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Human Factors in Traffic Management Centers: A Literature Review

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16. Abstract

The number of vehicles is increasing faster than the number of new roads being built, resulting in more freeways experiencing heavy traffic. Although traffic management centers (TMCs) are not new, growth in their number has only occurred recently. The purpose of this project was to review the current literature on human factors and interview local TMC personnel to address these 4 questions:

1. What are the goals, methods, and technologies used by TMCs?
   The 5 ideal goals are 1) maximize the available roadway capacity, 2) minimize the impact of incidents, 3) contribute to the regulation of demand, 4) assist in emergency services, 5) create public confidence in the TMC.
2. How are TMCs similar to control centers in other domains?
   TMCs have been compared to air traffic control (ATC), vessel traffic services, and computer network management. Although some similarities existed, little evidence of human factors considerations existed in any domain except ATC.
3. What TMC human factors studies or guidelines exist?
   Previous studies have examined operator capabilities, monitor viewing distances, camera controls, and other TMC systems. Georgia Tech provided guidelines in the *Human Factors Handbook for Advanced Traffic Management Center Design*.
4. What TMC human factors topics require further research?
   Several TMCs mentioned a need for traffic-information website guidelines.

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Human Factors in Traffic Management Centers : A Literature Review

UMTRI Technical Report 99-5
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1 Background

Building more roads to meet the increasing traffic demands is often not fesible due to the high construction costs and the lack of available space in urban areas. To support more efficient use of the existing road network, the United States passed the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991. The Transportation Equity Act for the 21st Century (TEA-21) replaced the ISTEA in 1998 and guarantees funding for many intelligent transportation systems (ITS) and safety-related projects from 1998 to 2003. Advanced traffic management sytems (ATMS) is one of the primary ITS applications. Two key aspects of ATMS have been efforts to communicate information about traffic congestion to the public and efforts to manage traffic congestion.

2 Issues

Traffic management centers (TMCs) are one core element of ATMS. If TMCs are to be effective, they should be easy to operate and provide useful information to the public and to traffic control personnel in a timely manner. The purpose of this report was to review the current literature on human factors considerations in the TMC. Additionally, supporting interviews were conducted at local Michigan traffic management centers. From the literature review and the interviews, future research needs were identified. The following 4 issues were examined in this report:

1) What are the goals, methods, and technologies currently used by TMCs?
2) How is traffic management both similar to and different than other domains?
3) What TMC human factors issues have already been studied?
4) What guidelines already exist for the design of TMCs?

3 Findings

1. What are the goals, methods, and technologies currently used by TMCs?

According to Folds et al. (1993), the mission of an ideal traffic management center is "*to facilitate the safe movement of people and goods, with minimal delay, throughout the roadway system.*" In support of this mission statement, the following 5 objectives or goals universal to all TMCs were identified:

1) *Maximize the available capacity of the area-wide roadway system.*
2) *Minimize the impact of roadway incidents (accidents, stalls, and debris).*
3) *Contribute to the regulation of demand.*
4) *Assist in the provision of emergency services.*
5) *Create and maintain public confidence in the TMC.*

2. How is traffic management both similar to and different than other domains?

The Devoe et al. (1979) study revealed many human factors problems with the design of vessel traffic service centers that were also common to traffic management centers. Although there are many similarities between them, little evidence of human factors considerations was found in regards to the design vessel traffic services centers.

3. What TMC human factors issues have already been studied?
At the time of this report, several published empirical human factors studies specific to issues encountered in traffic management centers were found in the literature. The studies were conducted at the Georgia Tech Research Institute, the Texas Transportation Institute, and the University of Michigan among others. These papers cover the following topics:

	GT	TTI	UM
1) Required operator capabilities	√		
2) Monitor-viewing distances and camera controls	√		
3) Usability of computer based operator support systems	√		
4) Design of incident detection support systems	√		√
5) Design of message posting systems	√	√	

4. What guidelines already exist for the design of TMC's?
The only well known set of guidelines, *Human Factors Handbook for Advanced Traffic Management Center Design* (Kelly, 1995), was written at the Georgia Tech Research Institute. Most of the guidelines in the handbook tend to be very general in nature (e.g., Guideline 3/10 - Consider Operator Workload); however, given an audience with limited human factors expertise, the guidelines and format appear to be very useful and easy to follow. Topics include:

1) Principles and methods of user-centered design
2) Function allocation
3) Basic human error and error-analysis methods
4) Basic human performance limits (stress, attention, memory, and decision making)
5) Job design and workload
6) Anthropometry and physical ergonomics in design
7) Displays, data presentation, and controls
8) Basic user-computer interface design

4 Conclusions & Recommendations

The Georgia Tech guidelines seem fairly complete and detailed, so to prioritize the guidelines and identify gaps would not be the best use of remaining resourses. It was apparent, however, that there was not much data to guide system developers with regards to information dissemination. Further, an examination of current practice identified a growing use of the web as an information dissemination, but no guidelines specific to map-based web sites. Therefore, it is recommended to shift the attention of the project to the following topics:

1) What are the advantages and disadvantages of various information dissemination mechanisms ?
2) What design guidelines should be followed for an easy-to-use traffic-information web site?

5 References

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2) Folds, D., Brooks, J., Stocks, D., Fain, W., Courtney, T., & Blankenship, S. (1993). *Functional Definition of an Ideal Traffic Management System.* Atlanta, Georgia: Georgia Tech Research Institute.

3) Kelly, M.J. (1995). *Human Factors Handbook for Advanced Traffic Management Center Design.* Atlanta, Georgia: Georgia Tech Research Institute.

PREFACE

This report represents the first of several in a project funded by the Matsushita Communication Industrial Co. Ltd. (Panasonic) at the University of Michigan Transportation Research Institute (UMTRI). Mark Kojima served as the project liaison from Panasonic.

The purpose of this effort was to review the current literature on human factors in the design of traffic management centers, interview personnel at several local traffic management centers, and identify topics that need further research.

The interviews were conducted at the Michigan Department of Transportation's (MDOT) Detroit Metropolitan Transportation Center and at the Road Commission for Oakland County's traffic management center. We would like to thank Tom Mullin and Ray Klucens of MDOT and Gary Piotrowicz of the Road Commission for Oakland County for their time and efforts to make the interviews possible.

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INTRODUCTION

Overview

As reported by the Federal Highway Administration's *Highway Statistics Summary to 1995*, in 1995 there were over 201 million vehicles registered in the United States and over 176 million licensed drivers who travel a total of over 2.4 trillion miles each year. Although both the number of vehicles and the number vehicle miles driven have more than doubled in the past 25 years, the number of miles of road has only increased by about 5 percent (from 3.73 to 3.91 million miles). (See Figure 1.) Given the increased demand without increased capacity, it is not surprising that the Federal Highway Administration currently estimates that 13.4 percent of the interstates and freeways in urban areas frequently experience heavy or near capacity traffic, which generally leads to reduced speeds and increased travel time. Even worse, 17 percent of the interstates and freeways frequently experienced traffic levels at or above their capacities causing instabilities in flow, more commonly known as "stop and go traffic."

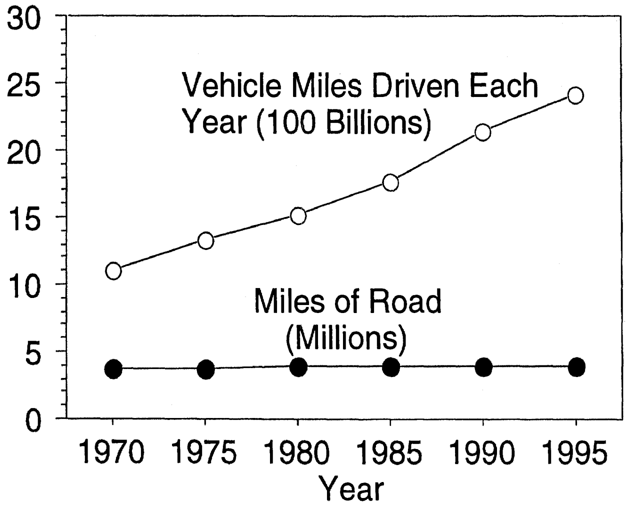

Figure 1. Changes from 1970 to 1995 in miles driven and miles of road.

Building more roads to meet the demand has become difficult, if not impossible, due to the high costs associated with highway construction and the lack of available space in urban areas. This prompted the United States to pass the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991. ISTEA established the IVHS (intelligent vehicle-highway systems) program (currently known as ITS, intelligent transportation systems) with the goal of improving the safety and efficiency of surface transportation. Along with increases in safety and efficiency, ITS also promises to minimize the impact of motor vehicles on the environment (Hancock and Parasuraman, 1992).

As mandated in ISTEA, the organization now known as ITS America (a national public/private partnership) was empowered with the task of coordinating the development and deployment of ITS. At present, the ITS movement is still a fairly decentralized venture of the federal, state, and local governments, researchers, auto manufacturers, and other private entities such as electronics and software companies. The ITS movement is decentralized in the sense that each city has formed its own partnerships to develop the technologies it feels most appropriate. The current authorization and funding for ITS projects in the United States comes from the Transportation Equity Act for the 21st Century (TEA-21). TEA-21 guarantees funding for many ITS and safety-related projects from 1998 to 2003.

Two key efforts promoted by ITS include an effort to communicate information about traffic congestion to the public and an effort to manage that traffic congestion. In the near future, traffic management centers will play a key role in information collection and dissemination, traffic-capacity optimization, and automotive-safety enhancement. Although traffic management centers have existed in some cities for decades, growth in their number is only a recent occurrence. To date, some 75 urban centers throughout the United States have traffic management centers or programs. Information about specific cities and the technologies they employ is archived on the Oakridge National Laboratory Intelligent Transportation Infrastructure Deployment web site (http://itsdeployment.ed.ornl.gov/).

Issues

If traffic management centers are to be effective, they should be easy to operate and provide useful information to the public and traffic-control personnel in a timely manner. The purpose of this report was to review the current literature and research on human factors considerations in the design of traffic management centers (TMC). Additionally, interviews were conducted at two local Michigan traffic management centers. Between the literature review and the interviews, it was hoped that insights could be provided on the directions where future research was needed. The following 5 broad issues were examined in this report:

1. What are the goals, methods, and technologies currently being used by traffic management centers?
2. How is traffic management both similar different than other domains?
3. What traffic-management-center human-factors issues have already been studied?
4. What guidelines already exist for the design of traffic management centers?
5. How should TMC tasks be allocated between operators and equipment?

