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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Configuration Management in Transportation Management Systems

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

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This synthesis report will be of interest to state transportation departments and regional and local agencies, as well as to the consultants that work with them. It identifies how configuration management (CM) is currently being developed and used by transportation management systems. It is intended as a resource document for professional just beginning to apply CM. This report can be used as a reference tool by agency managers and administrators, as well as other technical personal, in both the public and private sectors, to locate more in-depth material to support CM programs. The document addresses the fundamental concepts and principles of CM, the need for CM within transportation management systems, and available CM resources (including books, standards, websites, and software tools). It also contains information about the status of CM within transportation departments and detailed case studies of the use of CM both outside of and within the transportation field.

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Configuration Management in Transportation Management Systems

A Synthesis of Highway Practice

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SUBJECT AREAS
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communication and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NOTE: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis report will be of interest to state transportation departments and regional and local agencies, as well as to the consultants that work with them. It identifies how configuration management (CM) is currently being developed and used by transportation management systems. It is intended as a resource document for professionals just beginning to apply CM. This report can be used as a reference tool by agency managers and administrators, as well as other technical personnel, in both the public and private sectors, to locate more in-depth material to support CM programs. The document addresses the fundamental concepts and principles of CM, the need for CM within transportation management systems, and available CM resources (including books, standards, websites, and software tools). Also, it contains information about the status of CM within transportation departments and detailed case studies of the use of CM both outside of and within the transportation field.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board includes a glossary. This is in addition to an Appendix containing an example CM tool.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the available information was assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the author's research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

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This study was managed by Donna L. Vlasak, Senior Program Officer, who worked with the consultant, the Topic Panel, and the Project 20-5 Committee in the development and review of the report. Assistance in project scope development was provided by Stephen F. Maher, P.E., Manager, Synthesis Studies. Don Tippman was responsible for editing and production. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

Crawford F. Jencks, Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-5 Committee and the Synthesis staff.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated. In particular, Bayne Smith of the Georgia Department of Transportation provided invaluable assistance in describing the agency's configuration management program.

CONFIGURATION MANAGEMENT IN TRANSPORTATION MANAGEMENT SYSTEMS

SUMMARY

Configuration management, a process developed to control change in complex information technology-based systems, has attracted an increasing amount of attention from the transportation engineering community. As intelligent transportation systems (ITS) deployment accelerates, and transportation departments develop and operate increasingly complex transportation management systems, the need for configuration management grows. This synthesis examines configuration management from the perspective of transportation management systems by (1) exploring the fundamental concepts of configuration management, (2) analyzing the key functions of transportation management as they relate to configuration management, (3) presenting the results of a survey of transportation officials, and (4) describing a case study of the configuration management process used by the Georgia Department of Transportation.

The configuration management process includes four basic elements. First, system component *identification* is required to support tracking unique system elements. Second, a *control* process is required to ensure that system configuration changes are carefully considered before implementation. Third, *status accounting* is necessary to ensure that the system and changes are well documented to support maintenance, operations, enhancements, and integration. Finally, *audit and review* should be used to validate the quality of the system's configuration throughout its life cycle. As seen in these four elements, configuration management is in no way a highly technical or mysterious tool. Rather, it is a formal process intended to support effective system development and maintenance. Experience has shown that the development of configuration management plans, formal documentation of an organization's approach to configuration management, is the critical starting point for a sound configuration management process. Standards to support the development of configuration management plans are available from a number of sources, such as the Institute of Electrical and Electronics Engineers (IEEE Standard-828-1998 is described in more detail in chapter 3 of this report).

Transportation management systems are complex hardware/software systems that seek to improve surface transportation services through information and management/control strategies using resources such as traffic signals and incident management services. These systems have historically experienced steady change, in terms of technology, size, and complexity, making configuration management a necessity.

There are many configuration management resources available to support the transportation community, including a large number of books and websites. In addition, a number of commercial configuration management software tools have been developed to assist organizations in the tasks of configuration management. These tools support configuration management primarily from a software development perspective. A review of these tools

reveals that although they may be of great use in certain aspects of transportation management system configuration management, their focus on the development of software in the system's life cycle limits their overall effectiveness in transportation management system application.

A survey of transportation departments indicates that transportation management systems are in the early stages of configuration management application. Only 62 percent of freeway management systems and 27 percent of signal systems reported the use of configuration management. Furthermore, only a few of those systems reporting the use of some form of configuration management had actually developed a formal configuration management plan to guide the process.

In addition, the need for differing levels of configuration management, depending on the relative complexity of the system, was evident because the more complex systems in the survey tended to have a greater likelihood of using configuration management.

A number of other important points concerning the state of the practice of transportation management systems and configuration management were revealed in the survey.

- Transportation departments, contractors, and consultants all have critical roles and responsibilities in configuration management, which tend to change throughout the life cycle of a system.
- The majority of survey respondents did not use a configuration management software tool, most likely because these tools have largely been designed to meet the needs of the software development community.
- Most respondents did not include the entire range of activities in their configuration management processes. The majority of the systems did include some form of formal identification, but fewer included change controls and status accounting and auditing.
- Very few of those currently involved in configuration management have received formal training.
- The greatest benefit of configuration management cited by the survey respondents was an improved ability to maintain and upgrade the transportation management system. This also points to the importance of configuration management in supporting large-scale, multiple-system integration at a regional level.
- The greatest cost of configuration management cited by the respondents was from consultant contracts and agency staff time requirements.

Clearly, there is room for improvement in the use of configuration management within transportation management systems. Fortunately, the need and justification for configuration management is becoming better understood. When asked to rate if the overall benefits of configuration management were worth the costs, on a scale of 0 to 10 (with 10 being complete agreement and 0 being complete disagreement), 77 percent of the agencies gave a rating of 7 or higher.

Although the use of configuration management within transportation management systems is essential, there are a number of characteristics of transportation management systems that make its effective use challenging. To expedite the effective application of configuration management in transportation management systems, the following recommendations are offered.

- Configuration management can play a critical role in the long-term success of transportation management systems, particularly as systems grow in size and regional integration of systems becomes more prevalent. The national transportation operations' community should promote the use of formal configuration management policies, programs, and recommended best practices in the development, implementation, integration, management, and operation of transportation management systems and other ITS applications.

- Just as transportation management systems vary considerably in size and complexity, so too must the application of configuration management. There is a need for technical guidance, recommended practices, and resource materials to aid transportation departments in accurately determining the level of configuration management needed to support their various systems.
- Commercial configuration management tools do not fully meet the requirements of transportation management systems. These tools should be designed specifically for the requirements of transportation agencies.
- Transportation agency personnel (in addition to contract and consultant personnel) should be trained in configuration management. Such training materials should be geared specifically for the use of configuration management within transportation management systems.
- Although this report like most configuration management reference materials focuses on the configuration management process, transportation agencies should develop sound configuration management programs to support the individual processes. The program should establish an institutional framework for, provide sufficient resources to support, and ensure that configuration management will be used in all aspects of a systems' life cycles—from the definition of requirements, to system development, to operations. Configuration management programs are currently in their infancy in a small number of transportation agencies. The performance of these programs should be documented and the knowledge and experience gained made available to other agencies.
- The federal government should assume a leadership role in expediting the use of configuration management. The following actions are recommended:

  - Given the progress in configuration management made by several agencies, a good first step towards expediting the use of the process would be to sponsor scanning tours and documenting the successes of these agencies.
  - Initiate research and development to create and prototype specific configuration management tools.
  - Develop technical guidance; recommend best practices, training, and workshops to assist with raising the awareness; transfer new and innovative techniques; and develop the capabilities of state and local agencies.

CHAPTER ONE

INTRODUCTION

BACKGROUND

As the surface transportation infrastructure has developed, it has become clear that continual maintenance is necessary to preserve the quality and operational integrity of the system. This reality has led departments of transportation (DOTs) to devote large portions of their resources to manage, operate, and maintain this system in order to realize a full return on the investment that has been, and will continue to be, made in the infrastructure. In addition, sophisticated tools, such as bridge and pavement management systems, have been developed to efficiently track and allocate maintenance resources. However, because surface transportation systems have traditionally been comprised largely of "physical" infrastructure (i.e., pavements, bridges, guardrails, etc.), maintenance has been directed towards managing its deterioration.

Recently, emphasis has been placed on the active management of traffic flow using the surface transportation infrastructure. This area, which is often categorized under the umbrella of intelligent transportation systems (ITS), has in recent years witnessed a significant investment in public and private funds. ITS have been made possible largely because of advancements in information technology that support the monitoring and communications requirements of system management. Just as the physical infrastructure system requires constant maintenance, the relatively new, information technology-based transportation management systems also require such attention. However, experience has revealed that these systems require a different approach, policies, programs, procedures, skills, and tools than are needed for the maintenance of traditional physical transportation infrastructure.

The transportation industry is not alone in the use of information technology to support system operations (e.g., the defense, telecommunications, and the utility industries have experience in this area). What has been found is that although maintenance of individual components and devices in an information technology-based system is critical, this must be coupled with careful control of the system's *configuration*, which is defined as the function and/or physical characteristics of hardware, firmware, software or a combination thereof as set forth in technical documentation and achieved in a product (Buckley 1996). In other words, changes in individual components, which in turn change the overall system's configuration, lead to systemic alterations that impact the operational effectiveness and integrity of the system. To address this, a process known as configuration management has been developed to assist in the control of change in complex systems.

The importance of configuration management in supporting transportation management systems is becoming apparent. For example, in a presentation to the ITS America 2000 Annual Meeting, Joe Stapleton of the Georgia DOT stated that "You cannot maintain and operate a complex system without configuration management." Furthermore, configuration management is important at a number of levels in ITS. From an individual system perspective, configuration management is needed to support development and day-to-day operations and maintenance. From a regional perspective, configuration management provides the foundation to support the development and maintenance of a regional architecture, and the effective integration of multiple systems owned and operated by different agencies. Because of this, the transportation and public safety communities, including DOTs, police departments, consultants, and contractors, are beginning to apply configuration management. The management systems used by these agencies encompass a variety of implementations, including traffic signal, freeway management, computer-aided dispatch, tunnel control, and electronic toll and traffic management systems. They are characterized by complex software integrated with a large amount of field equipment by an extensive communications plant. Given the pace of change in modern transportation management systems and ITS, and the unique characteristics of these systems, there is a need to capture transportation experience with configuration management and to identify quality resource materials to support the transportation engineering community.

PURPOSE

The purpose of this synthesis report is to identify how configuration management is currently being developed and used by transportation management systems. In addition, it is expected that this synthesis will serve as a resource document for transportation departments just beginning to apply configuration management. Specifically, the synthesis addresses:

- Fundamental concepts and principles of configuration management,
- The need for configuration management within transportation management systems,
- Available configuration management resources (including books, standards, websites, and software tools),
- The status of configuration management within transportation departments, and
- Detailed case studies of the use of configuration management both outside of and within the transportation field.

State-of-the-practice information was gathered by means of a written questionnaire (Appendix A). This questionnaire was sent to all state DOTs. A thorough literature search and interviews with transportation professionals supplemented the questionnaire.

Given the importance of configuration management as a tool to support ITS programs, this report is intended for a wide audience. From this report, public agency managers and administrators can learn about those fundamentals and resources needed to implement policies, programs, procedures, and technical resources required to support configuration management. Technical personnel, both within public agencies and the private sector, should use this report as a reference tool to locate more in-depth material to support configuration management programs.

Finally, it should be noted that this report focuses on configuration management within a single transportation management system. This application of configuration management at a fundamental level is essential for sound system operation. In addition, it provides the foundation for regional ITS integration. Although the report does not focus on configuration management from an architectural or regional integration perspective, this should not be construed as meaning that configuration management is not important in these areas. Readers are encouraged to apply the principles of configuration management identified in this report to any regional, statewide, or agency-level integration efforts.

ORGANIZATION

This synthesis is organized to provide an introduction to configuration management in transportation management systems. Progressing from general concepts to a detailed case study, the synthesis is intended to provide a foundation in configuration management for transportation professionals.

Chapter 2 provides a summary of configuration management concepts and principles. Both configuration management processes and plans are addressed in this chapter. In addition, this material is presented in the context of a general transportation management system to illustrate the applicability of configuration management to such systems.

Chapter 3 provides background on those configuration management resources available to transportation professionals. This chapter is not designed to provide an exhaustive list, but rather to identify a few key resources best suited to transportation professionals. The chapter concludes with a discussion of commonly used configuration management software tools.

Chapter 4 details the current state of the practice of configuration management in transportation management systems. It identifies some key trends as well as gaps in the current practice.

Chapter 5 presents detailed case studies to help the reader better understand how configuration management may function within a state department of transportation. The use of configuration management in companies with characteristics similar to transportation management systems is described first. This is followed by an in-depth case study of the Georgia DOT's use of configuration management in their Navigator transportation management system.

Finally, chapter 6 summarizes the major findings of the report and offers recommendations for improving and accelerating the use of configuration management in the transportation community.

CHAPTER TWO

BASIC CONCEPTS OF CONFIGURATION MANAGEMENT

Given the continual evolution of information technology-based systems, there are a large number of definitions of configuration management. The following is an excellent, concise definition that best describes configuration management, particularly in the context of transportation:

> Configuration management is the discipline of identifying all components and their relationship in a continually evolving system for the purpose of maintaining integrity, traceability, and control over change throughout the lifecycle (British Standard BS 6488).

This chapter provides background on configuration management. First, the general elements of a configuration management process are identified and described. This is followed by a general description of the link between configuration management and transportation management systems. The chapter concludes with a discussion of configuration management plans.

