U.S. Department of Transportation

Federal Highway Administration

Configuration Management for Transportation Management Systems:

A Primer

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Contents

Introduction

Configuration Management (CM) describes a series of processes and procedures developed in the information technology community to establish and maintain system integrity. It is an integral part of the systems engineering process. While some of the terms used in CM may be unfamiliar to transportation professionals, the core concepts and practices of CM are not technically complex. Rather, they represent sound practices in developing and maintaining any system. As you will see in this document, CM makes sense for use in transportation management systems (TMSs).

"Configuration Management, applied over the life cycle of a system, provides visibility and control of its performance, functional and physical attributes. …

- EIA Standard 649

The purpose of this primer is to identify for a non-technical audience the key aspects, identify issues for their agencies to consider, identify the benefits or value, profile successful practices, describe why and identify opportunities how agencies may benefit from and why they should consider or using various configuration management procedures, techniques, tools, or requirements into their policies, programs, and day-to-day activities.

Purpose of CM

There are two fundamental purposes of CM – to establish system integrity and to maintain system integrity. To an individual who designs, develops, operates, or maintains complex TMSs, the definition of integrity is well understood:

- A system with integrity is one in which all components are well defined and documented.
- A system with integrity is one in which a working baseline is always available to implement and provide transportation management services.
- A system with integrity is one that can be readily integrated with other regional intelligent transportation systems (ITS).
- A system with integrity is one with a high degree of traceability – allowing one to easily identify how system functions are provided technically.

The importance of CM in establishing and maintaining a functionally sound TMS cannot be overstated. However, CM can consume significant amounts of resources including staff time and money. For this reason, developing a CM program that fits the needs of a particular system is vital to its success. In other words, CM programs are not one-size-fits-all entities. Some may think that CM is too large an undertaking to be worth it for his or her system or that the agency cannot possibly implement such a program. Although CM, and its complexity, can and should grow as a system grows, it does not need to include each and every item described in this document.

Benefits of CM

As TMSs are becoming more sophisticated through the addition of new subsystems, integration with other systems, and overall physical expansion, the need to control the rapid pace of change has become apparent. One problem that has been discovered as these systems change is that groups within an agency often work independently of each other, conducting changes without consulting one another and documenting the changes improperly. If the entire system is to undergo a major change or upgrade, this can present a significant problem. Contractors or agency personnel often will have to devote significant effort to retracing the steps taken for minor changes to the system to understand the current status. Doing so obviously requires major outlays of time and money.

A CM Program Will Ensure:

- *Documentation is accurate and consistent with the actual physical design of the item.*
- *An accurate, up-to-date baseline of the system exists, if needed for disaster recovery.*
- *Administration of change decisions are handled with a system-wide perspective in mind.*
- *Requirements are tracked throughout the life cycle creating an accurate record of the status of the system.*

A proper CM program will ensure that documentation (requirements, design, test, and acceptance documentation) for items is accurate and consistent with the actual physical design of the item. In many cases, without CM, the documentation exists but is not consistent with the item itself. For this reason, contractors and agency staff will frequently be forced to develop documentation reflecting the actual status of the item before they can proceed with a change. This “reverse-engineering” process is wasteful in terms of human and other resources and can be minimized or eliminated using CM.

Some of the other benefits of CM, which hopefully will never be needed, are its provisions for disaster recovery. Because a CM program should ensure that an accurate, up-to-date baseline of the system exists, the re-engineering process should be far less costly. Without CM and the associated baselining process, entire subsystems would require redesign at a much higher cost, and the recovery process would be greatly lengthened, if even feasible.

CM also provides for administration of change decisions with a system-wide perspective in mind. The configuration control board (CCB) has personnel with various areas of focus and from various departments within an agency. All proposed changes to the system are considered by the CCB in terms of the system, not just particular subsystems. Using tracking tools, unapproved changes can be detected and fixed more easily.

In cases of subsystem or system development, CM allows TMS management to track requirements throughout the life cycle through acceptance and operations and maintenance. As changes are inevitably made to the requirements and design, they must be approved and documented, creating an accurate record of the status of the system. The CM process may be (and ideally should be) applied throughout the system life cycle. Over time, CM will reduce operating and maintenance costs, while improving system performance and reliability.

CM Overview

CM Process

CM is the practice of handling changes systematically so that a system maintains its integrity over time. CM involves the policies, procedures, techniques, and tools to: manage, evaluate proposed changes, track the status of changes, and to maintain an inventory of system and support documents as the system changes. CM programs and plans provide the technical and administrative direction to the development and implementation the procedures, functions, services, tools, processes, and resources that are required for successful development and support of a traffic management center (TMC).

In cases of subsystem or system development, CM allows TMS management to track requirements throughout the life cycle through acceptance and operations and maintenance. As changes are inevitably made to the requirements and design, they must be approved and documented, creating an accurate record of the status of the system. The CM process may be (and ideally should be) applied throughout the system life cycle.