AN OVERVIEW OF THE TRAFFIC MANAGEMENT CENTER

History and Organization

The most prevalent theme echoed in the literature on traffic management centers was that each center is unique. Generally speaking, two types of centers exist: (1) very new centers and (2) legacy centers. The legacy centers generally started smaller in size and staffing, lower in technology, and more specific in their mission since they were created for more immediate needs. One good example is the center in New York City. Its initial purpose was to control the signal timing throughout the city and monitor the tunnels leading to Manhattan Island for incidents. Currently, under the 1996 Federal Highway Administration's Model Deployment Initiative, the New York legacy traffic management centers are evolving to provide travelers with real-time travel information by integrating of information provided by 14 different area agencies.

Legacy traffic management centers are often faced with the challenge of taking on new roles and responsibilities, causing the need to increase in size and staffing. Whereas before these centers operated independently, they now need to develop lines of communication and partnership agreements with other agencies. Finally, one of the most critical problems faced by legacy centers is dealing with evolutionary technology upgrades. The technology used to monitor older sections of the roadway may be completely different than the technology used to monitor the newer roadway sections. As noted in several interviews with local Michigan traffic management centers, these issues of integrating older and newer systems often prove to be the most problematic from both a technical standpoint and an interface-design standpoint.

Center uniqueness is also a result of the organizational relationships within and outside the center. Traffic management centers can be run by a multitude of government branches including state, county, and city transportation agencies. Funding for a specific center generally comes in varying amounts from several sources including the aforementioned government branches and from private company partnerships. According to surveys sent by the Federal Highway Administration (Alsop, 1996), these private partnerships can include the following:

- Joint ventures between government branches (e.g., state and city governments build a joint center)
- Contracted services (such as a private company running the day-to-day operations of the state's traffic management center)
- Contracts with software providers for additional software development and expansion
- Hardware or communications agreements (such as a local phone company providing lines of communications between centers)
- In-vehicle-technology field testing with automakers or electronics manufacturers
- Information dissemination partnerships or agreements (with radio stations, cable TV, and local and cellular telephone companies)
- Coordination with major sports arenas, civic centers, attractions, and public transportation providers for special events

Furthermore, each center may also have varying partnerships or agreements with emergency services (police, fire, and ambulance), motorist-assistance programs, and road maintenance agencies. In some cities (e.g., Detroit) the traffic management center is collocated with the 911 police dispatch center. In other cities (e.g. Chicago), the traffic management center is closely linked to its own emergency patrol vehicles, which provide both general motorist assistance as well as the first emergency response to an incident. Each of these relations and partnerships affects the flow of information to and from the individual traffic management center.

This list of partnerships is not exhaustive. As the ITS movement grows and evolves, more partnerships will occur. In the near future, traffic management centers may expand their control through partnerships to provide information on daily and special-event parking availability. Increased coordination with and reporting of road construction delays would also seem to be the next logical step. Finally, as more states, counties, and cities build traffic management centers, overlaps between centers will require partnerships or agreements between adjacent centers.

Summary of Goals

Folds, Brooks, Stocks, Fain, Courtney, and Blankenship (1993) attempted to identify the mission and goals of an ideal traffic management center through a series of interviews with designers and operators. The interviews determined that the overall mission of a traffic management center was "*to facilitate the safe movement of people and goods, with minimal delay, throughout the roadway system.*" In support of this mission statement, 5 ideal goals or objectives universal to all traffic management centers were also identified and are listed below.

1. *Maximize the available capacity of the area-wide roadway system.*

Since ITS has grown from the fact that new roads cannot be built to meet the capacity needs of today and tomorrow, it is not surprising that one goal of the traffic management center is to maximize the available road capacity. The throughput can be increased by distributing the traffic load more evenly throughout the roadway network and throughout the day. Accomplishing this goal means diverting traffic from highly traveled routes to alternate routes and influencing trip-departure times. Interestingly enough, as noted by Hancock and Parasuraman (1992), the goal of optimizing system-wide traffic flow is seemingly counter to the goals of other ITS technologies, because in order for the TMC to optimize the flow on the network, it must undoubtedly suboptimize the travel times for many individuals.

2. *Minimize the impact of roadway incidents (accidents, stalls, and debris).*

Incidents are perhaps the single worst threat to efficient and predictable traffic flow, because they can severely reduce the available capacity on a freeway. Several studies from Detroit, Chicago, and Texas (Everall, 1972) showed that incidents caused a capacity reduction disproportional to their actual severity. Thus, a single lane blockage on a 3-lane freeway would reduce the capacity by 50 percent even though only 33 percent of the freeway's physical capacity had been eliminated. Furthermore, capacity was often reduced by as much as 33 percent even when no lane blockage occurred (when incidents were on the shoulder or in lanes in the opposite direction, a phenomena known as gapers block). Although the prevention of some incident types is possible through ramp metering and messages providing advanced warnings of congestion, preventing all incidents is currently impossible. Thus, the rapid detection and removal of incidents is critical to maintaining optimal traffic flow.

3. *Contribute to the regulation of demand.*

Typical congestion can be thought of as overcrowding. It occurs when the demand for a road exceeds its capacity (Everall, 1972). If the demand is increased due to a special event (sporting events, concerts, fairs, etc.), then congestion is likely to occur. Similarly, if the capacity is reduced due to major incidents, weather, or construction, then the demand is likely to exceed the reduced capacity, causing congestion. In these circumstances, the traffic management center may proactively or reactively try to persuade drivers to reschedule trips, reroute trips, carpool, or take public transportation. To accomplish this, relations must be established between the traffic management center and the media, event organizers, construction companies, and local attractions, so that timely information can be provided to travelers.

4. *Assist in the provision of emergency services.*

Although the strategies and methods may vary between control centers, most modern traffic management centers have been charged in one way or another with assisting or coordinating emergency services. At the very least, when incidents such as crashes or stalled vehicles are detected, the traffic management center will need to contact an emergency service to assist the motorists. Often when traffic management centers are equipped with cameras that can see the incident, the role of the operators will include coordinating the incident response by providing any necessary details such as injuries or towing needs to the emergency dispatch operator. In this role, the traffic management center can enhance the safety of the motorists by providing faster medical care or by providing aid to stranded motorists.

The extent to which traffic management centers assist emergency services is by no means limited to road incidents. In the event of an emergency evacuation, such as for a hurricane, the traffic management center may play a large role in coordinating the evacuation and directing traffic to safety. Similarly, in the event of a fire or nontraffic-related incident, the traffic management center would help route emergency services to the incident. One incident of this nature occurred when an airliner crashed next to a major freeway in Holland. The traffic management center was required to coordinate emergency vehicles, helping them to reach the disaster site without delay.

5. *Create and maintain public confidence in the TMC.*

Critical to the success of any traffic management center is its ability to maintain the public's trust and confidence. Since the center does not have control over individual vehicles (namely their routes, destinations, or times of travel), the center must rely on its ability to influence the decisions of drivers. As noted by Hancock and Parasuraman (1992), the central assumption behind the first 4 goals stated above is that typical drivers will be informed of traffic congestion, rationally decide to avoid the congestion, and act accordingly to minimize its impact on their travel (helping to alleviate congestion). If the information provided by the traffic management center is not timely, accurate, and complete, then drivers will learn to mistrust the information, and the traffic management center will lose what little influence it had on traffic.

Imagine the frustration and annoyance experienced by drivers receiving inaccurate information about an incident in the express lanes, prompting them to select the local lanes, only to find out that the incident did not exist, and the advice broadcast by the traffic management center unnecessarily delayed their trip. Equally frustrating to drivers is incomplete information. During an event on Chicago's museum row, portable variable message signs were placed along the freeway informing drivers of congestion ahead and diverting traffic headed towards museum parking to an alternate exit. Once the stream of cars exited the expressway, no other information was given. Ironically, the surface-street signs for museum parking directed the cars right back onto the freeway, further adding to the congestion and confusion.

Lessons from past traffic management centers have shown that the implementation of new technologies can also have long-lasting effects on the public's opinion of the traffic management center. For the Minnesota Department of Transportation (Stehr, 1991), the worst public reaction to their ITS program came from the implementation of ramp metering. During the first few days, ramp metering produced excessive surface street congestion, bus delays, and countless letters of protest. Although later implementations of ramp metering were more gradually introduced having less impact on the surface-street traffic, resentment towards the ramp-metering system still exists despite the improvements in freeway traffic flow provided by the system.

Although these 5 broad goals ideally apply to all traffic management centers, not all traffic management centers have found these goals feasible to achieve. Interviews with local Michigan traffic management centers revealed that operationally, many of these goals are unattainable. For example, when alternate routes are not available or adequate public transportation systems do not exist, the traffic management center can do little to affect the driver's route or mode of transportation. Similarly, if the center does not have adequate camera coverage, funding to fully staff the center, and partnerships with a centralized police dispatch center, then there is little that the center can do to assist in the provision of emergency services during incidents.

Since the capabilities of the centers are always changing, the goals and methods also tend to change with time. Although both of the interviewed centers originally set out to detect and manage incidents, it became apparent later on that neither center was technologically capable of detecting incidents (through sensors or video) faster than drivers would report an incident using their cell phones. As new technologies emerge, such as enhanced, cell-phone 911 service and in-vehicle crash-detection systems, it is likely that the capabilities of the traffic management centers will continue to change allowing some to better achieve the idealistic traffic management center goals.

Methods and Technology

Although the current technology in many fields changes rapidly, the methods used by and available to traffic management centers have remained relatively unchanged for the past few decades. Understanding the cognitive demands and human factors issues involved in traffic management center design requires understanding of the flow of information both to and from the traffic management center. The center collects information about the current traffic conditions from many sources (see Table 1). The sources can be classified into three general categories: (1) remote telemetry, (2) visual images, and (3) verbal reports. A primary task of the traffic management center is to integrate all of the different information sources (which may not all arrive at the same time) and create a representation of the current traffic situation.

