Transportation Management Center Concepts of Operation

Implementation Guide

December 1999

Foreword

Dear Reader,

We have scanned the country and brought together the collective wisdom and expertise of transportation professionals implementing Intelligent Transportation Systems (ITS) projects across the United States. This information will prove helpful as you set out to plan, design, and deploy ITS in your communities.

This document is one in a series of products designed to help you provide ITS solutions that meet your local and regional transportation needs. The series contains a variety of formats to communicate with people at various levels within your organization and among your community stakeholders:

- Benefits Brochures let experienced community leaders explain in their own words how specific ITS technologies have benefited their areas;

- Cross-Cutting Studies examine various ITS approaches that can be taken to meet your community's goals;

- Case Studies provide in-depth coverage of specific approaches taken in real-life communities across the United States; and

- Implementation Guides serve as "how to" manuals to assist your project staff in the technical details of implementing ITS.

ITS has matured to the point that you are not alone as you move toward deployment. We have gained experience and are committed to providing our state and local partners with the knowledge they need to lead their communities into the next century.

The inside back cover contains details on the documents in this series, as well as sources to obtain additional information. We hope you find these documents useful tools for making important transportation infrastructure decisions.

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Executive Summary

Agencies responsible for managing large-scale transportation resources face many challenges. Typically, such agencies are required to deliver increasing service with limited expansion of their asset base. Many of these agencies are using technology to gain additional benefits from existing resources. One common technical approach is to implement a facility or system through which management and coordination of technology and other transportation resources takes place. Such a facility is often referred to as a transportation management center (TMC).

TMCs are neither a new idea, nor are they limited to the relatively recent intelligent transportation systems (ITS) program. Transit properties have been managing their fleets, whether rail or bus, from such centers for many years. Similarly, large traffic signal systems have been under central control for many years. Illinois Department of Transportation has been managing freeway incidents from its Chicago TMC for over four decades.

TMC Technologies

- ***Communications***
- ***Computing***
- ***Display***
- ***Sensors***
- ***Actuators***

The number, size, and complexity of TMCs is growing rapidly. Many of the latest TMCs involve staff from multiple agencies and jurisdictions. These centers focus on integrated transportation management, often applying state-of-the-art technology so that both personnel and systems can work together effectively. The experiences of the agencies implementing and operating these facilities can be of great value to agencies considering their own implementations.

An agency implementing a TMC should plan the TMC as carefully as it would plan any high-cost, high-visibility investment. An important tool in such planning is a “concept of operations.” It develops answers to the questions “What do we want to do?” and “How do we do it?” for the TMC. It also guides many areas of preparation for the facility. It looks closely at the functions which the TMC must perform and the broader functions whose performance the TMC supports.

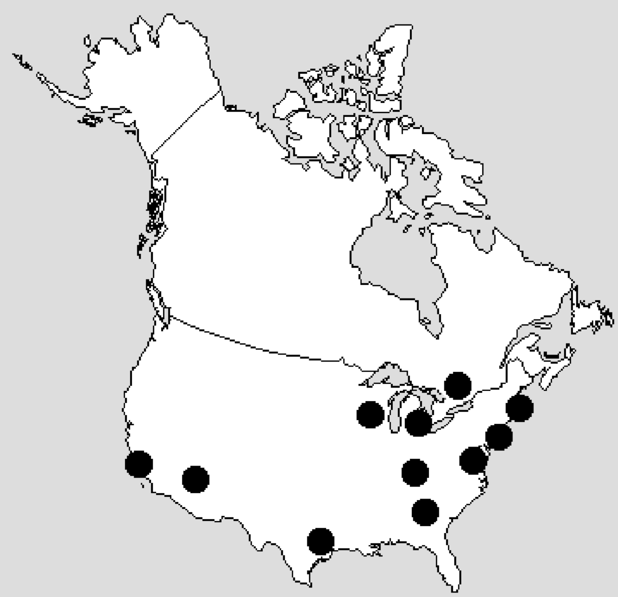
The concept of operations is often the first detailed examination of the idea for implementing a TMC. It will provide guidance and direction to help ensure that the subsequent procurements result in the type of facility and systems that best serve the agency’s needs, and which represent an effective utilization of limited budgetary funds. It will also assure that the operational needs of the TMC are consistent with the resources and policies of the responsible agencies. Thus, a path can be laid for successful operations and maintenance, realizing the maximum possible benefit from the investment.

The concept of operations, a component of a systems engineering approach, is developed early in the transportation planning process. It receives input from the relationships, roles, needs, goals, plans, and programs of the responsible agencies. It provides important outputs to be used in defining the systems it will contain and support, and in planning for the operations and maintenance processes. It also supports planning for the training and documentation which will enable TMC personnel to perform effectively. It considers the process which the TMC will use to monitor its own workload and performance levels, and how it will identify and implement improvements.

Executive Summary

The following document will assist agencies in developing a concept of operations by providing insight into each of the topics a concept of operations is likely to contain. Examples of operational considerations from TMCs in the United States and Canada, including ones operating in both large metropolitan areas and in medium or smaller areas, are highlighted.

An extensive list of reference materials on both concepts of operations and on TMCs is included. Many of these materials are new, developed as part of the United States DOT's efforts to share the experiences of agencies which have implemented and are running such facilities.



Location of TMCs included in this study

Part 1 : Introduction

Focus of the Document

Purpose

The purpose of this document is to assist agencies which are planning, designing, implementing, or operating and maintaining transportation management centers. This document specifically should assist these agencies in:

- Understanding what a concept of operations is
- Understanding how to develop an effective concept of operations
- Understanding how to use a concept of operations in planning, design, procurement, implementation, or operation and maintenance of a TMC

The issues, processes, and concepts contained in this document are drawn from freeway, arterial, and transit management examples, and thus should be applicable to a broad range of transportation management situations.

Audience

There are three primary audiences for this document:

- Agencies planning to implement a TMC
- Agencies currently operating a TMC, and seeking to improve the TMC's operation
- Agencies currently operating a TMC, and planning to replace major systems in the near-term time frame

The document, having been assembled from inputs received from agencies operating freeway management systems, traffic signal control systems, and transit (both bus and rail) management systems, should prove to be of value to a wide range of transportation management agencies. It also reflects lessons learned in concepts of operations for command and control centers in other areas, such as spaceflight control and air traffic control.

The document will also prove to be of value to agency teams who work closely in joint management of transportation, such as at the 4 agencies in the Houston TranStar TMC, Caltrans' 8 urban TMCs, each of which is jointly owned and operated by Caltrans and the California Highway Patrol, or Maryland's satellite TMCs, each of which is located in a Maryland State Patrol barracks.

Organization

Rationale

Part 1 of this document provides an introduction to the purpose and audience, the need for a concept of operations, the challenge faced by transportation managers, what a concept of operations is, and how a concept of operations is to be used.

Definitions

Part 2 of this document begins by describing the types of transportation management centers in which a concept of operations is applied, and the types of functions performed in each. This part concludes by describing the benefits of a TMC in managing transportation resources.

Issues

Part 3 describes the preparations for developing a concept of operations, and places it into the context of both a systems engineering approach and the transportation planning process. Part 3 then describes the inputs to the concept of operation, the analysis and processes performed in developing it, and how it serves to support development of additional documents.

Lessons

Part 4 walks through each section of a concept of operations and discusses considerations in each. Where major alternatives exist, such as manual or highly automated operation, or agency or contractor operation, these alternatives are raised and key points for each primary alternative are described.

Resources

Part 5 provides guidance on topics ranging from resources which can be of assistance in exploring many aspects contained within a concept of operations, to the general area of operations and maintenance, to other issues relevant to the modern TMC. This part also includes acknowledgments and references, and an index to assist in navigating through the document to specific topics or interest areas.

What is a Concept of Operations?

In its simplest definition, a concept of operations for a TMC defines what the center accomplishes, and how it goes about accomplishing it. Thus, it defines functions (what is accomplished) and processes (how they are accomplished). The concept of operations ideally addresses both operations and maintenance of the TMC, and the resources for which it is responsible. It describes the interactions that occur within the TMC, and between the TMC and its partners (firms and agencies) and customers (motorists, media, etc.) in managing transportation. As a tool developed primarily in the planning stage, it often works at a summary level. It is not intended to serve as an operations manual, although it may follow a similar outline.

At its most summary level, the outline for a TMC concept of operations contains the following topics:

- The Systems
- Operational Facility Needs
- Integration and Testing
- Coordination
- Performing or Procuring Operations and Maintenance
  - Workload and Performance
  - Organization
  - Nonstandard Operations
  - Fault Detection and Correction
  - System Maintenance
- Training and Documentation
- Operational Procurement and Contracting

How is a Concept of Operations Used?

The concept of operations, describing the functions of the TMC and how they will be performed, can be applied throughout the TMC planning, design, implementation, and operations/maintenance program. Specific examples where it can serve an important purpose include:

Functions

- The concept of operations may be the first definitive expression of how the TMC's functions will be performed. Thus, it can support resource planning for the physical space requirements, hardware and software specifications, the staffing, and some allocation of responsibilities between the implementing parties.

Consensus Building

- The concept of operations can serve, at successive levels of detail, as a component of consensus building by the partners performing those functions, who have already begun to define the requirements, as well as the mission/vision/goals/objectives of the TMC.

Training

- The concept of operations also addresses the training program required for the staff and the documentation which they will require in performance of their duties.

Interactions

- The concept of operations should also identify the interactions between organizations involved in performing the TMC's functions. Thus, it will identify the points at which agencies or functions within an agency interact, and how that interaction may take place:
  - Who initiates
  - What information is provided
  - What response is needed
  - What communications means are applied
  - How the response is confirmed
  - What form the feedback loop takes to assess effectiveness, modify the response if needed, and terminate it when appropriate

Why Agencies Need a Concept of Operations

The development of a concept of operations is a tool used by agencies to identify their optimal solution based on their preferred approach, their capabilities, and their constraints.

The agency desiring to implement a TMC faces a significant challenge in defining to its system designer exactly what the agency wants designed, and how the agency wants it designed. Without this guidance, the designer may either make a "best guess" at the agency's needs and desires, or may come forward with a solution which was developed to meet the needs of another (possibly quite dissimilar) agency and transportation situation. Often the result is not what the implementing agency desired.

As an example, often the agency faces constraints which must be reflected in the system design. These constraints may dramatically affect how the system operates. A common example faced by most agencies is a limit on the number of operations personnel who may be dedicated to the TMC. The TMC's workload can be measured in such quantities as number of vehicles to be dispatched and monitored, or the number of incidents occurring which require active management. Since the workload is outside the control of the TMC, the system must support addressing this workload within the staffing constraints. In this example, a small staff addressing a substantial incident management workload will require significant automation, i.e., automatic incident detection rather than manual scanning of detector data or camera images, and recommended incident solution scenarios, rather than manually created solutions developed on-the-fly by the operator.

Constraints on Agencies

- Ensuring adequate staffing levels and budget for TMC operations and maintenance
- Losing qualified TMC maintenance personnel to the private sector
- Addressing technological evolution and obsolescence
- Estimating the time it takes for a TMC to become operationally stable
- Mitigating false alarm rates
- Workloads

A similar example involves the skill level of TMC operators. If the staffing budgetary constraints limit the agency to hiring non-degreed individuals without experience in control center operations or traffic management, then the system is the primary tool which the agency has to control the quality and effectiveness of the outcome of the operations process. In such a case, the system must serve as the "expert" supplementing the operator, rather than calling upon the operator to make skilled traffic management decisions, often under real-time crisis conditions.

What Challenges Do TMC's Face?

The modern transportation management center is challenging to implement, operate, and maintain.

- The TMC is often the focal point for monitoring and control of tens of millions of dollars of highly visible transportation resources, on which the surrounding community rapidly becomes dependent. If the system does not work well, the agency's credibility can be negatively affected in the media and among individual travelers.
- The TMC planning, design, and implementation involve not only several departments within the implementing agency (or agencies), but also the efforts of a variety of private sector product and service providers. This requires both significant coordination and ongoing effort to build and maintain consensus.
- The TMC may be in planning, design, and implementation several years, requiring it to deal with multiple technology generations.
- Often, multiple individuals and organizations are involved in any given transportation situation, with differing (and potentially unclear) roles and responsibilities. These participants may be acting from incomplete understandings of the situation and with differing motivations and priorities. Communication and coordination between the participants is seldom complete.
- In general, each transportation situation is unique, requiring a customized response. Situations typically arise without warning, and the impact can create inconvenient and potentially dangerous conditions for tens of thousands of travelers.
- The conditions with which the TMC must deal change rapidly, and often unpredictably. The resources used by the TMC in executing its response may be impacted by the very situation to which it is reacting. For example, the congestion caused by a HAZMAT spill may make it difficult for the HAZMAT response unit to reach the incident site.

The challenges faced by the TMC can be divided into two primary categories: those related to technology and integration of technology, and those related to institutional issues. Each category is addressed below.

Technologies and Integration of Technologies

By definition, the TMC is highly dependent upon technology to accomplish its mission. Its area of responsibility is often geographically quite large (statewide or corridor-wide in some cases). Therefore, monitoring transportation conditions and monitoring and controlling devices (either vehicles or stationary field equipment) require that the TMC employ modern communications and computing resources.

The workload these devices carry is almost unimaginable by standards from 10 years ago. Communications data rates and switching speeds, and computer processing speeds and backplane bandwidths are multiple orders of magnitude higher than was possible only a few years ago. The expanded workload is possible because of advances in both hardware and software capability. The typical freeway management system core software may contain hundreds of thousands of lines of application source code (not including the operating system and any commercial off-the-shelf applications such as a database management system). Thus, the technological complexity of the systems on which the TMC depends is a major operational management challenge.

The integration of such a variety of technologies is also a major undertaking. While standards are developing at a rapid pace, current ITS implementations continue without the benefits of simplified integration which these emerging standards will provide. Once standards exist, TMC agencies still will need to address integration of current systems with “legacy” systems, often containing significantly different types of technology. Such interactions, along with the standards which may support them, will likely have been identified in the region’s ITS architecture. In its most detailed form, the regional ITS architecture will define not only the systems and subsystems which interact, but also the information which they share, and may provide some detail on how the information is exchanged. Furthermore, integration has proven to be a complex function to define, procure, manage, and measure.

The agency owning the TMC thus faces a daunting challenge of implementing, operating, and maintaining not only a complex transportation environment, but a mass of complex (and not always very compatible), and rapidly evolving technology.

Institutional Interactions

The multitude of institutional interactions necessary in order to optimize transportation operations further challenges the agency. Transportation can seldom be managed unilaterally if optimal conditions are desired. Travel patterns require interaction between transportation modes, between agencies within jurisdictions, and across jurisdictional boundaries. Thus, the actions of one agency may greatly impact the conditions under which another must labor, and the ability of an agency to optimize travel conditions will almost undoubtedly depend upon cooperation between several agencies.

Interagency cooperation should be a part of every phase of the TMC, from planning through operation and maintenance. In order for the agencies to work together effectively, there should be governing mission, vision, strategy, goals, and objectives related to the TMC. These should be clearly traceable to each agency’s own defining statements.

> Examples of cooperative roles of multiple agencies in TMC operation include the Detroit TMC, which is jointly staffed by Michigan State Patrol and Michigan DOT. State Patrol dispatchers provide incident information to the MDOT TMC operations contractor who provides responses and verification and dispenses traveler information.

The concept of operation should document the roles and responsibilities of each agency clearly, and should address with appropriate detail the resources which each agency will apply or contribute. The concept of operation extends to describing not only what each agency will do, but how it will do it. This combination of information should serve as a basis for a complete understanding, and therefore full consensus, on how the TMC will operate. This is discussed in more detail in Part 4 in the areas dealing with coordination and conflict resolution.

As noted in the Detroit example above, interactions are not limited to the public sector participants. Interaction between public and private sector organizations in the TMC are increasingly common, either under more common contractual arrangement or as part of public-private partnerships.

> The Massachusetts Highway Department has implemented Boston's Integrated Project Control System, and has contracted its operation and maintenance to the Massachusetts Turnpike Authority.

In most multiagency TMCs, some coordinating forum exists in order to address issues, assure regular and full communication, and to identify opportunities for improvement. This often takes the form of interagency committees, typically at multiple working levels.

> In the AZTech model deployment, interagency coordination took place at multiple levels. Committees were created at senior executive, executive, project, and technical working levels to assure communication and coordination, and to allow each agency or private sector partner to voice its concerns and participate in decision making.

Equally complex is the interaction within the agency implementing a TMC. In many state transportation departments, planning, design, construction, operation, and maintenance are separate entities. These units are often also divided by lines between the headquarters organization and district offices. In order to achieve the desired capability and impact from the significant investment in a TMC, effective interaction between these units is critical at all stages: prior to it achieving operational status, on an ongoing basis as it is operated and maintained, and as it evolves.

Summary

The purpose of this document is to assist agencies either planning or operating a TMC. It describes what a concept of operations is, how to develop one, and how it can be used in all phases of a TMC program, from initial planning through operation and management. Its objective is to demonstrate the utility of a concept of operations, and then to facilitate the preparation and use of concepts of operations by a range of agencies responsible for managing elements of a complex transportation environment.

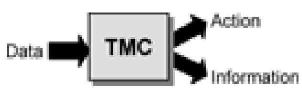
Transportation management, and therefore the applicability of a concept of operations is not a process limited to major metropolitan areas. However, it is made more complex in large diverse environments, such as those where many jurisdictions and agencies interact, and in diverse regions (urban and rural, interstate corridors and city streets) where many potentially conflicting transportation needs change rapidly and require constant attention and active management.

Part 2: Types, Functions, and Benefits of TMCs

This section defines the types of transportation management centers on which the guide is focused, their functions, and their benefits.

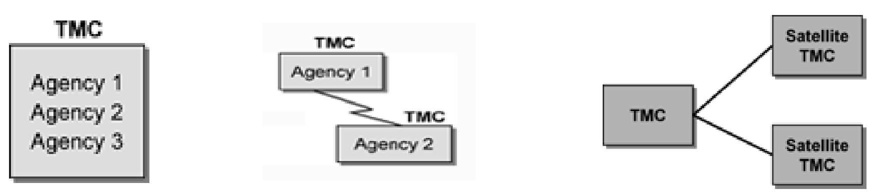
Definition of a Transportation Management Center

The transportation management center is the hub or nerve center of a transportation management system. It is where information about the transportation network (freeway system, traffic signal system, or transit vehicle network) is collected and processed, and fused with other operational and control data to produce information. The information is then used by system operators to monitor the operations of the transportation system and to initiate control strategies to effect changes in operation. It is also where agencies can coordinate their responses to transportation situations and conditions. Furthermore, the TMC is the focal point for communicating transportation related information to the media and the motoring public. (1)



This document is intended to work for any level of centralization/ decentralization supporting a metropolitan area, region, or state. The primary center may serve as the locus of all transportation management activity, may direct the actions of the other centers, may merely coordinate the efforts of the other centers, or may interact with the other centers only through the complementary exchange of information (potentially including voice, image, data, and video).

TMCs around the U.S. work with various levels of distributed approach, varying from the classic central facility to virtual TMCs with workstations at the component agencies, and with those agencies interacting electronically or by radio and telephone. The attractiveness of the virtual approach is that it avoids a major investment to design, construct, and operate a central facility, and may allow the involved agencies to avoid creating of full-time staff positions dedicated to transportation management. The primary drawback of such an approach is that it depends on longer, less direct lines of communication. Insofar as the concept of operations is concerned, each performs the same functions and accomplishes the same interactions and information movement, but through differing communication methods.



A Centralized Approach vs. Distributed Approaches

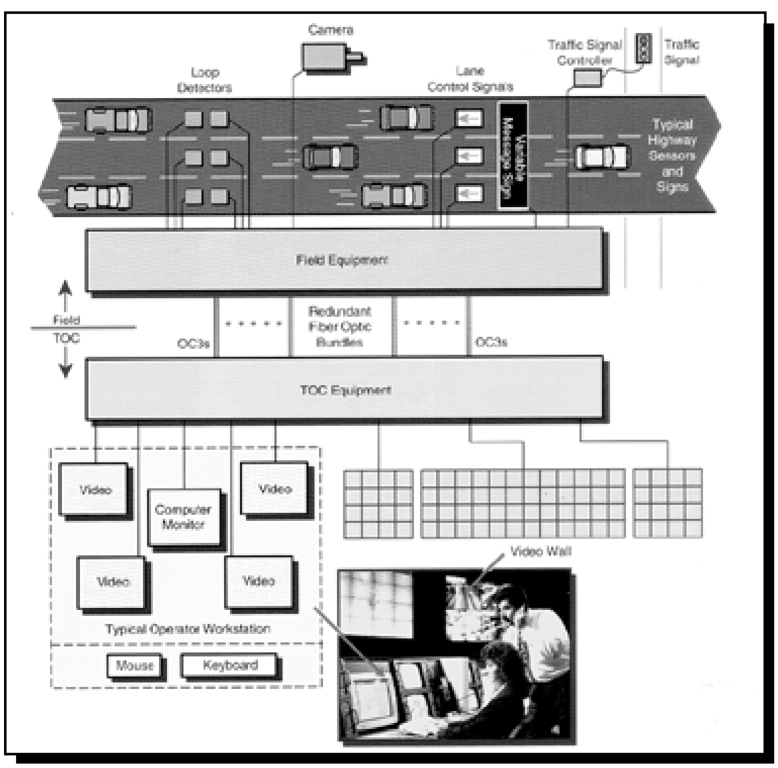
Types of Transportation Management Centers

Freeway Management Centers

A freeway management center is typically responsible for the monitoring and control of traffic on an interstate highway or comparable limited access roadway. The typical freeway management center will focus its efforts on detection, verification, and active management of incidents which reduce roadway capacity; on distribution of information to travelers; and on optimization of roadway capacity through active strategies such as ramp metering. Additional functions, such as a motorist assistance patrol, may be managed from within the freeway TMC.

In the typical freeway management centers, operators receive notice of incidents through:

- A network of sensors (loop detectors, radar, etc.) which continuously monitor traffic flow (speed, occupancy, and/or volume)
- Motorist calls from roadside telephones, cellular phones, or those relayed via the “911” network
- Vehicle “probes” such as those monitoring flow of vehicles (including passenger and commercial vehicles, transit buses, law enforcement vehicles, or maintenance vehicles) which carry radio frequency transponders or are actively transmitting location derived from on-board global positioning systems.
- Monitoring video images from roadside cameras



TransGuide Architecture Diagram

Following notification, incidents are typically verified through these same cameras. Incident responses vary, including notification to law enforcement, emergency services, HAZMAT, maintenance, motorist assistance patrol, wreckers, and posting of messages to approaching motorists via variable message signs and highway advisory radio. Readers interested in further detail regarding freeway management are referred to the FHWA Freeway Management System Guide (please see references in Part 5).