The general CM process is described graphically in figure 1. While not shown in figure 1, a CM plan is integral to the process. The CM plan is the document that will guide the CM program of a particular group. Plans typically are established at the outset of the CM program and undergo changes as the system evolves and as areas where the plan can be improved are identified. Contractors, in conjunction with the particular agency that will be using the CM program, often develop the plans. The benefit of the CM plan is that it provides a central location for all CM program information.

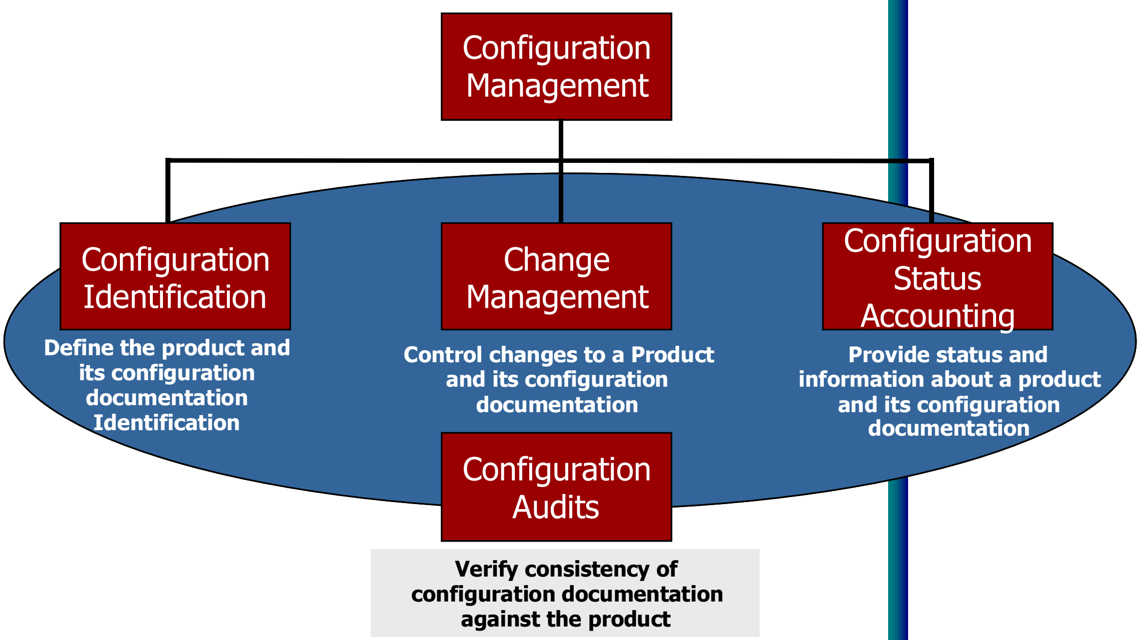

Figure 1 Configuration Management Process

Configuration Identification

Configuration identification refers to the activities and processes dedicated to creating and maintaining full documentation describing configuration items. The goal of configuration identification is to provide a unique identifier for each item to help track the changes to that item and to be able to understand its place in the system. Often, identification involves recording the identifier, maintenance history, relevant documents and other information that will simplify the change process in the future. Configuration identification may be defined as anything that has a function in the TMS. Therefore, system components classified in the broad categories of software, cabling, and hardware are considered as configuration items, in addition to system requirement and design documentation.

Configuration identification includes processes such as item naming, drawing and document management, information management and baselining. Configuration identification is the first and possibly most time-consuming process in CM, and if done correctly, will result in significant long-term benefits. The items selected for configuration identification depend upon the scope of the effort. For example, configuration identification may be constrained to software items or may be larger and include system level components ranging from software, hardware, firmware, documentation, and perhaps the CM plan. The plan serves as the primary resource for any questions pertaining to the CM program. The benefits of configuration identification are to provide a means of unique identification of system components to support traceability and change management processes. Proper identification minimizes confusion over various versions of configuration items and facilitates the change control process by allowing items to be more easily tracked as they undergo change.

Change Management/ Change Control

Change management, or change control, is the process of assessing the impact of a possible change to a system, determining the fate of the proposed change, executing the approved changes, and ensuring that the change is carried through to the proper documentation. Usually, a change is proposed by someone who is working with the particular part of the system that will be changed. Change requests are submitted to the relevant administrative body for review. This body is normally referred to as a change control board (CCB). The CCB will review the proposed change, determine its effect on the overall system and decide whether or not to proceed with it. An important part of change control is ensuring that the change itself is documented and that the relevant configuration item's (CI) documentation now reflects that change.

The primary benefit of an effective change control procedure is that proposed changes are evaluated in terms of their impact on the entire system. Change control allows the changes to be reviewed by personnel with a variety of interests and areas of specialty. This minimizes the negative impacts of changes on other components of the system. Change control also ensures that the changes are properly implemented and within schedule and cost constraints.