The most common form of remote telemetry is from loop detectors embedded in the pavement. These devices provide binary information about the presence or absence of vehicles above them. Using computers, loop-detector data can be processed to provide lane-occupancy and speed information. Other information provided by remote telemetry can include (1) the state of variable message and highway advisory radio signs, (2) the state of closeable gates, barriers, and the signs used in conjunction with these reversible lanes, and (3) the state of remote communication systems.

A second source of information comes from the visual images provided by remote cameras. These cameras can be used to monitor the state of traffic flow and the status of many remote systems (such as the gates, barriers, and variable message signs). They are also used to detect, verify, or monitor incidents on the road. Operators may have access and control over as many as 100 or more cameras (and some centers are planning to increase the number to over 300).

The final source of information received by traffic management centers is from verbal reports. Generally, these are phoned in or overheard from other broadcasts (either independent, commercial-radio traffic reports or police and private radio). The reports could involve incidents, stranded motorists, or infrastructure maintenance needs.

Although the traffic management center has limited direct control over the traffic, a few methods of direct traffic control were found to be used by some centers and are listed in Table 2. As mentioned earlier, the traffic management center's ability to quickly assist in detecting and clearing incidents is, perhaps, the most effective means of traffic control. Other methods such as ramp metering and the use of reversible lanes are only effective in certain circumstances.

The majority of the traffic management center's influence comes from the center's ability to advise travelers by providing them with real-time traffic information, incident locations, and alternate routes. To categorize the different information dissemination technologies and strategies used by various centers, the Federal Highway Administration administered a survey to 31 traffic management centers (Alsop, 1996), the results of which are summarized in Table 3.

Table 1. Information sources.

Technology	Description and Uses
Inductive loop detectors	Embedded in or buried under the pavement, these devices detect the magnetic fields of vehicles. They can be used alone for occupancy data or in pairs spaced ~20 feet apart for speed data (typical sample rates of 30+ Hz).
Other nonintrusive magnetic, acoustic, microwave, infrared, or ultrasonic sensors	Similar in function to the inductive loop detectors, only using other technologies for vehicle detection. (U.S. Department of Transportation, 1997.)
Electronic toll collection, (ETC) (http://www.ettm.com/)	Although ETC was primarily developed to fully automate toll collection improving traffic flow at toll booths, cities such as Chicago are using the ETC sensors and cameras to estimate traffic conditions on the tollways where no other information infrastructure exists.
Remote telemetry	Although the loop detectors and sensors previously mentioned fall into this category, the TMC may also receive remote telemetry on the operating conditions of VMS signs, reversible lanes, gates, and barriers, lighting, cameras, and other equipment.
Closed-circuit TV	Cameras currently provide video images for operators to detect/verify incidents, monitor traffic conditions, and verify variable message signs or other equipment states. Newer video detection software may also be used to turn CCTV cameras into virtual loop detectors, automatic incident detectors, and travel time estimators (based on license plate tracking).
Aerial surveillance	Helicopters are used by many news stations to provide independent traffic updates to their listeners. Although most centers do not have their own aerial surveillance, they may share information with others who do.
Emergency callboxes or telephones	Generally placed along the roadway or at accident investigation sites to assist stranded motorists. Calls may be routed to the TMC or to 911 dispatch (police) directly.
Cell phone hotlines	Some TMCs have hotlines where motorists can call in to report an incident. Others have contracted out motorists with specific daily routes to report traffic conditions and travel times.
Motorist assistance	Many TMCs operate or are partnered with a motorist assistance or emergency traffic patrol program which can provide traffic and incident reports.
Police reports	TMCs often exchange information with police and emergency services through partnership or by monitoring the police band radio.

Table 2. Direct controls over traffic flow.

Technology	Description and Uses
Police, motorist assistance, and maintenance crews	In the event of a crash, road incident, or equipment failure, the TMC can call upon others to assist in dealing with the incident and returning traffic flow back to normal.
Traffic light timing	Many legacy TMCs were built to control traffic signal timing, and thus the operators can adjust the timing on arterials if diverting traffic from the freeways becomes necessary.
Entrance ramp closures	Congestion often occurs when freeway entrance ramps are too densely spaced or have poor geometries (causing entering traffic to merge at slower than normal speeds). Although rarely used, peak-period ramp closures have been used in several cities to aid in reducing localized freeway congestion.
Entrance ramp metering	Less drastic than ramp closures, ramp metering limits the number of vehicles entering the freeway to keep the demand below the freeway's capacity. To be effective, ramps must have adequate storage space for vehicles waiting in the queue and alternate routes leading downstream to divert traffic around congestion. Without easily accessible alternate routes, traffic will merely back up on the ramp and congest the surface streets. The TMC generally has control over the metering rate.
Reversible lanes	Generally consist of separate lanes used when traffic is directionally imbalanced during the morning and evening rush hours. The TMC will have control of access to the lanes and the direction of flow through a series of gates, barriers, and signs.
Variable speed limits	This control is designed to smooth traffic flow and prevent rear-end collisions by reducing the speed of traffic upstream from congestion (Wilkie, 1998). Although currently successful in some European countries, early tests in the U.S. were unsuccessful and have since been abandoned because motorists did not comply with the limits set by the variable speed limit signs (Everall, 1972).

Table 3. Indirect controls or information dissemination strategies.

Technology	Description
Variable message signs (VMS)	Signs can be rotating drum, fiber optic, LED, flip disc, or other technologies and either placed in fixed locations or portable (pulled on a trailer). Varying rules and degrees of automation exist between centers for composing and distributing messages on the VMS network.
Highway advisory radio (HAR)	HAR uses low power broadcasts on the AM band to provide traffic information to drivers from the TMC if the driver tunes to the HAR station. Some cities have combined HAR with information signs along the road that will flash when the HAR is broadcasting relevant information.
Cable TV	Real-time video and traffic conditions are being broadcast by some TMCs through private and public partnerships between cable companies. This mode of communication hopes to influence travelers' departure times, modes of transportation, or routes before they begin their trip
Highway advisory telephone (HAT)	Still an emerging technology, some TMCs have a phone line for drivers to call in and hear prerecorded messages on traffic conditions, which could influence drivers before they leave or during their trip depending on when they call.
Internet: web pages and E-mail	Many cities have established web sites with everything from traffic reports to up-to-date still pictures from various freeway cameras. Some also have an E-mail subscription where the TMC automatically generates and mails a daily report specific to the subscriber's needs.
Information kiosks	Generally most useful for mass transit information. Many cities are installing kiosks with real-time traffic information in public buildings and tourist sites, though some cities have reported that the influence of these kiosks is small compared with other methods.
Commercial media partnerships	Partnerships can be simple such as those that provide the media with traffic information or more complex such as exists in Minneapolis where a local radio station broadcasts reports taped live at the TMC every 10 minutes. Some cities have found weak partnerships to be less desirable because there is no guarantee that the media will quickly and adequately disseminate information.
Fax/text pager	Either through the TMC or a private service, a personalized fax or text message page (including pagers installed in vehicles) can be sent to subscribers detailing traffic conditions on their daily route.
Vehicle navigation system (VNS) traffic information service	An emerging technology through many pilot projects. Information could be transmitted to the driver through services such as those tested in the FAST-TRAC project (Troy, MI) or by the Etak systems (San Francisco, CA). Such systems could provide optimal turn-by-turn navigation or real-time traffic conditions broadcast on an FM subcarrier and overlaid on an in-vehicle map.

SIMILARITIES BETWEEN THE TMC AND OTHER CONTROL CENTERS

Computer Network Management

Murray and Lui (1997) described the traffic management center operations by introducing the term *hortatory operations.* This term refers to the type of management where the operators have limited direct control over the individual system elements (i.e., the traffic) and must depend upon the broad dissemination of information to influence the system. Salient features of hortatory operations include the following:

- Limited direct control over the network
- Almost no direct control over the vehicles traveling the network
- Influence over the network is gained by providing information about the network
- Operators receive and review large amounts of raw data
- Limited tools exist for comprehensive analysis, prediction, and recommendation
- Several different organizations have access to the network data and reports
- Coordination between different organizations is required
- Information is collected in various formats, accuracies, and real-time availabilities

The key element of hortatory operations (as described by Murray and Lui, 1997) is the inability of the management center to provide optimized routes or solutions for individual vehicles traveling the network. Each individual vehicle retains a high degree of autonomy making its actions difficult to predict or control. To influence the overall network, the management center must rely upon broad dissemination of network conditions, expected delays, and alternatives.

Computer network management was one instance of hortatory operations described by Murray and Liu (1997). Companies such as Advanced Network Services (now known as ANS-WorldCom) are charged with managing the large networks that make up the backbone of the U.S. Internet. The network operations centers operated by these companies include comprehensive system-monitoring facilities to allow for problem tracking and resolution, but the ability to coordinate the routing of message traffic is limited due to the fact that the network is composed of numerous relatively independent switching nodes. The network operations centers also have little direct control over fixing problems since much of the physical equipment is often owned by different companies and located across the continent. When problems occur, the successful coordination of several organizations is required to resolve a problem.

Vessel Traffic Services (VTS)

Under the operation of the U.S. Coast Guard, vessel traffic services operates control centers in the crowded ports along the U.S. coasts. Vessel traffic-management operators monitor the weather, the shipping traffic, and anchored vessels to maintain safe travel and reduce the probability of collisions or groundings (Devoe, Abernathy, Royal, Kearns, and Rudlich, 1979). Although in rare circumstances the vessel traffic management center can specify when or where a vessel may transit, the vessel traffic management center is similar to hortatory operations in that the individual vessels act autonomously under the direction of their own captains, and vessel traffic services has little direct control over the actual maneuvering of the vessels. The vessel traffic management center primarily influences the network by communicating advisories directly to the vessels via radio.