Readers seeking a comprehensive list of freeway management centers are referred to the ITS deployment tracking database supported by Oak Ridge National Laboratory for United States DOT, at the web site (http://www-cta.ornl.gov/research/its/index.htm)

Traffic Signal System Centers

Traffic signal system centers typically focus on the monitoring and control of traffic signal networks on urban surface street networks. The functions performed in such a network include monitoring of functional status of all equipment in the signal network, and dispatch of resources to return malfunctioning equipment to operational status. The center may also participate in testing changes and expansions to the signal network. The center typically monitors flow of traffic on the surface street network, and intervenes by adjusting signal timing whenever necessary.

The architecture of traffic signal systems varies greatly, from fully distributed to fully centralized, and from simple time-of-day operation to highly complex real-time traffic adaptive systems. Although the architecture influences the location of the computing resources used by the traffic signal system center, it does not generally influence the center's concept of operations, in that the center still communicates with the field equipment, using that equipment to monitor and respond to transportation conditions. The architecture does significantly influence the maintenance concept of operations, however.

Similar to freeway management centers, traffic signal system centers that have access to resources to identify incidents would take similar actions as described above to identify and address incidents on their road networks. The signal system center may also interact with the freeway center by altering signal timing to create diversion routes around major freeway incidents. Projects such as DIVERT in Minneapolis demonstrated this capability.

Examples of traffic signal control centers include the RESCU center in Toronto, New York City's signal center, and the ATSAC center in Los Angeles. Another interesting example is the SCATS center in Sydney, Australia, which is responsible for approximately 4000 centrally controlled intersections, and which is staffed and operated by the local police, under regional law.

Transit Management Centers

Transit management centers are typically tasked with tracking and supporting fleets of transit buses or railcars. It can be particularly critical in mixed fleets, where coordination of the bus/rail interface is essential to client satisfaction and to cost-effective operation of the transit network.

Bus vehicle location and tracking technologies range from simple tracking through radio communication with the vehicle operator, to systems with on-board global positioning systems which transmit vehicle location second-by-second to the center. Bus fleet management systems may also capture vehicle condition information and vehicle performance compared to schedule. In the latter situation, the center may have cooperatively-implemented traffic signal priority for transit vehicles, allowing buses to reduce some variance from schedule by either early initiation of or extended green cycles on the traffic signals along the vehicle's route. Newer systems also allow transmission of mayday signals from the vehicle, allowing the center to contact appropriate emergency services and public safety officials. The transit management center also maintains voice communication with the vehicle drivers. For bus networks, transit management centers may be able to alert drivers to problems along their routes, allowing alternate routing where permissible. Similarly, bus transit management centers may capture traffic information from their drivers, which can be passed along to traffic signal or freeway management personnel.

Paratransit management centers function much as does a taxicab company, receiving requests for rides (with varying requirements for advance notice), matching these to vehicles and currently planned trips, and communicating with vehicle operators.

Rail transit management centers typically monitor railcar and track condition, managing departure times in order to control headway, developing and implementing alternate track routing around malfunctions, and serving as the hub for dispatch of maintenance.

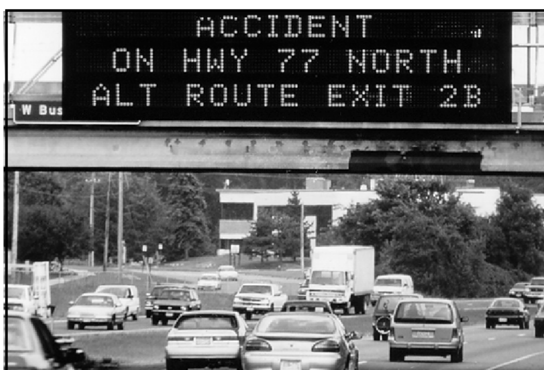
Many fine examples of transit management centers exist in the U.S. and elsewhere, including the MARTA center in Atlanta, the WMATA center in Washington, D.C., and the BART center in California's bay area. Typically agencies manage multiple fleets, i.e., fixed route bus, paratransit, charter, (heavy) passenger rail and light rail, and may have multiple centers, with system-level integration where the vehicle networks and schedules interconnect.

Functions of Transportation Management Centers

Center-Specific Functions

Roadway Management

Roadway management is the monitoring and control of the flow of traffic of a recurring nature by the TMC. Its most common components are active flow balancing between alternate routes (such as that performed by the COMPASS system in Toronto, Ontario), provision of relative travel times for alternate routes (such as that provided by the MONITOR system in Milwaukee), and ramp metering (such as that found on the roadways in the Seattle area). Control of HOV facilities is also included in this category, especially when the HOV lane is reversible, and its operation may include gates or relocating a movable barrier.



Incident Management

Incident management includes two components: incident prevention and incident response. In prevention, the TMC acts to avoid impact from situations which could result in incidents. Common approaches include providing traveler warnings of unsafe or congested roadway conditions, motorist assistance patrols, "push-off" bumpers on agency vehicles, roadside accident investigation sites, effective management of lane closures (often more a form of mitigation than prevention), and rapid dispatch of resources to repair road damage or to remove debris.

Incident response aims to reduce the impact of an incident which has already occurred. The primary component is the rapid reduction of impact (reducing the number of lanes closed and creating alternate routes), termination of impact by incident clearance (and removal from view, if possible), and roadway cleanup. Incident management also includes providing traveler information regarding the incident (or incident impact), in hopes of reducing the number of vehicles delayed by the incident and minimizing the likelihood of secondary incidents.

Fleet Management

Fleet management includes the monitoring and active management of a group of vehicles operating on the roadway or rail network. The most common component is vehicle location monitoring, either automatically (via automatic vehicle location technology) or manually (by radio contact with the vehicle operator), from which schedule adherence and vehicle headways can be determined. Active response to these parameters could include altering the duration of one or more vehicle stops, or activation of traffic signal priority. Automated train control technology actively manages vehicle headway in real time by:

- Managing railcar departures at route starts
- Adjusting station stop times
- Regulating vehicle speed
- Inducing stops enroute
- Routing railcars alternately, based on track activities, track conditions, or other relevant factors.

Additional information which may be received by the fleet management center includes various vehicle status information (engine temperature, oil pressure, etc.), passenger activity information (embarkations and debarkations), and fare data. In some cases, video may be transmitted from the vehicle to the center as an element of passenger security, as may a "mayday" signal from the vehicle operator. The information provided by the vehicle operator by voice (radio) to the center is relatively unrestricted, and often includes vehicle, passenger, operator, and traffic condition information. Actions by the TMC in response to these types of information could include dispatch of assistance resources, a replacement vehicle or operator, an additional or larger vehicle if loads exceed the current vehicle capacity.

Traffic Signal Control

Traffic control consists of monitoring and responding to traffic flow on the signalized roadways and to the condition of the traffic signal network. The TMC may adjust signal timing plans (either directly by altering the plan currently in operation, by activating an existing alternate plan, or by uploading and activating an alternate plan), or may change the mode of operation of one or more signals (to flash, actuated operation, or fixed-time operation). The TMC may also dispatch maintenance resources to address signal system problems or may request dispatch of law enforcement to direct traffic if signals at an intersection becomes inoperable. The TMC may also attempt to restart or correct faults in the signal system or with the communication with the signal system. If the signal center has appropriate assets, it may also perform incident management, and may provide traveler information to travelers on the roadways under its jurisdiction.

System Control and Data Acquisition

System control and data acquisition (SCADA) functions are performed by many TMCs, but are not specific to the type of infrastructure managed. The best examples of SCADA functions are related to tunnels, and include:

- Ventilation
- Fire detection and suppression
- Pumping
- Electrical system control (load control, switching)
- Security monitoring
- Motorist telephone system

In the Arizona TrailMaster TMC, SCADA functions also include control of irrigation in the highway medians. Another type of SCADA function, at the Boston Central Artery/Tunnel Integrated Project Control System, is AM/FM rebroadcast.

Center-to-Center Coordination

Cross-center coordination begins not when the center is operational, but during initial planning, design, and implementation. Involving all agencies active in the situations addressed by the TMC ensures that the center is optimally configured, equipped, and staffed to achieve full benefit from the taxpayer investment. Ideally, the concept of operations will reflect the actions and methods of each partner in transportation management, and will reflect the resources and capabilities necessary to achieve the chosen operational method.

Information Sharing

The focus of cross-center coordination is the sharing of information. Typical examples of infrastructure-based information sharing include messages on variable message signs and highway advisory radio. Non-infrastructure intensive traveler information includes provision of information via broadcast media, press, Internet, telephone systems, or via fax.

Information sharing may occur at any time, i.e., as part of event planning, during an event, or following the event as a “post mortem” evaluation. In event planning, agencies should work to comprehensively detail the actions to be performed, identifying who is responsible for each action, and how information will flow during the event. During the event itself, sharing information on what is transpiring and how, and on how each agency is responding adds to the total effectiveness. In a post-event analysis, careful consideration of how the event proceeded, step-by-step, and of how improvements can be achieved is beneficial. This includes both planned events (such as parades) and unplanned events (such as traffic incidents).

> Good examples include the detailed plans prepared by Houston Metro's law enforcement staff at the TranStar control center detailing freeway, arterial, transit, and crowd control plans for major events such as the annual Rodeo.

Center-to-center coordination is of even greater importance for traffic signal systems. Where neighboring centers control signals along a primary signalized corridor, coordination is critical to achieving optimal flow conditions. Interaction may take place in real time or may only be necessary if conditions are changing in the centers, such as for special events or construction-related lane closures.

Benefits of Transportation Management Centers

Transportation management centers provide numerous benefits. Studies to date have yet to separate the benefits of a transportation management system itself from the benefits of housing the system in a center. Several benefits specific to systems with a dedicated center are demonstrated:

- TMC centers provide enhanced communication in all aspects of transportation management (planning, design, implementation, operation, maintenance) when the involved parties are co-located in the center. This includes both daily communication, and communication for special circumstances such as special events or an unusually severe incident.
- Similarly, if each of the participating agencies had to staff its own full-time position when managing separately, total cost might exceed that realized by sharing responsibilities between fewer staff.
- A dedicated facility is often able to justify investment in assets which increase the overall system reliability (such as an uninterruptable power supply with diesel generator backup power) but would not be practical for distributed sites. This also applies to special skills, such as database or network administration or configuration management, which may only be justifiable for the larger facility.
- Agencies working closely together in a TMC typically produce a more consistent, unified response to a situation, increasing the overall effectiveness of the transportation resources.

Additional benefits information for many types ofITS programs supported by TMCs can be found in "Intelligent Transportatiion Systems Benefits: 1999 Update," prepared by Mitretek for the USDOT (EDL number 8323).

Benefits Target the Traveling Public

Part 3: Setting the Stage for Development of a TMC Concept of Operations

The Context of a Concept of Operations

The concept of operations described here makes use of many outputs of the transportation planning process in identifying the functions and approaches which it describes. Although a very generalized concept of operations is developed during planning, the version described here occurs after transportation needs have been identified and very high level requirements determined. This is a logical point at which to include the concept of operations, as it would be difficult to accurately make critical design decisions without much of the analysis performed in developing the concept of operations.

What Activities Lead up to Preparing the Concept of Operations?

Several broad areas of activity must precede development of the concept of operations. These include understanding transportation needs, building or improving relationships, and discussing resources. The end products of these become inputs to the concept of operations. The relationships that are built or clarified during these activities are also important to understand in developing the concept of operations. There are also two important items to consider in the approach to developing the concept of operations: how it deals with growth and evolution, and how the document itself will be maintained.

Plan for Growth and Evolution

The concept of operations is critical in planning for the growth and evolution of the TMC which may result from increases in the physical size of the region for which the TMC is responsible, addition of new capabilities to the TMC's scope (such as adding highway advisory radio to supplement variable message signs), and implementation of new generations of technology. Each of these will impact the operational procedures, and may cause significant changes to the overall operational approach for the TMC. A change in the concept of operations can be the foundation for defining the detailed design for each type of change, providing a basis for ensuring that the technical solutions offered by vendors effectively support the chosen operational direction.

The technical changes being considered may impact many components of the concept of operations. A significant upgrade in the level of automation in the TMC's computer system could result in changes in staffing level, qualifications, training, and documentation, as well as in the skills and resources necessary to maintain such automation. As an example, implementing a computer system which applies advanced technologies, such as object-oriented programming or neural networks, would likely demand additional training or systems personnel.

> The concept of operations can incorporate actions which facilitate evolution of the TMC and its systems. Milwaukee's MONITOR TMC plans for replacement of its information technology equipment on a 3-year basis, and has incorporated this process into its operational and maintenance plans. Essentially, its concept of operations is an ongoing evolution of the information technology tools it uses.

Define the Document Maintenance Method, Responsibility, and Timing

The concept of operations provides input to decisions throughout the TMC's life. Thus, it is essential that it be kept up-to-date so that it can serve as a resource for ongoing operations and planning. In particular, it must remain consistent with the operations and maintenance methods in use. It is a major element in the operational documentation of the TMC. It is appropriate for the concept of operations to be managed under the TMC's formal configuration management program, and for an organizational unit to be responsible for its periodic review and maintenance. This would also include review and revision whenever significant changes are made in the systems or procedures of the TMC.

Applying a Systems Engineering Approach to Developing the Concept of Operations

What is a Systems Engineering Approach?

System engineering involves the application of efforts to:

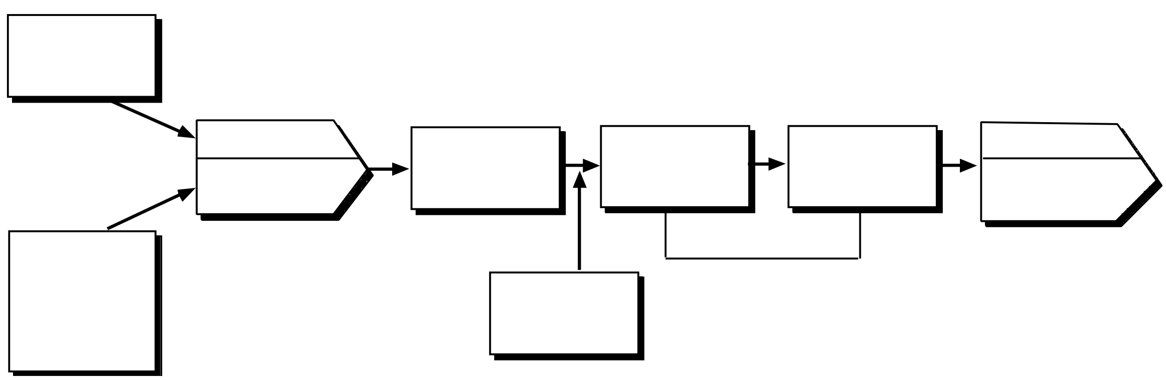
1. Transform an operational need into a description of system performance parameters and a preferred system configuration through the use of an iterative process of functional analysis, synthesis, definition, design, test, and evaluation;
2. Incorporate related technical parameters and assure compatability (sic) of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design; and
3. Integrate performance, producibility, reliability , maintainability, manability, supportability, and other specialties into the overall engineering effort. (2)

"Regardless of the system type and size, one begins with an identified need and a completed feasibility study for the purposes of establishing a set of requirements, constraints, and design criteria. Based on the results, functional analyses and allocations are generated to apportion the appropriate system-level requirements down to the subsystem, unit, and lower levels of the system.

System analyses are accomplished to evaluate the various alternative approaches that are considered feasible in meeting the identified need. The output reflects a preferred system configuration. Inherent in this activity of requirements identification, analysis, and system definition are the feedback provisions…The systems engineering process is continuous, iterative, and incorporates the feedback actions necessary to ensure convergence." (3)

Where Does the Concept of Operations Exist Within the Systems Engineering Approach?

The concept of operations is classically viewed as an element in the feasibility study stage of the system engineering approach. The concept of operations is developed after the mission/vision/goals/objectives have been developed, and after needs and high-level requirements have been identified, but before detailed requirements definition and high level design begins. The concept of operations answers many of the questions which determine feasibility. This is a two-way interaction. The concept of operations should not reflect a cost of operations or implementation which is infeasible; similarly, the first reasonably accurate estimate of these costs will be based on the resource requirements described in the concept of operations. Important considerations in other areas impacting feasibility can be derived from the concept of operations as well, such as the level and types of interaction needed between agencies involved in transportation management, and the systems they apply to perform their duties.



What Inputs are Needed to the Concept of Operations?

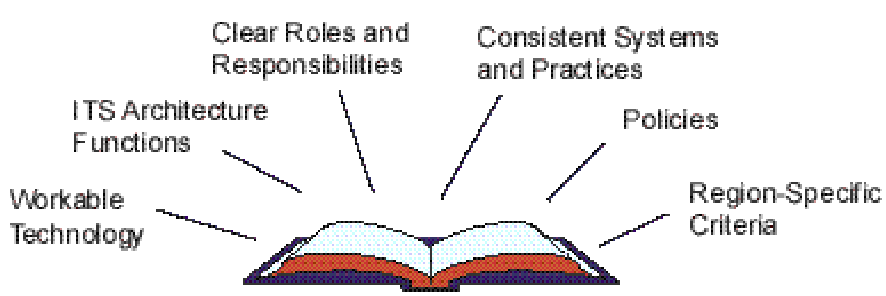
In the following sections, we will present inputs to the concept of operations, and additional efforts which will benefit from the information assembled in the concept of operations.

The Process of Gathering Inputs

The first step in preparing a meaningful concept of operations is to understand the needs as viewed from the parties involved in the relevant area's transportation, and their respective roles, responsibilities, approaches, and plans. This gathering of inputs occurs, at different levels of detail, throughout the transportation planning process, and continues as the program proceeds to design and implementation. The development of a regional or statewide transportation strategy, an ITS strategic plan, or an ITS deployment plan will involve gathering inputs from and building consensus among many agencies responsible for different aspects of transportation management. Thus, these documents and others, such as a telecommunications plan, serve to identify the needs which the TMC must support, the resources which may be available to support them, and the plans or activities of partners with which the TMC must coordinate. These are all important inputs to the concept of operations, laying a foundation for further discussions of the TMC's objectives, resources, and methods.

The process described here works at multiple levels. An example might be the definition of roles and responsibilities, where each agency partner enters the process having accepted a general role in TMC operations (e.g., incident management), but where the output of the concept of operations provides specific details of which agency provides which individuals in the operations (e.g., the state DOT headquarters provides the console operators; the state DOT district provides maintenance; the city provides communications; and the county provides facility support). Thus, roles and responsibilities are both an input (at a general level) and an output (at a more specific level) of the process of developing a concept of operations.

In situations where formal acknowledgement of each organization's roles and responsibilities is appropriate, memoranda of understanding or operational agreements may be prepared. These agreements clearly describe what each organization will provide in the operational context, and thus provide a clear



Inputs Necessary to the Concept of Operations understanding of what can be expected by and of each participant. The agreement will also normally specify the time period during which it is in effect. Such agreements are typically signed by senior officials of the respective organizations, and represent a commitment, much as would a contract, for the organizaion's participation. Many examples exist of such agreements. Readers may want to refer to the agreements developed by the teams participating in the Metropolitan Model Deployment Initiative projects for samples.

Systems And Practices

The systems and practices chosen for the TMC should be consistent with the region's goals, architecture, and the concept of operations. A primary purpose of the concept of operations is to assist in procuring the systems, whose performance will eventually drive workload, skills, and training considerations. Similarly, the concept of operations must reflect the realities of chosen practices.

> At Houston TranStar, the regional transit authority (Houston Metro) is responsible for the operations of the high occupancy vehicle lanes. Establishing practices for incident management which did not involve coordination between the Texas DOT (responsible for interstates), Metro, and the city and county (responsible for respective portions of the signalized road network) would likely result in a sub-optimal solution.

Policies

The TMC's concept of operations must naturally reflect local transportation policies. Such policies might include:

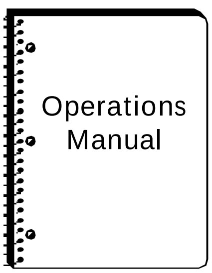
- The hours or extent of lane closures
- The types of data and information which can be released to the public
- How multiple agencies coordinate at an incident site
- At what organizational levels decisions are made
- Whether alternate routes can be suggested to bypass incidents
- The degree of headway or off-schedule variance before signal priority is given to a transit vehicle
- Whether TMC functions are performed by agency staff or contracted, and (if contracted) how they are contracted

Other Regional Impacts to Operations

The concept of operations must recognize and accommodate any other regional criteria that impact operations. This might include:

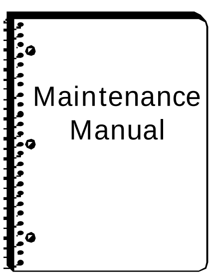
- A program of signal priority for emergency services vehicles through specific corridors
- Priority transit service for designated special event venues
- Allowing express buses to operate on certain portions of roadway shoulders prohibited to all other vehicles during peak periods or for special events
- The concept of operations will have to recognize standard operations and operations under nonstandard conditions, such as special events, irregular traffic patterns (e.g., near gaming facilities), or where severe weather or other emergency conditions are common (e.g., rock slide, snowfall, high water).

How do Outputs from the Concept of Operations Serve as Inputs?



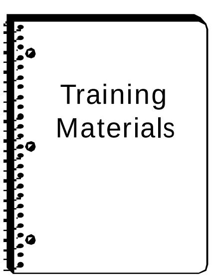
Operations Manual

The concept of operations contains many of the same categories of information found in the operations manual. The operations manual, which defines step-by-step how to perform each of the operator's jobs, also provides specific names and contact numbers for interfaces, where the concept of operations defines generically who should be contacted.



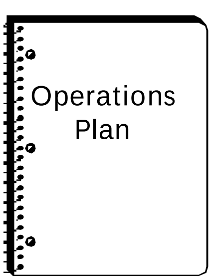
Maintenance Manual

The maintenance manual describes the same functions and methods as does the concept of operations, but in greater detail. It assists in defining the types of tools and test equipment required for maintenance, as well as the logistics concept (location and quantity of spares). Importantly, it outlines the interaction between operations and maintenance in identifying, verifying, fixing, testing, and returning to service any malfunctioning unit.



Training Materials

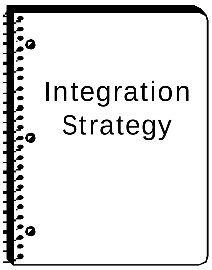
Since the concept of operations defines the functions to be performed, who will perform them, and how they will be performed, it serves as a source of input on the training materials that will be required. Not only does it indicate those functions for which training is required, but it provides basic guidance on the steps to be followed in performing them. In laying out the staff organization, it indicates the level of expertise and education to which the training materials should be targeted. Since it addresses the possibility of multiple systems and system migration over time, it indicates how training materials should be developed so they can be used as retraining is needed. Since it addresses the training program directly, it indicates what courses and/or certifications are needed, at what level(s), and for what types of training (initial, refresher, new concept introduction).