Configuration Status Accounting

Configuration status accounting (CSA) is the process of ensuring that all of the relevant information about an item – documentation and change history – is up to date and as detailed as necessary. A primary goal of CSA is to repose CI information necessary to support existing and future change control efforts. A typical CSA system involves establishing and maintaining documentation for the entire life cycle of an object. Status Accounting is ideally carried out in conjunction with change control.

The primary benefit of CSA is that it provides a methodology for updating all relevant documentation to ensure that the most current configuration is reflected in the configuration identification database. CSA accounts for the current status of all proposed and approved changes. The goal of CSA is to provide decision makers with the most up-to-date information possible. Having the most recent information about a CI or changes implemented for a CI helps to reduce research efforts in future change control activities whether implementing a new change or rolling back a change that had a negative or unexpected impact.

Configuration Audits

Configuration verification and audit is the process of analyzing configuration items and their respective documentation to ensure that the documentation reflects the current situation. Essentially, while change control ensures that change is being carried out in adherence with the CM plan, configuration audits ensure that the change was appropriately carried out. The most important goal of this process is to prevent lost time on future changes due to inaccurate documentation. If discrepancies are located between the documentation and the item, the personnel carrying out the audit will prescribe a course of action for remedying the problem.

The most important benefits of configuration audits are that they verify that changes were carried out as approved by the relevant administrative body and that documentation about an item reflects the current configuration. By ensuring that changes are properly executed and all documentation is updated, configuration audits will facilitate future changes to the system.

CM Implementation

As with any new initiative, a CM program must have a champion to spearhead its initiation. Sometimes, the champion faces a difficult battle, particularly due to cultural resistance within the agency. CM often is viewed as an expensive bureaucratic process with benefits that are hard to quantify. For this reason, the champion must educate decision makers and system staff on what CM is, and isn't, as well as describe the benefits of CM in a tangible manner. The champion must also secure funds or staff time to use in creating a CM plan for the program.

Once initial buy-in has been established, the next step is to create a CM plan. Depending on the complexity of the system, the plan may be developed in-house or by a consultant. Regardless of the developer, the agency must be actively involved in the entire plan development process. Once the plan is developed, the blueprint is in place to drive the program. The champion must make it clear to decision makers that the creation of the plan is but the fist step in the program. Committing to CM means a long-term staff, budget and procedural commitment.

CM Administration

The success of CM is solely dependent on how well an agency organizes itself to institute the required policies and processes. Depending on the size of the system and complexity of the CM program, the CM administration may be comprised of a large or small group of individuals. Regardless of the administration's size, the roles of each individual within the CM administration must be well understood. The CM plan should specify the responsibilities of each person involved in the CM decision-making process. In order for the CM program to be as effective as possible, it is ideal to include personnel from across the spectrum of departments, such as planning, management, technical/design, operations and maintenance, and financial. Doing so ensures that no areas are overlooked during the application of the CM program and reduces the chances of the CM activities of one group overlapping or conflicting with those of another.

Additionally, effective CM administration starts at the top. The TMS facility/system manager must play an active role in the CM program. In most cases this individual serves on the CCB and, in some cases, serves as the CM manager. In all cases, the TMS facility/system manager must fully support the program and become involved on critical change decisions.

CM Plan

The CM plan is the defining guidebook for a CM program. It defines all of the procedures, organizational responsibilities, and tools to be used within the CM process. The plan is the backbone of a CM program, and as such, must either include well-developed, detailed procedures or refer to their locations in other documents. Following a general description of CM plans from EIA 649, this section provides implementation guidance and best transportation practices as examples of these recommendations.

A CM plan clearly describes how CM is accomplished and how consistency between a system's configuration and the configuration records is achieved and maintained. The CM plan is a central source of information for the CM program. Typical contents of a CM plan include items such as:

- Personnel
- Responsibilities
- Resources
- Training requirements
- Administrative meeting guidelines
- Definition of procedures
- Tools/tool use
- Organization configuration item (CI) activities
- Baselining
- Configuration control
- Configuration status accounting
- Naming conventions
- Audits and Reviews
- Subcontractor or vendor CM requirements

Development of an effective CM plan for a transportation agency is not a turnkey job that can be completely handed over to a consultant. Although most agencies surveyed for this publication have used a consultant to support CM plan development, they agree that it is essential to have agency staff actively involved with, or leading the development of, the plan because agency staff has the best understanding of the system functionality and change control needs.

Given the active role required of a transportation agency in plan development, the next step is to become educated. Staff must understand the principles and concepts of CM, and there are numerous training opportunities available. For example, the National Highway Institute (NHI) has a course entitled Configuration Management for Transportation Management Systems (NHI Course No. 137042), which is designed for individuals engaged with or responsible for the planning, design, implementation, management, operation or maintenance of transportation management systems. In addition, the Configuration Management for Transportation Management Systems Handbook (FHWA Publication No. FHWA-OP-04-013) may be used for educational purposes.

