve, partial implementation, and the lack of communication. Further research may be conducted on the perspective of female maintenance workers and Union leadership to address the obstacles prior to the implementation of RCM.

Further qualitative studies should be performed with larger sample populations such that the results can be compared to the findings of this study. The impact of obstacles experienced from this RCM process analysis may be different from other transit agencies that implement the RCM process.

## SUMMARY AND CONCLUSION

This qualitative case study identified obstacles experienced by maintenance employees during the implementation of the RCM process at a single heavy rail transit agency. The current study also explored the outcome of the RCM process on the rolling stock with regard to change in availability, reliability, and safety.

Based on the analysis of data, seven themes emerged in regard to obstacles experienced by maintenance employees during the implementation of the RCM process at a single heavy rail transit agency. The first theme related to the problems with the predicted implementation time. The second theme was the effective communication methods used. The third theme was the influence of organizational culture on RCM implementation. The fourth theme was the effect of RCM processes on employees. The fifth theme was the most challenging aspects of implementing RCM. The sixth theme was the most significant obstacles of implementing RCM. The seventh theme was the impact of RCM on rolling stock.

The analysis revealed that there was very mixed results regarding the impact of RCM on the rolling stock. Some of the participants indicated that there was an increase in safety and reliability, whereas others indicated that there was a decrease in those aspects. However, the analysis revealed that the participants indicated that there had been a significant increase in rolling stock availability since pre-RCM. These results were not influenced by whether an employee was in a management position or a non-management position.

The current study yielded valuable insights regarding the perceptions of RCM implementation from the perspectives of both managers and non-managers. Participants indicated that the implementation of RCM took a significant amount of time and that the majority of the communication regarding implementation occurred directly. The cultural climate within the organization had an influence on implementation and one of the most challenging obstacles was receiving labor support that was needed. These findings have important implications for theory as well as future research and practice.

The findings in this study may assist political, federal government, and heavy rail transit leaders in understanding and making decisions about the challenges and obstacles of implementing an RCM-based maintenance program for rolling stock in mass transit systems in America. The study can be used to develop strategies to reduce the amount of maintenance required while enhancing rolling stock reliability, especially for heavy rail transit leaders who have been challenged by board members to do more with less funding.

## APPENDIX A: MILESTONES IN U.S. PUBLIC TRANSPORTATION HISTORY

(adopted from APTA 2006)

1827	New York: First horse-drawn urban stagecoach (omnibus) line
1830	Baltimore: First railroad (Baltimore & Ohio Railroad Co.)
1832	New York: First horse-drawn street rail line (New York & Harlem Railroad Co.)
1835	New Orleans: Oldest street rail line still operating (New Orleans & Carrollton line)
1838	Boston: First commuter fares on a railroad (Boston & West Worcester Railroad)
1827	New York: First horse-drawn urban stagecoach (omnibus) line
1830	Baltimore: First railroad (Baltimore & Ohio Railroad Co.)
1832	New York: First horse-drawn street rail line (New York & Harlem Railroad Co.)
1835	New Orleans: Oldest street rail line still operating (New Orleans & Carrollton line)
1838	Boston: First commuter fares on a railroad (Boston & West Worcester Railroad)
1856	Boston: First fare-free promotion
1871	New York: First steam-powered elevated line (New York Elevated Railroad Co.)
1872	Great epizootic horse influenza epidemic in eastern states kills thousands of horses
1873	San Francisco: First successful cable-powered line (Clay St. Hill Railroad)
1874	San Francisco: First recorded strike by street railway workers
1882	Boston: American Street Railway Association
1883	New York: First publicly operated cable-powered line (Brooklyn Bridge)
1883	New York: First surviving street rail labor organization (Knights of Labor Local 2878)
1884	Cleveland: First electric street railway line (East Cleveland Street Railway)
1886	Montgomery, AL: First semi-successful citywide electric street railway transit agency (Capital City Street Railway Co.)
1882	Boston: American Street Railway Association
1883	New York: First publicly operated cable-powered line (Brooklyn Bridge)
1883	New York: First surviving street rail labor organization (Knights of Labor Local 2878)
1884	Cleveland: First electric street railway line (East Cleveland Street Railway)
1886	Montgomery: First semi-successful citywide electric street railway transit