CONFIGURATION MANAGEMENT PROCESS

Although configuration management processes vary depending on the system and set of users, there are four general elements. These elements, identified in Institute of Electrical and Electronic Engineers (IEEE) Standard 729-1983, are listed below; each is followed by a simple, one-paragraph example to provide a more illustrative description (SEI 1990).

- *Identification*—A scheme is needed to identify the unique elements of the system, as well as their structural relationship. For each element, descriptors, such as name, version identification, and configuration identification, must be available. This aspect of configuration management is also referred to at times as compiling a system inventory; however, iden-tification must go beyond a simple list of system elements to capture the structural interaction of the elements.

  Generally, system identification is accomplished by defining system "configuration items." A configuration item is a piece or component of a system that performs a specific function in the system. For example, a loop detector is a configuration item in a transportation management system. In addition to identifying every item, it is crucial to include as much documentation on the item as possible. This documentation varies for hardware and software. The documentation for a hardware item includes technical drawings, specifications, user and training manuals, and a list of the other configuration items that either depend on it or interact with it in the system. Software documentation includes a complete documentation of a certain block of code or function. Again, with software it is crucial to list the other items that interact with this configuration item.

- *Control*—This aspect is concerned with careful consideration of changes to the system to ensure that a stable configuration is maintained. An important part of the control aspect is establishing and preserving a stable system baseline. Generally, a configuration control board is used to perform this control function. Changes to system configuration are only allowed upon authorization by this board.

  A good example of configuration control can be illustrated by describing the process established to change the system. Suppose a variable message sign needs replacement. If the identical type of sign can be acquired, then the system configuration will not be fundamentally changed. However, if the same model is not available and a replacement is required, then the configuration control board needs to evaluate and approve this replacement. This evaluation will determine whether or not other changes in the system, such as introducing a new protocol, will need to be made and, if so, what implications are there for such a change. Once a change has been made, it is documented and incorporated into the system baseline.

- *Status Accounting*—As the name of this element suggests, status accounting involves recording and reporting the status of system components and change requests. Status accounting is an on-going effort within configuration management to ensure that the system is well documented, and that necessary changes can be enacted with full information as to their potential impacts.

  Based on periodic requirements and queries to the configuration management database, configuration status accounting will produce a series of reports. The configuration management database is a collection of all data, history, and specifications for each of the configuration items in the system. Examples of common accounting reports include:
  - A list of approved configuration documentation;

- Status of proposed changes, deviations, and waivers; and
- Implementation status of approved changes.

- *Audit and Review*—This aspect of configuration management can be best considered a validation procedure. Audit and review ensures that the system components remain in an appropriate state throughout the system life cycle.

  There are three common audits included in configuration management. Functional configuration audits take place after the system hardware has been tested. These audits evaluate the results of all testing done to determine whether or not each configuration item meets functional and performance requirements. Once the functional configuration audit has been completed, the physical configuration audit evaluates the engineering drawings for accuracy. The point of this audit is to ensure that the drawings properly reflect the engineering model. Finally, in-process audits evaluate the implementation of the configuration management process to see that it is being performed as specified.

As evident in the above description, configuration management is not a mysterious or magical tool. Rather, it is a structured, detailed set of processes intended to help *people* carefully document the current configuration of their system, and to provide a sound basis from which to consider making system changes. These procedures are put into place and followed in order to achieve the primary goal of configuration management—to ensure the integrity of a system and make its evolution more manageable (SEI 1990). Given that the terminology typically used in configuration management is new to most transportation professionals, a glossary of commonly used configuration management terms has been included in Appendix C of this report. Finally, Figure 1 provides a graphical summary of the configuration management process in the context of the typical system life cycle.

The implementation of configuration management certainly does come at a cost. Primarily, the cost is realized in terms of those personnel requirements and resource requirements needed to develop a configuration management program, provide necessary processes, and support activities such as identification and status accounting. However, despite the resources required, it is generally accepted that the consequences of not using configuration management can lead to many problems and inefficiencies (SEI 1990). The level of configuration management to employ is directly dependent on the complexity of the system in question. This issue is best addressed in the following:

> Applying configuration management techniques to a particular project requires judgment to be exercised: too little configuration management and products will be lost, requiring previous work to be redone; too much configuration management and the organization will never produce any products, because everyone will be too busy shuffling paperwork (Buckley 1996).

Although widely accepted "rules-of-thumb" concerning the cost of configuration management do not exist, it is often assumed that the annual cost of sustaining configuration management for a system is roughly 1.5 percent of the system's development costs.

Finally, it should be noted that configuration management has been developed mainly in the software engineering community. As a result, configuration management is frequently viewed as a process that is only applicable to software development. However, although software development firms are arguably the biggest users of configuration management, the process is certainly applicable in the development and operation of complex hardware/software systems, such as transportation management systems. In the next section, a general functional description of transportation management systems will be used as a means to discuss general transportation-related configuration management issues.

TRANSPORTATION MANAGEMENT SYSTEMS AND CONFIGURATION MANAGEMENT

The implementation of transportation management systems can take numerous forms, and all of the following systems can be classified as such: freeway management, traffic signal, incident management, and tunnel control. In addition, as stated in the first chapter, multiple transportation management systems are often integrated with other systems on a regional level as part of larger, more comprehensive ITS. Although transportation management systems tend to possess unique characteristics designed to respond to particular regional transportation needs, all transportation management systems share the same four core functions: system state estimation, management strategy determination, management strategy execution, and management strategy evaluation/feedback.

The technical designs developed to provide this functionality vary widely. However, to provide a wide range of transportation management services, these systems typically rely on a complex integration of software, database management systems, communications infrastructure, central processing hardware, and field devices. This complexity leads to significant configuration management challenges in all phases of the system's life cycle, from development to operations and maintenance.

To illustrate the challenges of transportation management system configuration management we will (1) describe each core system function (which operate together

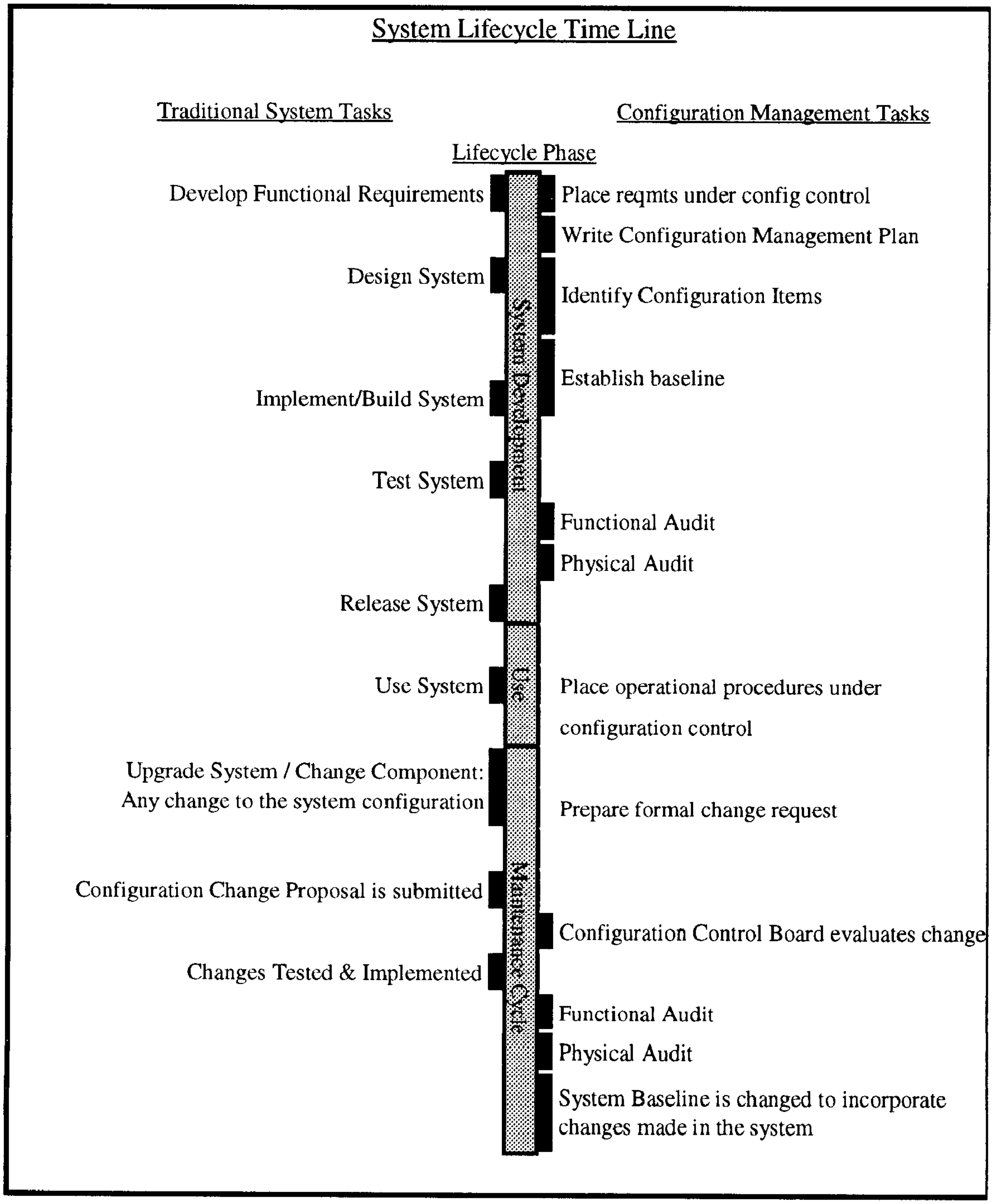

FIGURE 1 Configuration management process.

in a feedback loop as illustrated in Figure 2, and (2) discuss configuration management issues associated with each function. Note that this section does not attempt to identify every conceivable configuration management issue related to transportation management, instead the purpose is to illustrate a select number of key issues. In addition, many of the issues do not fit neatly under a single system function. This illustrates the integrative nature of transportation management systems.

System State Estimation

Functional Description

To actively operate the surface transportation system, it is necessary to understand, as fully as possible, the status of the system. For example, a basic home air conditioning system cannot function effectively without sensing the home's air temperature. Nor can a financial professional

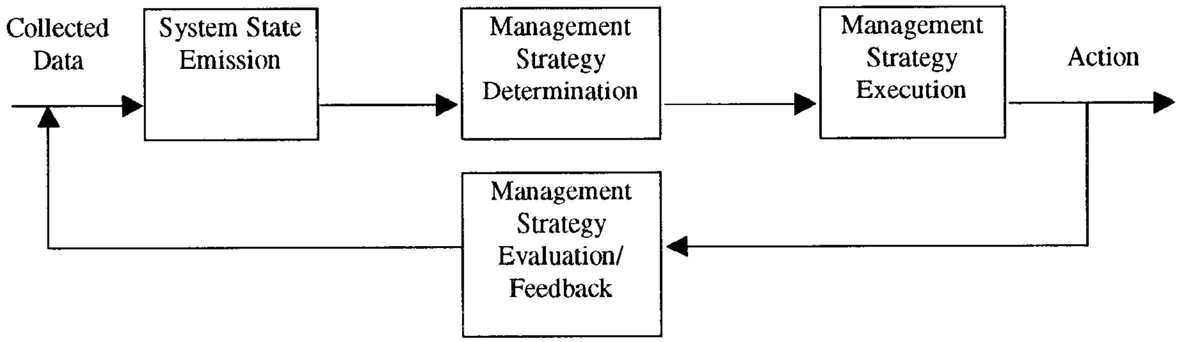

FIGURE 2 Core functions of transportation management.

"manage" an individual's investments without understanding the status of the markets and the individual's personal state (age, income, debts, etc.). In both examples, it is clear that neither management "system" can determine the complete system status. For example, the temperature in one room with the air conditioner's thermostat is not necessarily the same as that in another room of the home, and no one has yet been able to predict the behavior of the stock market. As seen in these examples, a management system uses a limited number of sensors to "test" strategic locations in a system to estimate the overall system status. This is exactly the case in transportation management. The system state estimate developed in this function is then used to allow for informed transportation management decisions.

Configuration Management Issues

Transportation management systems rely heavily on a variety of sensors to accomplish this function. When considering the large number of vehicle presence detectors (such as inductive loops) and closed-circuit television (CCTV) cameras, it is clear that this function requires a large number of hardware items that must be placed under configuration control. In addition, many of these devices require control software that uses proprietary interfaces, further complicating the management of change.

This function also requires significant communications capabilities to transmit the collected data. Many modern systems use fiber-optic communications networks. Not only do these networks include the media (in this case, optical fiber), but also a host of related electronic equipment. Finally, many systems include software to monitor the performance of the network. As the key integrative component, it is essential that changes to a transportation management system's communications infrastructure be closely controlled.

Management Strategy Determination

Functional Description

Once the status of the system has been determined, a key and often very difficult function is required; determining a management strategy (in other words, deciding what should be done to make the transportation system operate more efficiently, safely, and/or predictably). In addition, this includes determining when action should be taken. In many management systems, this is a relatively simple step. In the home air conditioning example cited previously, the cooling system is activated if the temperature is above a certain threshold, and it is deactivated if the temperature is below another threshold. In transportation management, this function is extremely difficult. The surface transportation system changes rapidly, and it is impossible to manage each individual entity traveling through the system. Traditionally, this function has been accomplished in a largely manual fashion. However, more and more tools are becoming available to supplement and enhance human judgment in this area.