Key Benefits of Creating a CM Plan Include:

- *Assurance that the appropriate CM processes are applied*
- *Detailed descriptions of responsibilities for CM activities*
- *Accurate knowledge concerning required resources*
- *A foundation for continued improvement*

- EIA Standard 649

Developing the CM Plan

Developing a CM plan is not a mysterious, magical process. Rather, it simply requires concerted effort and communication to ensure that the plan meets the needs of the TMS in question. This subsection summarizes the steps recommended in the "CM Plans: The Beginning of Your CM Solution" by Bounds and Dart.

Start with a standard. A number of good standards to guide CM plan development are available. The Bounds and Dart document includes a comparison of some of the more popular plans. In particular, the IEEE Standard for Software Configuration Management Plans (IEEE Std 828-1990) is recommended.

Create a template. Create a template/outline for the plan, which will guide deliberations in next steps.

Develop CM procedures. Develop the various procedures that the organization will follow in the CM program using the template as a guide. Doing so is by far the most difficult step in the process. It also will require involvement of individuals with expertise in the TMS as well as CM. Essentially, the team must study various procedures to find ones that will work for the agency.

Document. Document the procedures and other plan material developed in step 3.

Experienced CM professionals note that it is best to start out small and address the essentials.

The CM plan documents an agency's CM program. As the program progresses, the plan will need to change to reflect the changing environment. In addition, as a transportation agency gains experience in CM, this experience will dictate changes to the plan. A one CM official stated, "The old adage 'We don't know what we don't know' applies to CM. Most agencies have little or no experience and will find that their original plan will require multiple changes and modifications once put into effect. Experience will determine what works and what does not work for a given agency or situation." Clearly, the CM plan subsequently will change throughout the system's life cycle. For this reason the CM plan is subject to change control and should be treated as any other component of the TMS.

A common mistake of individuals just getting involved in CM is to attempt to develop an overly complex, comprehensive CM plan, which addresses every possible situation in a system changing through time. Experienced CM professionals note that it is best to start out small and address the essentials. The following page presents two examples of successful practices employed by transportation agencies in determining which items to include.

Successful Practice - Maryland CHART II System

The Maryland Coordinated Highways Action Response Team (CHART) II plan states, "the goal in selecting CIs is to provide meaningful management visibility and tracking." The plan also details the need for determining the overall structure of the system in order to determine the correct level of configuration identification. The plan states, "defining configuration identification at too low a level results in over-control of system development and overly complex and costly CM. On the other hand, identifying CIs at too high a level reduces management visibility into the project and can make progress difficult to control, manage, and verify."

After giving a general description of how to determine a CI, the plan goes on to detail the five major categories of CIs. Since the CM system only covers the software used in the CHART system, all items are categories of software, documentation, or related hardware (workstations, servers, etc.), but not hardware that is deployed in the field.

Successful Practice - Southern California Priority Corridor

The Southern California Priority Corridor (SCPC) CM initiative also has a policy regarding configuration identification. The plan states that CIs are "aggregations of deliverable documents, software products, and hardware." The plan also includes selection criteria that state that potential CIs should be evaluated on the basis of their impact on other projects, number of potential deployments, and impact on system consistency. Similar to the Maryland CHART II plan, a list of general categories that should be included in CM is included, although individual items are not named. The following is an excerpt of the CM plan, which lists the types of items that are to be maintained under configuration control:

- Developed software, firmware, and hardware.
- Supporting COTS software, firmware, and hardware.
- Project documents such as: Concepts of Operations, User and System Requirements, High Level and Detailed Designs, etc.
- Development systems such as: development environments, tools, COTS software, build notes and procedures, and all other information needed to fully develop the configuration item.
- Test systems such as: test environments, test plans, test software, procedures, simulators, tools, test equipment, COTS software, and notes used to verify the configuration item against requirements.
- Production systems such as: documentation, jigs, fixtures, "as built" drawings, bills of materials, and all other information needed to reproduce the configuration item.
- Supporting documentation such as: User's manuals, operational guides, training materials used to train users on the operation of the configuration item.
- Process artifact data such as: traceability matrix, requirements attributes technical review notes, etc.

CM Baseline

The concept of baseline is central in configuration management. In order to effectively implement a configuration management program in a transportation management system, one must fully understand baselines.

The concept of a baseline is not new or complex. In general, a baseline is a well-defined, well-documented reference that serves as the foundation for other activities. For configuration management a baseline is a stable, well-documented, and thoroughly tested version of the system at some point in its life cycle. For this reason, all CM activities should ensure that changes to a baseline are carefully considered and documented so that future baselines are solid.

Transportation management systems do not have simply a single baseline. If fact, during the life cycle of the system, multiple baselines will be established and maintained. Example system baselines for different points of a typical system life cycle are provided below.