Operations Plan

Outputs from the concept of operations should be useful inputs to and consistent with the operations plan. The following elements are found in an operations plan:

- Preliminary analysis
- Alternative systems analysis
- Procurement and system start-up analysis
- Special features analysis
- Analysis of laws and ordinances
- Implementation plan (previously operations plan)
  - Legislation
  - System design
- Procurement methods
- Construction management procedures
- Operations and maintenance plan
- Institutional arrangements
- Personnel and budget resources



Integration Strategy

The integration strategy is the demonstration of many of the key outputs of the system architecture. The concept of operations can provide inputs to the integration strategy, and should be consistent with it.

Technologies That Match The Goals

The technologies chosen to implement the systems within the TMC's responsibility should match the higher level goals reflected in the region's plans and the concept of operations. If the technologies require resources beyond those considered feasible, then they are unlikely to be used and/or maintained properly. In such a case, they will, at best, provide a poor image of the transportation management agencies, and could potentially create hazardous conditions for the area's travelers.

As an example, if a primary goal is to achieve a high level of integration in the region's transportation management systems, then selection of closed, proprietary solutions would create problems. If the region's agencies desire to rely upon the existing dial-up and leased-line communications network, then solutions which require high bandwidth or consistently high levels of transactions would be inappropriate.

> When it planned to test whether vehicle tracking (using global positioning systems-based automatic vehicle location systems) would improve the productivity and accountability of snow plows, Virginia DOT chose portable units, which could be moved between agency and contract snow plows as required, and which could be moved to other types of maintenance vehicles in the summer, possibly yielding similar benefits.

Roles and Responsibilities

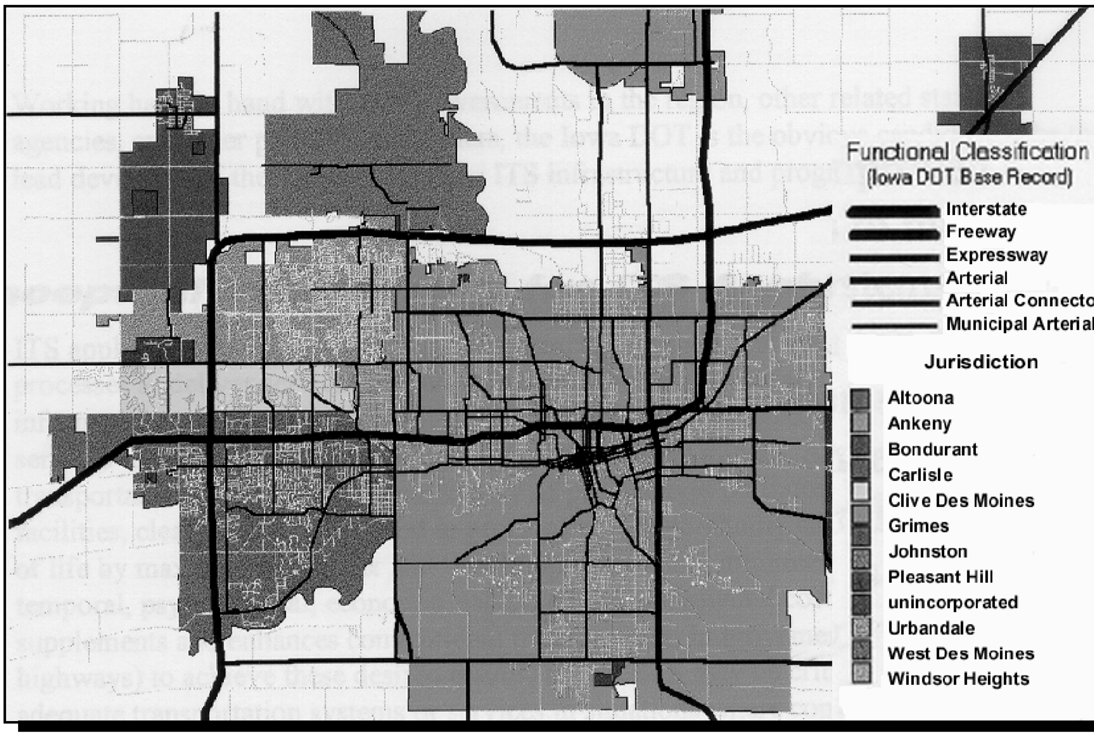
Agencies

The concept of operations defines the roles and responsibilities of both the primary sponsoring agency of the TMC (or the team of agencies, as in Houston TranStar) and of their partners in accomplishing the TMC's mission/vision/goals/objectives. This can include multiple internal and external agencies as well as private sector providers, both those under contract and those with whom noncontractual but cooperative relationships exist. In addition to the roles and responsibilities, the concept of operations defines how the organizations interact, beginning with what situation initiates contact, who performs it and how, what information or request is provided, what the process of response is, how progress is monitored and adjustments made, and how confirmation and/or closure is achieved.

An important element of jurisdictionality is the designation of interagency points of contact. Where the TMC is responsible for a multijurisdictional transportation region, it is particularly important that the appropriate law enforcement and emergency services agencies be contacted when needed.

> In the metro Des Moines, Iowa area, incident investigation responsibility on the area freeways varies depending on the county or township the roadway traverses. Thus, it is critical that the concept of operations reflect the appropriate contact protocol in order for the TMC to initiate this essential service.

Des Moines Area Transportation Jurisdictions



Media

While the role of the media in transportation management is relatively straightforward, the responsibilities should be clearly defined. These may include the timely dissemination of information, the dissemination of specific categories of information, or an agreement not to release inappropriate information. Responsibilities, regarding privacy, timeliness, and completeness of information are equally important to have well documented and understood.

Private Partners

Today's classic private partner relationship is with an information service provider in which the TMC provides raw or refined data to the provider, which is then responsible for making contractual arrangements for its distribution.

> As an example, the Metropolitan Transportation Commission, which is responsible for the San Francisco Bay Area's traveler information program, has implemented a performance-based contract with its information service provider which defines minimum service levels and rewards based on performance exceeding these goals.

Other types of private partners may include:

- Private transit carriers (taxis, limousines)
- Wrecker service
- Private operators of motorist assistance partners

Part 4: Development of a Concept of Operations

Introduction

The concept of operations for a TMC deals with a wide array of topics relating to the operations and maintenance of the TMC and its systems. In this part the primary subheadings in the concept of operations will be presented, along with considerations for the issues to be addressed for each, and examples from existing TMCs. The primary subheadings are:

- The systems
- Operational facility needs
- Integration and testing
- Coordination
- Performing or procuring operations and maintenance
- Training and documentation
- Operational procurement and contracting

Each subheading will address up to three additional levels of subtopics.

Level of Detail in the Concept of Operations

The concept of operations contains a modest level of detail for each topic. The discussion of each topic should be adequate to clearly identify:

- Each of the functions to be performed within the TMC
- Roles and responsibilities of the participating agencies
- The number of staff and their areas of responsibility
- The systems, tools, training, facilities, documents, and other equipment necessary for the staff to perform their duties
- The processes the staff will follow in performance of their duties, including interactions between the staff and between staff and external organizations

As an example, consider the situation where the TMC has detected a security breach at a transit station.

The following is an example of too little detail:

The intrusion is investigated by operations.

The appropriate level of detail would be:

The operator responsible for this station and this function will investigate the intrusion with the station video surveillance system and will contact the station manager by radio or telephone, involving the transit police and the TMC superintendent if the situation warrants.

An example of too much detail would be:

Operator position 4 initiates video surveillance by activating the following series of commands or screens… The operator cancels the intrusion alarm by mouse clicking on the flashing button on system screen 42…The operator contacts the station manager on radio channel 12, states the following information…and asks for the following information…The operator logs the intrusion in the system on screen option 5, including the following information…

This level of detail is appropriate and necessary in the operations manual, but is more than what is required for the purposes of a concept of operations.

The Systems

Performance Requirements

Capacities

A primary performance parameter which the concept of operations must consider is the demand for its services. The capacities which the TMC systems must support should be stated or outlined. Primary demands, such as the number of freeway incidents per day, the number of metered ramps, the number of signalized intersections, or the number of transit vehicles and vehicle routes, become determining factors when acquiring the support systems and when planning for the operations and systems space in the TMC. Related factors, such as the number of centerline miles of freeway under management, may also be relevant, but it is often the activity workload (number of transactions) which is most critical.

The concept of operations should include the breakdown of the capacity. For a freeway management center, this may be measured in quantities such as the number of incidents actively managed, the number of incidents detected but not requiring management, or the number of incidents reported but not confirmed. The concept of operations may also include comparative data, such as the number of vehicles actively tracked by and in communication with a single operator, comparing the plan with similar centers.

Centerline Miles	
Boston	7.5
Toronto	60
Long Island	165
Detroit	180
Milwaukee	63
Atlanta	220
Phoenix	254
Houston	122

Fixed Route Vehicles	
Milwaukee County Transit System	535
Ann Arbor Transportation Authority	82
King County Department of Transportation	1,343
Tri-County Metro. Trans. Dist.	659
Montgomery County Trans. Authority	99
Regional Transportation District	800

The concept of operation should also address how the system is operated in conditions where workload exceeds capacity. Assuming the TMC's systems remain operationally stable, typical approaches would include first-in-first-addressed or some form of triage based on identified factors such as incident severity.

Response Time

Response time is decomposed into multiple components within the concept of operations. The highest level component is the overall response time to a situation, i.e., how long it takes to get the correct resources to the scene of a freeway incident. Individual response time components typically include time to: detect, verify, and implement a response. The response itself may include development and implementation of a response plan, creation and activation of individual response components such as variable message sign messages, time to dispatch response personnel, for those personnel to reach the scene, and for them to assess the scene and implement site management elements such as cones, flares, and arrow boards.

Incidents may be subdivided into categories in order to make the answer more meaningful, separating injury incidents from those without injuries, and incidents requiring HAZMAT intervention from those not requiring these special resources. Once an overall response time goal is established (such as the 3 minute response time goal at the Boston Central Artery Tunnel's Integrated Project Control System), then the response time components can be further subdivided.

> In San Antonio's TransGuide system, for example, TMC response was further divided into a goal of 15 seconds from incident occurrence until it was automatically detected and an alarm sounded at the TMC, and two additional minutes until a workable initial solution scenario had been implemented by the operator.

> The city of Lexington, KY, strives to enact a corrective action within an hour after receipt of a traffic signal malfunctioning notification. This includes allocating 30 minutes for responding and 30 minutes for identifying and executing a corrective action.

Once such response goals are set, these goals can be applied further within the communications and computer system specifications to ensure that such functions as message transmission, screen refresh, and data retrieval support the more summary level goals. This can be a step in functional decomposition, the process of breaking each major process into its subcomponents and measuring each, which is a key element in the overall systems engineering process. Again, at this level, response goals and performance can be compared to benchmarks from other systems to assess realism. If questions exist regarding whether certain aggressive goals can be achieved, system prototyping may provide a reasonable indication of what can be realistically expected.

> The Southern California Priority Corridor ITS Showcase has used prototyping and prototype testing extensively in its implementation of object-oriented technology in types of transportation applications in which it has not previously been applied.

System Reliability	Down time per year (rounded up)
99.9%	9 hours (530 minutes)
99.99%	1 hour (53 minutes)
99.999%	5 minutes

Reliability

As with the other performance parameters, the concept of operations must set or respond to levels of reliability and availability which are operationally (and politically) acceptable and achievable. As with response time, the concept of operations may begin with overall system reliability, which can then be progressively broken down into its constituent components. Unlike response time, however, reliability of successive units generally are multiplied by one another, rather than being summed, as response times would be. There are a number of techniques for professional analysis of system and subsystem reliability, and for assessing the impact of failures (such as failure mode effects analysis). Readers are referred to quality systems engineering texts, to experienced systems engineering firms, or to the systems engineering department at a quality academic institution for details of performing reliability analysis and incorporating the results into the concept of operations.

Functions Performed/Provided

The most critical element of the concept of operations is that it properly describe the functions performed or provided by the TMC. This functional description (also a component of the system engineering process) provides the foundation on which all physical, operational, and systems parameters and performance will be based. Typically, the process of defining the functions is also performed in a top-down method, beginning with the most general (incident management, traffic signal operation, fleet management), and continuing to break each down into further components.

Steps in Incident Management

- Incident Detection
- Incident Verification
- Incident Response
  - Dispatch of response resources
  - Notification of Appropriate agencies
  - Provision of traveler information
- Incident Clearance
- Recovery
- Incident Site Management
- Traffic Management

Incident Management Successful Practices, FHWA, 1999

At some point in the process, the responsible organization (or organizational unit) must be defined for each function, and the resources necessary to perform each process should be identified.

Initial Concept of Operations

The concept of operations contains many components which impact the systems used to achieve the TMC's functions. The concept begins by determining the level of automation necessary for the operators to perform their duties. There is typically a direct correlation between the degree of automation, and the amounts of computing and communications equipment, and the communications network (layout, interconnection, and bandwidth) which are required. In related areas, the interconnection of the internal network(s) with the external network(s) will need to be considered, as will specific power and heating/ventilation/air conditioning requirements. Facilities must also be provided for systems administration and network management personnel and assets.

Initial Development of Requirements Documents

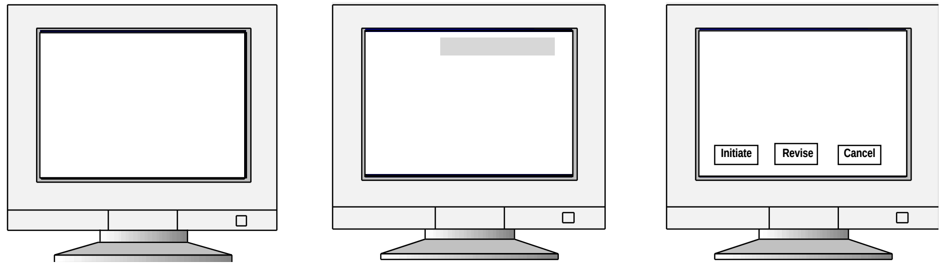
The initial systems requirements documents are typically developed based upon the user services identified in the regional ITS system architecture. They are expressed using the operational techniques that reflect the constraints and preferences of the relevant participants. Using the system architecture, requirements can be detailed down to a data flow level, and data elements can be identified using the relevant data dictionary standards. This level of detail is typically inappropriate in initial requirements documents, which should focus on functions that the systems perform.

Level and Type of Automation

Some of the most critical decisions in the concept of operations are the level and type of automation provided to the operations staff to perform their functions. As in any process and information driven system, the degree of effective automation governs the number, workload and qualifications of the staff, and thus determines the volume of transactions which they can reliably support. Furthermore, the degree of automation greatly influences the quality and/or consistency of the actions by the staff under both recurring and non-recurring conditions.

It may be appropriate to review the types of automation applicable to the TMC's processes at this point. Certain constraints may be introduced if pre-existing technology selections have been made, e.g., vehicle speed can only be estimated from single loops; double loops or other technologies are necessary for true speed measurement.

Using incident management as an example, several key automation decisions are critical to the TMC's success. Although incident detection by observation of scrolling video images has been used in some locations historically, most systems



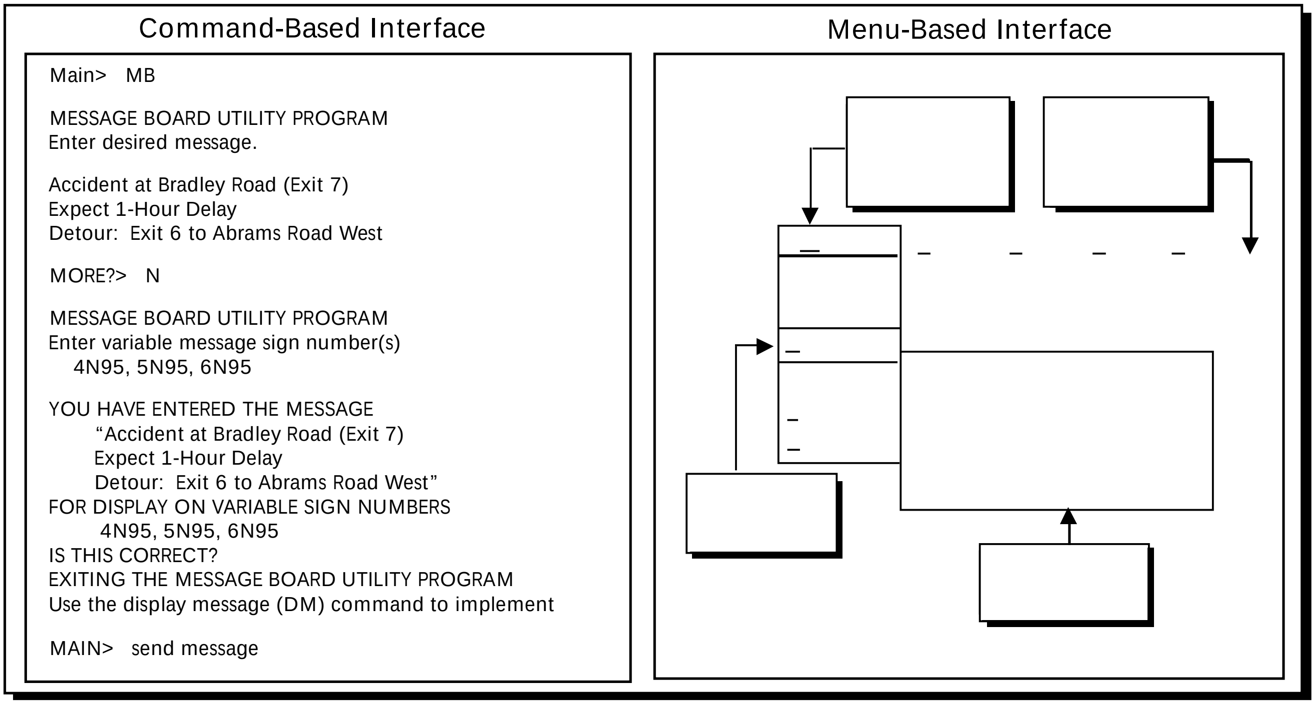
now apply some form of flow monitoring and incident detection algorithm or information gathered from E911 calls to automatically report suspected incidents or recurring congestion to operators. Once an incident is confirmed (again, the selection and preliminary aiming of the camera may be automated or performed manually), then the development of an incident resolution scenario can be performed with various levels of automation. This may range from a totally manual approach of selecting various devices (variable message signs, lane control signals, ramp meters) and then manually creating and transmitting messages or commands to each, through selection of messages from a library of prepared messages, to selection of a coordinated set of messages and commands from a database. Alternately, it may be based on an incident "template," substituting the names of the actual incident site locations into slots in the template. Although various claims have been put forward, there has thus far not been a truly "expert system" or other artificial intelligence solution demonstrated for incident scenario preparation, although theoretically such a system would be possible.

In Toronto's COMPASS TMC, the system automatically calculates travel times for both express and local routes, and places travel time messages on the blank variable message signs.

In San Antonio's TransGuide TMC, the system automatically recommends tailored incident solution "scenarios", providing specific variable message sign messages by sign and location, as well as other actions which can mitigate incidents and congestion.

ATSAC Center, in the City of Los Angeles, relies on the traffic response feature for planned events minimizing the need for operator intervention. Optimum timing strategies are developed and made available to the system representative of various event sizes—light, heavy, and no event. However, the management of heavy events still requires operator intervention to identify optimum response plans and duration—before, during and after the event. The events are managed based on a traffic management plan that identifies routes and associated restricted/blocked movements.

Other activities to be addressed in decisions on the degree of automation include such things as the degree of automatic logging of information and actions by the system, and the amount of information manually added to the incident log based upon operator observation.



Human Factors Handbook for Advanced Traffic Management Center Design, FHWA, 1999

Human Factors of User Interfaces

The human factors decisions reflected in the concept of operations will have significant impact upon the facility, the staffing, and the systems components of the TMC. Key decisions, such as the use of voice recognition technology, placement of video in windows on the workstation, or use of handsets or headsets for radio and telephone communications can have major impacts on the effectiveness of the working environment, and on the cost and time to implement the system. Classic decisions in computer user interfaces, such as the extent of use of pull-down menus, pop-up windows, and command line interfaces will be required, often on a subfunction-by-subfunction basis. Considerations such as the level of experience and knowledge of the operations personnel and the degree of training provided to them must be considered in order for the human factors decisions to be consistent with the remainder of the concept of operations. More subtle decisions, such as the use of noise reduction technologies in the control room, lighting, the color patterns of computer screens, the order of progression between fields on a screen, the breakdown of mandatory and optional fields on data entry screens, and the number of screen levels necessary to reach often-used functions, can become critical to the pace of decision making and implementation, particularly in crisis operation.

In the Washington, D.C. WMATA train control system, the screen presents an image which visually depicts the rail line under the operator's control. Major items such as stations are represented along the tracks. Each item is an icon, further detail for which can be obtained by clicking on the item. At the lowest level of detail, clicking on an item provides textual information about the item, including both static and real time status.

Every action impacts the time and effort required by the operator to perform a function and the quality and consistency of that performance. Human factors decisions are major determinants of the resources necessary to carry out the functions established for the concept of operations, and in how the concept of operations describes the way the functions are carried out.

Interested readers are referred to the advanced traffic management systems human factors guide prepared by Georgia Tech Research Institute for FHWA (see References section) for more details in the area of human factors.

Control Architecture

Device Access by Agencies

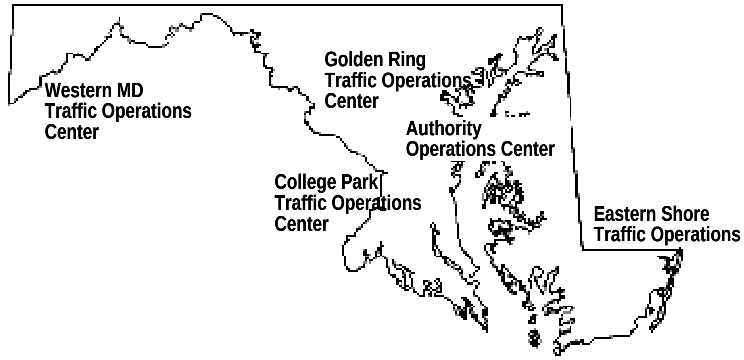
The concept of operations reflects several elements of control architecture and how they are carried out. A primary level of control architecture is not only what agency is responsible for each action, but also how agencies share access to common resources, and what agencies can perform critical actions under nonstandard circumstances (such as emergency operations or shortage of essential staff).

Traditional jurisdictional lines of authority have for some time complicated decisions on sharing access to transportation management resources. In many cases, for example, the city along whose highways variable message signs were positioned, could not access them since the operational responsibility and capital ownership rested with the relevant state agency. A similar and common complication was that an agency managing one roadway would be unable to view video images from cameras placed by another agency on nearby alternate routes, thus denying both agencies a full understanding of the situation.

Technological barriers have also driven some multiagency concepts of operations to reduced efficiency, due to incompatibility of software, data transmission protocols, or video images. With the progress toward completion of ITS standards, and increased application of efficient commercial standards, many of these barriers can be overcome.