Configuration Management Issues

The core transportation management system software plays a central role in supporting the determination of a management strategy. This software is responsible for processing data from the field, displaying it, and providing analysis support to aid operators in selecting a course of action. The development of this software has proven to be quite complex, and as systems grow and change, modifications are constantly required. As a result, the software can be considered as constantly being in a quasi-development state. Given the critical role that it plays, configuration management is essential to ensure that the changes can be made effectively, and to provide a sound baseline that can be used when changes are unsuccessful, to restore a prior, stable state.

Management Strategy Execution

Functional Description

The concept of this function is quite simple. Once a strategy has been decided upon, it must be executed. In transportation management, this function relies on using a combination of control and management tools and resources, varying from traffic signals to traveler information devices such as variable message signs and highway advisory radio.

Configuration Management Issues

An interesting issue in this function arises as transportation management systems become increasingly integrated with external systems (such as those of private information service providers). As data are exchanged between these systems, it is essential to control changes related to the interface. For example, a change in the detector numbering scheme will impact the use of data provided to information service providers. Without a clear understanding of the relationship between all system elements, this change may go unnoticed. The result could be errors propagated to a traffic information map provided to the public via the Internet or in-vehicle services.

Management Strategy Evaluation/Feedback

Functional Description

This function completes the "feedback loop" commonly seen in classic control and management systems (see Figure 2). This is a particularly important function for transportation management, because it is necessary to continually evaluate the effectiveness of management strategies that have been employed. Not only does this allow for immediate opportunities to refine the management strategy (at the tactical level), but it also allows transportation managers to better understand how to use the management and control tools and resources at their disposal (at the strategic level).

Configuration Management Issues

As one considers the performance of past management strategies, it is essential to understand the configuration of the system at the time the strategy was used. Given that the tools at an operator's disposal are constantly changing (variable message signs are installed, sensors and other devices periodically fail, etc.), it is important to know what could and could not be used for a particular incident. By carefully tracking and documenting the configuration of the system over time, this information will be readily available.

Getting Started—Configuration Management Plans

As demonstrated in the section on Configuration Management Process, configuration management is fundamentally a structured, organized approach to managing change in a system. Therefore, there are two "prerequisites" to a successful configuration management program. First, it is critical to establish the institutional support of the configuration management program. As stated earlier, configuration management requires resources—primarily in terms of professionals' time and commitment. Without support from high levels of an organization, a program cannot succeed. Likewise, without the support of technical personnel who will be ultimately responsible for carrying out the process, configuration management will not be successful. Finally, it is important to understand that configuration management is an ongoing process, and that the agency support must be continual.

The next step, once institutional support has been established, is to organize the configuration management process, by developing a configuration management plan. This plan is a formal written document that outlines the configuration management process that an organization will use to manage change in a system. For example, the configuration management programs of the Texas DOT's Transguide System, and Caltrans District 7 Operations Center, were founded by the development of formal configuration management plans. In both cases, the DOT enlisted the help of a consultant to prepare the plan.

A typical configuration management plan begins by defining the organization of the process, in particular, the responsibilities of various parties should be clearly described. The plan should then summarize how the organization will accomplish the basic elements of the configuration management process. First, identification standards are defined, including baselines, change control forms, and libraries. The next part of the plan typically addresses control, including change request procedures and the configuration control board. Status accounting is covered next, including descriptions of required reports and their respective audiences. Audits are also addressed, including who does them and what is done. Finally, training needs and contractor/subcontractor responsibilities are also covered.

A good first step in writing a configuration management plan is to review available standards. An example outline of a generic configuration management plan, adapted from Dart and Bounds, *Configuration Management Plans: The Beginning of Your CM Solution* (1998), is presented here. A commonly used configuration management plan standard will also be introduced in chapter 3.

Outline of a Configuration Management Plan

I. Introduction
  A. Scope

B. Definitions
C. References
D. Tailoring

II. Configuration Management Organizational Issues
A. Organization
B. Responsibilities
C. Relationship of configuration management to the project life cycle

III. Configuration Management Activities
A. Configuration identification
1. Specification identification
2. Change control form identification
3. Project baselines
4. Library
5. Backup and disaster plans and procedures

B. Configuration control
1. Procedures for changing baselines
2. Procedures for processing change requests
3. Organizations assigned responsibility for change control
4. Change control boards
5. Interfaces, overall hierarchy
6. Level of control—identify how it will change through the life cycle
7. Document revisions
8. Automated tools used to perform change control

C. Configuration Status Accounting
1. Storage, handling, and release of all project media
2. Types of information needed to be reported
3. Reports to be produced
4. Release process
5. Document status accounting and change management status accounting that need to occur

D. Configuration Auditing
1. Number of audits to be done and when they will be done (internal audits and configuration audits)
2. All reviews that configuration management supports

IV. Configuration Management Milestones
A. Define all configuration management project milestones (e.g., baselines, reviews, and audits)
B. Describe how the configuration management milestones tie into the software development process
C. Identify what the criteria are for reaching each milestone

V. Training
Identify the kinds and amounts of training (e.g., orientation and tools)

VI. Subcontractor/Vendor Support
Describe subcontractor and/or vendor support and interfacing, if applicable

CHAPTER THREE

CONFIGURATION MANAGEMENT RESOURCES

The synthesis team reviewed a wide range of configuration management resources in order to identify those that are of the most use to the transportation management community. This chapter provides a summary of these resources. Note that this is a very dynamic field, and that new resources are available quite often. This chapter does not contain an exhaustive inventory of resources, but rather a targeted description of resources best suited to the transportation industry. Resources are organized in four categories: books, configuration management plan standards, websites, and configuration management software.

BOOKS

A review of general books on the topic of configuration management revealed two books well suited for an introduction to the topic for transportation engineers. Complete reference information for these books along with a brief summary are provided here.

Buckley, F.J., *Implementing Configuration Management, Hardware, Software, and Firmware,* IEEE Computer Society Press, Los Alamitos, Calif., 1996

This book is recommended for transportation professionals because it directly addresses configuration management in software/hardware systems. The first chapter provides a general description of configuration management and a definition of the purpose to "maintain the integrity of the product throughout development and production cycles." Chapter two provides a description of the configuration management environment, which includes development and production. Chapter three covers configuration management planning, including the development of a plan and the associated procedures. The remainder of the book thoroughly details each step of the configuration management process. There is an appendix containing definitions, acronyms, and abbreviations. A strength of this book is that it provides example configuration management plans: one general and one for a fictional power plant. In particular, the plan for the power plant provides strong similarities to transportation management systems.

Mikkelsen, T. and S. Pherigo, *Practical Software Configuration Management, The Latenight Developer's Handbook,* Prentice–Hall, Upper Saddle River, N.J., 1997

This book provides a very practical introduction to configuration management. It begins with an introduction that discusses the principles of configuration management as well as introducing fundamental concepts and terminology. The next section discusses practical issues from both the individual user and team perspectives. The last part of the book focuses on configuration management tools, describing many public domain and commercial tools. Of particular interest to transportation management is that the book also provides insight into the use of configuration management during system operations and maintenance (not just development). Finally, the book comes with a CD-ROM, which includes configuration management tools designed to provide the reader with opportunities for hands-on experience.

CONFIGURATION MANAGEMENT PLAN STANDARD

An excellent resource in support of the development of configuration management plans is the *IEEE Standard for Software Configuration Management Plans* (IEEE-828-1998). The standard addresses all levels of expertise, the entire system life cycle, roles of outside organizations, and the relationships of software and hardware. It provides an extensive list of items for consideration in key component areas. The standard supplies a list of possible interfaces and the information that must be defined for each interface. It also presents a list of issues that must be addressed for subcontracted and acquired software. It handles each component of the configuration management process thoroughly and provides a section-by-section cross reference back to the general standards. This standard is listed as IEEE-828-1998 and is available online at http://standards.ieee.org.

WEBSITES

An Internet search on the term "configuration management" results in thousands of selected pages. As is becoming evident on the World Wide Web, the level of quality of the content varies considerably. In this section, we identify three outstanding web-based resources for configuration management that also contain extensive links to other good resources.

***Software Configuration Management,* Carnegie Mellon, Software Engineering Institute, Pittsburgh, Pa. [Available at: http://www.sei.cmu.edu/legacy/scm]**

In 1984 the Software Engineering Institute (SEI) was established by the Department of Defense to advance the practice of software engineering. It has emerged as one of the leading worldwide authorities on software engineering. This site serves as the portal to the various papers, reports, and presentations developed by SEI on the topic of configuration management. For example, one can use this site to find an excellent reference paper entitled, *Configuration Management (CM) Plans: The Beginning to Your CM Solution.*

Configuration Management Information Center—CMStat, San Diego, Calif. [Available at: http://www.pdmic.com/cmic]

This site, maintained by a private configuration management company, provides a very good general overview of configuration management. In particular, it describes the benefits of incorporating configuration management in complex systems. In addition to this static information, the site also includes an online survey that can be completed and submitted. Those that complete the survey are e-mailed the results of the survey to date.

Configuration Management—Quality Resources Online [Available at: http://www.quality.org/html/config.html]

This website provides a large number of links to a variety of websites and documents concerning configuration management, including links to lists of books and training courses. The website also includes links to documents providing detailed explanations of configuration management.

SOFTWARE TOOLS

Configuration management software tools are just what their name implies—tools to help in the configuration management process. There are many tools available with varying levels of functionality. It must be understood, however, that these tools do not "create" configuration management within an organization, rather they can be used to help an organization improve its ability to manage change in a system. The purpose of this section is not to recommend a particular tool for use in transportation management systems, but instead introduce the functionality of configuration management tools. Furthermore, it must be noted that commercial configuration management tools are intended primarily to support configuration management of software development. This creates challenges in using these tools to manage change in software/hardware systems such as transportation management systems.

Most configuration management tools can be thought of as specialized database systems. On the software side, the database will hold all of the different segments of the source code. As such, the tool will maintain a current baseline for the software development. From this baseline, segments of code can be "checked out" for modification. After the code has been modified, it can be tested against the existing baseline. If the code is functional and works as intended, the modified code can be checked back in and merged with the existing baseline. If the code does not work, the database has the capability of reverting back to the baseline as it was before the code was modified. The bottom line in managing software code is ensuring that a consistent, working version persists.

Configuration management software tools have many features that are important in the development and maintenance of a system. The ability to support multiple users is one feature that many commercial tools have. This feature supports different people working on the same project at the same time without interfering with each other, and is often referred to as parallel or concurrent development.

Maintaining correct software component versions is usually facilitated by the use of version directories. A reference directory includes a complete source tree of all configuration management-maintained components required for the software build. This strategy has a number of advantages. It is far more efficient and less error-prone than each developer maintaining a complete copy of the source code. It is a more scaleable solution that can handle large and complex projects. Finally, it relieves developers of the burden of ensuring that they have the right versions to build against.

Configuration management software tools also allow for organizations to define a model for a particular development and maintenance process. This model reflects the way changes are made within the configuration management process of a particular organization. The use of the model allows an organization to tailor its software tool to reflect their unique requirements as defined in their configuration management plan.

Finally, configuration management software tools typically include the ability to support problem tracking. Problem tracking informs the user when problems arise in the system following changes. Many tools have extensive reports that go along with this to supplement user discovery of mistakes.

Appendix B describes the functionality of a sample tool, Harvest, in more detail, to provide the reader with a better understanding of the capabilities of configuration management software tools. It should be noted that the use of Harvest should not be interpreted as an endorsement of this product, but rather to allow for a more detailed description of capabilities.

CHAPTER FOUR

STATE OF THE PRACTICE IN TRANSPORTATION

Given the significant role of configuration management in a complex system, it is important to understand how it is currently being used in transportation management. A survey was conducted in the spring of 2000 to determine the use of configuration management by transportation departments in the United States. Of the 38 responses, 62 percent of freeway management systems, but only 27 percent of signal systems, use configuration management. This points to a need to educate those within the transportation engineering community about the need for configuration management in order to realize a significant commitment of resources to this important activity.

This chapter details the results of the survey, which are presented in terms of the primary survey sections: Transportation Management System Characteristics, Configuration Management Plan, Configuration Management Process, Configuration Management Organizational Issues, Benefits/Costs of Configuration Management, and Testimonials.

TRANSPORTATION MANAGEMENT SYSTEM CHARACTERISTICS

The first section of the survey was intended to determine the size and extent of the responding agency's transportation management system(s). This information provided the background needed to identify trends in the use of configuration management.

The survey's first question asked about the core functions provided by the transportation management system. Respondents were to check all that applied, and if a particular agency performed more than one function, then the sample size would increase accordingly. Counting each function independently increased the sample size from 38 to 42. The resulting functional descriptions of the systems were as follows: 20 freeway management systems, 15 traffic signal systems, 2 automatic toll collection systems, and 5 tunnel control systems. Figure 3 illustrates the percentage share of the functional classes of systems.

Respondents were also asked to provide information concerning the size of their system(s). This information was provided in terms of the number of signalized intersections, the lane-miles of coverage, the number of CCTV cameras, and the number of variable message signs, depending on the functional class of the system. They were also asked about the number and type of detectors, and the number of ramp meters, lane control signals, road weather sensors, and toll tag readers. The purpose of these questions was not to collect large quantities of data describing system size, but rather to provide a "check" to ensure that the responses regarding configuration management were not skewed towards one particular size or type of system. A review of the responses indicates that the survey achieved a representative sample of the range of system classes and sizes throughout the country.

A key finding of the survey was that a relatively low percentage of transportation management systems use configuration management. What was particularly notable is that only 27 percent of signal control systems reported using configuration management, whereas 62 percent of freeway management systems, which includes automatic toll collections systems and tunnel control systems, reported using configuration management. Another clear trend in the survey responses is that the likelihood of a transportation management system using configuration management is dependent on the size of the system. Larger systems are more likely to use configuration management, as seen in Figure 4.