1888	Richmond, VA: First successful electric street railway transit agency (Union Passenger Railway)
1889	New York: First major strike by street railway workers
1892	Indianapolis: First national street railway labor union founded (now called the Amalgamated Transit Union)
1893	Portland, OR: First interurban rail line (East Side Railway Co.)
1894	Boston: First public transportation commission (Boston Transit Commission)
1895	Chicago: First electric elevated rail line (Metropolitan West Side Elevated Railway)
1897	Boston: First electric underground street railway line
1897	Boston: First publicly-financed public transportation facility (street railway tunnel)
1898	Chicago: First electric multiple-unit controlled rail line (Chicago & South Side Rapid Transit Railroad Co.)
1904	Bismarck, ND: First state-operated street railway
1904	New York: First electric underground (and first 4-track express) heavy rail line (Interborough Rapid Transit Co.)
1906	Monroe, LA: First municipally-owned street railway
1908	New York: First interstate underground heavy rail line (Hudson & Manhattan Railroad to New Jersey)
1910	Hollywood, CA: First trolleybus line (Laurel Canyon Utilities Co.)
1912	San Francisco: First publicly operated street railway in a large city (MUNI)
1917	New York: Last horse-drawn street railway line closed

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## APPENDIX B: TRANSIT AGENCIES IN NORTH AMERICA

Illustrated below are the 14 heavy rail rapid transit systems located in North America. Additionally, it contains the number of track miles, the name of the transit system, and the number of stations found at each of the respective transit agency (APTA 2006).

### Heavy Rail Transit Agencies Mileage and Station Data

Primary City	Transit Name	Track Miles	Stations
Atlanta, GA	Metropolitan Atlanta Rapid Transit Authority	103.7	38
Baltimore, MD	Maryland Transit Administration (MTA)	34.0	14
Boston, MA	Massachusetts Bay Transportation Authority (MBTA)	108.0	42
Chicago, IL	Chicago Transit Authority (CTA)	287.8	144
Cleveland, OH	The Greater Cleveland Regional Transit Authority	41.9	18
Los Angeles, CA	Los Angeles County Metropolitan Transportation Authority	34.1	16
Miami, FL	Miami-Dade Transit (MDT)	55.9	22
New York, NY	MTA New York City Transit (NYCT)	835.0	468
New York, NY	Port Authority Trans-Hudson Corporation (PATH)	43.1	13
New York, NY	Staten Island Rapid Transit Operating Authority	32.7	23
Philadelphia, PA	Port Authority Transit Corporation (PATCO)	38.4	13
Philadelphia, PA	South Eastern Pennsylvania Transportation Authority	102.0	75
San Francisco, CA	San Francisco Bay Area Rapid Transit District (BART)	267.6	43
Washington, DC	Washington Metropolitan Area Transit Authority	225.3	83

Illustrated below are the 29 light rail transit systems located in North America. Additionally, it contains the number of track miles, the name of the transit system, and the number of stations found at each of the respective transit agency (APTA 2006).

### Light Rail Transit Agencies Mileage and Station Data

Urbanized Area	Transit Agency	Track Miles	Stations
Baltimore, MD	Maryland Transit Administration (MTA)	54.0	32
Boston, MA	Massachusetts Bay Transportation Authority	78.0	25
Buffalo, NY	Niagara Frontier Transportation Authority	14.1	7
Cleveland, OH	The Greater Cleveland Regional Transit Authority	33.0	8
Dallas, TX	Dallas Area Rapid Transit (DART)	98.4	34
Dallas, TX	McKinney Avenue Transit Authority	2.8	0