Baselines in the System Life Cycle

- **Concept of Operations Baseline** – This baseline is established at the conclusion of the system conception stage. In most cases, it may be considered the formal concept of operations document developed for the system. Note that the intention of this baseline is to clearly establish the basic requirements that the system will fulfill.
- **System Baseline** – This baseline may be considered to be the final functional requirements developed for the system. This is an excellent example of a change to a system baseline that should be carefully controlled through the configuration management program. By establishing and maintaining formal system baselines, project team members will not be able to add/delete requirements without the full team (and usually the CCB) fully considering the ramifications.
- **Subsystem Baseline** - This intermediate baseline between the functional baseline and the development baseline falls after the requirements are completed and preliminary design work has established a mapping of high-level functions to system components.
- **Development Baseline** – This baseline may be considered to be the detailed design document completed before system development begins. Once system development begins, there will be significant pressure to change system design due to a myriad of reasons (desired new functionality, changes in technology, impediments to development, etc.). It is essential to carefully control these changes to design to maintain the integrity of the system.
- **Product Baseline** – This baseline essentially documents the "as-built" design that reflects the completed system. The product baseline is the result of the series of changes that have been made to the original developmental baseline during the system development process. Ideally, if the developmental baseline is under configuration control, the product baseline will simply be the evolution of the developmental baseline through the various system acceptance and verification tests, as governed by the CCB.
- **Operational Baseline** – Given the constant pressure for change, transportation management systems are truly "living" systems. In other words, the product baseline will change with time to adapt to the necessary changes. During system operations, it is essential to maintain the operational baseline to reflect changes that have been approved through the configuration management process and implemented.

Baseline Elements

Some baselines purely involve documentation, while others include software, hardware, and so forth. Typical baseline elements are:

- Documentation – This is an element of each and every baseline. In some cases, such as the functional baseline, documentation is the entire baseline. In other cases, documentation supplements other elements.
- Configuration items – Particularly in the case of software, configuration items themselves should make up portions of the product and operational baseline. For example, the source code for the product baseline should be kept in conjunction with the documentation.
- Change documentation – All documentation resulting from the configuration management change control process should be maintained as part of the appropriate baselines, which allows for traceability in the change management process.

Below are two descriptions of agencies that use baselines in the configuration management of their TMSs.

Successful Practice - Georgia NaviGAtor

The Georgia NaviGAtor CM manual states, "The baseline configuration is established at a point in time when GDOT initiates formal control over documentation, drawings, and/or software." Of the agencies that were surveyed for this report, GDOT is the only agency whose plan details the time when a baseline is to be established. After a set of plans has been given to the DOT for a certain project and reviewed to see that all requirements have been met, the agency can baseline that set of plans. From that point on, any changes made during construction should be subject to the change control process.

Successful Practice - Maryland CHART II System

The CHART II CM plan lists five major baselines that are to be included as part of the system life cycle. Under this system, which treats baselines at a project level rather than at an individual item level, the baselines consist of all relevant configuration items (documents, software, and other items). Similar to the multiple, concurrent baselines outlined earlier, the CHART II plan stipulates that at any point the project may be supporting multiple baselines. As an example, the plan says that Release 1/Build 2 may be operational while Release1/Build 3 may be in development and Release 2/Build 1 may be in design. As is standard with baselining procedures, CHART II baselines are modified using the change control process.

Current Practices

TMS Characteristics

A survey was conducted in the spring of 2000 to gauge the use of CM by transportation agencies in the United States.[1] The results indicate a need to educate the TMS community about CM in order to realize a significant commitment to this valuable resource-saving activity. The survey also revealed that many of the complex TMSs in this country are not using a formal change control process. This lack of formal change control processes calls into question the very integrity of many of these systems.

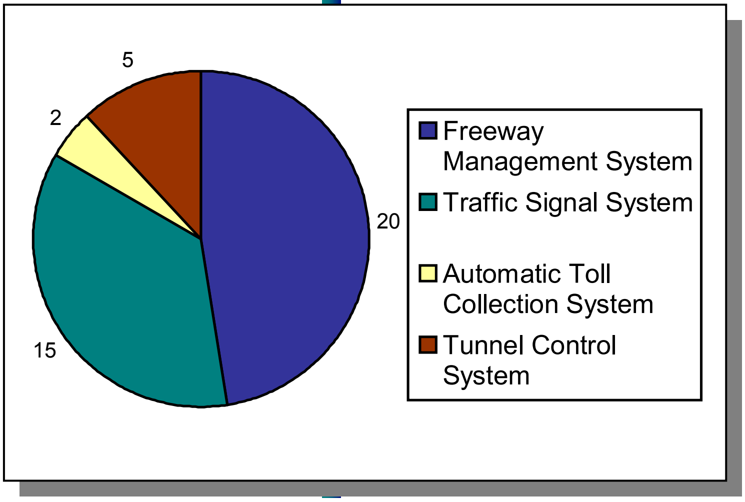

Figure 2. Use of CM According to TMS Function

The first question of the survey asked about the core functions provided by the TMS. 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. Figure 2 illustrates the percentage share of the functional classes of systems.