Transportation agencies have used different types of core system software in transportation management systems. The software can be classified as custom developed software, where the agency either does or does not own the source code, or the software can be "off-the-shelf," as purchased from a vendor. Fourteen departments use custom software in which the agency owns the source code and 10 use custom software in which the agency does not own the source code. Eleven agencies use an off-the-shelf software package purchased from a vendor. Figure 5 illustrates the distribution of software types.

Most of the core transportation management system software was purchased in the 1990s. To quantify the size of the software systems, the average size of the survey responses is 264,000 lines of code and 94 megabytes of executable code. Finally, it is interesting to note in Figure 6 that agencies are much more likely to use configuration management if their system uses custom software. This likely reflects the fact that changes to a custom system are more likely (and feasible) in one built specifically for the agency's requirements. Furthermore, this also reflects the wider use of configuration management in freeway management systems. Of the 11 off-the-shelf systems identified in Figure 5, 8 are signal control systems. This is consistent

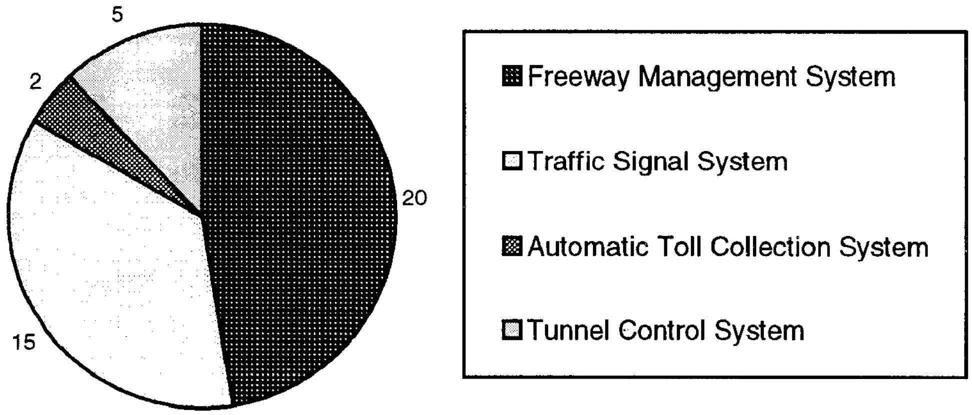

FIGURE 3 Functional classes of systems.

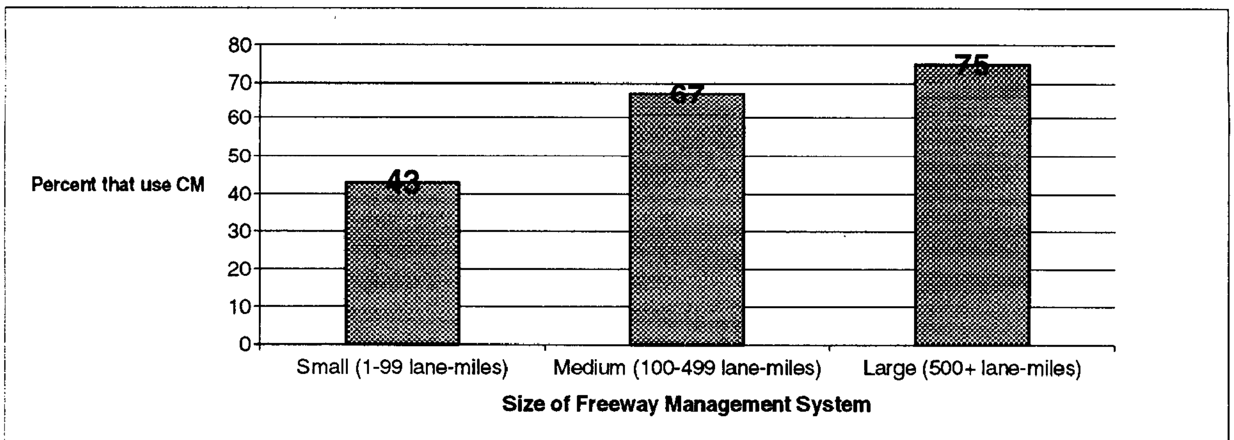

FIGURE 4 Configuration management use by system size.

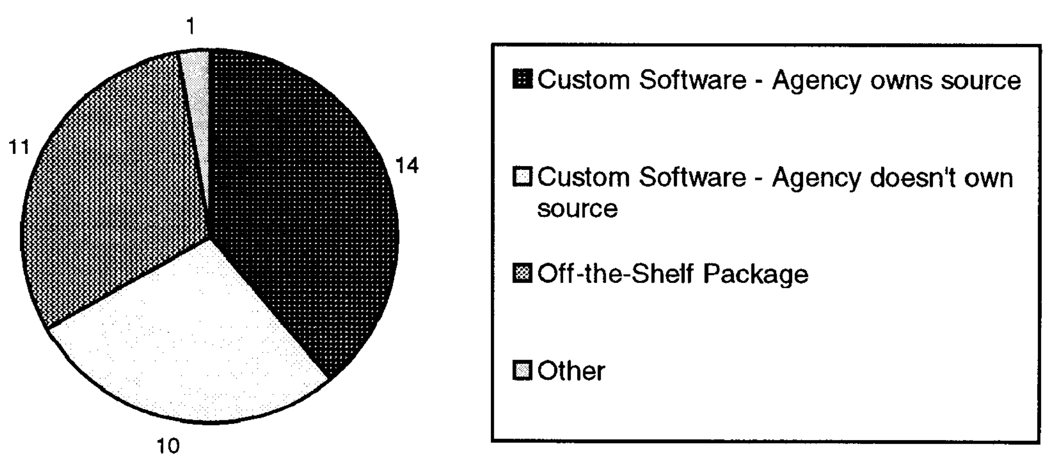

FIGURE 5 Core system software.

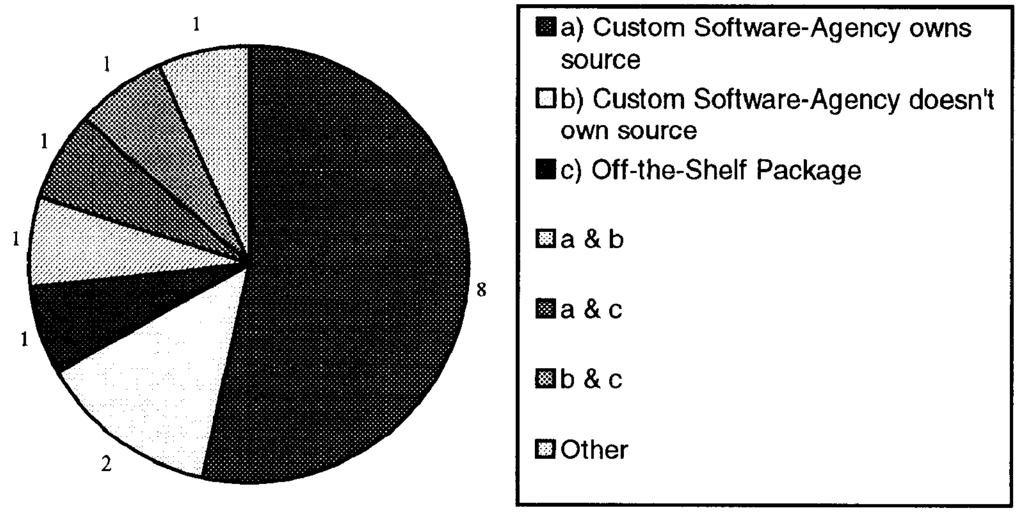

FIGURE 6 Use of configuration managment based on software "class."

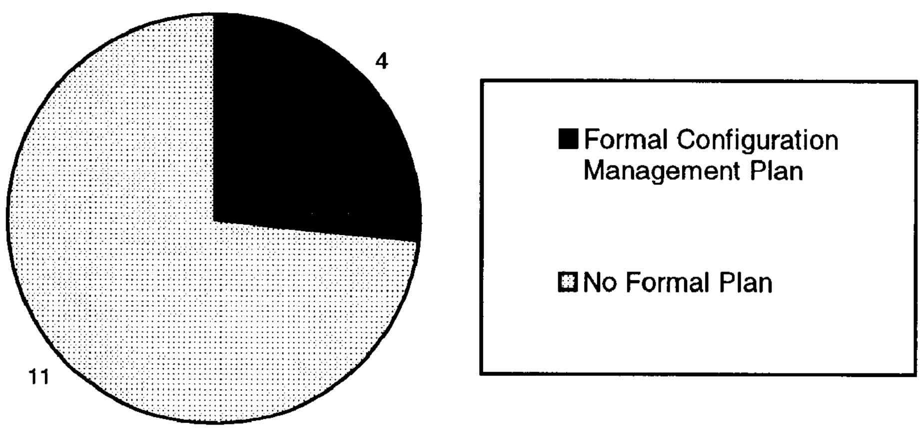

FIGURE 7 Percent of agencies using configuration management that have a formal configuration management plan.

with the finding that only 27 percent of signal control systems use configuration management.

CONFIGURATION MANAGEMENT PLAN

Given the size and cost of many of the transportation management systems being operated in this country, many transportation agencies have realized the need to institute formal configuration management to control the change in the systems. However, many transportation agencies do not become aware of this need until after the development phase of a system, when system operation and maintenance begins. This is particularly evident in the general lack of formal configuration management plans in transportation management systems. As seen in Figure 7, of the 15 agencies that use configuration management, only 4 had a formal configuration management plan.

The four agencies that do possess a formal plan report that the plan is very important in ensuring an effective configuration management process. On a scale of 1 to 10 (10

TABLE 1
ELEMENTS OF CONFIGURATION MANAGEMENT PLANS

Region	CM Organization	CM Responsibilities	CM Training	Configuration Identification	Configuration Control	Status Accounting	Configuration Auditing
Miami	X	X		X	X		
Los Angeles	X	X	X	X	X	X	X
Charlotte	X		X	X	X	X	
Georgia	X	X			X		X

TABLE 2
CONFIGURATION MANAGEMENT PLAN RESOURCES

Region	IEEE Standards	Software Engineering Institute	Department of Defense Standards	Sample CM Plans
Miami		X	X	
Los Angeles	X			X
Charlotte				
Georgia	X	X		X

being highly effective and 0 being completely ineffective) the importance of the plan on the effectiveness of the configuration management process received an average rating of 7.25. However, not one of these agencies required system contractors to deliver a configuration management plan in their request for proposals for the initial system. This illustrates a potential disconnect between the development and operations/maintenance phases of transportation management systems.

Configuration management plans can address several different areas including, but not limited to, configuration management organization, configuration management responsibilities, configuration management training, configuration identification, configuration control, configuration status accounting, and configuration auditing. The four regions and their plans' respective elements are illustrated in Table 1. Note that all plans address organization and configuration control, but only half of the plans address training, accounting, or auditing.

The agencies used many resources in the development of their respective configuration management plans. These resources included, but were not limited to, IEEE Standards, the SEI, Department of Defense Standards, and Sample Configuration Management Plans. Table 2 shows the resources used by each region.

Both transportation agency staff and consultants were used to create the configuration management plans. To provide some context in terms of the resources required to develop the plans, Miami reported spending 800 hours on their plan, whereas the Georgia DOT spent more than twice that (however, the Georgia system covers many more lane-miles than does the Miami system). In terms of funds, Los Angeles invested $80,000 on their plan, whereas Georgia invested $193,000.

CONFIGURATION MANAGEMENT PROCESS

The next section of the survey dealt with issues related to the configuration management process used by the transportation agencies. One of the first issues addressed concerned the type of tools used by agencies to support these processes. Figure 8 illustrates the tools used by transportation agencies and their relative frequency of use. It should be noted that the three respondents who reported Excel as their configuration management tool have used this spreadsheet package as a simple means to document configuration items. It does not provide the full functionality that the other tools include.

The survey results reveal that at different stages of the transportation management system's life cycle, different organizations (the transportation agency, the agency's consultant, or the agency's contractor) led the configuration management process, as seen in Figures 9–12. Although the transportation agency is most likely to lead the configuration management process during the planning, and operations and maintenance phases, a consultant is usually responsible for configuration management during the design and development phases. Furthermore, some agencies preferred to use the system's contractor during the design and development phases. This illustrates a key challenge in transportation management system configuration management—coordinating the involvement of multiple parties in configuration management throughout the life of the system.

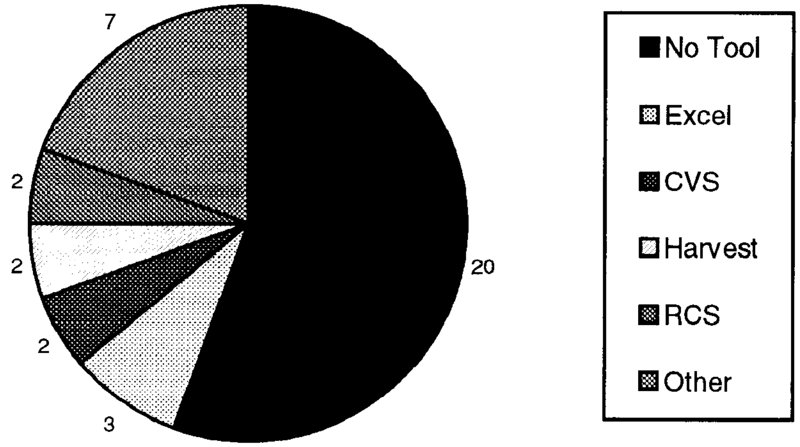

FIGURE 8 Configuration management tools used by agencies.