<b>Urbanized Area</b>	<b>Transit Agency</b>	<b>Track Miles</b>	<b>Stations</b>
Denver, CO	Denver Regional Transportation District (RTD)	32.1	23
Galveston, TX	Island Transit	5.0	3
Houston, TX	Metropolitan Transit Authority	20.0	16
Kenosha, WI	Kenosha Transit (KT)	1.9	2
Little Rock, AR	Central Arkansas Transit Authority (CATA)	2.8	NA
Los Angeles, CA	Los Angeles County Metropolitan Authority	116.3	49
Memphis, TN	Memphis Area Transit Authority (MATA)	10.5	7
Minneapolis, MN	Metro Transit	24.2	17
New Orleans, LA	New Orleans Regional Transit Authority (NORTA)	26.0	9
New York, NY	New Jersey Transit Corporation (NJ TRANSIT)	67.1	49
Philadelphia, PA	South Eastern Pennsylvania Transportation Agency	171.0	46
Pittsburg, PA	Port Authority of Allegheny County (Port Authority)	44.8	25
Portland, OR	Portland Streetcar	5.0	0
Portland, OR	Tri-County Metropolitan Transportation District of Oregon (TriMet)	92.9	62
Sacramento, CA	Sacramento Regional Transit District	62.6	4
Salt Lake City, UT	Utah Transit Authority (UTA)	37.3	23
San Diego, CA	San Diego Trolley, Inc.	97.0	49
San Francisco, CA	San Francisco Municipal Railway (MUNI)	72.9	9
San Jose, CA	Santa Clara Valley Transportation Authority (VTA)	71.5	57
Seattle, WA	Central Puget Sound Regional Transit Authority (ST)	1.8	6
Seattle, WA	King County DOT— King County Metro	2.1	9
St. Louis, MO	Bi-State Development Agency (METRO)	81.0	28
Tampa, FL	Hillsborough Area Regional Transit Authority (HART)	3.2	8

Illustrated below are the 21 commuter rail transit systems located in North America. Additionally, it contains the number of track miles, the name of the transit system, and the number of stations found at each of the respective transit agency (APTA 2006).



**Commuter Rail Transit Agencies Mileage and Station Data (a)**

<b>Urbanized Area</b>	<b>Transit Agency</b>	<b>Track Miles</b>	<b>Stations</b>
Anchorage, AK	Alaska Railroad Corporation (ARRC)	46.2	10
Baltimore, MD	Maryland Transit Administration (MTA)	471.0	42
Boston, MA	Massachusetts Bay Transportation Authority	648.4	126
Chicago, IL	Northeast Illinois Regional Commuter Railroad	1,144.0	230
Chicago, IL	Northern Indiana Commuter Transportation District	130.0	20
Dallas, TX	Dallas Area Rapid Transit (DART)	20.7	4
Dallas, TX	Fort Worth Transportation Authority (The T)	22.6	5
Hartford, CT	Connecticut Department of Transportation (CDOT)	106.0	8
Los Angeles, CA	Southern California Regional Rail Authority	631.0	53
Miami, FL	South Florida Regional Transportation Authority	104.0	18
New York, NY	Metro North Commuter Railroad Company	802.7	109
New York, NY	MTA Long Island Rail Road (MTA-LIRR)	701.1	124
New York, NY	New Jersey Transit Corporation (NJ TRANSIT)	1,016.4	167
Philadelphia, PA	Pennsylvania Department of Transportation	144.4	12
Philadelphia, PA	South Eastern Pennsylvania Transportation Authority	695.0	156
San Diego, CA	North San Diego County Transit District (NCTD)	83.7	8
San Francisco, CA	Peninsula Corridor Joint Powers Board (PCJPB)	136.7	34
Seattle, WA	Central Puget Sound Regional Transit Authority (ST)	146.0	9
Stockton, CA	Altamont Commuter Express (ACE)	90.0	10
Syracuse, NY	ON TRACK	3.5	3
Washington, DC	DC Virginia Railway Express (VRE)	190.0	18

Illustrated below are the 14 transit systems other than heavy rail, light rail, or commuter rail located in North America. Additionally, it contains the number of track miles, the name of the transit system, and the number of stations found at each of the respective transit agency (APTA 2006).