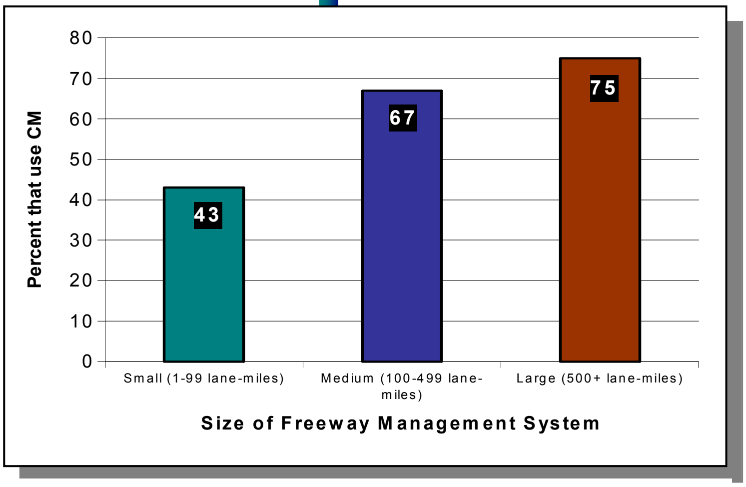

Figure 3. CM Use by System Size

A key finding of the survey was that a relatively low percentage of TMSs use CM. What was particularly notable is that only 27 percent of signal control systems and 62 percent of freeway management systems reported using CM.

Another clear trend in the survey responses is that the likelihood of a TMS using CM is dependent on the size of the system. Larger systems are more likely to utilize CM, as illustrated in figure 3.

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[1] This survey was originally conducted for an NCHRP Synthesis project. The full results of this project are published in NCHRP Synthesis 294 (2001).

Benefits/Costs of CM

Most of the agencies responding to the survey reported that the benefits gained from CM were well worth the costs required. Table 1 presents the average survey rating for a series of CM benefits. The ratings were on a scale of 0 to 10, with zero representing no benefit and 10 representing the highest level of benefit. Note that according to the survey responses, the largest benefits of CM are seen in the ability to maintain systems and in improved system reliability.

Table 1. Average Benefits Ratings for CM (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

Finally, when asked to rate if the overall benefits of CM 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. Again, this strongly indicates that of the relatively small percentage of agencies using CM, the experience has been positive.

CM Benefit Testimonials

"With almost 20 years experience in the design, implementation, modification and expansion of our system, the benefits of quickly being 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, CM can provide a constant understanding of the current state of the system…. The key factor in CM is having a central repository of information for reference as personnel changes occur over the life of the system. It also is 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."

- Comments obtained from Spring 2000 survey of transportation agencies

CM Tools and Training

Many of the currently available tools and training programs are designed specifically for software development. Some, such as issue tracking tools and document management tools, have relevance in a wider range of CM applications, including TMS. When considering the selection of a tool, an agency should consider its level of "ownership" of the various TMS components. Lower levels of ownership, as is the case for an agency that has purchased a license for a commercial-off-the-shelf signal control package, often require minimal tools for CM assistance. High levels of ownership, such as when an agency has supported the development and maintenance of a completely custom application, require full support from CM tools.

Furthermore, keep in mind that CM tools are merely *tools,* which often require significant training of agency staff in order to realize their benefits. Commonly used CM support tools are described below; specific tools available on the market are not described because of the rapidly changing industry.

Issue Tracking Tools

Issue tracking tools (ITTs) are among the most commonly used tools for CM program support. These tools support decision makers in tracking changes as they progress from approval to completion. One of the most important characteristics of these tools is that they provide administrators the ability to assign changes to various personnel and then track the changes.

Document Management Tools

Document management tools can be very supportive of CM programs. With projects often having hundreds of documents in both paper and electronic form, archiving these documents and making them easy to locate and access once archived is extremely important. Software tools that accomplish this task have the potential to shorten project length, save money, and prevent confusion for those involved in the project.

Process-Based CM Tools

Process-based configuration management tools are intended to facilitate the *software* development and modification processes. These tools act as a central location for all information regarding such effort and seek to minimize confusion among participants about the tasks that they are expected to achieve. Popular applications in this field will document and log software modifications or additions to the system to facilitate backtracking and increase knowledge of the total process.

CM and Version Control Tools

An important consideration in a CM program is that there will be more than one version of many software applications—representing different baselines for these system elements at various stages of the system life cycle. Version control tools assist the user in resolving the differences in the software applications relevant to their system. Version control tools often prevent or manage concurrent access to the same code files to facilitate concurrent development. Much like merge tools discussed next, version control tools compare two versions and then automatically present to the user a report detailing the major differences, such as changes, additions, removals, moves, and renames.