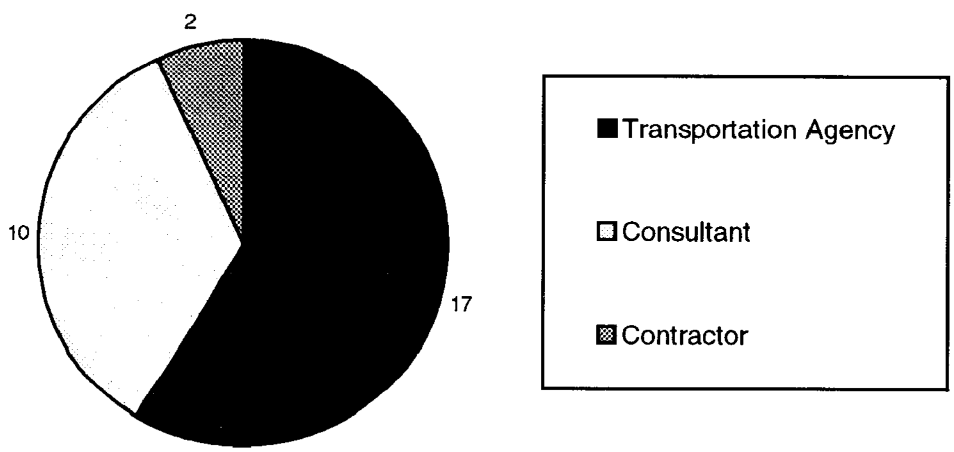

FIGURE 9 Lead organization during planning phase.

As stated in chapter 3, configuration management is traditionally linked to managing change in software development.Therefore, not surprisingly, the largest number of transportation agencies used configuration management with the software elements of their transportation management systems. However, as seen in Figure 13, many of the agencies also used configuration management to manage change in the following subsections of their transportation management systems: computer hardware, field equipment, databases, and communication systems.

As described in chapter 2, the configuration management process generally consists of the following basic activities: configuration identification, change control, and status accounting and auditing. Some departments surveyed included all of these activities, whereas others included just a few. Figure 14 illustrates which activities were most frequently included in configuration management processes. Note that the totals in this figure are derived from the 19 respondents who indicated that they use some sort of formal configuration management process.

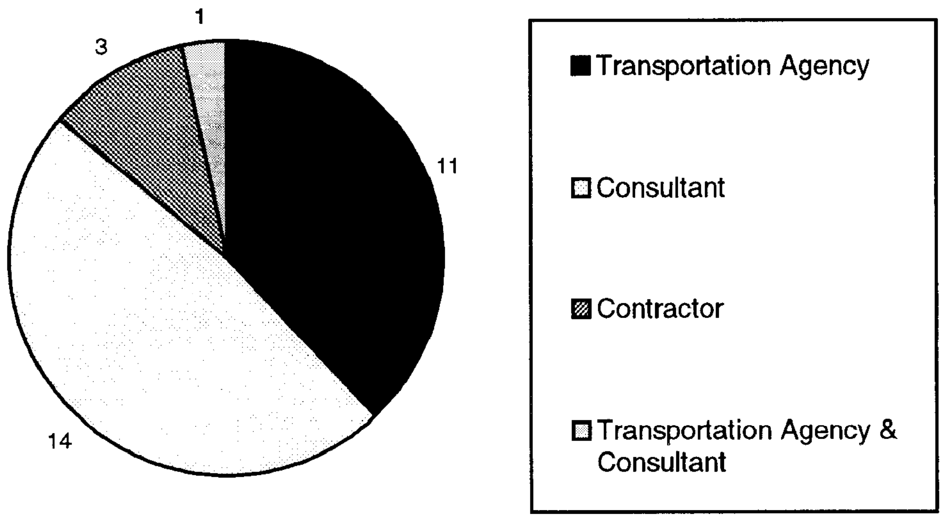

FIGURE 10 Lead organization during design phase.

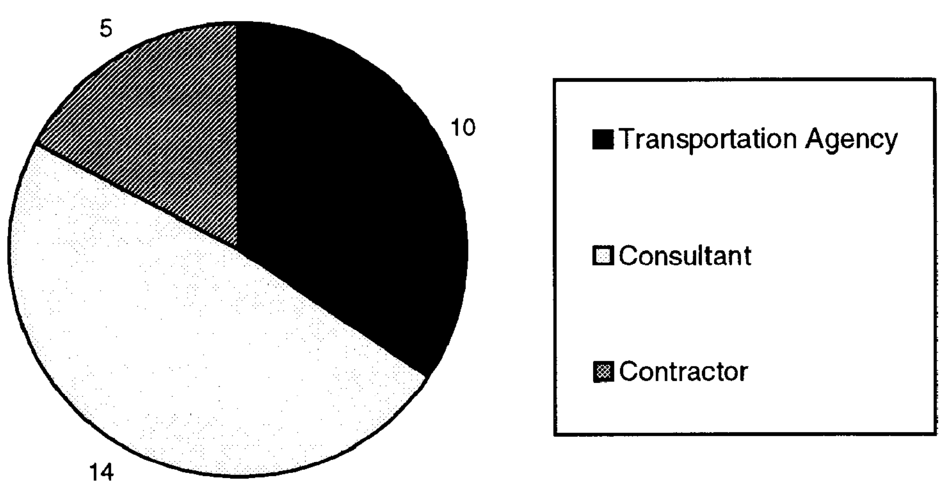

FIGURE 11 Lead organization during development phase.

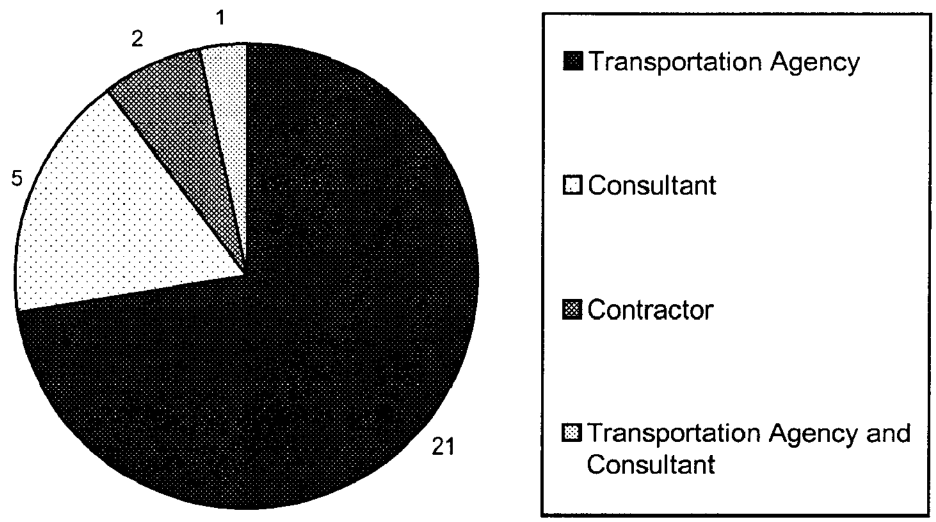

FIGURE 12 Lead organization during operations and maintenance phase.

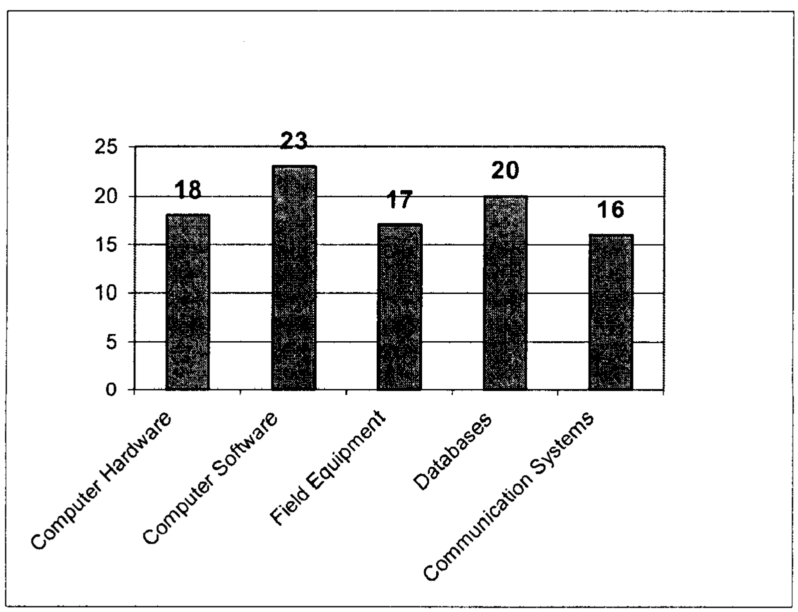

FIGURE 13 Subsystems covered by configuration management.

CONFIGURATION MANAGEMENT ORGANIZATIONAL ISSUES

As seen in Figures 9–12, transportation agencies are centrally involved in configuration management through all phases of the transportation management systems' life cycle. Even during the phases in which they generally choose to utilize a consultant or contractor for configuration management support, the agency is still ultimately responsible for changes in the system. This section of the survey addressed two key organizational issues, the use of change control boards and training.

Eight of the agencies surveyed used formal change control boards to oversee configuration management activities. The boards ranged in size from 1 to 16 people,

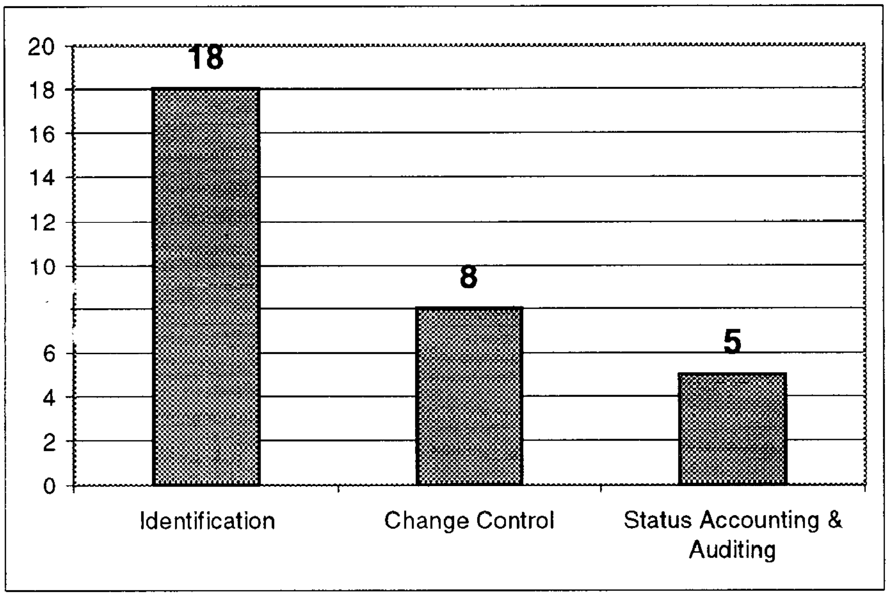

FIGURE 14 Agencies including configuration management.

TABLE 3
AVERAGE BENEFITS RATINGS FOR CONFIGURATION MANAGEMENT (Scale: 0–10)

System Reliability	System Maintainability	Ability to Upgrade System	Ability to Expand System	Ability to Share Information with Other Systems	Ability to Integrate with Other Systems
7.8	8.3	7.5	7.4	5.8	5.7

with the average being 5. Most boards met several times a month and during any emergency situations. More detail describing the change control board used by the Georgia DOT is provided in the case study described in chapter 5.

A surprising finding from the survey is that only 7 out of 29 (24 percent) of the individuals responsible for configuration management had actually received formal training in the area. Those that did receive training most often obtained the training in a short-course format. This finding points to the need to provide better configuration management training opportunities to support the transportation engineering community.

BENEFITS/COSTS OF CONFIGURATION MANAGEMENT

Most of the agencies responding to the survey reported that the benefits gained from configuration management were well worth the costs required. Table 3 presents the average survey rating for a series of configuration management benefits. Please note that the ratings were on a scale of 0 to 10, with 0 representing no benefit and 10 representing the highest level of benefit. Note that according to the survey responses, the largest benefits of configuration management are seen in the ability to maintain systems and in improved systems reliability.

Survey respondents also rated various configuration management costs on a scale of 0 to 10, with 10 being the highest cost and 0 being no cost at all. An important result in this section of the survey is that none of the cost categories received an average score greater than 4.1 out of 10. This indicates that most of the agencies using configuration management find the associated costs to be reasonable. The areas that require the greatest levels of resources are agency personnel time requirements and consultant contract costs. The complete results are displayed in Table 4. Finally, when asked to rate if the overall benefits of configuration management were worth the costs, on a scale of 0 to 10 (with 10 being complete agreement and 0 being complete disagreement), 77 percent of the agencies gave a rating of 7 or higher. Again, a strong indication that of the relatively small percentage of agencies using configuration management, the experience has been positive.

CONFIGURATION MANAGEMENT BENEFIT TESTIMONIALS

Some of the most important information gathered from the survey process can be found in the "testimonials" of agency personnel on their experiences with configuration management. As the following statements show, most of the individuals were strong supporters of configuration management.

TABLE 4

AVERAGE COST RATINGS FOR CONFIGURATION MANAGEMENT (Scale: 0–10)

Agency Personnel Time Requirements	Consultant Contract Costs	Configuration Management Tool License Fee	Training Costs	Lost Productivity Due to Configuration Management "Overhead"
3.9	4.1	1.9	2.8	2.4

With almost 20 years experience in the design, implementation, modification and expansion of our system, the benefits of being quickly able to recover from problems by returning to an earlier working state are enormous. Our system has been very dynamic, and there is always some area where we are working on an improvement or upgrade, while still actively managing traffic.