> The concept of operations for freeway management in Maryland includes a Statewide Operations Center and regional “satellite” centers. The satellite centers are located at Maryland State Patrol barracks around the state. These centers perform local traffic management during one or two shifts per day, with control reverting to the Statewide center when the satellite center is offline. The Statewide center also assumes control if a satellite center goes offline because of a weather-related or other local emergency

Several TMCs have developed very mutually beneficial concepts of operations for late evening shifts. Typically, workloads decrease during late night periods, and full staffing of each position by its responsible agency would be wasteful. Thus, often agencies will pool resources, leaving fewer operators responsible for the full range of operations during these low activity periods.



System Security Levels

A variety of system security approaches are found in TMC concepts of operations. These include complex multilevel approaches where each individual is identified to one or more levels within a series of security tiers. Typically each tier has defined privileges and priorities in access to system devices and functions, which also defines explicitly to which systems he/she has access and over which functions he/she has control. Each individual may also have a customized user configuration. The user configuration may include elements of the operator's human factors preferences such as degrees of loudness of system alarms or color, position, and brightness of system messages and alarms.

Much simpler schemes include those where a common system identification and password exist (typically controlled by a supervisor), which is used by all operations (and often other) staff. Typically, systems personnel and consultants (such as those performing system administration, testing, or development) are provided other identifications and passwords, so that these individuals cannot inadvertently implement transportation management measures which could create a hazard or a misleading impression for the public or the agency's vehicle operators.

In almost all systems, system administration functions (such as database management and access to the server or network operating system) are limited to systems personnel, and are accessed separately from the primary operational applications. These functions typically require their own identifications and passwords, and may (as they are typically commercial off-the-shelf products) may require multiple levels of security before access is achieved. It is important for the concept of operations to recognize that these functions must also be performed, for the necessary resources to be identified and understood, and for their performance to be included in the overall concept. Failure to perform these functions can result in significant system performance degradation, often demonstrated in unexpected, unpredictable, and inexplicable system behavior.

Although less of a factor, it is also worth considering the type and levels of security necessary for remote access into the key system(s). It is almost a certainty that key personnel will need access to the system from a remote location at some point in time. Almost all systems provide some form of dial-in access, even if it uses a simpler user interface in recognition of the bandwidth demands of a fully graphic user interface. Since the dial-in capability represents a potential weak point in the total security program, careful planning, and perhaps consultation with a security expert, is warranted. Conversely, creating such a burdensome security program that dial-in access is tediously slow and failure prone defeats the purpose of having established the function.

Dividing Responsibility Between Staff

The concept of operations must clearly identify the staff position or positions responsible for each of the functions it defines, as well as the interactions between the staff during their activity. This interaction would consist of:

- Sharing information that might be useful
- Transferring responsibilities from one individual to another
- Requesting information or action of another individual
- Developing consensus on a joint response
- Requesting authorization or some other form of decision for an action

The division of responsibility between staff members may reflect several philosophies of division of effort:

- By function (e.g., operator A responsible for ramp metering or for motorist assistance patrol coordination)
- By level of responsibility (e.g., lead operator or shift supervisor)
- By geography (e.g., operator A responsible for northwest quadrant of the region or for I-17)

Function

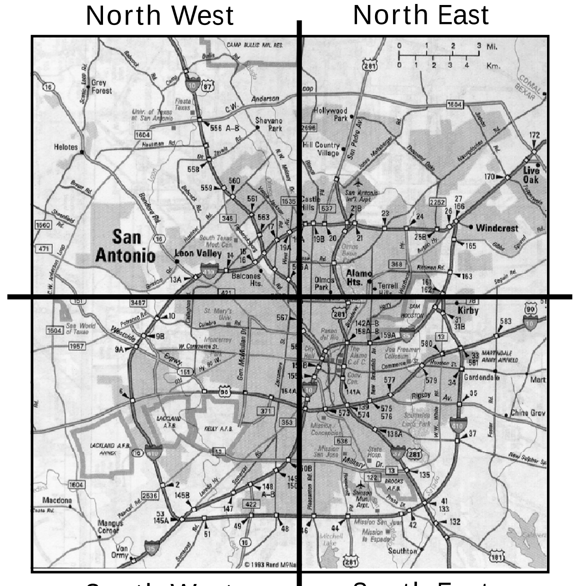
- Safety Service Patrol Coordinator
- Ramp Meter Controller
- Traffic Signal Controller
- Lane Closure Controller
- Travel Advisory Telephone Response

Level of Responsibility

- Lead Operator
- Shift Operator
- Senior Operator
- Operator

Geography

North West | North East



South West | South East

In research of North American TMCs, these are the functional divisions most commonly identified in freeway, traffic signal, and transit management centers. Each philosophy requires explicit identification of the method of coordination for each of the interactions listed at the beginning of this section.

In San Antonio's TransGuide TMC, responsibilities are divided between operators geographically, with each operator managing all functions within a sector of the total roadway network. In Houston's TranStar center, incident management operators divide incidents as they arrive, balancing workload. Management of ramp metering is performed by a separate operator, as is management of the adjacent high occupancy vehicle lanes, which are the responsibility of another agency. Both approaches (geographic, functional) are effective, and can be used to equitably balance workload.

Communications Architectures

The concept of operations may also need to reflect the capabilities or constraints of the communications architecture. The most common limitation is on message length or periodicity of transmission (i.e., a device that is polled only every half hour). This architecture may create situations where control of a device or information about a device is not immediately available, or where the device is found to have gone out of service since its status was last verified and reported. The concept of operations must indicate what actions are to be taken in such situations.

Similarly, the concept of operations must reflect the activities, effort, and time necessary to access devices that are communicated with only on an as-needed basis (i.e., dial-up, cellular dial-up, or cellular digital packet data) basis, and must also indicate what actions are to be taken if the device is inaccessible. The most often cited case of this situation is of portable variable message signs with cellular access, which may become inaccessible when an incident occurs in the cells surrounding the sign (which become saturated by motorists on their own cellular phones).

Devices in the System and Their (Inter)Operation

Field Devices

The most common difference in concepts of operations in TMCs around North America is how they address common functions with differing field devices. Not only must the concept of operations identify the functions to be performed in support of each device, but it must also explain how each device is used as a tool in performing the higher level functions (such as incident management).

Field Device Examples

- The TMC in Chicago, which for many years had no video access, developed alternate methods for incident verification such as radio reports from DOT personnel reaching the incident scene.
- TRANSCOM, owning no assets, developed incident management strategies based on requesting support from its member agencies, who would in turn use their own assets in the incident area.
- The San Francisco Bay Area, which has had limited detectorization on its area interstates, has developed a variety of alternate methods for incident detection.
- The TransGuide system implemented video cameras with unusually high (48:1) magnification in order to be able to acquire additional information about each incident, thus being able to dispatch additional resources (such as HAZMAT and emergency medical services) immediately upon incident verification.

Similarly, unique local problems with transportation resources have required creation of unusual operational procedures.

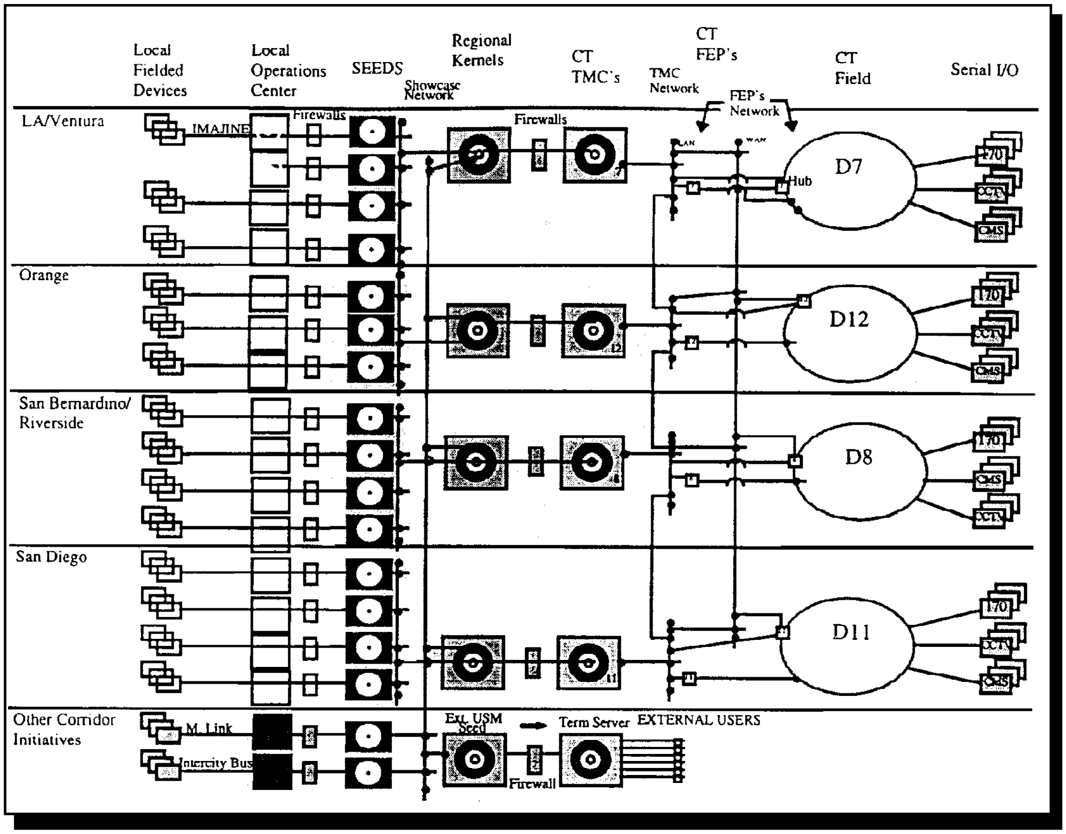
Houston, after experiencing two fatalities within a few weeks from individuals entering its reversible high occupancy vehicle lanes against the gates, not only implemented full manual verification of lane status between closing entry from one direction and opening for entry from the other, but also began stationing law enforcement officers in vehicles at the closed entrances.

Computer and Communications Design (Local Area Networks and Wide Area Networks)

The primary aspect of the computer and communications design which impacts the concept of operations is the degree of integration of data and control of applications resident on different computers. The impact of nonintegrated applications is typically a requirement for duplicate entry, or physical movement by the operator to separate workstations in order to complete the required functions. This was especially common in early implementation TMCs, where vendors provided stand-alone, proprietary TMC control computers for their field equipment.

A common situation requiring a concept of operations that recognizes multiple procedures due to lack of integration across platforms is in TMCs which host aging legacy systems as well as newer, more modern system expansions. Often the legacy system is expensive and difficult to port to a new platform, since in many cases the software source may be unavailable, it may use protocols which are unavailable for more modern platforms, or the system may be in a language which would require extensive modification (including operating system calls) in order to migrate it. Thus, the agency faces the challenge of operating essentially two separate systems in the same control room.

Southern California ITS Showcase High-Level Communications Architecture



Legend:

CT	Caltrans	D 11	District 11	LAN	Local area network
D 7	District 7	FEP	Front end processor	WAN	Wide area network
D 8	District 8	M. Link	Modal link		

Source: Southern California Priority Corridor Intermodal Transportation Management and Information System (Showcasee) Scoping and Design - Final Implementation Plan (3/97)

An example of this challenge is the Michigan ITS Center, which hosts a legacy freeway management system (dating to the early 1960's) on 32 centerline miles of the M10 Lodge Freeway, and is implementing a modern system on 150 centerline miles of regional roadways. A similar situation can exist as a transit property transitions from a legacy vehicle location system, such as a signpost system, to newer technology, such as the global positioning system.

The situation of multiple, non-integrated computers is still not unusual in smaller urban areas, where the expense of implementing and maintaining a comprehensive system would be difficult to justify. It is also a challenge where integration is desired across modes (i.e., feeding automatic vehicle location data from transit probes to a freeway management system, or closely integrating multiple closed loop (often highly proprietary) signal systems with one another or with an adjacent freeway management system.

Operational Facility Needs

There are many elements that must be considered in the concept of operations that act as factors in the selection of facility location, layout, and size. It would be difficult to determine an "ideal" amount of floor space based only on the area of coverage of or the functions performed in the TMC.

As seen in the table below, square feet and number of operators vary widely, based upon many elements in each TMC's concept of operations, including the variety of organizations (and elements of each organization) housed in the TMC, the diversity of functions performed by the agencies, the type and level of automation used by the staff, and the level of public visibility chosen by the TMC.

TMC Participants

	Boston	Toronto	Long Island	Detroit	Milwaukee	Atlanta	Phoenix	Houston
Functions in Control Room	Traffic Operations, Tunnel Control	Traffic Operations, Vehicle Information	Traffic Operations, MAP, Traveler Information	Traffic Operations, MAP	Traffic Operations	Traffic Operations, MAP, Traveler Information, Broadcast	Traffic Operations, Incident Teams, Broadcast	Traffic Operations, Transit Dispatch, Law Enforcement, MAP, Broadcast
Other Functions in TMC	Various (Major Office Building)	Planning, Design, Training, Maintenance, Various (Agency Office Building)	N/A (State Office Building)	Design	Planning, Design, Inspection, Outreach	Planning, Design, Training, Senior Management, HOV & CVO Enforcement, Outreach	Design, Analysis	Projects, Design, Special Events, Emergency Operations, Outreach
Agencies in TMC	MHD, MassPike	MTO	NYSDOT, Contractor	MDOT, Mich. State Patrol	WisDOT	GDOT (Multiple Functions)	ADOT, Arizona State Patrol	TxDOT, Metro Transit, City, County
Approx. TMC Area	5000 sq. ft.	2500 sq. ft.	3000 sq. ft.	14,000 sq. ft.	6500 sq. ft.	73500 sq. ft.	18000 sq. ft.	54000 sq. ft.
Control Room Size	2400 sq. ft.	1800 sq. ft.	625 sq. ft.	3,600 sq. ft.	600 sq. ft.	1300 sq. ft.	2400 sq. ft.	3600 sq. ft.
Number of Operator Positions	10	9	5	6	3	12	6	18

SCADA—System Control and Data Acquisition
HOV—High Occupancy Vehicle
MHD—Massachusetts Highway Department
CVO—Commercial Vehicle Operations
MAP—Motorist Assistance Patrol
MTO—Ministry of Transportation, Ontario

Source: Metropolitan Transportation Center Concepts of Operations Cross-Cutting Study, FHWA (9/99)

Lessons Learned

Several lessons have been observed in studies of TMCs in the U.S. and Canada:

- Location Relatively central location seems to be better than sites remote from the area of responsibility. If, however, this places the TMC in an area at risk for conditions that would complicate operations (i.e., adjacent to a facility which might cause fire, explosion, or HAZMAT conditions which would require evacuation of the TMC, or at a location where road access is hampered by recurring congestion), then alternate locations should be considered.
- Road Access Convenient access to the primary road network is important. This increases in importance if the TMC also hosts maintenance facilities, or if the motorist assistance patrol or other fleet function is garaged at the TMC. The route of access is also important, particularly if clearances or turn radii are limited.
- Parking Adequate parking is also important. Most TMCs also serve as locations for multiagency coordination (lots of meetings), requiring parking for visitors from other facilities. Parking is also important if the TMC is a main component of the image program of the transportation management agencies, which regularly would bring many visitors to the facility.
- Older Buildings If the TMC is hosted in an older building, then the age and capability of the wiring and other building infrastructure (including load bearing capacity) must be carefully evaluated.
- Existing Utilities There may also be reason to consider the history of the facility if it has had previous uses. Pre-existing facilities such as communications conduit and closets, duplicate power grid connections, or preparation for service as an emergency shelter can be valuable assets. In contrast, if areas of the facility present conditions which may be hazardous due to emissions or electromagnetic and radio frequency interference, then alternate locations may be appropriate.
- Security The security of the site and of the facility is important to the staff, and can be critical to operational stability in times of emergency operation. Security is likely to be a major consideration if law enforcement agencies are onsite, due to the presence of weapons and the sensitivity of the information in their computer and communications systems.
- Media Access There are multiple approaches to providing either onsite or offsite media access, almost all requiring cabling arrangements to support transmission of video and computer images.
- Support Proximity Proximity to other agency facilities is particularly important if a key support function (such as equipment maintenance) is provided from that facility, if there is constant face to face interaction with persons from that facility, or if key decision making authority is held there.

Needs or Desires Identified

The concept of operations specifies criteria needed for design of the TMC facility. The two primary components are the total space required, and the layout of the facility.

Required space is driven by the functions which are performed in the TMC, which are specified in the concept of operations. The concept of operations should identify not only essential functions, but also those which participating agencies desire to have in the TMC if space and other resources allow, either immediately or later. This may also include expansion of baseline functions from 2 to 3 shifts, or from fixed route transit to include on-call transit services.

Benchmarks based upon other TMCs in the U.S. and Canada are available for comparison, in determining the relevant square footage for each function, also based upon how it will be performed (see FHWA's TMC Concept of Operations Cross Cutting Study). The number and arrangement of operators in the control room, and the types of computer resources and display systems should be compared in order to determine if models with larger amounts of space per operator (such as the Boston IPCS) or smaller amounts (such as Milwaukee MONITOR) are an appropriate basis for estimation. Similarly, benchmark facilities will provide relevant figures for the support areas, such as computer and communications rooms, projection areas for video display systems, laboratory and maintenance areas, visitor areas, and planning areas.

Facility layout considers not only what functions are performed, but how they are performed; these are the natural components of the concept of operations. The concept of operations identifies common interactions within the TMC. Thus, the concept of operations is a useful tool in plotting the patterns of motion or communication within the facility. By recognizing these patterns while developing the facility layout, movement of personnel and assets can be optimized, appropriate security maintained, and noise and motion disturbance minimized.

The converse of this situation also applies; the concept of operations can be driven by the space available. If available space is fixed, then a concept which is compatible with this space must be developed. If limited operator space is available, then the concept must reflect the increased automation which will allow the operators to manage larger bases of assets. If consolidated space is not available, then the concept must reflect a method of operation in which key personnel can interact via voice, data, video, and image transmission.

Plans or Capability for Expansion

In planning the required space, the concept of operations for current operations must be considered, while allowing for foreseeable expansion. In many cases facilities have found that, once operational, additional partners who previously had been hesitant were eager to move into the facility. In many cases, presence of these additional agencies will support significant progress in integrating transportation management processes and resources. Each may require not only office and console space, but possibly additional communications, power, heating/ventilation/air conditioning, and other facility resources. These agencies may also be attracted by the benefits that the enhanced safety and security of the facility would provide to their operations.

Other growth factors to consider include the possible addition of new functions (such as a traveler information center or emergency management center) to existing functions; that the eventual transportation network under the TMC's management will eventually become much larger; that the TMC's scope may be expanded (from metropolitan to regional or statewide), and that the existing approach to a function may be altered in a manner requiring more space (moving broadcasters into the center instead of transmitting data to an offsite location from which broadcasting occurs). Other less traditional partners, such as academic institutions, may become interested in workspace in the TMC, in order to have easy proximity to the data and video which are easily and inexpensively accessible there.

Special Accommodations

Maintenance Needs

The concept of operations may reflect a broad range of maintenance functions within the TMC, or alternatively, how the TMC interacts with the remote maintenance facilities and personnel. In either case, the concept may serve as a resource to identify unique communications, electrical, vehicle (garage), dock, ventilation, security, and storage requirements supporting the maintenance portion of the concept of operations. In order to effectively test new equipment, new or potential models of equipment, modified equipment, malfunctioning equipment, or repaired equipment, maintenance will often require special power (possibly DC, or voltages such as 220, 40, 12, and 5 volts) which are not standard to most buildings. Access to the voice, video, and data streams in the TMC may be necessary to verify proper equipment operation, or to diagnose problems with equipment either in the laboratory, or in the field.

The process through which Maintenance identifies or is notified of malfunctions, how diagnosis takes place, how equipment is removed from operation, tested, repaired, and replaced, and how Operations continues its functions under conditions of malfunction or loss of devices, and how Operations may support Maintenance in testing of replacement equipment, should all be reflected in the concept of operations.

> The City of Los Angeles ATSAC Center system polls all field devices once per second. This enables the system operator to automatically detect operational failures (flashing traffic signals, communications failure, etc.) on a second-by-second basis. ATSAC operator typically notifies the City's Maintenance Yard within one minute after receipt of automated notification.

Personnel Needs

The concept of operations may reflect a relatively spartan existence for TMC personnel and simple single or dual shift operation, or instead may reflect capability for around-the-clock operation. The latter is almost always the case when the facility is used under emergency conditions, particularly where weather may restrict the ability of personnel to depart safely, or of new personnel to arrive reliably. In these conditions, the concept may identify time (on or off duty) for the use of fitness facilities, along with the showers, and locker room which would be suitable. The latter may also be included if the maintenance portion of the concept reflects personnel working under conditions of duress, i.e., high heat and humidity, or where conditions are contaminated with soil or other materials.

Overnight facilities are typically only included if it is anticipated that personnel will be held over under emergency conditions.

Other Functions Within the Facility

A consistent finding in research on TMCs is that there is a measurable benefit from the interaction of personnel involved in the full range of life cycle stages, i.e., planning, design, construction, operations, and maintenance. The sharing of information between these personnel typically results in implementation of superior systems, and in higher reliability and functionality of existing systems. Thus, by identifying the regular interaction between these groups, the concept of operations can alert the facility designer to the need for the groups to be located in reasonable proximity to one another, to allow adequate parking if they are not co-located, and to provide adequate meeting and team working spaces for their interactions.

> A similar benefit occurs when personnel assigned to one function are able to participate in others. The Milwaukee MONITOR freeway management center offers several good examples. At MONITOR, maintenance personnel perform system startup, which is typically an operations function. Operations and design personnel were participating in construction inspection, and an operator was leading the MONITOR outreach program. Similarly, in Long Island's INFORM program, maintenance personnel routinely participate in system testing and approval.
>
> Related benefits can be derived from adjacency of support departments such as information technology, planning, outreach, and training as found at Georgia NaviGAtor, Milwaukee MONITOR, and Toronto's COMPASS.

Integration and Testing

Introduction

Every TMC undergoes a constant process of change. This may include growth of systems, evolution of technology, improvements in procedures, or changes brought about by external influences such as opening of a new interchange or an agency change in hiring policy. The results of these changes impact the concept of operations. The concept also needs to incorporate the process of executing the predictable. This portion of the concept of operations addresses the testing and implementation of systems changes.

Here we have divided testing into two phases for simplicity, system testing, and acceptance testing.

System Testing

System testing is defined here as the testing which takes place before final acceptance testing is attempted. Thus, it incorporates all stages of testing up until a completed change is submitted for acceptance testing.

Test Points

> **Common Levels of Testing**
>
> Component
> Subsystem
> System
> Acceptance

The concept of operations needs to recognize that testing takes place at multiple times during the TMC's lifetime. This includes the initial testing of the new system, testing after upgrades of the commercially provided software, and testing as new functionality is added. During implementation, testing may also occur at multiple points, including at the manufacturer's site, at the subassembly level, and at the assembly level. Both cost and time required increase as the number of test points is increased, although assurance of proper system functionality increases as well. A logical and balanced plan for testing is required in order to minimize cost and time for repetitive testing, while also minimizing expensive and time consuming debugging of fully assembled systems.

