TRAFFIC INCIDENT MANAGEMENT
STATE OF THE ART REVIEW

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EXECUTIVE SUMMARY

Traffic incident management (TIM) is a critically important piece of every transportation network management program. It should be considered in all stages of developing and implementing a network management and operations program as a key to reducing congestion. TIM programs have existed for more than 20 years.

For the purpose of this paper, the definition of traffic incident is “any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand.” This definition will provide the necessary broadness for types of traffic incidents that are going to be addressed here and for the adjustment to new ways of defining traffic incidents.

Activities related to incident management are one of the major responsibilities of traffic and transportation engineers. This report is focused on tools and strategies implemented in the area of Traffic Incident Management (TIM). Definitions and classifications of traffic incidents are presented at the beginning of the report. Stages in TIM are presented based on the most detailed approach in the available literature. Finally, this report explains the application of Variable Message Signs (VMSs), 511 Service, Highway Advisory Radio (HAR), and ramp metering in TIM process.

1. INTRODUCTION

Activities related to incident management are one of the major responsibilities of traffic and transportation engineers. Traffic incident management (TIM) is a critically important piece of every transportation network management program. It should be considered in all stages of developing and implementing a network management and operations program as a key to reducing congestion. TIM programs have existed for more than 20 years. At first they were developed to provide safe and efficient clearance of traffic incident site. Modern TIM programs and support systems have expanded their activities to response time optimization, increasing the accuracy of incident verification, and investigating the incident prediction techniques. The main purpose and basis of all incident management programs has always been the reduction of traffic congestion.

Traffic congestion can be classified as recurrent and non-recurrent. Recurrent congestion is a known occurrence that can be addressed by employing measures ranging from the building of new roads to ride-sharing programs. Non-recurrent congestion is largely produced by traffic accidents, such as vehicle disablements and flat tires, and is a major cause of the decline in mobility in the United States. There is also a symbiotic relationship between congestion, both recurrent and non-recurrent, and traffic accidents. This vicious cycle is a major problem that threatens mobility and safety [1.].

Traffic incidents have been identified as one of the major contributors to increased congestion. The National Traffic Incident Management Coalition (NTIMC) estimates that traffic incidents are the cause of about one-quarter of the congestion on U.S. roadways, and every minute a freeway lane is blocked due to an incident results in four minutes of traveler delay time. It has been shown that improved TIM reduces both overall incident duration as well as secondary crashes. The impact of this reduction incident duration is demonstrated by a study published in the ITS Journal that estimates the likelihood of a secondary crash increases by 2.8 percent for every minute that the primary incident remains a hazard.

Traffic incident management (TIM) is the systematic, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of traffic incidents, and improve the safety of motorists, crash victims, and traffic incident responders. Effectively using these resources can also increase the operating efficiency, safety, and mobility of the highway. This results from reducing the time to detect and verify a traffic incident occurrence, implementing the appropriate response, safely clearing the incident, and managing the affected flow until full capacity is restored [1.]. Incident management is the coordination of activities undertaken by one or more agencies to restore traffic flow to normal conditions after an incident has occurred. A well-organized and coordinated incident management operation will reduce the cost of the incident in terms of delay and wasted fuel.

A TIM program is a logical, structured, and integrated set of traffic incident management activities tailored to a specific geographic area. It includes policies, strategies, and technologies integrated into a multi-agency, multi-jurisdictional environment aimed at reducing the occurrence and impact of traffic incidents. To be successful, a TIM program must be on-going actively administered, organizationally structured, inter-jurisdictional, multi-disciplinary, and fully documented [1.]. The TIM program should be developed and managed in conjunction with the area's freeway management and operations program [2.]. From the perspective of a freeway management and operations program, TIM is often a major element, if not the cornerstone. The organization of the TIM program and the operational responsibilities of its participants should fit into the organization structure of the region, recognizing the existing assignment of traffic incident management activities and addressing gaps and overlaps in those assignments. Moreover, like all programs and activities that are intended to improve the operation of the transportation network, the performance of a traffic incident management program should be regularly monitored and assessed, potentially resulting in changes and refinements.