The condition and future of vessel traffic services parallels that of automobile traffic management according to the survey and descriptions provided by Hoffman, Dion, and Riley (1997). Similar to automobile traffic management centers, vessel traffic management centers were reported to be unique from location to location using different computer hardware and software and varying amounts of automation (some locations were even fully manual with no computer assistance). Despite the differences in methods, several tasks were found common to all Vessel Traffic Services which have parallels in automobile traffic management centers including the following:

- Monitoring communications (radio)
- Watching CCTV monitors and computer displays
- Keeping track of the overall traffic in the area (integrating information)
- Logging vessels (similar to logging incidents in the TMC)
- Predicting the future traffic situation (to aid in providing advisories)
- Communicating advisories to the vessels in the area about the traffic

As part of the process of assembling human factors guidelines for the design of Vessel Traffic Services control centers, Hoffman, Dion, and Riley (1997) identified common human factors problems at those centers. A comparison between the documented VTS problems and their similarities to problems found in the TMC is listed in Table 4. The problems noted could generally be classified into 4 categories: alarm problems, data entry issues, display design issues, and overall system problems.

The Devoe, Abernathy, Royal, Kearns, and Rudlich (1979) study revealed many human factors problems with the design of vessel traffic service centers that were also common among traffic management centers. Although there are many similarities between vessel traffic services and traffic management centers, little evidence of human factors consideration was found in regards to the design of vessel traffic services centers. The fact that many of the problems experienced in vessel traffic services (such as the design of alarms and displays) have already been addressed in abundance in the human factors literature suggests that the problems could have been avoided had human factors been considered during center design.

Table 4. Comparing human factors problems found in VTS with problems in the TMC.

Category	Human Factors Problems in VTS	Similarities to TMCs
Alarms	1. Often over 40 different alarms are provided when only 5 are used. 2. Alarms too loud and therefore turned off.	Alarm problems possibly encountered, but not specifically referenced in regards to TMCs.
	3. Alarms often override each other or are overridden by an alarm to alert the operator that a previous alarm wasn't answered.	
Data Entry (logging vessels)	1. Too much data entry required during high traffic times causing operators to revert to manual (paper) methods.	Similar issues found in TMCs. Guidelines by Stocks, Folds, and Gerth (1996) recommend that the automated systems assist operators in data entry.
	2. Interface-design issues such as inadequate feedback and help, poor forms, and poor menus.	Similar issues possibly encountered, but not specifically referenced.
	3. Awkward data-entry process (the order of forms not consistent with the order of operations).	Similar issues may occur when additional information is received after an incident report has been filed.
	4. Form design inadequate - not enough spaces allowed for items.	No reference.
Displays	1. Clutter - too much information was displayed in too many windows. 2. Difficulty navigating the system.	Similar problems occur in TMCs as noted by Kelly and Folds (1998).
	3. Windows often pop up and interrupt the operator.	Similar TMC problems (noted by Stocks et al., 1996) were resolved by introducing an automatic queuing system to prevent interruptions.
	4. Inconsistent abbreviations and equipment terms. 5. Poor display colors (orange cursors and black/dark icons to represent alerts).	Inconsistency and poor color usage have been noted by Kelly and Folds (1998). Often a color on one subsystem was used to represent bad, while on another system it was used to represent normal.
	6. Access to more detailed information about a vessel is gained by entering a long string of numbers, not the vessels displayed name.	Similar problem noted by Stocks et al. (1996) in reference to camera access.
System	1. System often slows and crashes during high workloads.	Issue not addressed in TMCs.

Air Traffic Control (ATC)

The overall air traffic control mission has been described as *the safe and efficient flow of traffic from origin to destination* (Wickens, 1997). Although this seems similar to the traffic management center's mission, the two control centers differ greatly in the means through which they accomplish their goals. Air traffic controllers track and direct each individual plane from its departure gate to its destination gate through a network of 428 airport control towers, 25 air-route traffic control centers, and 318 flight service stations which are all under the central control and regulation of the FAA. The entire system has evolved under the tight control of the FAA over the last 50 years primarily in response to accidents and disasters.

The primary task of the air traffic controller is to keep a maximum separation between planes. Traffic congestion is generally managed through the scheduling of arrivals and departures at the airport. The maximum number of safe arrivals and departures per time period for each airport is already known. Traffic jams due to unscheduled delays are handled by adjusting the course, speed, or even departure time of incoming planes and the departure times of outgoing planes to keep all of the planes a safe distance apart without stacking them in a holding pattern around the airport.

Given the high degree of control over the individual system elements, ATC does not fall into the same category (hortatory operations) as traffic management centers. However, despite the difference in the amount of control the operators have over the system, many tasks performed by the ATC operators are similar to tasks performed by TMC operators. Several tasks routinely performed by air traffic controllers (as described by Hopkin, 1995) include the following:

- Monitoring radar displays to identify every aircraft and its position
- Predicting the future state of each aircraft to detect possible collisions
- Monitoring the automated systems, which may be providing instruction to aircraft
- Visual monitoring of airport traffic (from the tower)
- Coordinating with other controllers to pass off their responsibility for an aircraft
- Keep an official record of air traffic control actions and incidents

Many of the basic attempts to define the limits of human performance arose from the study of aviation and the mismatches between people and the systems they needed to operate. Several key human factors problems relating to ATC (as summarized by Hopkin, 1995) include:

- Operator selection and training
- Display-viewing distance and illumination
- Work-rest cycles
- Aging and burnout
- Task-design mismatches such as excessive memory requirements or inappropriate information formats being provided to the operator

The design guidelines that have been accumulated in the field of aviation on these topics, as well as basic information on the topics of human anthropometry and workstation design, can be found in the *Human Factors Design Guide* (Wagner, Birt, Snyder, and Duncanson, 1996) published by the FAA. An index of topics and subtopics covered by this publication can be found in Appendix A.

EMPIRICAL HUMAN FACTORS STUDIES IN THE TMC

At the time of this report, several published empirical human factors studies specific to issues encountered in traffic management centers were found in the literature. The studies were conducted at locations including Georgia Tech Research Institute, the University of Michigan, and the Texas Transportation Institute. These papers cover the following topics:

- The required operator capabilities
- Monitor-viewing distances and camera controls
- The usability of computer-based operator support systems
- The design of incident detection support systems
- The design of message posting systems

Required Operator Capabilities

Mitta, Folds, and Fain (1997) tested two operator groups on their ability to solve traffic-management problems. The first group of 24 subjects was referred to as the NonTech group as they were recruited from technical and vocational schools in the Atlanta metropolitan area. The NonTech group consisted of individuals with a more practical, application-oriented education. The second group of 10 subjects was referred to as the Tech group, as they were recruited from the Georgia Institute of Technology and represented individuals with a theoretically based education (college students).

The subjects were asked to monitor 24 simulated camera sites for the presence of incidents. When incidents were detected the subjects were asked to fill out an electronic incident report specifying the incident location. Performance was measured in regards to the number of incidents correctly detected, the number of missed incidents, the number of false alarms, the average detection time, and the location accuracy. Note that location accuracy was the number of extra roadway links contained within the incident boundaries such that a measure of zero indicated perfect accuracy. The results of the experiment are shown in Table 5, and the only significant difference observed between operator groups was in the category of location accuracy. The Tech group was able to specify the incident location slightly more accurately than the NonTech group suggesting little basis for TMC operator positions requiring a college degree.

Table 5. Incident detection performance by operator group.

Performance Measure	Tech Operators	NonTech Operators
Number of hits	15.0 (2.1)	13.5 (4.3)
Number of misses	6.0 (2.1)	7.4 (4.3)
Number of false alarms	2.1 (1.2)	2.9 (2.0)
Average detection time (min)	9.87 (1.5)	9.99 (1.89)
Average location accuracy	0.39 (0.17)	0.53 (0.21)

Note: Table entries indicate group means and (standard deviations).

Monitor Viewing Distance and Camera Controls

To determine the appropriate monitor-viewing distance, Beers and Folds (1996) tested 22 subjects (recruited from local universities and ranging in age from 18 to 45) on their ability to read a 2x2 array of 13-inch video monitors placed at varying distances. Each subject viewed the array at 1-foot increments between 2 and 13 feet along a 40 degree angle from the workstation. Subjects watched the monitors for traffic incidents, and when an incident occurred, they were asked questions regarding the number and type of vehicles involved. The subjects were asked to enter the camera identification number into a text editor. (The camera identification was a string of random alphanumeric digits in 15-point text overlaid on the video, and the vehicles' screen dimensions each ranged from 8 to 80 mm.)

The study concluded that performance (the subjects' ability to interpret the video and read the text) began to drop when the monitor-viewing distance exceeded 5 feet. Subjective ratings by subjects also confirmed that the closer viewing distances (near 2 feet) were preferred by the operators. The study's recommendation was to locate monitor banks within 5 feet of the operators; however, the effects of using larger monitors, larger text labels, or cameras with zoom capabilities was not discussed.

To determine the optimum camera controller, Coon and Folds (1996) conducted 2 experiments where subjects used 24 simulated cameras to detect and report incidents. When an incident was detected, the subjects recorded the camera number and direction of each incident as well as the number of vehicles involved.

Their initial experiment compared the operators performance using manual camera controls with using 2 preset camera views. In this experiment, an unreported number of subjects were given 24 cameras to monitor (12 with manual controls and 12 with preset controls). The preset cameras had 2 default views, one looking in each direction of the roadway. Both camera control types had manual zoom capabilities. This experiment found that neither configuration was optimal. Using purely manual camera controls required considerably more manipulation resulting in longer response times to incidents. However, using the presets alone did not allow the operator to thoroughly investigate the incident since the incident was not always clearly in view of the preset.

In their second experiment, 6 subjects were tested on 3 different hybrid remote camera control designs which integrated both manual and preset controls. (See Table 6 for descriptions of the camera-controls designs.) Each subject spent 30 minutes using each of the camera-control designs to monitor all 24 remote cameras, again with the task of detecting and recording incidents.

Table 6. Descriptions of the tested camera controls.

Condition	Description
Toggle	This mode utilized the arrow keys and the 'F1' key. Initially the camera appeared in preset mode where they arrow keys switched between the default presets. Pressing the 'F1' key switched the camera controls to manual mode where the arrow keys controlled pan, tilt, and zoom.
Combined	This mode was similar to the toggle mode; however instead of having a toggle switch ('F1'), simultaneously pressing the arrow key and the 'alt' key allowed the operator to manually control the camera's pan, tilt, and zoom.
Enhanced Manual	This mode did not utilize the presets. The arrow keys always provided manual control of the camera, however when the 'alt' key was pressed with the down arrow key, the camera flipped to view 180 degrees from where it was previously looking.