Duration

The concept of operations needs to recognize and address the length of time necessary for satisfactory system testing. This is driven by two perspectives. First, the TMC's operational capability may be reduced during testing, both by diversion of staff resources to performing the testing, and by loss of functional reliability of the existing system while testing is underway. Because of this, the concept of operations must address how the TMC's mission is accomplished in such times of reduced capability.

Conversely, the concept of operations is also a resource through which the necessary duration of testing can be assessed. As the single document which best describes the operations of the facility and its systems, it is an outstanding source for information to determine the length of system testing period which will provide assurance that the implementation process is ready to proceed to its next stage.

> At ATSAC, new hardware, devices, and software are typically tested on the simulator. The length of test depends on the nature of change that is being introduced. It could vary from one hour to many months or even years. If many software bugs are detected, the test may be prolonged. If a new device is added, it is tested at the component level and hub level, and TOC (server) level. Contractors generally do the installations of new devices. These devices are tested at various levels, including bench and component (installed), prior to terminating associated cables to the hub. The TOC tests at the server level to ensure overall operations and performance. The acceptance criteria are specified in the specifications in the form of required features, functions, and performance characteristics. Test procedures are developed based on the specified features and functions and used to conduct acceptance tests.

System Testing Results

There are several other key testing criteria which the concept of operations should address, because they impact the resources available to execute its primary mission, and because the operations and maintenance staff are highly valuable resources in assuring that the testing is performed in a way that guarantees the most meaningful results. Among the items to be addressed in the concept of operations are:

- By whom will the testing be performed
- By whom will the testing be witnessed
- Under what conditions will the tests be executed
- What constitutes successful test completion
- How results are documented

Defining Acceptance Criteria

In the same way that the concept of operations is an effective resource in determining the length of testing necessary to ensure meaningful results, it is also an important resource in defining the performance levels and outputs which constitute acceptable acceptance test completion.

Many situations may occur which interfere with orderly completion of testing. During testing of an advanced traffic management system, for example, often minor bugs are uncovered in the software which do not indicate a complete failure of the system, and which should typically not require a complete restart of the testing cycle. Similarly, equipment failure due to damage beyond the control of the contractor and agency (i.e., motorist or weather induced failure) can have a similar effect. A set of logical procedures for identifying the malfunction, repairing it if appropriate, and resuming testing at an appropriate stage is necessary if the testing is to accomplish its primary mission, assurance of an acceptably functioning system.

System Integration

Creating and Tracking Requirements

The first essential component for the concept of operations to recognize in system integration is that it must capture and track the full set of requirements for the integration process. Integration is considerably more than the "connect and test" process familiar in electrical contracting, involving as it does the joining of hardware, software, and communications (possibly delivered as a service) into a single functioning entity.

In particular, the concept of operations should recognize the interaction of system integration with operation. If the system undergoes integration of a modification during normal operation, or is undergoing initial integration during a period of partial operational status, the concept of operations should recognize and address the impact of integration upon the operational status, and of the ways in which operations can assist in achieving successful integration.

Generating or Capturing Test Data

The concept of operations must also recognize the timing and process for generation or capture of test data. The data used in testing must demonstrate both the range of conditions faced by the systems under test, and should test each situation sufficiently to demonstrate lack of variability between test cycles. The typical TMC generates massive volumes of data, which may be stored temporarily, permanently, or not at all. An analysis of the operating conditions and cycles of the TMC will assist in identifying for the concept of operations the appropriate periods, types, volumes, and durations for data collected and retained. It will also assist in understanding how this process should be repeated if either internal configuration or external transportation patterns or operations change.

Integration of New Systems with Legacy Systems

The agency facing the challenge of operating both legacy and new generation systems generally has a limited number of options. The optimal solution is to fully integrate the two systems (such that the separation between the systems is invisible to the operator) or to replace the legacy system completely, accomplishing the same end results. This can be accomplished by creating a stand-alone interface which translates between the systems, or by modifying one or both systems to create a direct system/system interface.

The impact on the concept of operations is that:

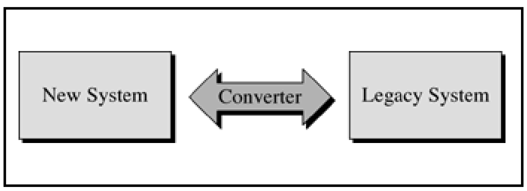
- Certain information on the secondary or remote system may not be available
- Information on the secondary system may be assumed (rather than determined through an active inquiry)
- Functions and capabilities on the primary and secondary systems may be unequal
- Responsiveness of the secondary system may be slower than for the primary

Less pleasant, although sometimes inevitable, is the operation of the systems in parallel, with operators called upon to work with both in their "native" modes. The operator is required to move from system to system, making inquiries and implementing commands through the various system interfaces.

Regardless of the method of integration, operation of multiple parallel systems also requires additional maintenance and system support resources, and places additional demands on the facility concept of operations including the need for additional space, power, heating/ventilation/air conditioning, and communications access. As the legacy system ages further, additional space may be required for a more intense maintenance program in order to keep it operational, and to store the spares that become more scarce and expensive as time passes.

Creation of Interfaces

If both systems are retained, interfaces between the two can be created so that data and commands are passed between the two. This type of interface acts as a converter, translating information and commands from each system into that of the other. Often the operator interacts with the newer of the two systems, placing the older system in a form of "remote" operation from the operator's primary interface. The interface may also act as a repository of information on the equipment that the other system contains, so that the operator cannot send impossible commands to the remote system. The interface may retain information on the status (or at least the commanded status) of the external system, so that inquiries by the primary system can be satisfied.



Modification/Adaptation of Systems

A second alternative is to modify one or both systems to create a direct interface. Often this is performed by creating an input/output module in one system (typically the newer one) which views the older system as simply another form of field equipment. Thus, the operator works with the interface of the primary system, which deals with the secondary system through its standard processes. As with the stand-alone interface, additional actions, such as retaining the commanded status of the secondary system, may be required which are not typically required for more flexible remote systems.

Impacts of "Parallel Operation"

As described above, operation of two (or possibly more) systems:

- Increases storage space and inventory management requirements
- Increases the workload and the complexity of operation
- Creates a need for additional training and documentation
- May slow response
- May increase the likelihood of errors

The prospect of an operator rolling from workstation to workstation, mentally coordinating actions, is an uninviting one. It is inefficient, and prone to error. It creates situations where uncoordinated actions may occur, reducing the impact of the TMC's efforts, and possibly dangerously confusing vehicle operators.

> In its earliest days of operation (before acquiring the TranStar name), Houston's interim TMC featured three variable message sign computers, each linked to variable message signs from a different vendor. To implement a regional solution, the operator had to move to each workstation and enter commands in its respective interface and language.

The maintenance impact of multiple, nonintegrated systems is similar inefficiency. Maintenance units must maintain tools, test equipment, documentation, and skills for two possibly significantly different systems, increasing cost and decreasing the effectiveness of the maintenance program.

Integrating Multiple Centers

Deciding What Information to Share (Benefits of Integration)

When integrating multiple centers, the concept of operations of each center changes to recognize access to additional information, and actions necessary to carry out the movement of that information. This form of integrated operation typically increases the effectiveness of each center, providing a superior overall perspective of the area under control, and making clearer the impact of actions taken by any individual center.

A primary step in achieving this integration is the selection of which pieces of information will be shared, and how the information will be available. If information currency is an issue, then each concept of operations may be impacted, either by the increased inquiry workload, or by the recognition that some information available from remote sites may be less than current.

> Many of the Southern California ITS Showcase projects involve sharing information between TMCs. In the InterCAD project, incident related information is shared between the computer aided dispatch systems of several regional enforcement and EMS agencies at federal, state, and local levels. Appropriate information is shared with the regional Caltrans TMC through a bi-directional Internet link.

Two primary alternatives for sharing of information are “push”, where the originating center automatically transmits the information to the other center, and “pull”, where the receiving center inquires for information it desires, receiving that information as the result of actions following the inquiry. In a common client/server environment, a combination of the two may result from the receiving center “subscribing” to information from the originator, who then automatically transmits the desired information until the subscription indicates otherwise.

Deciding Whether/How to Share Control

A major issue requiring careful examination while planning interaction between centers is the decision of whether centers will share control of one another's assets. The primary deciding factor is typically legal or regulatory in nature, of whether the employees of the first jurisdiction can legally take actions which can impact the citizens of the second jurisdiction. Issues of liability for damage to each jurisdiction's equipment must also be addressed.

The impact on the concept of operations may be quite large, allowing each center to alter its staffing and shift profile. Operational procedures may differ between the centers, requiring additional training, documentation, and conflict resolution procedures. Workload may change as well, depending on whether each center uses the other's assets in its stead, or only under unusual circumstances.

Developing Interagency Agreements

Because of the many impacts of shared control, formal interagency agreements are necessary before such activity begins. The concept of operations should provide a clear vision of the specific actions which can and will be taken, and of the potential impacts of those actions. The processes for informing responsible personnel and decision making or authorization will need to be clearly stated in the agreement, and appropriately reflected in the concept of operations. Memoranda of understanding, signed by senior agency officials, clarify both the strategy and the specific actions which can be expected from each agency partner during system operation, and how information moves between the agencies.

Creating Interfaces

The movement of information and sharing of control between centers will be greatly expedited by the use of standards. A major step will be the availability of the center-to-center portion of the National Transportation Communications and ITS Protocol. This protocol will provide a common language for the movement of information and control between centers. It will exist in two forms, each recognizing a different systems paradigm. The structured model of information management will be applied in the DATEX version, whereas an object oriented model will be in the CORBA version.

Coordination

Introduction

Interorganizational and intraorganizational coordination and cooperation are essential for the TMC to accomplish its mission effectively. The concept of operations should identify the role of each cooperating agency and organization in accomplishing the mission/vision/goals/objectives of the TMC, proceeding to successively more detailed levels of description of the methods in which the organizations interact. The most fundamental analysis documents:

- The circumstances which bring about interaction
- Between whom the interaction takes place (which organizations, at what levels)
- How it takes place (vocal, telephone, radio, fax, e-mail)
- What the interaction contains (what information, what request)
- How each party responds to the interaction (information, action, request for additional information or support)
- How the interaction continues or resumes (monitoring and reporting of status of causative situation; thresholds for additional action)
- What triggers termination of the interaction (return to baseline conditions)
- How the interaction is documented
- How the termination is confirmed

List of TRANSCOM Member Agencies

- Conn. Dept. of Transportation
- Metro Transportation Authority
- MTA Bridges & Tinnels
- NJ Dept. of Transportation
- NJ Transit
- NJ Turnpike Authority
- NYC Dept. of Transportation
- NY State Dept of Transportation
- NY State Police
- NY State Thruway Authority
- Palisades Interstate Park Commission
- Port Authority Trans-Hudson Corp.
- Port Authority of New York and New Jersey

The level of interaction may be high, constituting an ordinary component of most activity, particularly in TMCs housing several agencies, such as Houston's TranStar facility or San Antonio's TransGuide TMC.

> TRANSCOM in the New York/New Jersey/Connecticut region began its existence essentially as a "switchboard" for interorganizational interaction, receiving information from one organization and distributing it to others. TRANSCOM added value by taking a regional view, and requesting or recommending actions by organizations other than the one(s) originating the information. For example, a major problem in the Lincoln Tunnel could result in requests for changes of signal timing, transit capacity, lane allocation, and various traveler information actions on the part of several agencies whose jurisdictions would be impacted, and whose resources could contribute to an effective response to the incident.

An element which the concept of operations must consider, particularly when dealing with sharing of video or information from law enforcement agencies, is the level and method of providing security to information which may be sensitive.

> Caltrans and the California Highway Patrol, who co-operate the 8 urban TMCs in the state, continue to work on optimal protocols to ensure the security of sensitive information while ensuring the timely and efficient passage of information which can bring about a broad and effective response to changing transportation conditions.

In similar circumstances common in TMCs, procedures and technical solutions have been implemented to assist in preventing inappropriate video surveillance, or to prevent unnecessarily graphic video content from becoming broadly available (i.e., released to an information service provider). Often these procedures correspond to formal policies within the agencies.

Conflict Resolution

Within the System

Whenever interaction occurs, the potential exists for conflict over the course to be pursued. This conflict may exist within the implementing agency or system, or between organizations. Because of the complexity of such situations, the concept of operations does not attempt to define every solution, but instead describes the process followed to achieve resolution.

Within the single agency or system, an example of a conflict in a freeway management center would be interacting incidents which call for different messages on a single variable message sign. While the optimal solution to one incident may be to move traffic to the right lanes, the solution to the other incident may be the reverse, to move traffic to the left. Achieving a coordinated solution is critical, as the confusion caused by conflicting information can create highly dangerous traffic movements. The conflict is most often discovered when two requests are made for use of the same resource, such as two requests are made to place messages on the same variable message sign.

Roles and Responsibilities

The concept of operations should identify procedures for resolving conflict both with and without supervisory intervention. If a procedure is established which allows the operators to resolve the situation in an acceptable manner, this is preferred. In situations which are too complex for such a resolution, then the process for intervention by the lead operator or operations supervisor is required.

This paradigm also holds in situations where conflicts occur between agencies who work in a coordinated manner in the TMC. This can be further complicated, for example, when parties at the problem site (train operator, station manager, law enforcement officer, incident clearance team) are also acting to resolve the problem, but may not be in constant communication with the TMC. In such situations, it is critical that all parties involved understand the roles, responsibilities, and limits of authority of each.

> In the Michigan and San Diego TMCs, for example, state DOT TMC operators and law enforcement dispatch personnel work in close proximity within the control room. If an officer requests traffic management actions in conflict with the current strategy, or if the DOT operator plans to implement a traffic management action in conflict with the site management plan, operators and dispatchers work through the details (with appropriate supervisory approval) to arrive at a satisfactory solution.

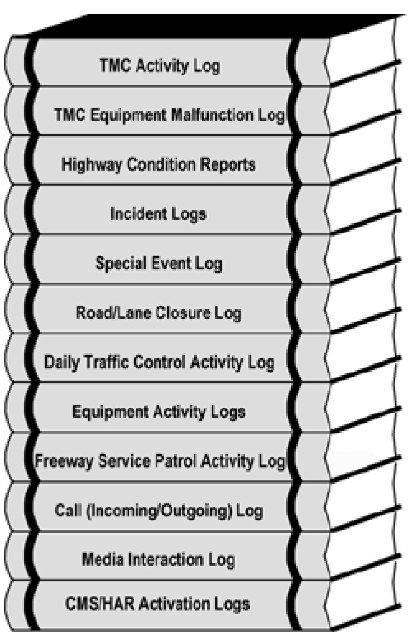
In the interest of improving operations, the process of logging the situation, communications, actions taken, and approvals should be recorded using a combination of manual record keeping and the information normally stored by the TMC's systems. This information is then available for later analysis.

Performing or Procuring Operations and Maintenance

Workload and Performance

Schedules

One of the most important elements of the concept of operations is the period of operation of the various functions within the TMC. Typically there are peak periods of activity. There may not be adequate workload to justify operation around the clock (although access to personnel performing other functions in these inactive periods and remote access to the system may allow the TMC to provide an enhanced level of service even in these low demand periods). Although ordinary demand may decrease late at night, during weekends, and holidays, it is not unusual for construction activity to peak at these times, thus increasing the need for some of the TMC's activities. Similarly, functions performed daily or weekly (such as distribution of construction schedules and other planned road closures, or planning for special events) need to be considered in the total work schedule, in order to ensure that adequate worker hours have been planned to accomplish the TMC's mission.



Shifts

As described above, TMC activity somewhat naturally breaks itself into shifts (although major metropolitan areas where the AM and PM peaks have merged at midday face an unusually challenging situation).

Shift-Change Procedures

Shift change procedures describe the formal process for transfer of responsibility from one shift team to the next.

Documentation During Shifts

The shift change procedure normally recognizes the completion and storage or transfer of the documentation which has been compiled during the shift. Such documentation would commonly include various types of logs, including logs of communication, events, and actions taken. Logs of changes in status or of status checks may also be included.

Documentation During Shift Changes

Documentation prepared during the shift change typically includes a record of the processes or events which are being actively managed at the time of shift change, including the status of the event, the persons from whom the event is being assumed, and by whom it is being received. Shift change documentation may also record any specific information or resources transferred between the shift teams, such as the status of a device or the condition of the system.

Shift Change Roles and Responsibilities

In order to accomplish an orderly and efficient shift change, roles and responsibilities of both incoming and departing personnel at all levels need to be clearly identified in the concept of operations. Upon whom the burden rests for ensuring that the incoming team fully understands the operational status, and has full control of the systems and its resources, must be clearly understood. Special procedures for transition during critical operations (i.e., while a crisis is underway) are warranted, as an above-average number of resources may be in action, communication to parties outside the TMC may be much wider than normal, an extensive background may exist whose understanding is important, and the tension of the situation may create conditions for incomplete information transfer and comprehension.

Protocols

Shift change procedures are typically quite clear with regard to who must do what, and how it must be done in order to accomplish an efficient shift change. Such a procedure would normally include the information and documents (and their condition) which are to be stored or passed to the incoming shift. If shift transfer briefings are standard procedure, the responsibilities of both shifts are recorded. Procedures for shift change within the computer system are also clearly documented.

Dealing with Staff Shortages

One of the most challenging situations faced by supervision within the TMC is operation with fewer than expected personnel. The concept of operations should clearly consider the options for such situations. Several commonly identified methods include:

- Redistributing workload among the available personnel
- Decreasing level of service to one or more areas or functions of the TMC
- Retaining the current shift, and calling in the next shift early
- Calling in staff who are off that day
- Having management, supervision, or shift leads perform operations duties
- Having technical staff, training staff, or other TMC personnel perform operations duties
- Having maintenance personnel perform operations duties

- Accessing "volunteers" from other parts of the organization who have been appropriately trained
- Calling in previous employees who have moved to other parts of the organization
- Accessing additional staff from a temporary agency or from the academic institution who provide staff
- "Drafting" qualified personnel from the development or support contractor

Current Workload

Coverage and Services

The workload managed by the TMC can be measured in a variety of ways, often related to the resources under its management, and to the activity of those resources. For freeway management centers, this often involves the number of centerline or lane miles of instrumented roadway or roadway for which the TMC is managing incidents. It may also involve assessment of the number of incidents (possibly broken into classifications) which are managed per time period, and the numbers of calls received if the TMC serves as a point for direct motorist communication (as does the NaviGAtor TMC). Additional measures which consider the number of vehicles, vehicle-hours or vehicle-miles of operation, or "assists" per time period may need to be recognized if the TMC manages a motorist assistance patrol.

In using incidents as a workload indicator, some differentiation may be necessary. Unusual categories of incident, such as complex, extended duration hazardous material incidents, deserve separate recognition, as they place a considerably above average workload on the TMC. Conversely, secondary incidents, such as overheated vehicles and minor rear-end collisions (no injuries, both vehicles operational) within primary incident queues may require little attention and may not add significantly to the TMC's workload.

The conventional measure for workload of traffic signal operations centers is the number of intersections for which it is responsible. This measure may need to be modified with respect to the types and age of control at the intersections. Workload is significantly different on a network of traffic adaptive signals than it is for a network which requires constant manual intervention in order to achieve reasonable coordination. Since an increasing number of signal operations centers also perform some incident management, this workload will need to be recognized as well. Often, signal operations centers have a significant role in dispatch and coordination of signal maintenance personnel and may be responsible for a large and widely dispersed communication network. Each of these elements reflects a component of the measure of workload for the center.

In transit management centers, conventional workload measures have included:

- Total route mileage
- Number of routes in operation
- Number of vehicle miles per day or stops per day
- Number of vehicles in operation

High level measures may include the number of passengers served per time period, or the aggregate potential traveling population in the served area.

Special Event Staffing

- Athletic Finals
  - Olympics
  - Super Bowl
  - World Cup Football
  - Goodwill Games
  - Formula One Grand Prix
- Political Conventions
  - Democratic
  - Republican
- Industry Exhibitions
  - Comdex
  - SuperShow
- Regional Holiday Celebrations
  - Washington, D.C.
    - July 4th
  - Taste of Chicago
  - New Year's Eve—
    - Times Square

Special Event Staffing

Activity for special events can represent a significant portion of the TMC's workload, eventually consuming one or more staff persons full time. As special event related workload increases, this should be recognized in the workload analysis. TMC activity related to special events may include every step from initial planning through final cleanup after the event. Freeway management centers and those signal centers performing incident management have most commonly needed additional personnel to support special events. Signal operations centers controlling only signal timing less commonly needed additional staff, as did transit centers. Centers receiving traveler inquiries typically needed additional staff regardless of the center's primary function.

Although Atlanta's MARTA bus and train control centers typically require no additional staff to support special events, they used additional personnel during the 1996 Olympic Games, when the rail system carried five times its normal volume.

The city of Atlanta's signal operations center typically does not require additional staff during special events, although additional effort is common in the weeks leading up to an event, during which travel patterns are analyzed and special timing plans developed. These plans are entered into the signal system along with appropriate dates and times for their activation.

Other Duties or Functions of Operations Personnel

The TMC is a convenient and efficient location for performance of repetitive, sensitive, centrally coordinated transportation-related activity requiring support during extended hours. Because of this, it often assumes responsibility for such activities, which become part of its overall workload (see chart below). Each of these tasks represents a meaningful addition to the TMC workload, and should be documented in the concept of operations and recognized in workload calculations.

Various Additional Functions of Operations Personnel

- The COMPASS TMC in Toronto serves as the access point for information on commercial vehicles and loads for enforcement officers.
- The MONITOR TMC is required to pre-authorize any construction-related lane closure in the greater Milwaukee area.
- The Boston Central Artery/Tunnel IPCS TMC manages significant SCADA functions for the tunnel complex.
- The TrailMaster TMC in Phoenix also manages SCADA functions for its tunnel, and controls pumping and irrigation along the interstate medians

Organization

As with any operating entity, the organizational structure of the TMC directly impacts its ability to operate effectively, and should be recognized explicitly in the concept of operations. In particular, in TMCs where the level of automation is relatively low, and where liability issues and accountability dictate that decisions are based on judgements of highly experienced professionals, the levels and accessibility of management are an important component of the concept of operations.

Supervision

The number of levels of supervision and the reporting relationships can strongly influence both the quality of TMC activity and its ability to respond rapidly to changing conditions. Typically, there is a single supervisor responsible for control room operations to whom the operators report directly.