As in any large, complex system, configuration management can provide a constant understanding of the current state of the system.... The key factor in configuration management is having a central repository of information for reference as personnel changes occur over the life of the system. It is also a great aid in maintaining the system when items are replaced for repair. Technicians should have ready access to configuration data when installing or re-installing standard system components.

A formal, documented configuration control process can save operational costs over the life of the contract and mitigate the impact of personnel and equipment changes.

Finally, the Georgia DOT offered a number of excellent insights into the challenges of instituting configuration management in a transportation management system's organization.

- User acceptance is slow—people have to become convinced of the importance of configuration management over time.
- Development and implementation of configuration management requires a significant investment in both human resources and capital.
- Configuration management must be implemented as early as practical in the development of the system and continued throughout the system's life cycle.
- There is a delicate balance between the time spent on configuration management and the rewards to be gained.

CHAPTER FIVE

CONFIGURATION MANAGEMENT APPLICATION EXPERIENCE

The previous chapters have provided general information on configuration management processes, plans, and resources, and presented results from a survey of configuration management use in transportation management systems. To complement this primarily general information, this chapter details specific configuration management experiences of companies and agencies, both within and outside of the transportation engineering community. This material is intended to provide the reader with a more practical introduction to the potential for the use of configuration management within his or her own organization.

INDUSTRY EXPERIENCE

Configuration management was developed primarily in the aerospace, defense, and software industries. Companies and agencies in these areas have long established configuration management processes—as evidenced by the availability of standards from IEEE, the National Aeronautics and Space Administration, and the Department of Defense. However, configuration management is beginning to see use in industries outside of this founding group. This section briefly describes configuration management experience in companies that show strong similarities to transportation management systems.

Exide Electronics

Exide Electronics (Rational 2000) is a developer, manufacturer, and marketer of uninterruptible power systems and offers specialized power management systems that are sold and supported around the world. Within Exide, there is a group of engineers charged with writing the software behind power management products. These products are often part of mission-critical applications, such as those at the Federal Aviation Administration, American Airlines' SABRE network, and the Social Security Administration. Clearly, the availability requirements and the hardware/software system nature of Exide's products are closely related to typical transportation management systems.

Exide has experienced significant benefits from implementing a formal configuration management process. First, it has allowed for more efficiency in making system changes. "[Configuration management has] cut our overall product development time by at least one-third," said Roger Banner, Manager of Software Product Development at Exide. "[It] has helped my team reduce errors and prevent memory overrun even before getting to the testing cycle." This experience is significant in that it indicates that the time and resources required to institute a configuration management plan and process can be recovered by improved efficiency.

Datel Rail Systems

Datel Rail Systems (Rational 1999) develop customer information systems to support the rail network in the United Kingdom. Their systems help passengers monitor schedules and train progress by providing them with both timetable and real-time train information via a number of different display devices and audio systems. Similarly, railway operators depend on Datel's systems to help them manage the railway. Typical Datel systems include millions of lines of code. Essentially, Datel provides transportation management systems and services for the rail mode of transportation.

Since introducing configuration management tools into its development environment, Datel has realized a number of benefits—improved configuration control, increased speed of operation, improved documentation, and an overall increase in productivity. The improved documentation benefit is significant in that it provides a better ability to modify and integrate the systems at future dates. Such a benefit is particularly important in the era of intelligent transportation systems, as transportation agencies work to integrate multiple management systems.

Bell Atlantic Mobile

Bell Atlantic Mobile (MKS 2000), a provider of wireless communications services, owns and operates the largest wireless network in the eastern United States. Given the rapid pace of change in the wireless industry, from constantly changing price plans to different services offered, Bell Atlantic's core management systems must change quickly and without incident. For example, changes to mission critical systems, such as customer billing, often happen on a weekly basis. Bell Atlantic's billing system serves millions of people. The system records all calls made by every customer, processing billions of records annually. The billing system also supplies vital account information to over 2,000 customer service representatives. In addition, Bell Atlantic Mobile acquires new cellular markets and must integrate existing systems within their core system. The high rate of change and the need to integrate multiple systems is similar to the challenges found within transportation management systems.

Because of all these rapid changes and developments, Bell Atlantic Mobile has developed an extensive configuration management plan to guide their configuration management process. The company's experience has been that configuration management has improved productivity, allowed the management of multiple releases, and secured corporate software assets.

TRANSPORTATION MANAGEMENT CASE STUDY—GEORGIA DOT NAVIGATOR

Background

The Georgia Navigator is the transportation management system for the state of Georgia. The Navigator system was developed by the Georgia DOT (GDOT) in the early to mid-1990s in an effort to manage transportation in Georgia for the 1996 Olympic Games. The heart of the Navigator system is the GDOT Transportation Management Center, located in downtown Atlanta. The center is connected via a fiber optic network to traffic control centers in the city of Atlanta and the following metro Atlanta counties: Cobb, Clayton, Dekalb, Fulton, and Gwinnett. Remote centers also operate in the cities of Athens, Macon, and Savannah and at the Metro Atlanta Rapid Transit Authority. Each of the traffic control centers are owned and operated by the individual jurisdictions in which they reside.

The Navigator system integrates elements of freeway management, arterial management, incident management, and traveler information provision. Each of the Navigator control centers cooperate in the collection of data, dissemination of information to motorists, and control of traffic flow using devices such as CCTV, vehicle detection systems, changeable message signs, and traffic control signals. Since the Navigator system became operational in 1996, there has been a shift in focus from development of the system to expansion, operations, and maintenance. GDOT has a very aggressive expansion plan that will result in a twofold increase in system coverage in the next 3 years. With this rapid expansion comes the challenge to develop software improvements to support the addition of numerous field devices and operational procedures. The expansion will also result in an increased maintenance effort to support the field infrastructure.

To support and manage the many changes that face the Navigator system in the coming years, GDOT recognized the need to formalize the process of change control through configuration management.

> Configuration management provides formal change control of the Navigator system throughout all stages of expansion to include development, implementation, installation, test, and acceptance. It is intended to enhance the efficiency of the development effort by ensuring that the right work is being performed on the right version of application software or hardware system/subsystem. Finally, configuration management provides a mechanism for maintaining formal records of the Navigator system configuration to include software, communications cable plant, field equipment, communications electronics at hubs, and control center hardware. This enables GDOT to effectively and efficiently plan further expansions to the Navigator system in the future (GDOT 1999).

As stated earlier, the term configuration management has traditionally been used in conjunction with the development of software. In the Navigator system, configuration management is used to manage change in both software version control and hardware infrastructure management. Both the system software and hardware elements work in concert and each must be managed throughout the change process.

Configuration management begins with documentation of the system and a plan for tracking changes. The *GDOT Configuration Management Manual* is the guiding document for configuration management in Navigator. This manual establishes a management structure and formalized process for change management. To describe the process used by GDOT, we will structure the discussion using the four key elements of configuration management introduced in chapter 2.

Identification

Baseline documents have been developed for both the system software and hardware infrastructure. Using the baseline configuration, future changes to the system can be managed through the formal change control process.

System Software

The Navigator software is a distributed client–server architecture operating on a Unix platform. The Navigator software, comprised of over 200,000 lines of code, is divided into seven subsystems that handle specific services such as field device communications, database storage and retrieval, freeway traffic management, and support services. Each subsystem consists of one or more software applications, processes, and libraries. The system is also supported by a number of commercial off-the-shelf software packages supporting the operating system, database application, inter-process communications, etc.

Over the years, the Navigator software has been in a continual state of change. In the time leading up to and following the initial implementation of the system, constant changes were made to support enhancements and integration of new devices. The improvements to the system culminated with a major software review and release to support changes related to Year 2000 compliance. Once all changes were made to support Year 2000 compliance, the software was baselined as Version 1.0. The key items documented in the baseline system included:

- System source code,
- Commercial off-the-shelf products,
- Software development tools, and
- System hardware configuration.

Implementation of configuration management in software requires tools to manage the multiple software development efforts. GDOT uses the ClearCase tool by Rational Software. ClearCase provides a means to manage access to the software source code by multiple software developers, track changes during code development and assemble code into new versions.

The software build methodology is illustrated in Figure 15.

The baseline version of the software is indicated as Version 1.0. As new software builds are undertaken, the ClearCase tool allows the developers to access the source code through a central repository. In this example, the development team is working on Version 1.2, a major new release of software (indicated on the upper Development Branch). While this effort is underway, intermediate builds of software can be undertaken to fix software bugs (indicated on the lower Bug Fix Branch). As the intermediate bug fixes are released, these releases become the new baseline version.

For instance, as development of Version 1.2 continues in the Development Branch, a bug fix designated as Version 1.0.1 is undertaken in the Bug Fix Branch. Once Version 1.0.1 is completed, tested, and implemented, it becomes the baseline version. Other bug fixes, designated as Version 1.0.X can be implemented during the development of Version 1.2. Each 1.0.X release becomes the baseline during the development life cycle. Once work on Version 1.2 is complete and this version is implemented, Version 1.2 becomes the baseline and the process repeats.

The important feature of this process is that many different software development efforts can be undertaken simultaneously by multiple developers. The configuration management tool manages the withdrawals and deposits of software from the repository and documents and accounts for all changes. The configuration management tool also allows the developers to recreate any release of software at any point in time.

System Hardware

The Navigator system is supported by a vast system infrastructure that consists of a wide area network supported by a fiber optic communications backbone. Current construction projects will increase the size of the system dramatically over the next 3 years, as seen in Table 5.

TABLE 5

NAVIGATOR HARDWARE

Device	Existing	Planned
CCTV Cameras	66	221
VDS Cameras	317	605
CMS	41	33
Communications Hub	11	6

Much like the system software, the hardware infrastructure is in a constant state of change. This change occurs primarily through the addition of new field devices and maintenance activities. And like the system software, a baseline of the field hardware infrastructure must be created to manage change to the system. The baseline must account for every fiber, every hardware component, and every port in the system.

Managing the hardware infrastructure requires a tool that can automate the process. For communication and

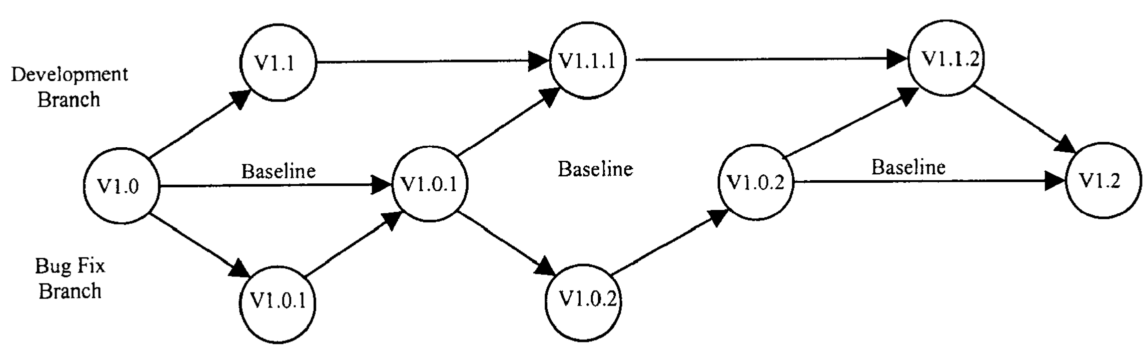

Figure 15 Software build methodology.

device infrastructure management, the department plans to use a support tool that provides the following functionality:

- Point-to-point tracking of cables or wires in the system,
- Identification of unused cables or wires,
- Alternate path routing,
- Device inventories,
- Graphical display of cable and hardware plant, and
- Integration with Help Desk software.

Utilization of automated tools for infrastructure management becomes critical as the size of the system expands.

Control

With the establishment of the system baseline, the process of change management can be initiated. The heart of the change management process is the Configuration Control Board (CCB), as shown in Figure 16.

Configuration Control Board

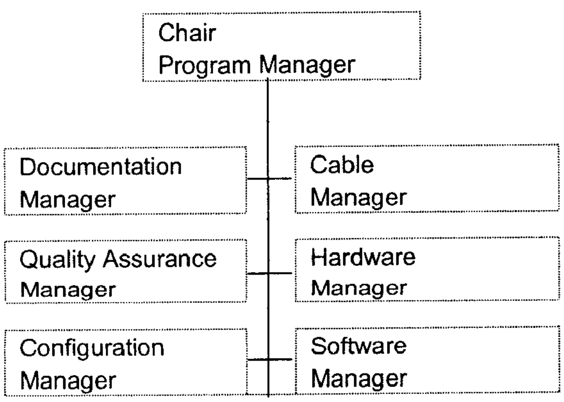

FIGURE 16 Configuration control board.

The CCB is staffed with key managers from within the Navigator organization. Each of the staff members has a distinct responsibility in his/her own area of expertise. The CCB membership consists of:

Chair (Program Manager)—conducts all formal meetings of the Board and is the final approval authority of all recommended changes.

Configuration Manager—sets all procedures and policies for configuration management.

Software Manager—provides day-to-day version control for system software and is the approval authority for all change requests to software.

Hardware Manager—responsible for system configuration, operations, and maintenance of all system hardware components.

Cable Manager—responsible for cable management. Maintains records of existing cable plant, manages requests for use of unallocated cable and device ports, and manages addition of new cable infrastructure.

Quality Assurance Manager—verifies that all configuration procedures are followed in accordance with the configuration management plan.

Documentation Manager—maintains all system documentation including design documents, specifications, hardware manuals, test plans, etc.

The CCB serves as the guiding force in configuration management by approving system configuration changes and ensuring that change documentation is maintained.

Accounting

The CCB meets on a regular basis to review all requests for change in the system. The System Problem/Change Request (SPCR) is the instrument used by the staff to initiate a change in the system. The process flow for the SPCR is illustrated in Figure 17.