Merging Tools

Merging tools are intended for software CM only. Merging tools are software applications intended to facilitate the merging of multiple sources of code into one final set of code. Merging tools are relevant for use in TMS change control of custom-developed application software. They aid the change control process by greatly reducing physical examination of source code and allowing programmers to more quickly establish new baselines.

Building Software

As its name implies, building software is intended to aid in the process of building software applications from a variety of components, and thus is intended for software CM only. Building tools resolve or highlight missing references, build projects in the correct hierarchical order, maintain dependencies between multiple projects, and inform each involved participant when a project has been added to or removed from the application on which they are working.

Programming Environments with Versioning

Programming environment tools also is a software-specific CM tool. Such tools can be very useful during software modifications across software platforms. They provide a consistent feel and functionality across heterogeneous systems and across diverse languages. The major operations that can be carried out using a tool such as this are: design, coding, testing, debugging, and maintenance. Programming environment tools can be invaluable to the change control process and can eliminate redundancy, a major source of inefficiency. Programming environments with versioning are among the most common tools currently used by transportation agencies to manage custom TMS software.

Infrastructure Relationship Management Tools

Infrastructure relationship management (IRM) tools constitute a relatively new category of CM support resources. They are designed to handle just about every facet of an information technology infrastructure and are suited well for use on ITSs. These tools minimize the effects of organizational change on a system by providing full documentation of items and their relationships to each other, providing up-to-date baselines for disaster recovery, and keeping accurate records of the changes to items and of the current system configuration.

Awareness Level Training

All management, design, development, and maintenance personnel must receive awareness-level training to familiarize themselves with the basics of CM before they are expected to become involved with implementing the program. Note that management levels above TMC management also should be included in the awareness training given upper management's role in resource allocation and project determination and programming. Short, half- or full-day awareness-level courses are recommended. In most cases, either internal agency personnel with significant CM experience or CM consultants would serve as good instructors for the course.

Targeted Training

Personnel essential to the CM program, such as those serving on the CCB or otherwise directly involved with recommending or making changes require extensive, targeted training. Personnel requiring targeted training are advised to take a weeklong seminar on CM, which provides in-depth exposure to the processes and intricacies of CM. The courses presently available for this level of training are heavily software-oriented, but are the best choice until more general, detailed CM courses become available.

While CM tools and are currently used within many TMSs, some agencies are reluctant to invest in these products. Some of the reasons that were cited for the hesitance to accept tools include cost, fear of increased staff workload, need for lengthy training, and the fact that many of the organizations would need to use only a small portion of a tool's capabilities.

Implementation Guidance

The following implementation guidance summaries distill all the information and recommendations provided earlier into a small number of essential guiding principles of a CM program. They combine information found in technical literature and standards with interviews of transportation professionals experienced with configuration management. The summaries are designed to help transportation officials apply these principals to TMSs.

Configuration Identification

- A CM manager should determine the agency's level of configuration identification *(part, subassembly, assembly, unit, group, set, subsystem, system)* based on the complexity of its system and the anticipated frequency of change.
- A tool, which can be anything from an extensive database to a spreadsheet, is the best way to keep track of configuration item information.
- For software, a tool that allows code to be checked in and out is essential to maintaining system integrity.
- Having a centralized authority, which determines configuration items and the necessary information to collect on each leads to a more standardized and accountable system.

Change Control

- CCBs should be established to make decisions regarding changes to the system.
- The CCB should have personnel from various departments and areas of expertise so that proposed changes may be reviewed from many perspectives.
- Agencies should use a formal change control procedure to ensure consistency and acceptance.
- After a change report is submitted, a CCB member or designated staff member should acquire and distribute the necessary information regarding the effects of the proposed change before the CCB meets.
- Tools should be used to help personnel keep track of changes in an efficient manner.

Configuration Status Accounting

- All changes should be recorded with detailed information, which can be used to determine whether the change was implemented according to design.
- A robust software tool should be used in carrying out all CSA activities. CSA should highlight any differences between a proposed change and the change as implemented.
- CSA reports should be used to assess the current status of a system.

Configuration Audits

- The appropriate personnel as chosen by the CCB should conduct configuration audits on a regular basis in order to ensure that the adopted CM policies are being used.
- The auditor is responsible for documenting the findings and initiating the necessary changes.
- Audits should be conducted in a standardized environment, which describes the auditor's responsibilities and supporting paperwork.

CM Planning

- A CM program requires a CM plan.
- The development of a CM plan must include the active involvement of TMS agency staff.
- Use the following document to guide plan development: CM Plans: The Beginning of your CM Solution (Bounds and Dart, 2001).
- Use a standard to guide development. Recommended: the IEEE Standard for Software Configuration Management Plans (IEEE Std 828-1990).
- Put the majority of the effort into crafting CM procedures that work for the agency and TMS.
- Start small – be sure to include essential elements and do not seek to address every possible system change scenario.
- Put the CM plan under CM control.