Camera performance measures recorded during the experiment were as follows: 1) the number for movements, 2) the time in-use, 3) the transition time, and 4) the parked time. No significant differences in performance or preference of the hybrid camera-control designs were found. Given no strong evidence to discount any of the designs, Coon and Folds (1996) recommended the combined design as it offers both the preset and manual controls with less of a chance for mode errors than the toggle design.

Computer-Based Operator Support Systems

Stocks, Folds, and Gerth (1996) prototyped 3 computer-based operator support systems: 1) the incident detection and location system, 2) the message posting system, and 3) the communication supports system. Each system went through a development phase to define the required features, internal and external pilot testing, and then they were used as the mock TMC systems for various human factors experiments performed at Georgia Tech Research Institute. Throughout the process, the various design features and guidelines described in this section were identified and developed.

The incident detection and location system (IDLS) automated the task of reviewing the road-sensor data and external communications to determine where incidents had likely occurred. Once presented with an incident report, the operator's task was to verify that an incident actually occurred. If an incident had occurred, the operator finished filling out the incident report (which was then saved) and posted the appropriate sign messages. Table 7 lists the observations and recommendations about the incident system which were noted during the system prototyping.

Table 7. Recommendations for the incident system.

Recommendation	Further Explanation
1. If the operator is busy, the receipt of new report should not interrupt the current task. It should be queued.	Multiple incident reports could occur in a short time period, and constantly interrupting the operator slows the entire process (by automatically switching windows).
2. Each new report should get the operators attention by playing a sound.	Some reports may have a higher priority. The operator should be a aware that a new report has entered the queue.
3. The sound should be distinct from other systems sounds.	Since multiple support systems and queues are likely, each queue should have its own distinct sound to help operators determine which system was sending the alert.
4. A direct link from the incident report to the data most likely able to verify the incident should be provided.	Providing a direct link from the report to the nearest camera or to the loop-detector data in that area (if no camera is available) saves the operator the time it takes to search for that data in the system.
5. The operator should be provided an easy way to view a queued report or postpone a report.	The operators need the ability to postpone or requeue a report in order to move to a more critical task.
6. A single action for rejecting a report should be provided.	False alarms are inevitable so the operator should be able to discard them quickly.
7. When an operator verifies an incident, all available information should be automatically input into the report form.	The operator should not need to waste time retyping information the support system has already determined, though the operator should still be able to edit that information.

The message posting system (MPS) automated the decision of what message to post and which signs to post the message on. The studies only looked at incident-related messages, while other messages (such as heavy congestion) were ignored. Table 8 lists the observations and recommendations regarding the message system which were noted during the system prototyping.

The communications support system (CSS) aided the operator in managing the information reported to the TMC from external sources (such as phone calls, E-mails, and radio transmissions). Often when camera coverage is lacking, the information provided to the TMC from external sources may be the only way to detect an incident. Table 9 lists the observations and recommendations regarding the communications system which were noted during the system prototyping.

Table 8. Recommendations for the message system.

Recommendation	Further Explanation
1. Similar to the IDLS, the MPS should utilize queues.	New message reports should alert, but not interrupt, the operator with a distinct sound.
2. Message reports should only be based upon operator-verified incidents.	The message system should only trigger once the operator has verified an incident and filed an incident report.
3. The message report should reference the incident report which triggered it.	Operators need to compare the incident severity and location to the signing response provided by the message system.
4. The entire response for an incident should be grouped in a single message-system report.	Operators found it difficult to verify the correctness of message reports when each sign change was located in a separate report.
5. The message report should provide the logic used to create the proposed response.	Operators found this helpful in verifying the correctness of the message posting system response.

Table 9. Recommendations for the communications system.

Recommendation	Further Explanation
1. The incident reporting hotline should record the calls so that the operator can sort them later.	When an incident occurs, the TMC may get many calls in rapid succession. Callers not handled promptly will become discouraged.
2. The system should provide a means of storing summary information on the incident time and location with the recording.	Time and location information can help the operators to group calls about the same incident together.
3. The communications system should use a similar (but separate) queue as described in the IDLS and MPS systems.	No reason was given as to why the communications system should have its own queue while the incident and message systems can share a single queue.
4. The communications system should have queue management tools to group several calls together into a single report, archive calls, and delete calls.	Operators were incident focused and preferred to have all of the information about a single incident accessible from one location or report.

Incident Detection Systems

Two key articles have been written on human factors in the design of automated incident detection systems. Such systems are designed to detect abnormally high congestion on a road segment which may indicate that an incident has occurred. The first study, conducted at Georgia Tech, examined the effects of the system's false alarm rate (incidents detected that did not occur), hit rate (correct incident detections), and detection latency (time elapsed) on operator performance (Mitta, Folds, and Fain, 1996). The second study, conducted at the University of Michigan, examined improving incident detection systems by adding qualitative data (operator heuristics) through an expert system (Murray and Liu, 1997).

Mitta, Folds, and Fain (1996) tested 20 subjects, both male and female, recruited from technical and vocational schools in Atlanta. Subjects were asked to monitor 24 simulated camera sites for incidents using the computer-based support tools described in Stocks, Folds, and Gerth (1996). Operator performance was gauged by the number of hits or incidents detected and the average detection time. Subjects were tested after a 2-hour practice session using each of the 4 conditions described in Table 10.

Table 10. Incident test conditions.

System Condition	False Alarm Rate	Hit Rate	Detection Latency (min)
1. IDLS Off	-	-	-
2. IDLS Performance Level 1	Low (1 per 15 min)	75%	6
3. IDLS Performance Level 2	High (1 per 7.5 min)	75%	1
4. IDLS Performance Level 3	Low (1 per 15 min)	40%	1

The results of the experiment showed that subjects performed best using the IDLS Performance Level 2 averaging a hit rate of 81 percent and a detection time of 3.33 minutes. The worst detection rate (63 percent) and slowest detection times were found when the IDLS was off (a mean detection time of 7.04 minutes compared with the mean detection time of 4.51 minutes when averaged over the IDLS on conditions). The study concluded that IDLS systems should be designed with the highest possible hit rate and lowest detection latency feasible.

Murray and Liu (1997) interviewed operators at the Michigan Department of Transportation (MDOT) traffic management center. Focusing on situations where no camera feed was available, the operators were asked how they identified and verified incidents to elicit the heuristics (rules of thumb) used by the operators. The operators revealed 75 statements which directly implied a general causal relationship between an event and an operator conclusion. The statements were reduced to general rules such as the following:

- If there is no timing gate nearby, then don't assume that speed values are correct.
- When high occupancy suddenly occurs but does not propagate, then suspect a faulty sensor, not an incident.
- If an incident is suspected, look for traffic patterns on adjacent roadways which suggest spectating behavior.
- External text reports are often inaccurate, look for partial matches.

Using an expert system to integrate operator heuristics with the quantitative sensor data, the time required to verify incidents was reduced by up to 3 minutes in certain scenarios; however, no additional incidents were detected.

Automatic Message Posting Systems

Folds and Fain (1997) compared 2 message posting systems using 16 subjects recruited from Atlanta-area technical and vocational schools. The first system simply suggested messages to the operator, but would not post the message without the operator's consent. The second system automatically suggested and posted the message on the VMS (although the operator was allowed to override the system and change the message).

The subjects were instructed to monitor simulated traffic for 2 hours during which a total of 16 incidents occurred. Both support systems correctly handled 12 of the 16 incidents. Performance was measured using the number of correctly handled incidents, the number of support-system errors detected (incorrect messages detected), and the time from the incident report until the messages were posted on the signs. The results are summarized in Table 11.

Table 11. Operator performance on automatic message posting systems.

Performance Measure	Message Posting System	
	Suggest Only	Automatically Post
Correct messages posted	10.5	12.5
Incorrect messages detected	1.0	1.0
Latency (min)	3.0	0.6

Overall, the operators handled more incidents correctly using the automatic message posting system, however the difference was not significant. The only significant difference between the two systems was the latency in getting the signs posted. With the automatic system, signs were posted faster; however, it should be noted that the operators task queue averaged 3 to 4 minutes. Therefore, the automatic message posting system posted the message 3 to 4 minutes earlier, but both the latency and accuracy in verifying the messages was the same in both systems.

VMS Message Construction

Dudek, Huchingson, Stockton, Koppa, Richards, and Mast (1978) created guidelines for the construction of messages to be placed on variable message signs. According to their report, one of the key concerns for city officials in using variable message signs for traffic management was maintaining credibility with the public. Given this criteria, the suggested sign-usage guidelines are listed in Table 12.

Additionally, the authors noted that when constructing messages, the traffic management center should consider for whom the messages are intended. During rush hours, the drivers will mostly be commuters traveling to and from work. Daily commuters will have detailed knowledge of their route, the cross streets on that route, the average travel time, and some level of traffic expectation. During off-peak hours and weekends, more drivers may be from out of town or less knowledgeable of the traffic network as they are traveling places they do not frequent daily. The weekend traffic will thus be less familiar with alternate routes, the local cross streets and landmarks, and traffic or travel time expectations. Depending on the composition of drivers, the street names used in daily traffic operational activities may not be the names that the drivers understand. In this case it might be better to reference the locations of congestion and incidents not by their cross street, but by their distance ahead relative to the sign.

Table 12. Recommendations for variable message signs (Dudek, et al., 1978).

Recommendation	Further Explanation
1. The information posted on a VMS should be accurate and timely.	Avoid using the VMS to display information that can be disputed such as travel times, and be sure to clear incident messages in a timely fashion.
2. Heavy Traffic, Congested, Normal Traffic, Stop and Go Traffic, etc. have vague meanings and shouldn't be used.	Delay and time saved messages are interpreted faster and are more effective in diverting traffic.
3. The VMS should not tell drivers information they already know.	"You are in heavy congestion" would not be an appropriate message. The VMS should be used to tell where congestion begins and ends.
4. Alternate routes should only be given if they result in significant time savings.	60% of drivers will divert given a 20 min delay. 95% of drivers will divert given a 60 min delay. Only 8% will divert given a 5 min delay. Delay is perceived relative to the overall travel time.
5. If drivers are told to divert, give complete detour instructions.	Never dump the drivers onto unfamiliar streets without complete and accurate directions including where they will re-enter the freeway.
6. Message formats should be consistent throughout the traffic-management system.	