### Other Rail Transit Agencies Mileage and Station Data

Urbanized Area	Transit Agency	Track Miles	Stations	Mode
Detroit, MI	Detroit Transportation Corporation	2.9	13	AG
Indianapolis, IN	Clarian Health People Mover	2.8	3	AG
Jacksonville, FL	Jacksonville Transportation Authority	5.4	8	AG
Las Colinas, TX	Las Colinas Area Personal Transit	1.4	4	AG
Miami, FL	Miami Dade Transit (MDT)	9.4	25	AG
Morgantown, WV	West Virginia University	8.7	4	AG
San Francisco, CA	San Francisco Municipal Railway (MUNI)	8.8	0	CC
Chattanooga, TN	Chattanooga Area Regional Transportation Authority	1.0	2	IP
Dubuque, IA	Fenelon Place Elevator	0.1	2	IP
Johnstown, PA	Cambria County Transit Authority (CamTran)	0.3	2	IP
Pittsburgh, PA	Port Authority of Allegheny County (Port Auth)	0.5	4	IP
Seattle, WA	City of Seattle—Seattle Center Monorail Transit	2.0	2	MO
Mountain Village, CO	Mountain Village Metro District	2.5	4	TR
New York, NY	Roosevelt Island Operating Corporation (RIOCC)	0.6	2	TR

*Note:* AG = automated guideway transit, CC = cable car, IP = inclined plane, MO = monorail, TR = aerial tramway.

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## APPENDIX C: INDIVIDUAL INFORMED CONSENT FORM

By signing this consent form, I acknowledge that Felix A. Marten, Jr. (the Researcher), a candidate for a Doctor of Business Administration degree at the University of Phoenix, has invited me to be part of a research study. I understand that the name of the study is "Reliability Centered Maintenance: A Qualitative Case Study of Railway Transit Maintenance." I further acknowledge that I understand that the purpose of this qualitative case study is to explore the obstacles encountered during the implementation of an RCM program and outcome in a heavy rail transit environment.

By signing below, I consent to participate in at least a 45-minute in-depth interview. I give a release allowing the researcher to record the interview and take notes during the conversation. Upon request, I understand I will have the option to review a transcript of the interview and suggest changes that more accurately reflect the information I shared. I fully and completely understand that my participation in this study is voluntary and confidential and that I can withdraw from the study at any time without penalty by contacting the researcher.

I understand that my identity will be protected, and that all the data provided by myself and all participants in the study will be grouped, and that only grouped data will be reported. To ensure that my identity is protected, the researcher will remove any identifying information from my interview transcript prior to entering it into the database of the study and substitute a coding system that only he will have access to. He will also keep the interview notes under lock and key at all times and keywords protect the database.

I fully understand that the researcher will publish the results of this research study but that my identity will remain confidential and all documents and databases pertaining to my participation will remain secured in the researcher's possession for three years after which they will be destroyed. I understand that in this research study there are no foreseeable risks to me. I also understand that there are no direct benefits to me but that the study may be helpful to others insofar as knowledge gained through this study may contribute to further RCM implementation in the transit industry or to leadership development both in RCM and non-RCM programs.

By signing this form I acknowledge that I understand the nature of the study, the potential risks to me as a participant, and the means by which my identity will be kept confidential. My signature on this form also indicates that I am 18 years old or older and that I give my permission to voluntarily serve as a participant in the study described.

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Print Name

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Date

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Signature



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## APPENDIX D: ORGANIZATION CONSENT AND CONFIDENTIALITY FORM

### AGREEMENT

**THIS CONSENT AND CONFIDENTIALITY AGREEMENT** (“Agreement”) is entered into as of August 25, 2008, by and between the {organization name}, a corporation organized under the laws of the {state or nation}, having offices at {physical address} and the {name of college or university}, an educational institution, having offices at {physical address}, {address of campus if different}, and {name of study’s primary investigator}, a student of {name of university or college}, who principally resides at {redacted} (“Researcher”).

**WHEREAS**, Researcher is a candidate for a {name of degree program} at {name of college or university}, who, as part of a degree requirement, is conducting a study entitled: {name of study} (“Study”), and **WHEREAS**, in conjunction with the study, Researcher desires to conduct up to 20 interviews with {organization name} employees to learn about those employees’ personal perceptions of {organization’s name} Reliability Centered Maintenance (RCM) Program for its {name of organization} fleet, and

**WHEREAS**, {redacted} consents to Researcher’s interviews, which will disclose proprietary and confidential information of {redacted} (“Confidential Information”), subject to the terms and conditions set forth herein.