Once a change request is submitted to the CCB, the first step is to determine if the request will actually result in a change in system configuration. Two examples and their flow through the configuration management process are detailed here.

<u>Change Request Example 1</u>

A communications switch in the system fails. The switch is not mission critical and is replaced by another switch that is the same model, utilizing the same firmware and number of ports as the old model.

In this example, the replacement equipment did not result in a change in the system configuration (software revision, port availability, etc.) and no changes in documentation are needed. This replacement is considered maintenance and no action by the CCB is needed.

<u>Change Request Example 2</u>

The same switch discussed in Example 1 fails and an exact replacement model is not available. A newer model with a later release in firmware and additional availability of ports is available. The implementation of this new switch will have an impact on the configuration of the system. The new revision of firmware may result in compatibility issues with other system components. The availability of

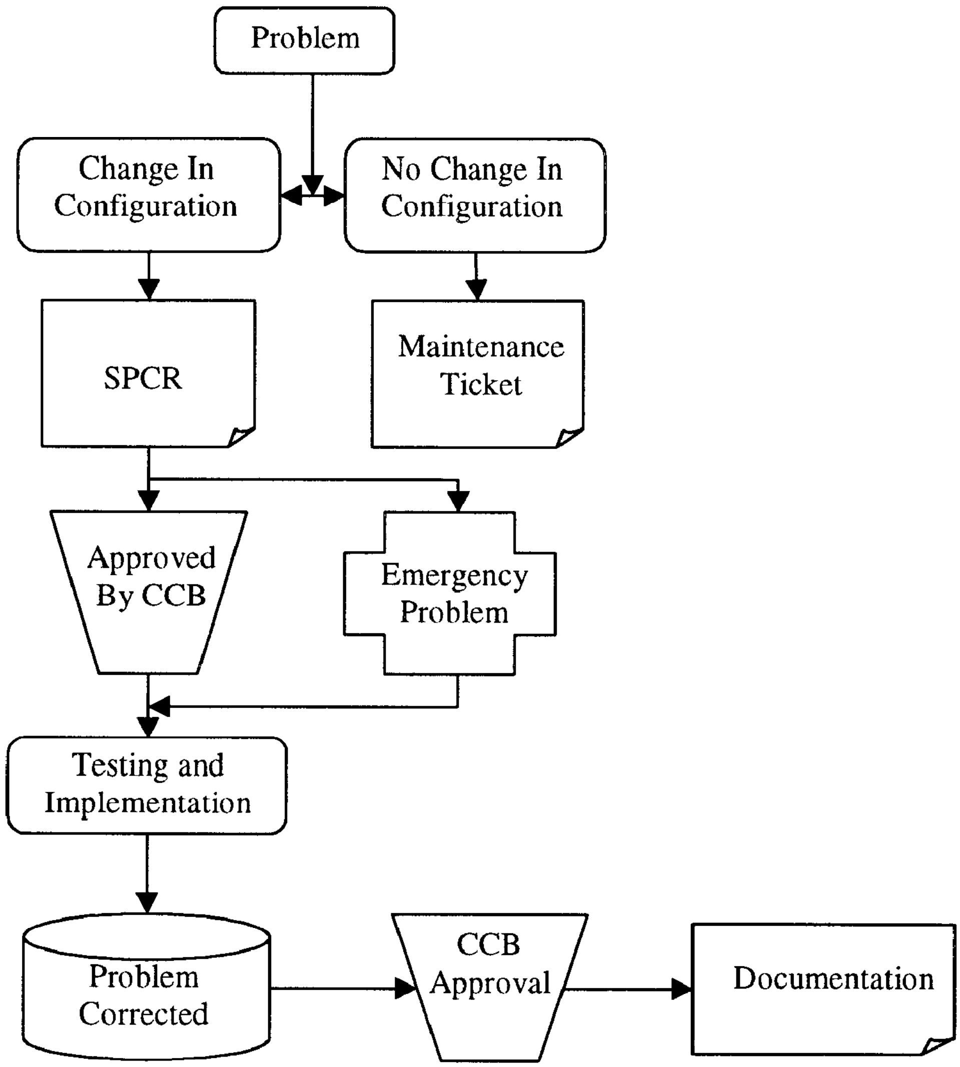

FIGURE 17 System problem/change request.

more ports will also have an effect on the future capacity of the communications system. Therefore, this change must be considered by the CCB.

Before the switch is installed, the maintenance technician must submit a SPCR to the CCB. Once the SPCR is received by the CCB, it is assigned to the hardware manager and software manager to determine potential impacts to the system. If the CCB finds that the new hardware is acceptable, approval is given for installation and testing. The hardware is then installed and a test report is created. If the testing is successful, the results are then presented to the CCB for final approval. Upon approval by the CCB, the documentation manager records the change in configuration.

In the two examples illustrated previously, one can clearly see the need for change control. If a new switch was installed without proper testing and documentation, future problems could result. The new version of firmware could possibly not support some of the features of the network management system. The additional ports would not be documented in the cable management system, and future port allocation studies would not indicate their presence. Having a formal change control process ensures that all potential liabilities associated with change are investigated and the results of all changes are documented.

The SPCR process can be either a manual, paper-based submittal or software can be purchased to automate and track the SPCR. GDOT is developing an Intranet application for submittal, management, and tracking of SPCRs.

Audit

GDOT performs several types of audits to ensure that configuration management procedures are followed. During the software development process, audits are performed at critical design reviews to ensure that proper configuration management procedures are being followed in code documentation and development. These audits include intermediate design reviews to ensure that the developers are adhering to software coding standards and providing proper software documentation. The audits also include periodic reviews of software development to ensure that the development conforms to the requirements established at the beginning of the project.

In the areas of hardware and documentation, audit procedures have also been established. These procedures include periodic reviews of the communications and hardware infrastructure, and reviews of changes to all documentation in the system.

CHAPTER SIX

CONCLUSIONS

Configuration management is playing a critical role in information technology-based systems, both in transportation and in other industries (as the examples in chapter 5 illustrate). Developers and operators of these systems have realized that careful control of change in the systems is essential to maintaining system integrity and supporting modifications, expansions, and integration opportunities. However, it is clear that configuration management does not come without a cost. As evident in the survey results and the case studies, an effective configuration management process requires a significant investment in terms of personnel resources and funding. As such, the key question facing operators of transportation management systems is not whether to use configuration management, but rather, to what level should it be incorporated? The following statement provides an excellent description of the challenge. "Applying configuration management techniques to a particular project requires judgment to be exercised: too little configuration management and products will be lost, requiring previous work to be redone; too much configuration management and the organization will never produce any products, because everyone will be too busy shuffling paperwork" (Buckley 1996).

The survey results clearly indicate that transportation management systems are in the early stages of the application of configuration management. Only 62 percent of freeway management systems reported the use of configuration management, and but 27 percent of signal systems use configuration management. Furthermore, only a few of those systems that used some form of configuration management had actually developed a formal configuration management plan to guide the process. The need for differing levels of configuration management depending on the relative complexity of the technology-based system was clearly evident in the fact that the more complex systems in the survey tended to have a greater likelihood of using configuration management.

A number of other important facts concerning the state of the practice of transportation management systems and configuration management were revealed in the survey.

- Transportation departments, contractors, and consultants all have critical roles and responsibilities in configuration management. These roles and responsibilities tend to change throughout the life cycle of a system.
- The majority of survey respondents did not use a configuration management software tool, most likely because these tools have largely been designed to meet the needs of the software development community.
- Most respondents did not include the entire range of activities in their configuration management processes. The majority of the systems did include some form of formal identification, but fewer included change control and status accounting and auditing.
- Very few of those currently involved in configuration management have received formal training in the area.
- The greatest benefit of configuration management cited by survey respondents was an improved ability to maintain and upgrade the system. This also points to the importance of configuration management in supporting large-scale, multiple-system integration at a regional level.
- The greatest cost of configuration management cited by survey respondents involved consultant contracts and agency staff time requirements.

Clearly, there is room for improvement in the use of configuration management within transportation management systems. However, the need and justification for configuration management is becoming better understood. This is evidenced by the fact that when asked to rate if the overall benefits of configuration management were well worth the costs, on a scale of 0 to 10 (with 10 being complete agreement and 0 being complete disagreement), 77 percent of the agencies gave a rating of 7 or higher.

As stated previously, the use of configuration management within transportation management systems is at a very early stage. As the results of the survey and case study indicate, there are a number of characteristics of transportation management systems that make the effective use of configuration management challenging. Based on these findings, the following recommendations are offered as suggested actions to expedite the effective application of configuration management in transportation management systems.

- Configuration management will play a critical role in the long-term success of transportation management systems, particularly as systems grow in size and regional integration of systems becomes more prevalent. Therefore, it is necessary that the national transportation operations' community recognize the need and promote the use of formal configuration management policies, programs, and recommended best practices in the development, implementation, integration, management, and operation of transportation management systems and other ITS applications.

- Agencies should begin by developing a configuration management plan using a standard, such as IEEE 828-1998.
- Just as transportation management systems vary widely in size and complexity, so too must the application of configuration management. There is a need for technical guidance, recommended practices, and resource materials to aid transportation departments in accurately determining the level of configuration management needed to support their various systems.
- Commercial configuration management tools do not fully meet the requirements of transportation management systems (as evidenced by the need for multiple tools for the Georgia DOT in chapter 5). There is a need to explore the development of configuration management tools designed specifically for the requirements of transportation agencies.
- Transportation agencies need to train their personnel (in addition to contract and consultant personnel) in configuration management. It would be ideal to develop training materials that are geared specifically for the use of configuration management within transportation management systems.
- Although this report, like most configuration management reference materials, focuses on the configuration management process, transportation agencies need to develop sound configuration management programs to support the process. The programs must establish an institutional framework for configuration management, provide sufficient resources to support configuration management, and ensure that configuration management will be used in all aspects of systems' life cycles—from requirements definition, to system development, to operations. At this stage, configuration management programs are in their infancy in a small number of transportation agencies. There is a need to track the performance of these programs and transfer knowledge and experience gained to other agencies.
- To expedite the use of configuration management, there is a need for the federal government to play a leadership role. The following actions are recommended:

  - Given the progress in configuration management made by a number of agencies, a good first step toward expediting the use of the process throughout the country would be to sponsor scanning tours and document the success stories of these agencies.
  - Initiate research and development to create and prototype specific configuration management tools.
  - Develop technical guidance, recommend best practices, training, and workshops to assist with raising the awareness, transfer new and innovative techniques, and develop the capabilities of state and local agencies.

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APPENDIX A

Survey Questionnaire

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Project 20-5, Topic 31-10

TRAFFIC CONTROL SYSTEM CONFIGURATION MANAGEMENT

QUESTIONNAIRE

Name of respondent: ______________________________

Title: ______________________________

Agency: ______________________________

Telephone number: ______________________________

Email address: ______________________________

Attached is a questionnaire seeking information on your agency's current use of configuration management in traffic control and transportation management systems.

Please note that the "formal" application of configuration management is relatively new in transportation engineering. Configuration management is defined as follows:

> **Configuration management is the practice of handling changes systematically so that a system can maintain its integrity over time. Another name for it is "change control." It includes techniques for evaluating proposed changes, tracking changes, and keeping copies of the system as it existed at various points in time.**
>
> *Steve McConnell, **Code Complete**, Microsoft Press, 1993*

Therefore, even if your organization does not use a formal configuration management process, you may be practicing a form of configuration management as you manage change in your traffic control systems. For example, activities such as maintaining equipment inventory databases and administering software updates and version changes are configuration management activities. Your responses to this questionnaire, whether you do or do not practice "formal" configuration management, are very valuable. This project will produce a report that promises to help transportation agencies better manage change in complex traffic control systems.

Given that many transportation agencies operate a number of traffic control systems, it would be appropriate and helpful if individuals responsible for each of your agency's systems complete a separate questionnaire. If you require additional copies of the questionnaire, please feel free to contact Brian Smith at the address/phone/email below.

This survey may also be completed on-line at the following address. In addition, you must enter the correct user identification and password to access the survey:

http://SmartTravelLab.virginia.edu/NCHRP/Survey.htm

User ID: survey
Password: cmtraffic

Please return the completed questionnaire (if applicable) and supporting documents to:

Brian L. Smith
Assistant Professor
University of Virginia
Department of Civil Engineering
351 McCormick Road
P.O. Box 400742
Charlottesville, VA 22904-4742

Phone: 804.243.8406
Fax: 804.982.2951
Email: briansmith@virginia.edu

If you wish, you may fax your response. If you have any questions, please feel free to contact Mr. Smith.

We would appreciate your response by **May 31, 2000**.

PART I. TRAFFIC CONTROL SYSTEM CHARACTERISTICS

Please answer the following questions to help us better understand the characteristics of your traffic control system.

1. Which of the following best describes your traffic control system?

   - ❒ Freeway Management System
   - ❒ Traffic Signal Control System
   - ❒ Automatic Toll Collection System
   - ❒ Tunnel Management System
   - ❒ Other (Please Describe): ______________________________

   ____

2. Please describe the relative "size" of your system (please fill in all that apply).

   Number of signalized intersections ______________________

   Lane miles of coverage ______________________

   Number of CCTV cameras ______________________

   Number of dynamic message signs ______________________

   Number of detectors ______________________

   Types of detectors (i.e., loops, etc.) ______________________

   Number of ramp meters ______________________

   Number of lane control signals ______________________

   Number of road weather sensors ______________________

   Number of toll tag readers ______________________

   Other ______________________

3. Please describe your core system software.

   - ❒ Custom software (agency owns source code)
   - ❒ Custom software (agency does not own source code)
   - ❒ "Off-the-shelf" software package purchased from vendor
     What is the name/vendor of this package? ______________________

   - ❒ Other (Please Describe): ______________________

   Year Purchased: ______________________

   Relative Size of System (Please complete if known)

   Number of Lines of Code (if known) ______________________

   File Size of Executable Code ______________________

4. Please describe your operations and maintenance resources. This should include resources for all software and field equipment that constitutes your traffic control system.