To recommend the specific content and format for variable message signs, 3 types of signs were identified: advisory signs, guide signs, and advance signs. The most relevant type of sign for freeway management is the advisory signs which displays information about incidents, the freeway status, and advice concerning the best course of action. Guide signs are used to help drivers follow an alternate route to their destinations by giving both directions and messages affirming that the drivers are still on route to their intended destinations. Guide signs are likely to be used on portable variable message signs for construction detours, planned events, and possibly extended major incidents. Advance signs are used to either warn drivers that important information will follow on the next variable message sign or direct drivers to another source of traffic information (such as "Radio Traffic Alert, Tune to 1606 AM").

Dudek, et al. (1978) recommend that the following elements be included in an advisory sign:

Message Element	Example
1. Problem statement	Accident at Telegraph Rd
2. Effect statement	Left 2 Lane Blocked
3. Attention statement	thru traffic
4. Action statement	Use Local Lanes

According to the recommendations, the advisory sign should present drivers with enough information to make decisions. The problem statement should convey the hazard (e.g., accident, construction, stalled vehicle, etc.) and its location. Although location can be given in the form of the nearest cross street, it was recommended that the location be given relative to the sign (e.g., 1 Mile Ahead) for the benefit of drivers who are unfamiliar with the area.

The effect statement should indicate the expected impact on the traffic. This includes statements such as ramp or lane blocked, expected delay, or miles of traffic backup. As discussed earlier, the use of statements like “Congestion Ahead” for the effect are vague and ineffective in helping drivers to make a decision. Statements like “Congestion From Point A to Point B” are more informative. Also, the use of the term “blocked” usually connotes a temporary situation such as one related to an incident; whereas, the use of the term “closed” connotes a more permanent situation such as one related to construction.

The attention statement is intended to inform a group of drivers as to the recommended alternative route if one exists. The affected group of drivers might be specified by their intended destination such as “Airport Traffic” or by their route such as “I-94 Eastbound Traffic.” If all traffic is affected or no alternate routes are available, then the attention statement may not be needed.

The action statement provides the driver with the recommended advice on how to deal with the incident. The action could be to take an alternate route or simply to slow down and be prepared to stop.

VMS Reading Time

The guidelines for the construction of messages for variable message signs created by Dudek, Huchingson, Stockton, Koppa, Richards, and Mast (1978) also summarized several studies pertaining to sign-reading times. Simply put, the driver must be able to read any messages posted on a variable message sign during the time that he or she is exposed to the sign. The maximum exposure time for existing signs can easily be calculated by dividing the sign’s legibility distance (the maximum distance from the sign that the driver can read the sign) by the operating speed of the traffic. Once the exposure time has been calculated, the maximum message length (excluding short or familiar words) can be determined using Figure 2 (Dudek et al., 1978) which summarizes the guidelines from Mast and Ballas (1978), Mitchell and Forbes (1942), and the British Road Research Laboratory (RRL) as referenced by King (1970).

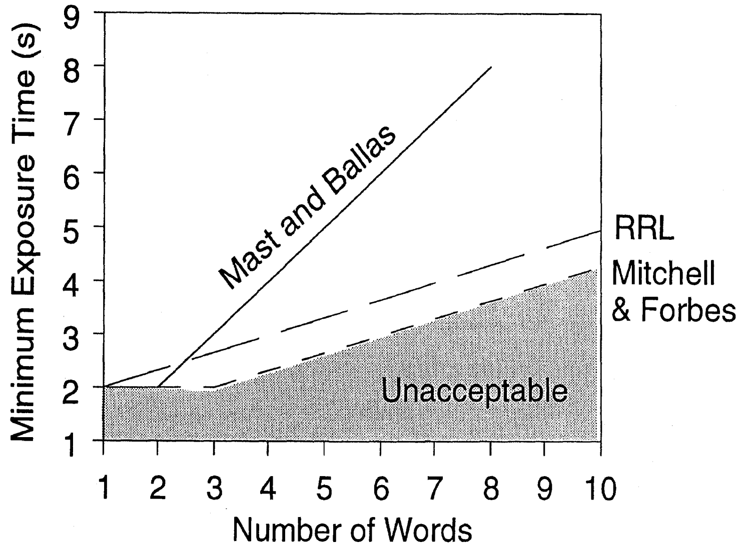

Figure 2. The relationship between exposure time and message length.

The most stringent minimum-exposure-time requirement was proposed by Mast and Ballas (1978) based upon limited in-vehicle human factors testing. In their study, 3 signs were viewed by drivers (see Table 13) and the resulting reading times were recorded. Although for a short 5 word message containing 2 units of information, the Mast and Ballas (1978) results (about 2.3 seconds of reading time) compared reasonably well with Mitchell and Forbes (1942) guidelines. Longer messages containing more information took considerably longer to read (approaching 0.8 to 1 second per word) than predicted by either Mitchell and Forbes (1942) or the British Road Research Laboratory (which both predict approximately .33 seconds of reading time per word).

Table 13. The results of the Mast and Ballas (1978) sign-reading time experiment.

Sign Message	Number of Words	Message Units	85th Percentile Reading Time
Heavy Congestion 2 Miles Ahead	5	2	2.3
Traffic Conditions Next 2 Miles Disabled Vehicle on I-77 Use I-77 Bypass Next Exit	13	6	6.7
Traffic Conditions on I-91 Normal on I-91 North Accident on I-91 South Use I-91 South Bypass	13	7	9.8

Note: The number of words excludes prepositions assuming 4-8 letters per word..

Additional variable message sign recommendations (given by Dudek et al., 1978) are summed up below:

1. From research in outdoor advertising, the general guideline is any message should be able to be read by the driver in 6 seconds or less.
2. For typical VMS applications, the message length should be kept under 8 words (excluding prepositions such as to, for, at, etc.).
3. Allow an exposure time of 2 seconds per VMS sign line, where each line contains a maximum of one unit of information.
4. No more than 3 units of information should be showed to drivers if the driver must remember all of the information. If one piece is minor and does not need to be remembered, a maximum of 4 information units may be shown.
5. Run-on, moving displays, or scrolling displays should not be used.
6. A sequential display (one that shows two discrete messages or message parts) should separate each message with a 1-second blank time.
7. When sequential displays are used, the required exposure time includes the minimum reading time for all messages and the blank times between messages.

EXISTING TRAFFIC MANAGEMENT CENTER GUIDELINES

The *Human Factors Handbook for Advanced Traffic Management Center Design* (Kelly, 1995) was written by the Georgia Tech Research Institute under contract with the Federal Highway Administration. At the time of this document, a second edition of the Georgia Tech Handbook was still being prepared. The 1995 version which was reviewed contained 13 chapters (see Appendix B for a table of contents) covering the following topics:

- The principles and methods of user-centered design
- Function allocation
- Basic human error and error-analysis methods
- Basic human-performance limits (stress, attention, memory, and decision making)
- Job design and workload
- Anthropometry and physical ergonomics in design
- Displays, data presentation, and controls
- Basic user-computer interface design

The handbook was intended for use by the traffic-management-center design team, assuming that the design team had little or limited knowledge of human factors. Each chapter includes both background information and specific guidelines (and references for those guidelines). Examples of past problems encountered in traffic management centers are often used to highlight or demonstrate the guidelines. The guidelines were developed from the following sources:

- Visits to existing traffic management centers
- A survey of the existing human factors handbooks
- Formal surveys of traffic-management-center managers and operators
- The comments of a working group composed of TMC managers and engineers

A brief review of the handbook found most of the guidelines to be very general in nature; however, given the intended audience, the guidelines and format appear to be very useful and easy to follow given a limited knowledge of the subject. The next revision of the handbook should contain more specific information and recommendations including those drawn from the Georgia Tech Research Institute experiments described in the previous “Empirical Human Factors Studies In the TMC” section of this report.

Interviews with local Michigan traffic-management-center personnel revealed that, little or no formal human factors considerations were used to construct or upgrade their facilities. In both of the interviewed traffic management centers, the human factors and usability was mostly handled by knowledgeable operators or managers. However, their influence was often hindered by the lack of human factors requirements or provisions in the actual contracts with the vendors and software providers. Given this widespread problem, the *Human Factors Handbook for Advanced Traffic Management Center Design* may provide a good starting tool to help managers and designers understand the human issues involved in constructing a control room.

FUNCTION ALLOCATION IN THE TMC

An Introduction to Function Allocation

One of the most common questions debated by designers is that of function allocation. Wickens (1992) offers 3 general guidelines on when automation should be used. First, automation should be used to perform functions that exceed human capabilities such as complex calculations or reactions to events that must occur faster than human are capable of executing. Second, automation should assist in performing functions human can do, but do poorly. Examples of this type of automation make up the class of systems commonly known as expert systems or artificial intelligence. Finally, automation should be used to assist humans in areas where they show limitations. Such implementations of automation recognize human performance bottlenecks and aid an operator by eliminating them.

As noted by Kelly and Folds (1998), automation strategies differ widely between traffic management centers. While some centers rely heavily upon the operators to perform most of the tasks, other centers are highly automated. In their survey of traffic management centers around the world, the degree of automation used for the task of changing the message on a variable message sign ranged from completely manual input (where the operator composed and keyed the message on the sign) to a completely automated response plan (where the computer determined the most appropriate message for each sign and automatically posted it).

The wide range of solutions for this single function is not surprising since function allocation has often been described as a trade-off between different performance measures and different political, social, and economic considerations (Chapanis, 1965). Also, as noted by Hopkin (1995), the decision to automate is usually technology driven and seldom incorporates the human factors considerations that are needed. The automatic toll booth (the coin basket type) is a classic example used to illustrate the complex issues encountered in function-allocation decisions. Human toll collectors can handle more vehicles per hour than the automatic toll collectors, and they are more flexible since they are able to make change and recalculate the toll based upon the vehicle type (Chapanis, 1965). However, performance was not the only factor in creating automatic lanes; the economic considerations in automating toll collection were also key. Automatic lanes were simply able to run 24 hours a day at less cost per lane than human-staffed lanes, and thus the task of collecting tolls was partially automated using a less than optimal system for over 30 years. Only recently has technology become available to provide greater speed and function for automated toll collection through the ITS Electronic Toll Collection System initiative. More information about this initiative can be found at http://www.ettm.com/.