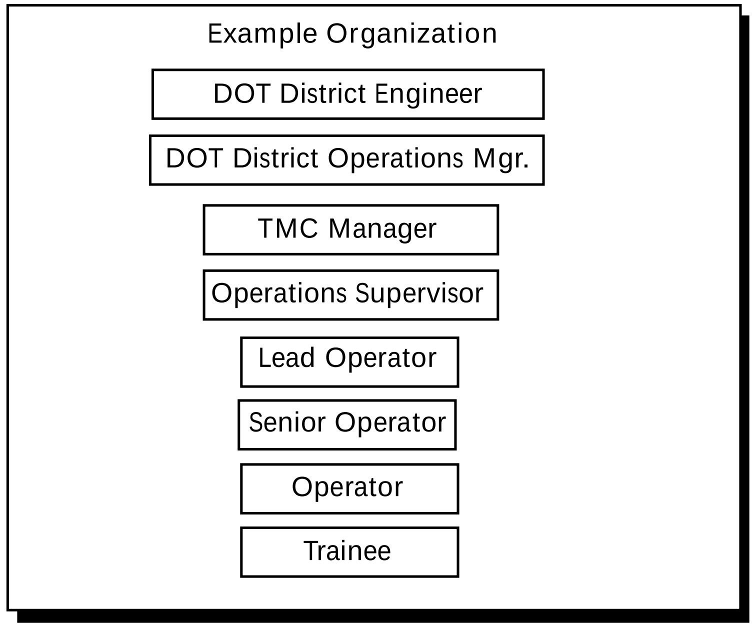
In some cases there are intermediate levels, such as the lead operator position in Toronto's COMPASS TMC, and the assistant operations supervisor in the Georgia NaviGAtor TMC. In Washington D.C.'s WMATA train control center, the assistant supervisor is actually the operations supervisor, with the supervisor having additional responsibilities beyond the control room operations.

Presence of additional senior levels of management within the TMC varies. The NaviGAtor TMC hosts additional levels of Georgia DOT management, including senior levels with statewide responsibility, as does the COMPASS TMC and the WMATA TMC (which is located in WMATA's headquarters building). In these cases, access to senior decision-makers and

Decision-Making Authority

The level of decision-making authority for the TMC operator varies, not surprisingly, based upon the skill levels of the operations staff and the level of automation provided.

The advanced traffic management system software in San Antonio's TransGuide TMC requires approval by the shift supervisor before any deviation is made from the system-recommended incident response. Similarly, at the Northern Virginia Smart Travel TMC, operator latitude is severely limited due to the low skill level of contract personnel retained as operators. At the other end of the scale, the lead shift operator at the Milwaukee MONITOR has broad authority to adjust traveler information messages, and can interface directly with the onsite law enforcement liaison in incident response.



Accessibility

In any situation where supervisory intervention is required, easy access to the decision maker is essential. Most TMCs place the shift supervisor's office in or adjacent to the control room, but typically in a separate office (providing sound isolation and privacy for handling personnel issues). Supervisors in essentially all TMCs surveyed carried pagers and/or cellular telephones whenever offsite or elsewhere in the building complex.

Some systems rely on a lead, experienced operator outside of prime shifts, with supervisory access from home. In these cases, often the supervisor has the capability to dial into the computer system (normally without video access due to communication bandwidth requirements) so that he/she can view the situation comprehensively before providing direction.

Other supervisory officials, such as the maintenance supervisor, may be similarly accessible. This is particularly important in work situations where required services are performed by personnel working under a collective bargaining agreement, whose efforts must be initiated by a member of TMC management.

Inquiries or Interest from Above

Particularly in difficult situations, the TMC is likely to receive inquiries from higher levels of agency management, or from other governmental officials. The concept of operations should provide direction as to how these inquiries are to be handled, as the impressions made upon such senior decision-makers can have a major impact upon their impressions of the effectiveness and importance of the TMC. In such situations, the balance between responsiveness and authority is delicate, as is the perspective from which the information is presented (details critical to the operator may be of little interest to senior management).

In situations where inquiries are received from outside of the agency, it may be appropriate (or agency policy) to involve or work through the agency's public affairs office.

For TMCs such as Georgia NaviGAtor, Houston TranStar, and San Antonio TransGuide which have dedicated public affairs staff onsite, this process is simplified, although the public affairs staff must be informed about any emerging situation before taking action.

Staffing

Number of Staff

The number of staff required is one of the most important elements of the concept of operations. This calculation must reflect all elements of the workload, including how the team is organized and deployed. There are no absolutes regarding the number of personnel per number of signalized intersections, number of transit vehicles dispatched, or centerline miles of freeway under incident management.

The primary determining factor is the set of functions which the staff are employed to deliver. In freeway management, for example, the responsibilities may include only incident management (detection, verification, action, monitoring, closure), or may also include various traveler information functions, interaction with a motorist assistance patrol, control of ramp meters, control of planned lane closures, and other functions (such as some forms of enforcement) which are not directly related to freeway management.

TMC Staffing

	Boston	Toronto	Long Island	Detroit	Milwaukee	Atlanta	Phoenix	Houston
Centerline Miles	7.5	60	165	180	63	220	254	122
Number of Operator Positions	10	9	5	6	3	12	6	18
Number of Prime Shift Operators	3+	3+	5	4	2+	5	2	12
Total Operations Staff	10	12	12	9	5	18	8	19
Number of Operation Staff Levels	3	3	2	2	1	1	2	1
Operations Staff Source	MassPike as Contractor	Agency Staff (FT and PT)	Contractor Personnel	Temporary Part-time	Staff, Students	Staff, Students	Agency Staff	Agency Staff
Number of Shifts	3	3	3	2	2	3	3	3
Backup Operations Staff Resources	Supervision, Off-shift, Overtime	Supervision, Off-shift	Contractor Responsibility	Supervision, Off-shift	Supervision, Professional Staff, Off-shift, Students	Supervision, Professional Staff, Off-shift, Students	Supervision, Off-shift	Varies by Agency

Source: Metropolitan Transportation Center Concepts of Operations Cross-Cutting Study, FHWA (9/99)

Although ITE has established a recommended practice regarding the ratio of engineering staff to signalized intersections, there is no comparable ratio of signal center operators to intersections, due to the many variations in complexity and workload in such centers.

Many factors, such as the level and types of automation provided, greatly influence the number of personnel required. Traffic adaptive signal systems require considerably less direct intervention than do less "intelligent" systems. Similar examples of significant productivity improvements include the use of computerized fax transmission to predefined lists of recipients, incident management systems which recommend tailored complete incident management solutions, and radio systems which allow connection of multiple parties, and which are integrated with intercom and telephone systems.

There are a variety of factors (listed below) that must be taken into consideration in determining the number of operations personnel for a traffic signal operations enter (TOC). There is no one formula to use in assessing this requirement:

- Frequency, duration, and overlap of work shifts and operations coverage during weekends and holidays
- Control sharing with other TOCs and/or TMCs
- Services/functions provided in support of disparate operational conditions including recurrent congestion, special events, and/or incidents
- Type, stability, and complexity of the communications system and associated electronic equipment and hardware
- Type and operational reliability of detection system
- Magnitude and complexity of advanced technologies including VMSs, CCTV, video sensors, advanced or adaptive traffic controllers, etc.
- Operational strategies deployed including fixed time, semi-actuated, full-actuated, time of day and day of week timing plans, traffic responsive, traffic adaptive, etc.
- Type and complexity of deployed traffic control systems (central vs. distributed)
- Uniformity in system design and operations across disparate control technologies deployed
- Standardization and operational integration of control equipment and hardware
- Response time requirements for corrective action
- Institutional arrangements and organizational structure for integrated and inter-jurisdictional traffic operations and service delivery

- Frequency and type of traffic control devices deployed and associated degree of automation for status polling and corrective actions
- Degree and complexity of interaction and coordination with other support agencies including the media, police, fire, transit, freeway management, etc.
- Level of data collection automation in support of traffic operations and design
- Availability and comprehensive of pre-defined response strategies and timing plans for non-recurrent conditions
- Implementation of low-maintenance and easy-to-operate systems based on effective integration of system planning, design, construction, and inspection in support of quality system operations
- Acquisition basis for signal system components and associated performance on a life-cycle cost basis
- Quality of response and preventive maintenance programs
- Community expectations as voiced in terms of requests for design modifications applicable to timing changes, signal phasing, pedestrian provisions, etc.
- Support requirements in response to legal inquires by law and insurance firms, rezoning applications, new developments, traffic impact studies, safety improvement studies, etc.
- Frequency of operational optimization, redesign, and system evaluation

Los Angeles' ATSAC Traffic Operations Center

The ATSAC TOC in Los Angeles is responsible for the Smart Corridor, Research Group, System Support, and the ATSAC traffic signal system. The TOC has a total of 20 staff for the operation, management, and design modification of 2,400 traffic signals controlled by 10 UTCS servers (400 traffic signals per server). The city's remaining 1600 traffic signals are not part of the ATSAC system, and are operated by offsite staff. They operate in either isolated mode or in coordinated systems based on predefined time-of-day and day-of-week timing plans that use time base coordination.

ATSAC management considers one engineer for every 300 traffic signals as adequate for effective traffic operations. ATSAC engineers are also tasked to resolve citizen complaints, perform signal coordination projects, and prepare safety and operations improvement studies. In March 1999, the City generated 220 timing charts reflecting control and operational changes made at 220 traffic signals. The ATSAC TOC maintains one engineer/operator on duty at all times during each work shift with more engineers provided if required to support special events or incidents. The functions performed include incident and/or system management. The operators are required to be engineers because they make traffic operations decisions. On normal days, the TOC has five engineers on duty whereas on "lighter" days, three engineers would be sufficient. However, there are always backup operators available.

The number of events/incidents that need to be operationally managed may range from 1 to 20 on a daily basis involving communications failures, incidents, events, flashing signal, etc. The TOC does not serve as the primary interface with the public. Traffic engineering and maintenance yards perform that function as needed and route resulting requests to the TOC for evaluation and action as appropriate. If calls are received at the TOC, they are generally redirected to other departments or divisions.

The TOC provides traffic information to broadcast media through a bulletin board system.

The TOC does not house any other division, department, or agency. Other divisions within the city's Transportation Department perform design and maintenance functions. However, monthly meetings ensure mutual understanding of needs and expectations including updating and maintaining specifications and traffic signal design approaches. ATSAC is involved in this process. The TOC uses radio, telephone, email, and monthly meetings to effectively interact with other divisions. The Maintenance Division is notified by the ATSAC TOC operator through phone and/or radio calls relative of malfunctions detected automatically by the system.

Traffic counts are collected manually and inputted in Synchro software to develop optimized system timings. The technician who programs system timings into the field-based controller is from the maintenance section. ATSAC attempts to synchronize 100 miles of streets per year (last year 121 miles of streets were upgraded). These street miles are selected to reflect congested streets with higher density of traffic signals, changing traffic patterns, and citizen complaints. Typically, the plans are developed for AM, PM, and off-peak periods.

ATSAC TOC also serves as an emergency center for the Transportation Department during major disasters. The TOC has a workstation that links to all different bureaus and departments within the city such as street maintenance, traffic signs, police, fire, etc.

Organization of Staff

There are many variations in the way in which the concept of operations may organize staff to perform the same set of functions.

> At Milwaukee's MONITOR TMC, each operator has full incident management responsibility, and incidents are divided between the team based upon current workload and knowledge of the incident area. Control of and dispersion of information about lane closures is performed by other personnel, outside the control room.
>
> In Georgia's NaviGAtor center, a separate operator is established for the area's highly successful HERO motorist assistance patrol, and another for construction related activities.

Method of staffing

The concept of operations should also recognize the approach to staffing the TMC. As discussed earlier in the section on agency policies, staffing flexibility is often greatly influenced by the method of staffing, i.e., agency full-time professional personnel, contractor personnel, or agency part-time or temporary personnel (such as students). Work rules are likely to be somewhat different for each group, as may be the level of expertise and productivity which can be expected, and possibly the degree of direct supervision which is required. These are all important determinants of the complete concept of operations.

> There are a great variety of approaches to staffing. Texas DOT's TransGuide operators are all career state employees. Seattle's TMC staffs exclusively with students. In Milwaukee, the MONITOR center typically pairs a student with a career operator on each shift. Long Island's INFORM center is staffed by contractor personnel, as is the Northern Virginia Smart Travel center.

Staff Career Paths

The concept of operations should recognize the career pathing approach for TMC operations and maintenance personnel. There are several reasons, including the reasonable length of time for which an individual can be expected to remain on staff. The concept itself should incorporate appropriate elements of the career program (which may include both agency policy and local or TMC policy). The most common element is the career progression of operations staff.

> At Georgia's NaviGAtor TMC, new hires are classified as "trainees" for their first 6 months, at which time they are eligible for promotion to operator status. This period includes the period during which they receive initial training. At Toronto's COMPASS TMC, operators can progress from the operator classification to shift lead, to operations supervisor, and can similarly transfer to other agency openings.

Staff Cross-Training

Cross-training, particularly in TMCs where functions are separated, provides an important degree of staffing flexibility. The concept of operations recognizes cross-training in two ways:

- It identifies the time during which the training is undertaken, recognizing that a single function is being performed by two persons rather than the single individual normally required.
- It identifies the ability to move an individual to a function in which he/she has been trained when the primary operator is unavailable.

Compensation Comparability to Industry

In a manner similar to career pathing, the concept of operations should recognize the impacts of the level of compensation of the TMC personnel. A level of compensation which is lower than for comparable positions in industry (or at other agencies) will typically result in a high level of turnover, and the consequent impacts on workload/level of expertise and training requirements. It also significantly influences the flexibility with which the staff are willing to perform their duties. In the clearest example, the differences between labor practices for personnel who are classified as salaried and those who are classified as hourly will greatly influence the concept of operations. Directly related to this is the TMC policy on regular and overtime pay.

Hiring Sources for TMC Operations Personnel

- Community Colleges
- Postings within Agency
- Agency Surplus Personnel

Common Backgrounds for TMC Operations Personnel

- Traffic Equipment Maintenance
- Air Traffic Controllers
- Radio Operators
- Clerical/Administrative Personnel
- Students
- Dispatchers

Sources for Hiring

The TMC may have a variety of sources for hiring of operations personnel. Agency policies on posting open positions may govern sources from which personnel are available. TMCs researched for this and related studies found great variety in sources and backgrounds, ranging from secretaries to former air traffic controllers. Toronto's COMPASS TMC had established a successful relationship with a local 2-year college which had a program in traffic operations, and which served as a source for several operators. Older freeway management centers cited a practice of hiring radio operators, who often came from their agency maintenance teams. Another common source was to draw from the ranks of traffic signal technicians, who are also typically used as operators in signal control centers.

> TMC opinions on the use of students as operators varied. Milwaukee's MONITOR TMC has had consistent success with students from its two nearby universities, as has Seattle's TMC. Arizona's TrailMaster TMC achieved some success with students, but found them prone to being diverted to study, particularly on late night shifts.

Several TMCs stated that engineers made poor operators, as the position did not call upon the required skills in a way that presented the career challenge that engineers often desired.

Transit TMCs commonly draw from the ranks of bus and train operators for their operations console positions. Not only do vehicle operators bring an in-depth understanding of the operating environment, but typically they are long term agency employees with a full understanding of the career options open to them.

> Atlanta's MARTA hires both vehicle operators and vehicle operations supervisors into its console operations positions. They have also had success bringing in personnel from their transit police organization. Their pay structure favors makes the transition favorable for employees with 5-10 years experience, but creates somewhat of a barrier after employees gain around 10 years of tenure.

Dealing with Stress

A statement commonly made regarding other types of control centers is that operations is "hours of tedium interspersed with moments of terror." This statement may also accurately describe TMC operations, particularly incident management. The concept of operations should recognize that operations and maintenance personnel may need periods of "decompression" during and following extended high-stress periods, and that it may be necessary to have replacement personnel available for these periods.

Turnover

The concept of operations should estimate the expected turnover, and should outline plans for interim shorthanded operation, additional training, interviewing and hiring, new hire supervision, and team integration which occur when new personnel are added to the operations team.

Operational Performance

What Types of Workload and Performance Analysis Are Needed?

Any operational organization working in a budget constrained environment will likely be concerned with improving its operational effectiveness. Parameters such as productivity, safety, and responsiveness are common targets for ongoing improvement. Typically, these parameters will be aligned with the TMC's mission/vision/goals/objectives.

Once the TMC team has established the parameters which it desires to monitor and improve, it will need to identify the data it needs. The concept of operations should reflect the collection and analysis of this data, the implementation of improvements based on it, and any actions resulting from the improvement.

What Data Does the System Collect Automatically?

One of the greatest benefits of the systems under a TMC's control is the volume of data which the system naturally collects. This data is not only essentially free, but is easily analyzed, and can provide both short- and long-term measures of performance. The answers to the question posed above regarding what data are needed will conclude by identifying data naturally collected by the system, or data which can serve as a surrogate to that which are needed. The relatively recent archive data user service added to the ITS national program plan and any standards which emerge from it may provide guidance on data format and retention.

If performance is an issue of concern to the operations staff, it may be appropriate to control access to the system's data. This same issue is appropriate to address if the system collects and stores data which may become evidence in any type of legal action. Appropriate system administration, including data security, would be reflected in the concept of operations.

Who is Responsible for the Evaluation?

The concept of operations would naturally include an indication of who will conduct the performance data analysis, on what interval, to whom the results will be disclosed and how, and what action may be taken based upon the results. There may be issues which need to be addressed regarding the independence of the evaluator, and whether the evaluation is performed objectively, or if its results are intended to justify actions which have already been set in motion. Timeliness of the release of the evaluation results is also key, such that actions can be taken to alleviate any situations which the evaluation uncovers before they become a serious problem with the operation.

In addition to the operational value of the evaluation, it may also be worthwhile to consult with the organizational element responsible for outreach. Outreach communication is much more effective if relevant benefits are identified from the operations and systems the TMC employs. It may be possible to economically incorporate components in the evaluation which provide this benefit information.

Is It Used in Personnel Evaluation?

One challenging circumstance is dealing with the possible results of the data. In particular, if data are used to determine performance of individual employees, and if compensation, promotion, or retention decisions are influenced by the results of the analysis, then issues of data contamination, morale impact, and lack of support for the data collection may create difficulties. If such is the case, it is appropriate to ensure that the data being analyzed truly represent the exact objectives and all of the objectives being sought, and that no opportunity exists for “gaming” the statistics to influence perceived performance.

System Performance

User Service Delivery and System Parameters

The concept of operations will need to state clearly the system performance objectives which have been established. Examples from a freeway management center might include the time to detect an incident, and the time necessary to formulate and implement a response. In a traffic signal control center, a comparable objective might be the total delay experienced for specific origindestination pairs (typically a corridor). In a transit management center, performance parameters might include the time required to respond to a radio inquiry from a fleet vehicle. The overall fleet performance parameters of on time arrival and headway maintenance are heavily influenced by the effectiveness of the TMC, but are also influenced by external factors such as the vehicle maintenance program.

Activity and Time Analysis; Who Does What, When, and How Long Does It Take?

Within the limits of variability, the activity within the control center can be measured using classic time and motion studies. Such studies should be useful from the perspective of identifying how to most effectively organize and divide the work and the resources necessary to perform the work. Examples would include:

- Measuring the actions necessary to access a commonly used document (such as a procedures manual or a directory)
- That every operator station should have its own copy
- That the copy should be conveniently accessible on the desktop, rather than being stored in a drawer or cabinet.

Similar human-factors-focused engineering review should be undertaken during design of the computer system user interface, in order to prevent situations where sequential actions require passage through a multitude of intermediate screens.

Process Improvement Program

How Process Improvements Are Targeted

An alert and motivated workforce and effective communication between supervision and the workforce will periodically identify potential improvements in the operational processes. Such improvements are likely to improve overall customer service and satisfaction, improve service quality and consistency, improve safety, and provide improvements to working conditions. A formal program for process improvement should be identified in the concept of operations. This program may be event driven or may include a formal periodic process of procedure examination. This program may exist within an existing agency program (such as a “suggestion” program or a program of “quality circles”) or may be separate from the overall agency process improvement program.

> An example of planned and cooperative process improvement from Arizona’s TrailMaster TMC is a list of computer system improvements which are identified by the operations staff, and which are jointly discussed by operations and systems units on a regular basis.

> Sources of Improvement Ideas
> - Suggestion Program
> - Operational Evaluation
> - Performance Evaluation Program
> - External Review
> - Process Improvement Team

How Process Improvements Are Made

Since any process improvement in a TMC is likely to require changes to training and documentation and may impact the performance evaluation program, the concept of operations should carefully consider how changes are implemented. The concept of operations should recognize entire process of:

- Taking an identified opportunity for change
- Verifying its value
- Discovering and resolving any potential negative consequences from the change
- Building support for the change within management and the work force
- Carrying the change to detailed design (if required)
- Developing the support resources (such as software) for the change
- Providing training after the change
- Testing the change
- Monitoring its performance
- Amending it if required

Nonstandard Operations

Nonstandard operations are a growing portion of the workload of TMCs. Nonstandard operations are broken into several categories: special events, emergency operations, and operation with partial functionality. The concept of operations should reflect the process of planning and general procedures for execution of plans to deal with both. A third category, where the TMC experiences failures of its own assets (internal, rather than external emergency) should also be addressed.

Developing Operational Strategies

Developing operational strategies for nonstandard operations is commonly a multiagency activity. The efficient flow of persons leaving a major event is affected by the actions of venue, law enforcement, transit, parking, and both arterial and freeway management organizations. The concept of operations should discuss the process these agencies will use to prepare and execute plans for managing the flow of persons and vehicles. Planning includes such activities as the estimated timing of actions, the expected volumes, and the responses by each of the participants. It should also reflect a “feedback loop” by which the effectiveness of the plan is reviewed in real time, and adjustments made (and communicated) to respond to variations from the expected.

> Houston TranStar provides an interesting example of interagency special event planning. The annual Rodeo event brings massive volumes of individuals and vehicles into the city for several days each year. The typical special event plan prepared by the TranStar agencies includes a detailed schedule of event activities, illustrated on a series of maps; a detailed program for movement of buses; road closures or restrictions (Rodeo includes horse-drawn wagon trains through the city); variable message signs directing traffic to designated parking facilities; interaction with the media as a form of dissemination of traveler information; and special adjustments to traffic signal timing and high occupancy vehicle periods to accommodate the unusual volumes and patterns of traffic movement. The plan describes the locations and roles of law enforcement.

TMCs may have to operate under difficult conditions related to civil or weather emergencies, or possibly to hazardous material conditions. As above, the TMC's plans must be well coordinated with the other agencies involved in handling such emergency conditions. Some classes of emergency situations are sufficiently common (hurricanes in Houston, flooding in downtown New Orleans) that specific plans are well developed. Other types, such as the Philadelphia "tire fire" are totally unpredictable, and must be handled by a more generalized type of plan.

The concept of operations component for this type of nonstandard operations begins by dealing with the condition of the TMC and its field assets, and of how the TMC can be staffed and operated under conditions where additional staff may not be able to reach the TMC. The method of communication between the TMC and civil authorities should be clearly defined, as should the process for developing and approving any actions taken by the TMC. The concept of operations should recognize that the TMC's field assets may not all be available due to damage or loss of power or communication, and that actions by maintenance units to remedy this situation may be delayed.