   Number of operations and maintenance personnel: ______________________________

   Annual operations and maintenance budget: ______________________________

PART II. CONFIGURATION MANAGEMENT PLAN

This section of the survey will help us better understand the development and use of your organization's configuration management plan. *Please note that a configuration management plan is essentially the same thing as a change control plan.*

1. Do you have a formal configuration management plan for your system? If so, please return a copy of the plan along with your completed survey.

   ❒ Yes ❒ No

   If "No"—please proceed to Part III.

2. Rate the importance of the configuration management plan to the overall effectiveness of your configuration management process (10 being highly effective and 0 being completely ineffective)?

   Rating: ____________________

3. In requests for proposals do you require system contractors to deliver a configuration management plan?

   ❒ Yes ❒ No

4. Which of the following areas does your configuration management plan address (please check all that apply)?

❒ Configuration Management Organization	❒ Configuration Management Responsibilities	❒ Configuration Management Training
❒ Configuration Identification	❒ Configuration Control	❒ Configuration Status Accounting
❒ Configuration Auditing	❒ Other: ______________________________	

5. What resources were used in the development of the configuration plan?

❒ IEEE Standards ❒ Software Engineering Institute (SEI) ❒ DoD Standards
❒ Sample Configuration Management Plans ❒ Configuration Management Tool(s) ❒ Books (list books below)
❒ Other ______
List Books: ______

6. Who created the configuration management plan?

❒ Transportation Agency Staff
❒ Original System Contractor
❒ Consultant
❒ Other (Please Describe): ______

7. Please estimate the amount of resources that were spent in the creation of the configuration management plan.

Hours ______
Dollars ______

8. At what stage of the project was the configuration management plan created?

❒ System Planning/Procurement
❒ Design
❒ Development
❒ Operations and Maintenance

PART III. CONFIGURATION MANAGEMENT PROCESS

This section of the survey will help us better understand how your organization carried out the activities defined in the configuration management plan. *These activities are referred to as the configuration management process. Even if you do not have a formal configuration management plan, it is likely that you still practice some form of configuration management.*

1. Do you have a formal document describing the configuration management process? If so, please return a copy of the document along with your completed survey.

❒ Yes ❒ No

2. Rate how well your organization executed the configuration management plan during the following phases (10 being well executed and 0 being poorly executed).

System Planning/Procurement: ______
Design: ______
Development: ______
Operations and Maintenance: ______

3. What configuration management tool(s) are you using?

❒ ClearCase
❒ Source Integrity
❒ Perforce
❒ Harvest
❒ TrueChange
❒ PVCS
❒ StarTeam
❒ Razor
❒ PCMS
❒ TLIB
❒ Continuus
❒ SourceSafe
❒ ADC/Pro
❒ CMVC
❒ RCS
❒ Other ____________________________________

4. In the table below please indicate with a checkmark the **lead** configuration management organization in each of the phases of your system's life cycle (if configuration management was not done during a phase please leave it blank).

	Transportation Agency	Consultant	Contractor
System Planning/ Procurement			
Design			
Development			
Operations and Maintenance			

5. Which of the following typical components are included in the configuration management process?

❒ Computer Hardware
❒ Databases
❒ Computer Software
❒ Communication Systems
❒ Field Equipment
❒ Other ____________________________________

6. Please check all of the configuration management activities that are included in your configuration management process.

❒ Configuration identification (unique identification for all system components)
❒ Established system baselines
❒ Backup and recovery plans and procedures
❒ Established change control board
❒ Established change control procedures
❒ Configuration status accounting and auditing
❒ Others ____________________________________

7. A configuration (or change) control board is normally established to oversee the configuration management activities. Please address the following issues related to your configuration management board:

- Who (organization/title) chairs the board?____________________________________
- How many serve on the board? ____________________________________
- Please provide a general description of the membership.
____
____
- How often does the board meet? ____________________________________
- What special events may trigger a board meeting? ____________________________________

PART IV. CONFIGURATION MANAGEMENT ORGANIZATIONAL ISSUES

This section of the survey is intended to help us better understand how configuration management is applied within your organizational structure.

1. Who is primarily responsible for configuration management for your system (please check only one)?

   ❒ Transportation Agency Staff
   ❒ Non-DOT Agency (such as a state "Department of Information Technology")
   ❒ Original System Contractor
   ❒ Consultant
   ❒ Other (Please Describe): ____

   ____

2. Have the individuals responsible for configuration management received formal training in the area? If so, please describe the type of training and the approximate budget dedicated to configuration management training.

   ____

   ____

   ____

PART V. BENEFITS/COSTS OF CONFIGURATION MANAGEMENT

This section is intended to help us gauge your experience with applying configuration management.

1. Please rate the benefits you have received (or would anticipate) from applying configuration management for the following categories (10 being the highest level of benefit and 0 being no benefit at all).

   System Reliability ____

   System Maintainability ____

   Ability to Upgrade System ____

   Ability to Expand System ____

   Ability to Share Information with Other Systems ______________________________

   Ability to Integrate with Other Systems ______________________________

   Other ____

   ____

2. Please rate the costs, as compared to the overall costs of system operations and maintenance, associated with applying configuration management for the following categories (10 being the highest cost and 0 being no cost at all).

   Agency personnel time requirements ______________________________

Consultant contract costs ______________________________

Configuration management tool license fees ______________________________

Training costs ______________________________

Lost productivity due to configuration management "overhead" ______________________________

Other ______________________________

3. On a scale of 0 to 10, please rate your level of agreement (10 being complete agreement and 0 being complete disagreement) with the following statement: "The benefits of configuration management are well worth the costs."

Rating: ______________

Explanation: ______________________________

____

____

PART VI. FREE FORM RESPONSE

We would value any additional comments you would like to offer regarding your experience (or lack of experience) in traffic control system configuration management.

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Thank you for your time in completing this questionnaire. If your agency has produced any documentation of your configuration management activities, such as a configuration management plan or a description of your configuration management process, we request that you return a copy of this documentation along with the completed questionnaire.

APPENDIX B

Responding Agencies

Kansas DOT
Connecticut DOT
Virginia DOT
City of Los Angeles
New York DOT
Wisconsin DOT
Washington DOT
Kimley-Horn & Associates (Miami TMC)
Oregon DOT
Illinois DOT
Montana DOT
San Jose DOT
TRW (Cincinnati TMC)
North Carolina DOT
Minnesota DOT
Cumberland Gap Tunnel Authority
TRIMARC
Idaho DOT
Caltrans
Lexington–Fayette Urban County Government
Georgia DOT
Massachusetts Highway

Note: Many agencies responded concerning multiple systems.

APPENDIX C

Example Configuration Management Tool—Harvest

Harvest is a commercial configuration management program marketed by Platinum Technology (www.cai.com). This appendix describes the functionality of Harvest in order to provide further detail on the capabilities of typical configuration management tools such as ClearCase, SourceSafe, and Razor. (It should be noted that the choice of Harvest for the appendix should not be construed as an endorsement of this particular product, it simply provides the context for discussing the features of configuration management.) In addition, a glossary for this appendix is included at the end of the section to help the reader understand terminology specific to configuration management and/or Harvest.

Harvest runs on multiple platforms and provides comprehensive change and configuration management solutions for cross-platform, client/server environments. Harvest integrates configuration management with change process automation and problem tracking, providing users with control over the entire software development and maintenance life cycle. Harvest also offers automated build support, supplied "out of the box" lifecycle models, reporting capabilities, and supports multisite development.

One uses Harvest by creating development and maintenance models using a small number of basic objects. These models include *environments, life cycles, views, processes,* and *packages*. An *environment* in Harvest is the control framework supporting a particular development and maintenance process. It includes a life cycle made up of states and processes. The *life cycle* defines how changes move from state to state and what activities can take place in each state. *Views* define the data that can be accessed from within a state in the life cycle. A *package* is the basic unit of work that moves through the life cycle. It typically represents a problem or an incident that needs to be tracked, the changes made in response to the problem or incident, and any other associated information. Using these models, an organization can control change to a software system through baselining, concurrent updates, and merging changes.

The *view* is a fundamental object within Harvest and provides the link between a life cycle, which defines a development process, and the actual data being managed. The concept of a view within Harvest consists of two parts. First, the view defines the inventory that users can access, and second, the view points to one particular revision of each data item.

Each environment has an initial view, called the *Master View,* when it is created. During setup activities, the environment administrator selects repositories to be part of the Master View. Repositories point to sets of external directories on the server where Harvest keeps the data items under its control. To facilitate the management of shared items, repositories can be added in a read-only mode. Developers or software maintenance personnel can check out items in the read-only repository, but they cannot be changed. This allows multiple developers to use items that are being managed and changed by other developers in charge of those particular components.

Two types of views can be created in Harvest to support maintenance and development: *working views* and *snapshot views*. *Working views* provide access to the data under Harvest's control so that it can be updated. They are also used to provide support for isolated work areas. This means, for example, that a group can test packages without being affected by ongoing changes being made elsewhere in development. *Snapshot views* play a role in the software life cycle that is very different from working views. A snapshot view is a read-only image of a working view at a certain point in time. Snapshots allow administrators to capture an image at significant points in its development. Once a snapshot has been created, it can be used to support other application management functions, such as permanent records, baseline foundation, or main line updates.

An important feature of configuration management tools is the ability to support concurrent changes to the software system by multiple parties. Harvest provides a concurrent update mode. This mode uses branching to control changes by multiple parties (referred to as *packages*, as defined previously). In its most basic form, branching allows development to take place along more than one path for a particular file or directory. If one developer wants to check out a file that another developer has already checked out, it is merely necessary to create a branch and then check out the file on the new branch (Appleton et al. 1998).

Only one level of branching is supported within an environment. Another way to look at this is that each branch "belongs" to the package that made it. All changes made by the package accumulate on that branch, allowing the package changes to be isolated from other packages. Branching can be used basically in two different ways: *item-level branching* or *package-level branching*.

Item-level branching is when sequential updating of items is enforced; only one user can check out an item for update. Other users must wait until the first user's modifications are complete before they can check the item out. This limitation may adversely affect the time required to develop or modify the software. Concurrent update can also be used to enforce a more structured form of *package-level branching*. When an environment is set up, administrators can require that all changes occur on branches by allowing only the concurrent mode of check out. By keeping all package changes on branches, users can gain an additional level of control over how changes progress in the life cycle. Because only changes on the main line are included in the inventory of a working view, keeping changes on a branch can be used as a way of managing development without affecting the views in a life cycle. Once changes have been made and tested, they can be merged to the main line and then become "visible" in a view.

Another important feature of a configuration management tool is its ability to integrate changes from multiple parties into the core software system. Harvest provides three ways to *merge* changes back to the main system: a process that merges packages across environments, a process that merges packages within an environment, and a process for interactively reviewing merged changes and resolving conflicts. The *cross-environment merge* process is used to bring changes made in one environment into another environment. Its most important use is with parallel development, when two or more environments are making changes to the same items. The *concurrent development merge* is used within an environment. It is specially designed to support package-level concurrent development. Once a package is selected, the concurrent development merge finds all the unmarred branches that belong to the package and merges them back to the main system. Once the merge operation has taken place through the cross-environment merge or concurrent development merge, the *interactive merge* process can be used to interactively review the merged versions and resolve any conflicts.

Glossary

Baseline—a product that has been formally reviewed and agreed upon. Subsequently, it serves as the basis for further development, and can be changed only through formal change control procedures.

Branching—development on a file can be done different ways.

Item-level branching—only one user can work on a file at a time.

Package-level branching—many users can work on a file, but the changes occur on "branches." Once these changes have been tested they can be merged onto the mainline.

Build—an operational version of a system that includes a specified subset of the capabilities that the final product will provide.

Environment—the control framework supporting a particular development and maintenance process.

Life cycle—defines how changes move from state to state and what activities can take place in each state.

Merge—changes done by different people integrated into the mainline.

Concurrent development merge—used in one environment to merge all branches of a package.

Cross-environment merge—changes made in one environment are brought into another environment.

Interactive merge—used after the cross-environment merge or the concurrent merge to review the merged versions and resolve conflicts.

Package—the basic unit, such as a problem that needs to be tracked or a change made in response to the problem, that moves through the life cycle.

Platform—the operating system, such as Unix, Windows, etc., that is being used.

Repositories—external directories on the server.

View—defines the link between the life cycle and the actual data.

Master view—initial view.

Working view—access to the data so it can be worked on.

Snapshot view—read-only view at a certain point in time. No changes can be made in this view, but it acts as a record of the data at significant points in its development.

APPENDIX D

Glossary

Baseline—The current working version of the configuration item. The baseline serves as a starting point for further development of new versions.

Configuration item—"A collection of hardware, software, and/or firmware, which satisfies an end-use function and is designated for configuration management" (Buckley 1996). Examples: loop detector, source code for function to set variable message sign.

Configuration management database—A collection of all the data, history, and specifications for each of the configuration items in the system. The configuration management database is often computerized, but it does not always need to be.

Develop—To design a system based on a set of requirements.

Implementation—To build the system based on the design from the development phase.

Release—The turning over from the programming or manufacturing team to the configuration management team and the software integrators. This is the point at which the product moves from the development phase to the use and maintenance phase.

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