Early Attempts at Function Allocation

The first formal treatment of the function-allocation question was by Paul M. Fitts (1951) in the form of a list describing the relative strengths of men and machines (see Table 14). As technology has changed, subsequent lists have been published, and the list approach to function allocation was eventually termed as the "MABA-MABA" list or the "men are better at - machines are better at" list (Parsons, 1981). (MABA-MABA lists are also known as HABA-MABA lists as the "m" of men is often replaced with an "h" for humans to remove gender bias, or they can be referred to as "Fitts Lists" in recognition of the original author.)

Table 14. The original Fitts list.

Humans appear to surpass present-day machines with respect to the following:

1. Ability to detect small amounts of visual or acoustic energy
2. Ability to perceive patterns of light or sound.
3. Ability to improvise and use flexible procedures.
4. Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time.
5. Ability to reason inductively.
6. Ability to exercise judgment.

Present-day machines appear to surpass humans with respect to the following:

1. Ability to respond quickly to control signals, and to apply great force smoothly and precisely.
2. Ability to perform repetitive, routine tasks.
3. Ability to store information briefly and then to erase it completely.
4. Ability to reason deductively, including computational ability.
5. Ability to handle highly complex operations, i.e., to do many different things at once.

The decision of whether or not to automate a task is not always straightforward since human performance data is not known or available on every conceivable task. According to Price (1985), lists and guidelines may be useful for forming the initial hypothesis on how to allocate functions, but there is no simple formula that can be used to calculate the best way to allocate functions. The optimal allocation of functions, in general, is not static — it can change quickly as new technology is introduced. Furthermore, the best allocation may not classify tasks as exclusively 100% the job of the human or the machine. Along this philosophy, Sheridan (1987) listed in the *Handbook of Human Factors* a spectrum of function-allocation possibilities or designs. (See Table 15.)

Table 15. Sheridan's levels of automation.

1. Computer offers no assistance, human does everything.
2. The computer offers a complete set of action alternatives.
3. The computer offers a few best solutions.
4. The computer offers one best solution.
5. Executes best solution with human approval.
6. Executes best solution after allowing a limited veto time for the human.
7. Executes automatically and notifies human of actions.
8. Executes automatically but only informs human if he inquires.
9. Executes automatically and only informs the human if it feels necessary.
10. Completely automatic, computers ignores human.

Common Problems with Automation

Often, some of the goals of introducing automation into a system follow a logic which states that automation will reduce the human workload and reduce the human errors in the system. Unfortunately, as described by Wickens (1992), as tasks become highly automated, the operators become supervisory controllers. Although the operators are given less to do, they are given more system components to monitor, and in general, humans are poor monitors. Humans are known to suffer performance decrements on vigilance tasks, and they are known to have biases such as automation overtrust or mistrust. These biases were demonstrated in a summary of several operator interviews (Kelly and Folds, 1998) which showed how one operator frequently altered the decisions made by an ATMS system, while another operator in the same facility was biased towards simply accepting the ATMS solution stating that the automation system should never be overridden.

The second common fallacy of automation is that automating a task will reduce human error. However, as noted by Wickens (1992), automation does not eliminate all human errors; instead, it leads to human errors on a higher level such as set up, design, or goal errors. As automation changes the nature of the tasks and the skills required to perform the tasks, it also changes the types of human errors possible. Thus, often implementing automation to prevent one type of error will result in the possibility of committing new errors. Automation can also allow an operator's skills to degrade resulting in overdependence on the system and a loss of control or flexibility of the system (Norman, 1988). The automation is, after all, only as good at its programming, and often it is difficult to anticipate and program all possible events that could occur in the system.

Wiener (1989) best summarized the most common problems with modern automation in his survey of pilots trained in the flight of glass cockpit (or highly automated) aircraft. In this study he reported that the three most common questions asked by pilots about the automation were:

1. "Why did it do that?"
2. "What's it doing now?"
3. "What will it do next?"

As indicated by these questions, the most common human factors problem experienced is a breakdown in communication between the automation and the operators. This breakdown in communication can result from inadequate feedback or incorrect user models of how the system works. Such a breakdown was illustrated in the Kelly and Folds article (1998). Shortly after an operator spent considerable time customizing a traffic light timing plan, the automation erased the plan without warning and inserted the preprogrammed afternoon timing plan. In this case, the breakdown in communication between the automation and the operator resulted in an increase in the operator's workload, instead of the decrease in workload for which the automation was designed.

Studies of Function Allocation in the TMC

Initial ATMS Function Allocations

Mitta, Kelly, and Folds (1996) specified 113 functions performed by operators which were required to satisfy the ATMS objectives. Each function was analyzed at each of 4 stages: input, processing, response selection, and output. At each stage the task was given one of the following ratings to indicate who was responsible for that part of the task's completion.

- H: The human was solely responsible for the stage.
- Hm: The human with a machine's assistance was responsible for the stage.
- Mh: The machine with human assistance was responsible for the stage.
- M: The machine was solely responsible for the stage.

After each stage of each function was rated, the operator's role in that function was classified as one of the following using the criteria shown in Table 16: direct performer, manual controller, supervisory controller, or executive controller. The entire list of 113 functions and their allocations as determined by Mitta, Kelly, and Folds (1996) can be found in Appendix C.

Table 16. Function human and machine stage configurations for operator roles.

Operator Role	Input	Processing	Response Selection	Output
Direct Performer	H or Hm	H	H	H
Manual Controller	H, Hm, or M	H, Hm, or M	H	H, Hm, or M
Supervisory Controller	Mh or M	Mh or M	Mh	M or Mh
Executive Controller	M	M	M	M

Approximately 40 of the 113 functions were allocated to the operator acting as a direct performer. Most of these functions involved communications activities such as receiving reports, requests, or comments from external agencies or individuals. Other functions assigned to the operator as the direct performer include the following: decisions concerning hardware, software, and personnel upgrades, public relations, and several administrative and clerical functions.

Of the remaining functions, 28 were allocated to the operator acting as a manual controller. Of these functions, the most notable were those associated with detecting, observing, and monitoring traffic incidents and anomalies since they essentially relied upon the human observer. Other functions assigned to the operator as a manual controller include information dissemination, training and planning, and database management.

Only 16 functions were allocated to the operator as a supervisory controller. These tasks consisted mainly of sensing the roadway visibility and surface conditions. Although sensors are often in place to help detect adverse conditions, the capability of these machines is limited, and operators must often visually verify the conditions.

Other functions in this category included assessing the current traffic load, predicting the near-term future traffic load, and selecting the optimal control option. The authors envisioned that much of the real-time traffic management would need to be automated given the relatively large and complex traffic networks; however, the operators would still be able to selectively intervene and override the automated decisions should errors or special situations be encountered.

Finally, the remaining 29 functions were allocated to the operator as an executive controller. The majority of these functions were associated with the receipt, transmission, storage, and retrieval of electronically formatted data from the network sensors, probe vehicles, and emergency vehicles. In the case of transferring or transmitting data, it was assumed that the content and intended destination of the information was already determined in a previous function, and the actual transfer of the data could be performed by the automation under executive control of the operator.

Function Allocation Recommendations

The Human Factors Handbook for Advanced Traffic Management Center Design (Kelly, 1995) listed 15 guidelines regarding function allocation which were derived from the "Fitts List." These recommendations are listed below in Table 17. Stressed in several of the recommendations was the warning to not let technology dictate function allocation. The specific task requirements should dictate if and how the task should be automated. Decisions should not be based solely on the availability of cheap or elegant technology.

Table 17. Function Allocation Recommendations from the
Human Factors Handbook for TMC Design.

Allocate functions to the machine when:

1. The environmental constraints limit human performance.
2. The task's sensory requirements exceed those of humans.
3. The task's speed or accuracy requirements exceed the abilities of humans.
4. The information arrives in such speed and volume as to overload the operator.
5. The task has excessive memory requirements.
6. The task requires continuous self-performance monitoring.
7. The task requires repetitive tasks or lengthy and laborious calculations.

Allocate functions to the human:

1. When the task requires interpretation of or response to unusual events.
2. In a way that balances or levels the operators workload.
3. Such that the operator recognizes or feels their contribution is meaningful.

Functions should be allocated to:

1. Make best use of the operator's abilities.
2. Maximize the system effectiveness.
3. Allow for a natural flow of information.
4. Allow human intervention when needed.
5. Allow the automation to assist the operator instead of impairing him.

CONCLUSIONS

As the cost of building more roads has become increasingly more prohibitive, over 75 cities and urban centers across the U.S. operate traffic management centers. The mission of these centers is to facilitate the safe movement of people and goods with minimal delay throughout the roadway network. Although traffic management centers vary in their scope and technology, the following 5 goals have been suggested for the ideal traffic management center:

1. Maximize the available capacity of the roadway system.
2. Minimize the impact of roadway incidents (accidents, stalls, and debris).
3. Contribute to the regulation of demand (proactively manage special event traffic).
4. Assist in the provision of emergency services.
5. Create and maintain public confidence in the traffic management center.

The specific goals of each traffic management center are likely to vary and change over time (even from conception to implementation), depending upon the resources, personnel, and equipment available to the center. For example, incident management may be an effective goal for a highway traffic management center, but for a center that manages arterials and city streets, the area to be monitored is too vast and the impact of incidents is too minor to achieve this goal. The center may also take on new roles throughout its life. One interviewed center was built with the goal of detecting and managing incidents, but after realizing that this goal was not feasible, the center found that it was in a perfect position to act as a much needed coordinator to keep track of the planned and emergency construction projects in its area.