Operation with Partial Functionality

The remaining type of nonstandard operations is when the TMC must operate without its full complement of resources. This includes damage to field assets, loss of power or communication between the TMC and the field, and failures within the TMC itself. Since most TMCs are provided with uninterruptable power supplies and backup generators, the internal failure more often takes the form of failure of a specific piece of critical equipment, such as a server, switch, or primary multiplexer.

The concept of operations deals with three steps in such situations:

- Identifying and confirming the failure, determining what has failed, and getting work underway to remedy the situation
- Understanding the impact of the failure and determining what types of workarounds are available
  - This may include backup systems, use of alternate or remote workstations, use of temporary or portable devices, dial-up instead of direct connections, or movement of personnel to the field to access the assets directly
- Communicating to the appropriate parties the impact, in order to manage expectations
  - This may include getting information to the pubic if the failure will be noticed

As with the other categories of nonstandard operation, the roles and responsibilities of parties within the TMC should be clearly understood. These roles may shift, depending upon the resources available to each unit of the organization, and how those resources can be applied in carrying out the TMC's mission.

Simulation

The concept of operations may define simulation as one method of preparation for nonstandard operations. It can be an effective method for testing the readiness and effectiveness of plans for nonstandard operations. As the desire of simulation is to determine the effectiveness of as much of the plan as possible, maximum use of real assets is favored. This may include use of a parallel portion of the main system, or use of the system or system workstations while they are offline. It may be possible to conduct reasonably full-scale simulations if the communication between the system and its field resources can be terminated during non-critical periods.

If the system is used as part of simulation, the data which it uses can come from three possible sources. The data may have been stored at another time, may be synthesized from a model, or may be have been manually created or modified to produce specific circumstances.

Smaller scale simulation can be performed as a tabletop exercise. Simulation is perhaps easiest for traffic signal systems, where many years of effort has been invested in developing accurate models of signal operation. Although such models must be properly calibrated to local conditions and configurations, use of simulation in improving performance under nonstandard conditions can be a highly effective method.

> Since the role of Boston's Integrated Project Control System includes both conventional traffic management and management of life critical situations (fire, smoke, flooding, contamination) in the Central/Artery Tunnel, desktop simulation is a regular exercise for the operations staff. The simulations achieve two purposes, both testing the plans themselves, and continuing to increase staff familiarity with the nonstandard procedures.

Fault Detection and Correction

Fault detection and correction are the activities requiring the most active interaction between the operations and maintenance units of the TMC. They are clearly among the most important activities undertaken in ensuring the operational effectiveness of the system.

Detection and Reporting of Suspected Failures

The concept of operations should clearly define the steps in the identification, documentation, verification, isolation, and remediation of failures. In most TMC systems, the system itself is the first source of an indication that an element of the system is malfunctioning. Since most systems perform some form of polling to verify status and capability of each element to which they are connected, then the system typically reports back any non-normal status, including the inability to establish communication with the device in order to check its status. Most graphically-based systems indicate a suspect device by changing its color, and possibly changing its appearance to "dashed" instead of solid, or from steady display to flashing display. Typically elsewhere within the system (possibly accessible by "clicking" on the device icon), an equipment alarm report will provide a specific message of the condition which the system has encountered.

Operationally, the concept of operations should identify:

- Who receives these alarms
- What they do to verify the alarm condition
- What they record and how
- Whom they notify, how they do it, and what information they provide
- Any assistance that they normally provide in immediate fault isolation
- How they notify others of the situation

This typically initiates a process of interaction between operations and maintenance, in which:

- System-generated or observed conditions are provided to maintenance
- Operations is informed of maintenance activity planned or underway
- Operations is asked to assist in debugging and testing fixes
- Operations is notified of the return of the equipment to full operational status

This communication can take place in a variety of ways.

> At Houston's TranStar TMC, operations and maintenance exchange daily spreadsheets covering the status, plans and activities, and changes of status of failed devices. Interaction also includes telephone conversations which may request operations to attempt a system-initiated restart of a device, or an investigation of device status at the vendor-provided control unit outside of the control room. This interaction is not necessarily limited to the TMC's assets.

> At Long Island's INFORM TMC, information received from many sources regarding the status of traffic equipment throughout the Island is received by the TMC, and passed to the responsible agency. Thus, a report of a failed signal or streetlight in one of the Island's many townships may come to INFORM, who then passes the information along to a designated point of contact at the responsible agency. TMCs with mobile resources (such as a motorist assistance patrol) or which serve as a central transportation point of contact for the region (such as Georgia's NaviGAtor or the Montgomery County, Maryland TMC) perform this service regularly.

Logging Suspected and Verified Failures

Both automated and manual logging of suspected and verified failures is critical to improving system performance. In the short-term, the logged information assists in isolating the fault and effecting repairs or replacement, and possibly for obtaining repairs under warranty provisions. In the intermediate term, this information is quite useful in planning and budgeting for preventive maintenance, including periodic replacement of units with limited service lives. In the longer term, the maintenance history of a device or class of devices provides the information which can be used to make purchase decisions for an overall upgrade of the system, or for expansion of the system.

Warranty Management

As mentioned above, the creation of a log of device performance is essential in managing warranty claims. This information should be adequate to link to the configuration management database (typically some unique identifier of the device), so that the required information on device series, model, and version are available. This information may also be useful in:

- Providing feedback to the vendor
- Developing workarounds such as changes in filter material or placing protective shielding around a device
- Isolating specific conditions where standard practices such as grounding or surge protection are not adequate

System Maintenance

The concept of operations (perhaps more appropriately the concept of maintenance) should describe in equal detail the maintenance practices necessary to ensure completion of the TMC's mission. In this document we will describe several components of the concept of operations, but will not attempt to fully treat the process of maintenance due to its complexity, and because much of it is performed outside of the TMC.

Configuration Management

The establishment and maintenance of an accurate and complete configuration database for all elements of the TMC and field hardware and software (and potentially vendor-provided services such as communications) is an essential element in conducting the maintenance program. These data are most easily assembled as the system is installed, but maintenance and upkeep of the database is necessary both as the system grows and as devices are altered and moved, so that the database is able to link to the device location, and preferably to its maintenance and performance history.

The concept of operations typically describes at least the process of entering and maintaining the configuration information in the database. It may go further to describe the analysis and use of the data.

The most common information in the configuration database regarding a device is its description, including manufacturer, model number, and serial number. If the TMC performs its own maintenance on the device, the database may include similar information on the major sub-units, such as the lens in a closed-circuit television camera or the network interface card in a workstation. For devices containing software, the database identifies the version of software currently loaded, the load date, who performed the load, and what modifications the new load contained.

Configuration management may be performed as part of the routine maintenance process, but the database will likely eventually become large enough that a dedicated resource is required. The use of a purpose-built application for managing the configuration data, and for performing the analyses it can provide, is also typical of larger systems. Standard practices for configuration management have been documented, and may be available from the federal government, from private consultants, or from some institutions of higher learning.

Agencies need to recognize both the importance of configuration management. Without configuration information, maintaining the highly technical equipment will become very difficult, and obtaining contract support, warranty repairs, spare parts, and upgrades will become very difficult. Making modifications to the extensive software upon which TMCs depend will be equally difficult if no current configuration information exists on the current code.

The potential cost of configuration management is easy to underestimate. The ongoing cost is often only the manpower and the configuration management system. The cost to document the configuration as it is created or installed is reasonably modest, perhaps comparable to the cost of a requirement for the implementer to provide quality as-built drawings. The cost to document configuration in arrears can be significant, as it will require both TMC and field research, and a full examination of the application system custom source code and the commercial software.

There are a variety of beneficial linkages of the configuration database to other systems. The configuration database may be linked to the malfunction reporting system, and is often linked to any automated maintenance management system that the TMC uses. Other possible linkages include:

- Design information
- As-built documentation
- Test plans and results

Logistics

Logistics deals with the management of resources necessary to carry out the maintenance program. This can be unusually complicated in situations where the resources maintained are mobile or widely distributed geographically, as in cases of a transportation corridor.

The logistics portion of the concept of operations focuses on tools, test equipment, spare parts and replacement units, and expendable supplies. It provides guidance on:

- Locations
- Quantities
- Device versions
- Documentation
- Maintenance procedures
- Points of contact for information
- Emergency suppliers

Logistics planning is an involved science, using significant amounts of information and algorithms to assist in optimizing performance while minimizing investment. Additional information should be available from sources similar to those cited above for information on configuration management.

Logistics requires more attention but can be more economical if agencies who own similar equipment share in the investments for logistics material.

Standard Maintenance Activities

Dispatch Function The primary maintenance activity within the TMC is often the dispatch of maintenance personnel for both preventive and emergency maintenance. The concept of operations should treat the maintenance dispatch function much as it does operations, addressing qualifications, hiring, shifts, training, documentation, workload, etc. The efficiency of the maintenance dispatch function is a primary determinant of the cost and effectiveness of the maintenance program, as the dispatcher is the primary communications link between the maintenance resources in the field and the TMC. The efficiencies that the dispatcher is able to create by logically grouping assignments and by understanding priorities, can assist the maintenance team greatly in achieving its role in the TMC's mission.

Responsible Parties TMC maintenance responsibilities may be distributed across several organizational units. Often telecommunications, information technology, TMC facility, and field assets are maintained by separate units. In some cases, these units may be widely separated organizationally, or in the case of multiagency facilities may not be organizationally related at all.

The key in such situations is that the concept of operations reflect effective methods of coordination, and a commitment to common goals. Communication is essential between the parties, often sharing even seemingly unrelated data. TMC operations may find itself serving as the "switchboard" between the organizations, forwarding information, as the acts of each impact the capabilities of the others.

A similarly complex situation exists when some or all of the maintenance activity is contracted by the TMC agency. As above, the information from each participant in maintenance needs to be shared, and records maintained centrally if at all possible. In the case of contract effort, additional technical information needs to be shared with the agency. For example, if preventive maintenance is contracted, equipment conditions (damage, unusual wear, unnoticed or pending failures) discovered during the preventive activities needs to be shared with the agency, so that emergency maintenance can be avoided. Also, for contractual maintenance, response times to correct problems need to be identified.

Preparations Coordination between maintenance and operations staff is particularly essential when maintenance activity will impact the operational ability of the systems upon which the TMC depends, or when actions by operations are required in order for maintenance to safely perform its tasks. The concept of operations should recognize that such coordination normally takes place at multiple times, often at:

- The beginning of a shift
  - what maintenance is planned
  - what will the impact be
  - what actions are required

- The beginning of a task
  - Change in status is taking place
  - Be aware of potential for danger to personnel
- Whenever the support is required during the task
  - Please take the specific action
- Whenever support can be terminated
  - The specific action can be reversed
- When the task is done
  - The device can be returned to the appropriate operational status
  - Potential for harm to maintenance personnel has been terminated
- At shift completion
  - Accomplishments during the period
  - Plans for additional action if required
  - Verifying changes in status of devices

Operational Impact In addition to the importance of effective maintenance on achieving operational goals, there is potentially significant impact from the way in which the maintenance is coordinated and carried out. Scheduling of maintenance activity which may make key assets unavailable needs to be closely coordinated with the TMC operations team. This applies not only to time of day and day of the week, but also to the ability of the TMC to respond to scheduled activities (special events, executive visitations, tours). Of particular importance are maintenance activities which may take the entire system offline, such as an upgrade to the server hardware, operating system, or core communications devices.

Software Maintenance Software maintenance may include types of activity which are not normally experienced by a infrastructure focused agency. Software maintenance will include:

- Ongoing debugging of operational code
- Small system improvements
- Adjustments to suit user needs and desires
- Modifications to suit unexpected conditions
- Additional information requirements (reports)
- Testing and implementation of operating system, networking, and commercial software upgrades, and the application modifications necessary because of these
- Additional protocols and device interfaces as new equipment is added and as standards become available or evolve
- System modifications to improve performance
- Additional algorithms or modifications of algorithms
- Addition of field devices or adjustments of their locations
- Modifications of road network displays and vehicle routes

This list is not intended to be exhaustive, but does reflect a sample of the activity that will be required. Along with most software maintenance activities will be requirements for updates to system and user documentation, training materials, and software configuration information.

Computer Hardware Maintenance Computer hardware maintenance typically includes not only standard maintenance activity, but a planned replacement program to prevent obsolescence. This program typically reflects replacement of the equipment long before it malfunctions, but is necessary because of the difficulty in acquiring either replacement parts or contract maintenance service on units which have been out of production for more than a year or two.

Emergency Maintenance Resources

The concept of operations should consider how the TMC can access logistical resources under emergency conditions. This may include identifying other agencies reasonably close by who own identical equipment, and from whom it may be possible to obtain spares on short notice outside the normal agency procurement process. The manufacturer's regional distributors may be similar resources, or may offer overnight delivery for critical parts. Arrangements to download software patches from dial-up or Internet connections may be part of this program as well.

Specific response times can potentially be specified in any maintenance or support contract, although cost and response time vary inversely. This has been the practice particularly with computer and large communications equipment for years, and continues to be a practical alternative for the TMC. The prospect of addressing the transit demands of a Sunday afternoon Superbowl game with the local transit advanced vehicle location system completely offline can quickly justify the cost of a rapid response support contract.

How is Training Procured and Maintained/Updated?

Training in a maintenance environment is at least as challenging as it is in the operations environment. Although innovative procurement methods are available which reduce the range of needs for maintenance training (by purchasing fewer different brands and models of the same general device), in general the need for training increases along with the age and size of the TMC's system(s). Training needs continue as maintenance personnel turnover or as new personnel are added to the maintenance team.

The product vendor is a common source of maintenance training, and is often the first source, perhaps procured as part of the implementation contract. The advantages of vendor training are that the training deals with the specifics of the devices being maintained, and the course materials are often the exact maintenance manuals needed. For new equipment, repeat training should be planned. More general, often multi-product courses in some fields are available commercially, although out-of-state travel may be required. Several TMCs reported excellent results, for example, in accessing commercial courses in maintenance of fiber optic communications systems. Either type of training will need to address, if possible, the challenging task of maintaining equipment in place, possibly in the bus engine compartment, at the street corner controller cabinet, or at the top of a 50 foot camera pole.

> Milwaukee's MONITOR TMC has had success in procuring fiber optic maintenance training for its personnel from a commercially available course. Relatively little travel was required, and the course documentation serves as excellent reference material after the training is completed.

System Management

System management here refers to the administration of the computer resources supporting the TMC's activity. The elements that the concept of operations will need to address in system management include:

- Access control
  - Who controls system privileges, how many levels are maintained, how often passwords change
- Network management
  - What network management tool is used, what performance parameters are monitored
- Backups
  - When they are performed, to what media, where they are retained and how long, how quickly restorations can be made, whether they are partial or complete, whether real time "backup" is achieved through mirroring
- Materials and supplies
  - Who can distribute the supplies, who controls purchasing them, what quality standards are established
- Upgrades and bug fixes
  - How quickly after release these are implemented, by whom, how they are tested with the custom applications
- Troubleshooting
  - What training and tools are acquired, what arrangements are made for expert assistance
- Monitoring system performance
  - What performance parameters are monitored, what thresholds are established, whether high load simulations can be conducted, how impact assessments are made, what program of ongoing fine-tuning is implemented
- User support
  - How users (particularly non-prime shift users) contact the system maintenance team, what level of responsiveness is desired, what kinds of things users are responsible for doing themselves

- Participating in testing
  - How system management participates in planning, executing, witnessing, and defining acceptability of tests
- Participating in system acceptance
  - How system management participates in planning, executing, witnessing, and defining acceptability of the system
- Participating in training
  - How system management participates in training for the non-systems elements of the system, whose inner workings they may benefit from understanding

Maintenance Monitoring

Record Keeping As in operations, keeping accurate and complete maintenance records is an important activity, and should be recognized in the concept of operations. Records regarding the reliability of equipment and the actions taken for both preventive maintenance and repair support warranty claims and improved design and operations decisions. Although such records are often paper-based (although laptop and handheld computers are changing this) and made in the field, they are eventually recorded in a central maintenance management database for further access and analysis.

Analysis The most common analyses of maintenance data include:

- The effort and resources necessary to maintain certain devices or types of devices
  - Mean time between failures
  - Mean time to repair
- The performance of devices
  - Reliability
  - Extent and type of required repairs
- The overall effort necessary to maintain the TMC's resources
  - Manpower
  - Consumables
  - Tools, test equipment, support equipment

These records support the objectives of improving system design by including optimal equipment as a system grows or is updated, and of obtaining proper budgetary resources for the performance of necessary maintenance functions.

Process Improvement Maintenance, as with operations, can undertake ongoing process improvement based upon its experience and that of peer maintenance organizations. In cases of unique requirements, special procedures can be developed which reduce repair cost and increase operational stability.

Examples include:

- The special procedure developed by Arizona DOT for repairing gunshot damage to variable message signs, where the DOT has changed from replacing three-character panels to repairing single character modules, resulting in dramatically reduced cost and decreased downtime for the equipment
- Procedures developed by Wisconsin DOT for excluding vermin from controller cabinets during winter weather (entering via conduit) has increased system reliability, decreased maintenance cost, and improved safety to maintenance personnel
- Refining maintenance procedures to reduce or eliminate lane closures, such as executed by Caltrans also has significant positive impact on travel and maintenance safety
- Documenting inspection results during performance of preventive maintenance, also an Arizona DOT activity, can facilitate both design improvements and can speed repairs if emergency action is required.
- Identifying and replacing operationally inadequate equipment (electromechanical controllers/cabinet) with solid state controllers/ cabinets have significantly enhanced operations reliability, performance consistency, and traffic safety in the City of San Antonio.

Training and Documentation

Initial Training

Personnel

The concept of operations should identify the type and source of training for personnel at the start-up of the TMC. The training will cover a broad range of topics including:

- Background of ITS and purpose of the system
- Operational procedures
- Nonstandard operations (special events, emergency conditions)
- Use of the computer system
- System administration
- Capabilities of the field equipment
- Equipment maintenance, testing, debugging, and repair

The types of training chosen, training duration, base (assumed) skill levels, resources, and skill verification methods should be reflected in the concept of operations. The concept should also consider how the initial TMC personnel will be updated as the system is debugged or as work-arounds are established during the period of operational stabilization, which may last for 1-2 years.

Training Resources

The resources procured for training are likely to serve as references for operations personnel for an extended period, and will likely continue to be used for training of incoming personnel. They may also serve as the foundation from which updated training material will be prepared (see next section). Thus, the form of the resources (both the form provided to the trainees, and the form in which the training maintenance team receives them) should be considered in the concept of operations.

Such resources take a variety of forms. Typical training materials are provided in binders, divided into chapters by the functions performed. The materials are typically delivered as viewgraph images, perhaps accompanied by explanatory text, and exercises with solutions. Reference documents may also be provided as part of the text, including background and technical material on the TMC and systems, as well as directories and related materials on organizations with which the TMC may interact.

Alternatively, training material may be provided electronically, perhaps on a compact disk, or stored centrally and accessible from the system workstations. This process simplifies keeping the materials up-to-date, but complicates the addition of notes, and can leave the operator without assistance in the case of certain system or communication failures.

The training material is typically procedurally oriented, grouping families of related actions, and demonstrating how each is executed, with some explanation of what the operator's actions cause to occur, and of the response, capability, limitations, and other reasonable expectations for the operation.

Upkeep of Training Materials

An essential element in the concept of operations is the identification of the resources and process for upkeep of the training materials. Few systems are implemented completely in a single program. Instead, most systems both grow and evolve, reflecting the success of their operation, the lessons learned during system stabilization, and the changes in technology that become available over time. Thus, training materials will require periodic update. An element of the organization should be identified who will be tasked with this upkeep as a primary level duty.

As an example, Georgia DOT has established within its operations organization a training unit responsible for training materials, with a broader base than the TMC. Thus, they are able to retain specialized expertise in the field of training, and to justify the effort to apply modern technology (such as hypertext) to improving their training resources. Their training manager, who has direct experience in TMC operations management, works closely with the TMC operations and maintenance units to ensure that the training resources are complete and accurate. Thus, the TMC is assured that the materials describing its procedures are current, as are its directories and technical references. The training unit has spearheaded efforts to provide the maximum portion of the material online, and accessible either directly from the freeway management application or from the system level.

Ongoing Training

Refresher Training for Existing Staff

An often overlooked component of standard operations (and therefore the content of the concept of operations) is refresher training for existing staff. It is the nature of operations that the great majority of activity is repetitive. Thus, the staff becomes highly experienced in a relatively small portion of the total functioning of the TMC. Operation tends to become rote, performed from habit rather than from a full understanding of the reasoning behind the process. The greatest challenge and greatest risk occur when less common functions are required, typically during emergency operational conditions. Thus, a need exists for periodic retraining of staff in the full range of operational procedures.

> For example, at Boston's Central Artery/Tunnel Integrated Project Control System, the operations supervisor periodically convenes "desktop simulations" of operations, focused on less commonly applied procedures, and on application of standard procedures but under nonstandard circumstances. This practice is of above average criticalness to the Integrated Project Control System team, as they are responsible not only for management of traffic in and around the Central Artery/Tunnel, but also for the full range of systems control (ventilation, pumping, fire control, electrical, security) functions which are necessary for the safe passage of vehicles through the tunnels.

Training for New Functionality and for New Operational Methods

The other most common circumstances warranting additional training are the addition of functionality to the system and the alteration of operational methods. The majority of systems begin with only basic functionality. It is the nature of initial investments in technology in transportation that key decision-makers desire to see proof of the effectiveness of the investment before additional funding is provided. Thus, the initial implementation often includes only core functions provided over a limited area. As the system becomes operational and its benefits are demonstrated and documented, additional funding for expansion and enhancement is likely. Thus, new capabilities are added, necessitating additional training for existing personnel.

Staff also require additional training when new and improved operational methods are developed. If these are methods for commonly performed operations, the training may, in fact, need to be repeated periodically, until previous habits are thoroughly extinguished.

The concept of operations should identify how this training is to be prepared and delivered, when, to whom, and in what form. The concept of operations will need to recognize, for example, the challenge of providing training to personnel working late night shifts, and to identify a method for assuring operational continuity while training is underway. Particularly in cases where the new operational methods represent additional workload, the concept of operations must consider how new methods will be introduced in such a manner as will generate compliant (and hopefully enthusiastic) behavior by staff.