**NOW THEREFORE**, in consideration of the promises and covenants herein contained, {redacted} and the University and the Researcher agree as follows:

1. Subject to the terms and conditions of this Agreement, {organization name} shall allow Researcher to conduct a telephone conference interview, lasting no longer than 60 minutes, interviewing up to 20 {organization name} employees who work on the {redacted}’s RCM program, for the purpose of gathering background data for Researcher’s Study. Interviews will be conducted pursuant to the “Individual Informed Consent Form,” which has been approved by the Parties to this Agreement and attached hereto as Appendix C.
2. For purposes of this Agreement, Confidential information shall include the identities of {organization’s name} interviewed for purposes of the Study. The Researcher and the University may publish the responses and the results of the interviews, but may not reveal {organization’s name} or its employees as the source of that information. Additionally, neither the Researcher nor the University shall attribute to {organization’s name} any of the background information from the interviews nor make any presentations that in any way identify {organization’s name}.
3. The Confidential Information disclosed to Researcher during those interviews, or to the University during review of Researcher’s Study, pursuant to this Agreement, shall be held in confidence according to the requirements of this Agreement. Neither the Researcher nor the University shall publish or otherwise disclose any of the Confidential Information to any person for any reason or purpose whatsoever, or use

any of the Confidential Information for any purpose other than as background data for Researcher's Study.

4. All Confidential Information disclosed during the interviews and under this Agreement shall remain the property of {organization's name}
5. Researcher agrees that if he makes Confidential Information to any other persons who may be assisting him in this study, such persons will be made aware of the confidential nature of such Confidential Information, and will be required to agree to hold such Confidential Information in confidence under terms substantially identical to the terms hereof.
6. The University similarly agrees that it will make Confidential Information available to its officers, employees, third party contractors, and affiliates only on a need-to-know basis, and that all such persons to whom any Confidential Information is made available will be made aware of the confidential nature of such Confidential Information, and will be required to agree to hold such Confidential Information in confidence under terms substantially identical to the terms hereof. The University shall instruct its employees and third party contractors of their obligations to maintain the confidentiality of Confidential Information obtained under this Agreement. Additionally, the University shall be responsible for any actions on the part of its employees and third party contractors for any improper disclosure of Confidential Information which is disclosed to such employee or third party contractor.
7. The Researcher and the University shall use the same degree of care and secrecy to protect the confidentiality of Confidential Information as it uses to protect its own proprietary or confidential information, and, in any event, shall not use less than a reasonable degree of care and secrecy to protect the confidentiality of the Confidential Information. The researcher will keep the consent forms under lock and key at all times and keywords protect the database.
8. If the Researcher or the University is confronted with legal action to disclose the Confidential Information, then the Researcher or University shall promptly notify {organization's name} in writing in order to enable {organization's name} to seek an appropriate protective order. The Researcher and the University shall reasonably assist {organization's name} in obtaining a protective order requiring that any portion of such Confidential Information required to be disclosed be used only for the purposes for which a court issues an order.
9. The Researcher and the University acknowledge and agree that because an unauthorized disclosure of the Confidential Information in violation of the requirements of this Agreement shall cause material and irreparable harm to {organization's name}, {organization's name} shall have recourse to all available remedies, at law or in equity, to compensate for any and all damages suffered as a result of any unauthorized disclosure in violation thereof.
10. The term of this Agreement shall commence on the date first written above and shall terminate December 31, 2013.



11. In the event that any of the provisions contained herein shall, for any reason be held to be invalid, illegal or unenforceable in any respect, such invalidity, illegality or unenforceability shall not affect any other provisions of this Agreement, and this Agreement shall be construed as if such provision(s) had never been contained herein, provided that such provision(s) shall be curtailed, limited or eliminated only to the extent necessary to remove the invalidity, illegality or unenforceability.
12. This Agreement shall be governed by and construed in accordance with the laws of the {state or nation of organization}.
13. Upon conclusion of Researcher's Study, Researcher shall provide {organization's name} with a copy of the Study and results. Additionally, upon termination of this Agreement, Researcher shall dispose of the Confidential Information obtained from the interviews in accordance with any written directions from {organization's name}.
14. The confidentiality rights and obligations set forth in this Agreement shall survive the termination of this Agreement.