Each traffic management center is also unique in the technologies and systems they use, but the reccurring theme, from both a technical and human factors standpoint, was the need to integrate a wide variety of systems. Often legacy centers are faced with the challenges of integrating older systems and technologies with newer ones, even though they were never meant to work with each other. As an example, older field-monitoring systems that are server based might be in place on some of the networked roads, while the newer roads in the network use hardware systems that have more intelligence in the sensor and do not require a central server. Human factors issues often arise when trying to integrate the vastly different interfaces of the various systems.

Another human factors issue found in many traffic management centers came from the fact that the control rooms were not static. A traffic management center needs to be designed for flexibility. The operators were often working with only partially functional systems because of continual upgrades, and given the varying private partnerships and agreements maintained by each center, the centers were often participating in research projects or pilot programs. These programs often required the addition of equipment and a small research staff to an already crowded control room.

At the time of this report, there were several published, traffic-management specific, empirical human-factors studies covering the following topics:

- The required operator capabilities
- Monitor-viewing distances and camera controls
- The usability of computer-based operator support systems
- The design of incident detection support systems
- The design of message posting systems

The first draft of *The Human Factors Handbook for Advanced Traffic Management Center Design* (Kelly, 1995) was also available. However, interviews with local traffic management center personnel revealed that the current research and guidelines were underutilized in the design and construction of even recent traffic management centers. In fact, for some applications, even the Windows style guidelines were not followed, and often the traffic management center operators had little control or influence over the final products they received. Although there is no substitute for integrating human factors into the design process, it would be recommended that *The Human Factors Handbook for Advanced Traffic Management Center Design* be referenced as a minimum standard in future contracts.

Although the Handbook covered many basic human factors issues and the current research has explored many design options, there has been little research reported (or guidelines created) in the following areas: traffic management center performance requirements, human factors considerations for information dissemination strategies, and human factors guidelines for real-time traffic information web sites. While much of the research has focused on comparing different design options (for camera controls, incident detection systems, message posting systems), little work has been done to define what the performance criteria for these systems should be. For example, how long should the system and operator team take to detect an incident, and how long should it take the operator and system to post a message or otherwise get that information out to the public.

Performance goals and criteria would likely be useful in helping traffic management centers evaluate the technologies available to them. For example, although the research may show that an automatic message posting system will help operators to post messages several minutes faster, a particular center may find that to meet the performance goals, their money would be better spent upgrading a slow sign-communications system. The designers could also use the performance goals to prototype and test different operator-system interfaces before they are built.

Guidelines for information dissemination was a second topic where little research was found. The questions asked by traffic management centers revolve around which technologies to invest in and how to successfully implement those technologies. While often the focus is on the cost of implementing the technology, the expected benefit of many information-dissemination technologies is still unknown. Some of the information-dissemination technologies from which a traffic management center has to choose include the following:

- Variable message signs (VMS)
- Highway advisory radio (HAR)
- Public TV and radio
- Cable TV
- Telephone hotlines
- Pagers, E-mail, and other personalized services
- Internet web sites
- In-vehicle systems

Specifically, the need for guidelines on web-based traffic-information sites was mentioned by several traffic management centers because frequently the development and maintenance of these sites is left to the personnel at the center (whereas other information-dissemination technologies are purchased from vendors). Information is needed on when drivers or users will actually look at a traffic-information web site, what they want to see, and how much time are they willing to spend to get the information they need.

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APPENDIX A - Table of Contents for the *Human Factors Design Guide*

Appendixes

APPENDIX B - Table of Contents for the *Human Factors Handbook for Advanced Traffic Management Center Design*

Note: The original table font is used to preserve the tables look and spacing.

FOREWORD

CHAPTER 1. HUMAN FACTORS AND THE TMC

CHAPTER 2. PRINCIPLES AND METHODS OF USER CENTERED DESIGN

CHAPTER 3. ALLOCATING FUNCTIONS AND ANALYZING TASKS

CHAPTER 4. HUMAN ERROR

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CHAPTER 6. JOB DESIGN

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CHAPTER 8. DISPLAY DEVICES

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CHAPTER 10. THE WORK SPACE

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CHAPTER 12. USER AIDS

CHAPTER 13. DATA PRESENTATION

GLOSSARY

BIBLIOGRAPHY AND REFERENCES

APPENDIX C - Summary of TMC Functions and Allocations

Function Definition		Human Role
Receive Input from Roadway Sensors and Cameras		
1	Detect vehicle locations	Executive Controller
2	Detect vehicle speeds	Executive Controller
3	Detect vehicle types	Executive Controller
4	Sense roadway surface conditions	Supervisory Controller
5	Receive BIT reports	Executive Controller
6	Receive ad hoc component status reports	Direct Performer
7	Sense visibility conditions	Supervisory Controller
8	Verify incident data	Manual Controller
9	Monitor incidents being cleared	Manual Controller
Receive External Information		
10	Receive traffic volume reports	Direct Performer
11	Receive probe vehicle reports	Executive Controller
12	Receive ad hoc travel time reports	Direct Performer
13	Receive ad hoc roadway condition reports	Direct Performer
14	Receive O-D data	Executive Controller
15	Receive commercial rail traffic data	Executive Controller
16	Receive ad hoc commercial rail traffic reports	Direct Performer
17	Receive weather service data	Executive Controller
18	Receive ad hoc weather reports	Direct Performer
19	Receive interagency incident data	Executive Controller
20	Receive ad hoc incident reports	Direct Performer
21	Receive interagency response data	Executive Controller
22	Receive ad hoc incident response reports	Direct Performer
23	Receive interagency emergency response data	Executive Controller
24	Receive ad hoc emergency response reports	Direct Performer
25	Receive interagency data on alternate transportation modes	Executive Controller
26	Receive ad hoc reports from alternate transportation modes	Direct Performer
27	Receive interagency special event reports	Executive Controller
28	Receive ad hoc special event reports	Direct Performer
29	Receive public comments	Direct Performer
Receive Requests for Information		
30	Receive requests for historical data	Direct Performer
31	Receive requests for simulation studies	Direct Performer
32	Receive requests for public relations activities	Direct Performer
Throughput		
33	Assess current load	Supervisory Controller
34	Anticipate near-term traffic conditions	Supervisory Controller
35	Identify traffic control options	Supervisory Controller
36	Predict traffic conditions given options	Supervisory Controller
37	Assess predicted traffic conditions given options	Supervisory Controller
38	Select best traffic control option	Supervisory Controller
39	Determine need for ATMS support	Supervisory Controller
40	Track special vehicles	Executive Controller

	Function Definition	Human Role
Throughput		
41	Assess traffic control system effectiveness	Supervisory Controller
42	Determine remedial maintenance needs	Supervisory Controller
43	Determine preventative maintenance needs	Supervisory Controller
44	Determine software upgrade needs	Direct Performer
45	Determine hardware upgrade needs	Direct Performer
46	Determine personnel upgrade needs	Direct Performer
47	Identify anomalies in traffic patterns	Supervisory Controller
48	Determine source of anomalies	Manual Controller
49	Determine ATMS responsibilities (for incidents)	Manual Controller
50	Determine need for incident services	Manual Controller
51	Determine appropriate ATMS responses	Manual Controller
52	Assess multimodal demand and capacity	Manual Controller
53	Identify demand regulation options	Manual Controller
54	Predict multimodal demand given options	Supervisory Controller
55	Assess predicted multimodal demand	Supervisory Controller
56	Formulate demand regulation recommendation	Direct Performer
57	Monitor compliance with current advisories	Supervisory Controller
58	Monitor general compliance with advisories	Manual Controller
59	Assess survey data	Manual Controller
60	Assess ad hoc public comments	Direct Performer
61	Plan public confidence enhancements	Direct Performer
Output		
62	Control access to roadway segments	Executive Controller
63	Control intersections	Executive Controller
64	Control railroad crossings	Executive Controller
65	Post route advisories on information outlets	Executive Controller
66	Provide route advisories to other users	Direct Performer
67	Post speed advisories on information outlets	Executive Controller
68	Provide speed advisories to other users	Direct Performer
69	Post mode advisories on information outlets	Executive Controller
70	Provide travel advisories to other users	Direct Performer
71	Post mode advisories on information outlets	Executive Controller
72	Provide mode advisories to other users	Direct Performer
Issue Requests		
73	Transmit electronic maintenance requests	Executive Controller
74	Issue special maintenance requests	Manual Controller
75	Issue upgrade requests	Direct Performer
76	Transmit electronic incident service requests	Executive Controller
77	Issue special incident service requests	Manual Controller
78	Issue requests for information	Direct Performer
79	Issue requests for on-site traffic control	Direct Performer
80	Transmit electronic incident reports	Executive Controller
81	Issue special incident reports	Manual Controller
82	Transmit electronic incident management reports	Executive Controller
83	Issue special incident management reports	Manual Controller
84	Provide historical traffic data	Manual Controller

	Function Definition	Human Role
Issue Requests		
85	Provide simulation reports and recommendations	Manual Controller
86	Provide public relations information	Manual Controller
Support		
87	Store network data	Executive Controller
88	Retrieve network data	Executive Controller
89	Store electronic incident data	Executive Controller
90	Store a hard copy of incident reports	Direct Performer
91	Retrieve electronic incident data	Executive Controller
92	Retrieve a hard copy of incident reports	Direct Performer
93	Perform data base management	Manual Controller
94	Provide traffic management training	Manual Controller
95	Provide maintainer training	Manual Controller
96	Provide incident management training	Manual Controller
97	Provide special events training	Manual Controller
98	Develop strategic traffic management plans	Manual Controller
99	Develop special event traffic management plans	Manual Controller
100	Develop traffic management contingency plans	Manual Controller
101	Receive directives	Direct Performer
102	Develop policy	Direct Performer
103	Specify procedures	Direct Performer
104	Implement policy and procedures	Direct Performer
105	Perform fiscal planning	Manual Controller
106	Perform budget tracking	Manual Controller
107	Perform evaluations	Direct Performer
108	Perform personnel selection	Direct Performer
109	Maintain personnel records	Manual Controller
110	Maintain communications with incident responders	Direct Performer
111	Coordinate multi-agency incident response	Direct Performer
112	Coordinate multi-agency response to other emergencies	Direct Performer
113	Coordinate multi-agency transportation planning	Direct Performer