Documentation

The concept of operations should identify what documents will be required for system planning, design, implementation, operations, and maintenance, and should identify how and when each will be developed or maintained. Some thought is appropriate at this point regarding the form which each document will take, i.e., should it be printed or available electronically, and if electronic, from which workstations or systems should it be accessible. This process of identifying the core documents (including training documents) will ensure that each step of the system development and operation process will be thoroughly documented and supported. Guidelines regarding documents may be established within the concept of operations, such as naming the parties involved in document review. Commitments may be made by the participating agencies regarding their response to draft documents under review. This identification of documents will also support the funding of the complete documentation set, and will support consideration of standards for the document tools (word processors, charting, graphic arts) which will be used in their preparation and maintenance. Categories of documents to be considered include:

- Log books
- Commercial hardware and software documentation
- "As-builts"
- Operations guides
- Reference documents
- Directories and contact plans
- Standard agency policies and TMC policies
- System "Help" features
- Timing plans
- Run plans

Document Management

Due to the essential nature of the extensive documentation, and to the need to keep the documentation synchronized with the resources and procedures, a formal program of document management should be identified in the concept of operations.

Versions The most important step in assuring that a document is up-to-date is establishing a configuration control process. As with the center's systems, the effective date of the document version should be recorded and available. Typically, this includes a description of the changes made in the latest revision, and by whom they were made. The version numbering scheme itself is not particularly critical, other than that it should make clear which version supercedes which other. There should also be a convenient reference point at which staff can determine which is the current version of a document.

Process of Updating Of equal importance to knowing the state of the current document is controlling the process of updating the document. If there is no control on the process, the document may contain preventable errors, or exhibit simultaneous changes made at cross purposes or changes that make it less useful. A formal assignment of responsibility and process for changing key documents should be recorded in the concept of operations, and followed.

Document Access   In the ordinary TMC, documentation is commonly available in two ways: as a printed document or electronically (on magnetic media or online, perhaps across a network). In the TMCs we studied, only printed materials and direct online access were found.

Many TMC documents may be made conveniently available either installed on the workstation, or on a server accessible across the local or wide area network. The advantage of online access is the convenience of tools, such as hypertext, which can assist the reader in finding related information when searching for a specific topic.

> Georgia DOT's NaviGAtor TMC has implemented many of its core operational documents online, including several with a "hyperhelp" function

Typically, physical control of sensitive documents is achieved by serially numbering the documents, and maintaining a log of the assigned holder of the document. This procedure is then coordinated with the organization's employee arrival and departure procedures to ensure that document assignment is properly recorded, and that documents are returned when the employee departs. Although some measures are available to complicate the process of photocopying portions of the document, these are often less than wholly successful, even in cases of highly sensitive material.

Operational Procurement and Contracting

The procurement method that the TMC implementing and operating agency chooses can have a very significant impact on the cost, capability, and success of the facility. Often the types of procurement method that best suit the needs of such a facility and its systems are somewhat different from the procurement methods the agencies most commonly use, particularly among infrastructure (freeway and arterial) focused organizations.

Operations & Maintenance Benefits in the Procurement Process

> **Benefits of involving operations and maintenance in procurement**
>
> Supports inclusion of features supporting efficient operation and maintenance
>
> Provides "reality check" for life cycle cost
>
> Builds "buy in" by operations and maintenance staff
>
> Assists in assuring inclusion of training and documentation for support
>
> Assists in identifying appropriate selection criteria and contractor performance measures
>
> Improves transition from development/ implementation to operation/ maintenance phase

One of the most critical lessons learned in the nearly two dozen TMCs surveyed for this guide is the importance of working across internal organizational boundaries. An excellent example of this within the TMC environment is the attainable benefits of involving the operations and maintenance staffs in the process of procuring both the TMC systems, and potentially the operations, maintenance, and other services that support them. The operations and maintenance staffs have a unique, long-term (life cycle cost focused) perspective, and can often readily identify aspects of the design and contracts which minimize workload, improve safety, and increase overall performance and reliability. This same perspective can add significant value in overseeing the design, development, and implementation contracts.

> At Milwaukee's MONITOR TMC, design, operations, and maintenance personnel are involved in "inspection" of implementation (construction) contract work. Operations staff at the Phoenix TrailMaster TMC have been aggressively involved in defining improvement needs for the computer system, working closely with design and systems staffs.

Selecting A Contracting Approach

Method of Defining Requirements

Perhaps the most important activity leading to the procurement of a TMC is defining the requirements. As discussed earlier, the development of a detailed concept of operations is part of this process. Typically, the requirements are developed from the top down, i.e., starting with general statements, and proceeding to successively greater levels of detail. This is the way that the national ITS architecture can be used as a tool; it starts with general "packages" and proceeds eventually to the specific data flows between "centers" and the data elements moving in those flows. Another common resource for defining requirements is to examine requirements statements from comparable TMCs, and from other types of control centers such as those for electric power generation, air traffic control, and communications network control.

A critical feature in the process of defining requirements is how they are compiled. The requirements should reflect the needs of all relevant parties, including not only the agency or department with the agency which will design or implement the TMC, but all departments and agencies who will be partners in its operations and maintenance. Another equally important component of the requirements definition process is that all relevant organizational levels must be meaningfully involved. Both of these approaches work to achieve two goals in defining requirements:

- All requirements are identified
- All involved parties are committed to achieving the goals

Procuring the Designer and Contractor

Timeframe The time necessary to procure the TMC designer and contractor is driven primarily by the existing agency's (or agencies') procurement practices, including the number of contracts into which the work scope is divided. It is important that adequate time be allotted to fully identify the requirements for the TMC during the design phase, and that they are carefully traced to elements in the design. Similarly, it is important that adequate time be provided for competing contractors to understand thoroughly the plans and specifications for the TMC, and for errors and omissions to be identified and corrected before final bids are submitted.

Types of Procurement Processes A variety of types of procurement processes are available for use in implementing the TMC and its systems (including, potentially, the field equipment used by the TMC). As explained in the "FHWA Federal-Aid ITS Procurement Regulations and Contracting Options" (FHWA, 12/97), some alternatives include:

- Design/bid/build (including possible 2-step, or prequalification of designers and contractors)
- System manager/system integrator
- Design/build (including design/build/operate and design/build/warrant)

Each of these approaches has various strengths, including differences in the time, cost, and responsiveness (and the type) of the contractor.

Price The cost to implement a TMC varies greatly, depending upon many factors. Freeway management centers in the United States vary from a few hundred square feet in an existing facility to over 50,000 square feet in a dedicated multipurpose facility, such as Houston's TranStar center. Primary determining factors in the size of the facility are the number of agencies present and the number of functions performed in the facility. Co-hosting of an emergency operations center significantly increases the size and cost of the facility, but presents a unique capability for highly coordinated emergency transportation operations.

Caution is noted as a 'rule of thumb' for estimating costs of design and construction of TMCs. TMCs are relatively specialized facilities, requiring many skills not needed in more ordinary buildings such as schools, manufacturing facilities, or offices. Of particular concern are the aspects of power, communications, heating/ventilation/air conditioning, and human factors of such buildings, which are easily overlooked by architects, engineers, and contractors who are not specifically experienced with such facilities. Additionally, TMCs are often quite visible to politicians, the public, media, and fellow transportation professionals. Thus, they are likely to require a level of "fit and finish" which is appropriate to this level of visibility, but which is likely above the norm for standard agency buildings.

Firm Fixed Price

Cost Plus
Fixed Fee

Cost Plus
Award Fee

Cost Plus
Incentive Fee

Types of Contracts As also described in the "FHWA Federal-Aid ITS Procurement Regulations and Contracting Options," there is a variety of contract types available for acquiring the services and products necessary to implement the TMC. As with the types of procurement, the types of contract which work best may be somewhat different from those most commonly applied by implementing agencies, in recognition of the amount of technical content and the degree of complexity in the center. It is critical to recognize the possibility that change during the design or implementation may be necessary, requiring a contract type which can be easily modified to the satisfaction of all involved, and where both risk and price are fair and equitable.

Procuring System Expansion Including Alternative Methods

Procuring expansion(s) to the existing TMC can be accomplished in somewhat more expedited manner than would typically be required for the initial system planning, design, and implementation. Often, system expansions are procured as expansions of existing contracts, or as task orders under existing blanket or 'on call' contracts. Expansions may also be performed as comprehensive (design/build or system manager) projects, rather than as separate discrete contracts using a more conventional design/bid/build approach. This may also include having the software modifications carried out under the same expansion contract which would include the alteration of the physical facility. Alternatively, the agency may decide to perform certain parts of the expansion (such as purchase of computing hardware or furniture) which it would ordinarily not perform in an initial implementation project.

Procuring Operations and Maintenance Services

Concept of Operations as a Scope of Services The concept of operations, as a definition of the functions to be performed and how they are performed, serves as an essential element of the scope of services when contracting for operations and maintenance. It provides an exhaustive description of the activity of the TMC, second in detail only to the operations manuals themselves. It identifies both the procedure (as described in detail in the operations manuals) and the extent or total workload, both of which are necessary in order to identify the number and type of resources, and therefore the cost to perform operations and maintenance.

Types of Services The services procured by a TMC fall into several general categories, along general lines of operations, maintenance, general consulting, installation, inspection, and testing. These categories cross both internal and external systems, and both hardware and software.

- Console Operations Console operations, the duty of the traffic management operator, is perhaps the most commonly contracted TMC function. The skill level required of contractor personnel is driven both by the degree of automation provided, and the level of supervision (either agency or contractor provided supervision). Contracting console operations both allows the agency to free rationed personnel slots for use in jobs which require the perspective of an agency employee, and allows the agency to place the burden of dealing with flexible staffing requirements upon the contractor. Depending upon the specification for the services, contracts can be firm fixed price, cost plus, or performance based.

> Examples of operations contracting include console operations at the Long Island INFORM TMC, the Northern Virginia TMC, and of the Boston Central Artery/Tunnel IPCS. Interestingly, while New York State DOT and Virginia DOT have contracted with the private sector, the Massachusetts Highway Department's contract is with the Massachusetts Turnpike Authority, another public agency.

- Maintenance Maintenance is also a popular function for TMC owner agencies to contract. Often a TMC contracts either emergency maintenance or preventive maintenance, or occasionally both.   Maintenance contracts may take a variety of forms:

  - Maintenance can be contracted in a single comprehensive contract
  - Preventive and emergency maintenance can be contracted separately
  - Maintenance for specific devices (i.e., closed-circuit television cameras, variable message signs) can be contracted separately
  - TMC and field equipment maintenance may be contracted separately

Preventive maintenance, often the first duty sacrificed when workload exceeds agency staff capacity, can be ensured when it is contracted and thus made independent of agency manpower limitations. Some maintenance can be contracted directly from device installers or vendors. This is typically the case for computer equipment, commercial software, and communications equipment. Often the maintenance contractor is required to utilize existing warranties to the maximum extent possible.

> The Texas DOT contracted for support of its TransGuide advanced traffic management system software system. Milwaukee MONITOR receives support of its communication system as part of its communication services contract. Georgia NaviGAtor contracts for maintenance of its variable message signs. The ATSAC center uses an onsite contractor for system software maintenance and enhancements.

- Consulting The TMC may find that it needs a general assistance consultant. Such a consultant can assist in:
  - Process and product evaluation and improvement
  - Preparation of requests for proposals and evaluation of proposals
  - Outreach
  - System support
  - Configuration management
  - System integration and testing
  - Training and document support
  - Coordination of system expansion with ongoing operations

While this is not an exhaustive list of functions which can be performed by a TMC consultant, it is a fairly broad range of examples.

- Installation The TMC may retain a contractor to assist in installation of new or replacement equipment. The contractor may perform various installations under a single contract, or each implementation may be contracted separately. Similarly, the TMC may retain a single installation contractor, or may retain multiple contractors based upon specific skill areas (communications, electrical, carpentry and indoor finishing, heating/ventilation/air conditioning).

- Inspection A very commonly contracted service for TMCs whose systems are expanding is inspection. Inspection here is defined very broadly, including “inspection” of computer software development, which would be defined as “independent validation and verification” in other industries. Contracting of inspection allows the agency to call upon specialized skills, potentially for limited periods, which are otherwise unavailable within the agency. It also allows the agency to significantly decrease its risk of accepting defective systems, even in areas of unusual specialties, and reinforces the agency’s position in situations which may lead to claims by the installer.

- Testing Testing is a less common but highly contractable service for TMCs. The science of testing is relatively complex, and can be both tedious and time consuming. Testing (including final acceptance testing) is the last opportunity during which the agency has significant leverage on the contractor(s) to make desired/required changes to the system. Retention of a contractor to ensure effective and exhaustive testing is a relatively economical option available to the TMC owner agency.

Procurement Selection Processes

There are a variety of methods for selecting an operations and/or maintenance contractor for a TMC. Multiple methods may be required because of the different types of skills required, based on the concept of operations. Traditionally, lower levels of skill have been solicited based upon price, whereas greater technical capability is acquired based upon the extent of experience and expertise. Some agencies have identified procurement methods which allow consideration of both qualifications and price. Dependence upon price alone has created situations where the quality of service was compromised, whereas dependence solely upon qualifications has created difficulties in remaining within a target budget.

Contract Alternatives In addition to using agency personnel to perform operations and maintenance functions within the TMC, some agencies have contracted out for these services. Contract alternatives have included:

- Standard consulting contracts
  - Typically cost plus fixed fee, to a negotiated price
- Temporary services
  - A specified base skill level and a per-hour rate
- Performance based contracting
  - Specific activity level objectives identified, and compensation dependent upon performance against these objectives

Each of these deals differently with the level of detail provided in the scope of services, and with the type of skills required and the variability of activity level in the operations and maintenance effort.

> The INFORM system on Long Island has been operated by consultants for several years. Typical operations personnel are experienced controllers (primarily air traffic controllers), capable of making judgments regarding the deployment of transportation management resources. Virginia's Smart Travel Northern Virginia TMC is staffed with personnel from a temporary services agency, who do not bring any extensive education or experience in traffic or transportation, or control center operations. These personnel must follow the written procedures closely, and are highly dependent upon the automated operation of the system. The San Francisco bay area Metropolitan Transportation Commission is proceeding with the performance based procurement of a system manager contractor for the TravInfo traveler information system in the San Francisco bay area. In this arrangement, the contractor will be expected to perform to documented levels of activity and success on a variety of factors.

Procurement Issues There are a number of potentially complicated issues in TMC service contracting:

- Longer contracts reduce procurement related administrative workload and create an incentive to reduce prices, but may make it more difficult for the agency to escape from a sub-optimal contract situation.
- Contractor performance can be influenced by many external factors beyond the contractor's control. Contractors may also be able to influence the performance factors working more to the letter than to the intent of the contract. Also, penalties that are too severe may place the contractor's business in jeopardy, whereas penalties which are too mild provide little incentive to improve.

- Standard agency payment processes may create situations where contractors must carry the cost of staff for an extended period before agency payment is received. As operations and maintenance contracts generate no identifiable "deliverables," payments based upon such measures may be difficult to trigger.
- The level of liability falling upon an operations contractor is often greater than that which would be borne by the contracting agency, due to the sovereignty of the governmental body. Thus, the agency winds up paying for a level of risk which did not exist when it performed the services itself.
- If the agency has the contractor provide tools, test equipment, and replacement parts, then the agency may pay a significant markup (or the contractor may not be fairly compensated for the cost of acquisition). If the agency provides these, the contractor may be disabled by difficulties in the agency procurement process, and may have little incentive to be frugal in their use.

Part 5: How Can I Find Out More?

Related Documents

Sample Design Documents

Review of design documents from peer agencies can provide significant insight when planning a TMC. Information could be made available from the TMCs investigated for this study (see reference list later in this section). An additional source of locations with operational TMCs is the Intelligent Transportation Infrastructure deployment status database maintained by Oak Ridge National Laboratory for USDOT, which is accessible via the ITS Joint Program Office's website (http://www.its.dot.gov).

Contacts at TMC Sites Visited		
Contegni, Joseph P.	Director of INFORM	New York State DOT
Gordon, James F.	TMC Operations Manager	Georgia DOT Transportation Management Center
Luchian, Sergiu F.	Projectwide Engineer	Massachusetts Highway Dept. Boston Central Artery/Tunnel Project
Shea, Jim	Manager, Traffic Operations Center	Arizona DOT
Whaley, John R.	Director	Greater Houston Transportation and Emergency Management Center
Young, Stephen D.	Freeway Operations Supervisor	Wisconsin DOT
Zeigler, Sam	TMC Manager	GDOT Transportation Management Center
Randy Bundy	Traffic Systems Manager	City of Atlanta
James Young	Project Manager ITS	Atlanta MARTA
Brian Gallagher, P.E.		City of Los Angeles
Ron Herrington, P.E.		City of Lexington, KY
Aubrey Burton	Assistant Supervisor	Washington, D.C. WMATA
Bill Corder, John Riehl	Sr. Engineer Technician	Montgomery County, MD

Human Factors Guidelines

The Georgia Tech Research Institute has developed a set of guidelines on advanced traffic management system human factors for FHWA, based upon learning from control centers outside of ground transportation, and upon simulation and laboratory work performed at the university. These guidelines (Human Factors Handbook for Advanced Traffic Management Center Design) are available from the ITS Electronic Document Library (EDL number 10303).

Institute of Transportation Engineers Recommended Practice for ITS Operation and Management

The Institute of Transportation Engineers conducted a series of workshops over a 3-year period to develop recommended practices for operations and management of ITS. Although the recommended practices are broader than TMC activity, they provide an excellent resource to use in planning or examining TMC practices. The practices will be available from the Institute's bookstore (web address http://www.ite.org).

Proceedings from the Institute of Transportation Engineers TMC Operations and Management Workshop

The Institute of Transportation Engineers convened three workshops during the preparation of its recommended procedures for operations and maintenance of transportation management systems, and has since conducted additional workshops and training courses in this area. Proceedings from these events may be available from the Institute's headquarters, at 202-554-8050.

Proceedings of Peer Workshop

In December 1998 a meeting of TMC operations professionals was convened in Phoenix under the auspices of United States DOT. This workshop shared the experiences of each TMC in ongoing operation.

NCHRP Synthesis 270

NCHRP Synthesis 270, Transportation Management Center Functions, A Synthesis of Highway Practice, documented functions of freeway management centers, and thus provides an extensive list of the types of activities which should be considered for inclusion in the freeway management TMC concept of operations. This document is available from the Transportation Research Board by phone at (202) 334-2933, or from the Transportation Research Board's online bookstore at web address http://www.nas.edu/trb.

Training

Relevant Professional Capacity Building Courses

The professional capacity building program develops and delivers around the country courses relevant to planning, design, deployment, operations, maintenance, and evaluation of ITS. The course catalog is available at http://www.its.dot.gov/pcb/98catalg.htm, and the master course schedule is available at http://www.nhi.fhwa.dot.gov.

Contact(s) at United States DOT

On the rear inside cover of this document, the reader will find a comprehensive list of the FHWA and FTA resource centers which can be contacted for assistance with transportation management center issues. On the rear outside cover, a phone number has been provided at the United States DOT ITS Joint Program Office, where the reader can receive direction to United States DOT headquarters staff who will be able to assist with transportation management center issues.

Peer-to-Peer Program

The peer-to-peer program provides pubic sector contacts who are willing to assist other agencies with questions and issues related to ITS implementation. This includes both telephone assistance and site visits for meetings/ presentations/discussions. To learn more about the program, visit their website at http://www.nawgits.com/fhwa/peer. Peer-to-peer services can be obtained by calling 1-888-700-7337, or by sending e-mail to dotpeer@erols.com.

Relevant Association Committees

For more information regarding transportation management centers and transportation management operations and maintenance, interested readers are referred to:

- The Advanced Traffic Management Systems and Advanced Public Transportation Systems Committees of ITS America
- The Transportation Research Board's Freeway Operations and Traffic Signal Systems Committees
- The American Public Transit Association
- The American Public Works Association
- The Institute of Transportation Engineers
- The American Public Works Association
- The American Association of State Highway and Transportation Officials
- The American Traffic Signal System Association

How Can I Find Out More About Concepts of Operations?

Documents

There are several sources for additional information which would be helpful in developing a concept of operations for a TMC. Printed resources which may be particularly helpful include related documents in this series of documents, including the TMC Concept of Operations Cross Cutting Study (federal document number FHWA-JPO-99-020, EDL number 10923), and the 8 TMC Case Studies (federal document numbers FHWA-OP-99-003 through FHWA-OP-99-010, EDL numbers 10943, 11063, 10944, 10963, 10983, 11103, 11123, and 11124). This Implementation Guide is available as EDL number 11494. A third quite useful document is the National ITS Systems Architecture, and particularly the Theory of Operations within it. The National ITS Architecture is available at web site http://www.odetics.com/itsarch.

Training

There are presently no training programs directly oriented to the preparation of a concept of operations for a TMC. However, the interested reader is directed to the web site for the National Highway Institute (http://www.nhi.fhwa.dot.gov) and the National Transit Institute (http://www.nti.fta.dot.gov) where the most recently available related course work can be found, including courses on the application of the systems engineering process and the use of the National ITS Systems Architecture in planning, design, implementation, and operations/ maintenance of ITS facilities.

Contacts

For appropriate follow-on contacts, the reader should investigate the directory in the pages preceding the rear cover of this document.

Acknowledgments

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- The Michigan Department of Transportation, and especially its MITSC TMC
- The Wisconsin Department of Transportation, and especially its Milwaukee MONITOR TMC
- The New York Department of Transportation, and especially its INFORM TMC and its operations contractor, Parsons Brinckerhoff Quade & Douglas
- The Georgia Department of Transportation, and especially its NaviGAtor TMC
- The Texas Department of Transportation, Harris County, the City of Houston, and Houston Metro, and especially their TranStar TMC
- The Massachusetts Highway Department, the Massachusetts Turnpike Authority, and especially their Integrated Project Control System TMC
- The Ministry of Transportation, Ontario, and especially their COMPASS TMCs in Downsview, Burlington, and Mississauga
- The Montgomery County, Maryland Department of Public Works and Transportation, and especially their Transportation Management Center
- The Washington Metropolitan Area Transportation Authority, and especially their train control center
- The City of Atlanta
- The Metropolitan Atlanta Rapid Transit Authority
- The City of Los Angeles, California
- The City of Lexington, Kentucky
- The Mitretek Corporation
- The Oak Ridge National Laboratory

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For further information, contact:

Federal Highway Administration Resource Centers

Eastern Resource Center
10 S. Howard Street
Suite 4000 – HRC-EA
Baltimore, MD 21201
Telephone 410-962-0093

Midwestern Resource Center
19900 Governors Highway
Suite 301 – HRC-MW
Olympia Fields, IL 60461-1021
Telephone 708-283-3510

Southern Resource Center
61 Forsyth Street, SW
Suite 17T26 – HRC-SO
Atlanta, GA 30303-3104
Telephone 404-562-3570

Western Resource Center
201 Mission Street
Suite 2100 – HRC-WE
San Francisco, CA 94105
Telephone 415-744-3102

Federal Transit Administration Regional Offices

Region 1
Volpe National Transportation Systems Center
Kendall Square
55 Broadway, Suite 920
Cambridge, MA 02142-1093
Telephone 617-494-2055

Region 2
Alexander Hamilton Federal Building
1 Bolling Green, Room 429
New York, NY 10004
Telephone 212-668-2170

Region 3
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Telephone 215-656-7100

Region 4
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