CM Baselines

- Keep formal baselines throughout the system life cycle.
- The establishment and maintenance of baselines begins at the concept of operations stage.
- Require contractors and consultants to deliver baselines as appropriate for the life cycle stage of the system.
- Above all else, concentrate on maintaining complete, up-to-date documentation in baselines.

Establishing a CM Program

- A CM champion is needed.
- Ideally, incorporate CM during the requirements and development phases.
- CM program begins with educating decision makers and staff on the realities of CM and the benefits of a CM program.
- Be sure all involved understand that CM is an ongoing program, not a short-term project.

CM Administration

- The TMS system/facility manager must play an active role in CM administration.
- The roles of all personnel must be clearly defined and the relationships among them must be understood.
- The CM plan should clearly state specific tasks and requirements of all personnel involved in CM administration.
- The personnel involved in the administration of a CM program must have a variety of focus areas including: management, planning, financial, and technical.

CM Manager

- A CM manager, employed by the transportation agency, must be formally established to lead the CM program.
- The CM manager will be the chair of the CCB.
- The CM manager should be an individual with an appreciation for technical considerations and who has a sound understanding of personnel, operations, and budgeting issues within the TMS.

Personnel

- Consider basic Knowledge, Skills and Abilities (KSAs) needed when selecting any staff member to be involved in CM program.
- CM manager must have strong TMS experience. CM experience is preferable, but in-depth training can be used as a substitute.
- CM facilitator must have experience with CM programs.
- Consider requiring the CM facilitator to be CMII Certified.

Budgeting Considerations

- Expect CM planning to require between 1 – 12 person months of effort.
- Annual costs of a CM program are generally 5 – 8 percent of initial system cost.
- Ongoing CM costs include staff time, consultant support, tool purchase/maintenance fees, and training.

System Life Cycle

- Configuration management should begin at the concept of operations stage of system development.
- Require consultants and contractors to deliver products that meet the requirements set forth in the configuration management plan
- Agencies that have started late should not try to "catch up." Simply begin applying configuration management as appropriate for the system's life cycle stage.
- It is rarely too late to implement CM and reap the benefits.

CM Tools

- An agency should carefully consider its level of system "ownership." Systems that require minimal CM activities do not warrant the purchase of high-end tools.
- Agencies should survey currently available tools. The INCOSE Web site provides a convenient place to begin this effort: (*www.incose.org*)
- Key issues to consider when choosing a CM tool include:
  - how many seats (licensed users) will need to be supported.
  - the need for a high skill level to effectively use tools. (PLANET estimates that it takes 6-12 months to become proficient with their software.)
  - including the use of the tool and the purchase of the tool in operations and maintenance contracts.

- An agency should expect to spend 10 to15 percent of original software cost on annual tool maintenance fees.
- The case study of GDOT presented in the next section provides excellent guidance on the process an agency should follow in choosing a tool for a particular CM program.

CM Training

- Provide awareness-level training for all staff involved in CM.
- Provide targeted training for key staff with essential CM responsibilities.
- The CM manager should lead the training program.
- Training must continue as the CM program continues.

Additional Resources and Training

The handbook entitled Configuration Management for Transportation Management Systems is intended to provide guidance for transportation professionals that are responsible for developing and maintaining complex Intelligent Transportation Systems (ITS) and TMS. The handbook expands on the information presented here, by detailing the various aspects and components of CM.

The documents listed below and additional training materials are available on the TMC Pooled-Fund Study website at http://tmcpfs.ops.fhwa.dot.gov/.

- CM for TMS Handbook, FHWA-0P-04-013, EDL# 13885
- CM for TMS Brochure, FHWA-OP-04-016, EDL# 13888
- CM for TMS Fact Sheet, FHWA-OP-04-017, EDL# 13889
- CM for TMS, NHI Training Course No. 137042, FHWA-NHI-03-119

Configuration Management for Transportation Management Systems
Summary Guiding Principals

1. Identify the context and environment in which CM is to be implemented and develop an appropriate CM plan accordingly.
2. Define procedures describing how each CM process will be accomplished.
3. Conduct training so that all responsible individuals understand their roles and responsibilities and the procedures for implementing configuration management process.
4. All items are assigned unique identifiers so that one item can be distinguished from other items.
5. Configuration documentation defines the functional, performance, and physical attributes of a system.
6. A baseline identifies an agreed-to-description of the attributes of an item at a point in time and provides a known configuration to which changes are addressed.
7. Each change is uniquely identified.
8. Consider the technical, support, schedule, and cost impacts of a requested change before making a judgment as the whether or not it should be approved for implementation and incorporation in the item and its documentation.
9. Implement a change in accordance with documented direction approved by the appropriate level of authority

"Configuration Management, applied over the life cycle of a system, provides visibility and control of its performance, functional and physical attributes. Configuration Management verifies that a system performs as intended, and is identified and documented in sufficient detail to support its projected life cycle."

EIA Standard 649

Configuration Management for Transportation Management Systems

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