**IN WITNESS WHEREOF**, the Parties hereto have caused this Agreement to be executed by their duly authorized representatives as of the date first set forth above.

**{Researcher's name}**

**{Organization name}**

By: \_\_\_\_\_  
 Name: \_\_\_\_\_  
 Title: \_\_\_\_\_

By: \_\_\_\_\_  
 Name: \_\_\_\_\_  
 Title: \_\_\_\_\_

**{Name of college or university}**

By: \_\_\_\_\_ Name: \_\_\_\_\_  
 Title: \_\_\_\_\_ Date: \_\_\_\_\_

Note: Signed copy by all parties on file.



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## APPENDIX E: NON-MANAGEMENT INTERVIEW SCHEDULE

1. What is your age? What is your gender? What is your education level? How many years on the job?
2. Why did the transit agency decide to implement an RCM Program?
3. What factors influence the incorporation of an RCM program into the organization strategy?
4. What was the difference between the plan for implementation and the actual full implementation?
5. How did the project sponsor communicate the goals and objective of the RCM process?
6. What was learned about effective staff communication methods for understanding RCM goal and objectives?
7. What factors are important when considering a change in organizational maintenance strategy? How does organizational culture play a role in the implementation?
8. How does an RCM program complement the day-to-day actions of an average employee?
9. What was the most challenging aspect of the implementation of the RCM program into the existing organization? How did senior management support the implementation?
10. What kinds of obstacles were encountered during the implementation of the RCM process? Which were the biggest barriers? How did the organization overcome these barriers? If not overcome, what was done?
11. How did the Union perceive the value of RCM process for the Union membership? Was there any concern or resistance from the Union leadership?
12. Based on your experience after fully implementing the RCM program, how would you compare to pre-RCM times the reliability, availability, and safety of the rolling stock?



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## ABBREVIATIONS AND ACRONYMS

AAA	American Automobile Association
APTA	American Public Transportation Association
BART	Bay Area Rapid Transit
BDM	Breakdown Maintenance
CBM	Condition-Based Maintenance
CI	Continuous Improvement
CMMS	Computerized Maintenance Management System
FAA	Federal Aviation Administration
FBM	Frequency-Based Maintenance
FMECA	Failure Mode, Effects, and Criticality Analysis
FRA	Federal Railroad Administration
GAO	General Accounting Office
HVAC	Heating, Ventilating, and Air Conditioning
JIT	Just-In-Time
MTBF	Mean Time Between Failures
OEE	Overall Equipment Effectiveness
PM	Preventative Maintenance
RCM	Reliability Centered Maintenance
ROI	Return on Investment
RS&S	Rolling Stock and Shop
TOD	Transit-Oriented Development
TPM	Total Productive Maintenance
TQM	Total Quality Management
Wye	Having a shape similar to the letter Y; in this report, refers to a triangle of railroad track



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## ABOUT THE AUTHOR

### **FELIX A. MARTEN, JR., DBA**

For more than 20 years, Dr. Felix Marten has been employed with San Francisco Bay Area Rapid Transit District (BART). He and his team are proud of the fact that they completed and opened the San Francisco Airport extension. His efforts and former team continued to work to bring BART to San José, air BART to the Oakland International Airport, and eBART to connect into the Antioch/Byron area.

Dr. Marten has served in many positions with the BART district, including computer specialist, train control engineer, supervising engineer, manger of operations liaisons, and his current position of assistant superintendent of systems maintenance, where he oversees the maintenance of several divisions of the District. Dr. Marten has taught classes in business; operations management; physics; intermediate algebra; operating systems; analog, digital, and industrial electronics; and PC troubleshooting. He also headed the Cisco Networking Academy Program.

Dr. Marten has a B.S. in electronic engineering technology, and in computer engineering technology from Cogswell College, an M.S. in electrical engineering from International Technological University (ITU), an M.S. in public administration from Golden Gate University, a certificate in project management from U.C. Berkeley, and is a Cisco Certified Academy Instructor (CCAI). Additionally, Dr. Marten completed his dissertation to earn a D.B.A. in business administration from the University of Phoenix (UOP).



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