Several ITS components can support and enhance a traffic incident management program, including surveillance to detect and verify incidents, disseminating information to travelers regarding the resulting congestion and alternatives, improving response via the coordination afforded by a Traffic Operations center, as well as the real-time sharing of information among the affected agencies. Additionally, the various activities and coordination needs for traffic incident management parallel those associated with special event management and emergency/evacuation management.

2. TRAFFIC INCIDENT DEFINITION

According to Federal Highway Administration TIM Handbook published in 2000 [11.], "Traffic incident is any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand. Such events include traffic crashes, disabled vehicles, spilled cargo, highway maintenance and reconstruction projects, and special non-emergency events."

Manual of Uniform Traffic Control Devices [4.] defines traffic incident as "an emergency road user occurrence, a natural disaster, or other unplanned event that affects or impedes the normal flow of traffic."

The definition of an incident has changed after the events of September 11, 2001, and major weather events like Hurricane Katrina in 2005, and the role of TIM obtained the national importance in the United States. The broad scope of National Incident Management Systems (NIMS) developed by the U.S. Department of Homeland Security includes ensuring that U.S. roadways are available for incident response and has an enormous impact on emerging as well as established TIM programs. In agreement with NIMS concept, every TIM program is required to have three components:

- **Strategic:** How to plan, prepare for, and measure performance.
- **Tactical:** How to execute the plan and manage resources.
- **Support:** How to incorporate the tools and technologies to manage and communicate information.

Starting in 2009, the TIM program evaluation procedure for each state measures the emergency preparedness. The National Incident Management System (NIMS) requires the use of the Incident Command System (ICS) at traffic incident management scenes. The Incident Command System (ICS) is a standardized, on-scene, all-hazards incident management approach:

- Allows for the integration of facilities, equipment, personnel, procedures, and communications operating within a common organizational structure.
- Enables a coordinated response among various jurisdictions and functional agencies, both public and private.
- Establishes common processes for planning and managing resources.

ICS is flexible and can be used for incidents of any type, scope, and complexity. As a system, ICS is extremely useful; not only does it provide an organizational structure for incident management, but it also guides the process for planning, building, and adapting that structure. Using ICS for every incident or planned event helps hone and maintain skills needed for large-scale incidents.

Though the definition of traffic incident has expanded, the opportunities for addressing core transportation issues remain:

- Incidents are estimated to cause more than 50 percent of total delay experienced by motorists in all urban areas. Of this, 25 percent is caused by traffic incidents such as crashes, stalled vehicles, roadway debris, and spilled cargo [15.]

- Secondary crashes are estimated to cause 18 percent of all fatalities on freeways [15.]

- In 2002, approximately 50 percent of all police, Emergency Medical Services (EMS) personnel, and firefighter fatalities occurred as a result of transportation incidents (either accidental or "struck-by" incidents or crashes in pursuit or other line-of-duty activities).

- Between 1997 and 2006, 17 percent of the accidental law enforcement deaths were the result of “struck-by” motor vehicle incidents occurring during activities such as traffic stops, roadblocks, directing traffic and assisting motorists. [U.S. Department of Justice, Federal Bureau of Investigation, Washington, DC, 2006]

For the purpose of this paper, the definition of traffic incident is “any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand.” This will provide the necessary broadness for types of traffic incidents that are going to be addressed here and the adjustment to new ways of defining traffic incidents.

Before starting any traffic incident analysis, it is very important to specify the types of incidents that will be addressed. Incident classification will provide a way to organize the information about the number of incidents of various characteristics. For the purpose of this paper the classification is going to provide the background for incident response evaluation. This is very important from the Traffic Operations Center (TOC) standpoint, because it could lead to change or support of certain decisions that TOC managers and operators need to make during the incident management procedure. It is important to mention that each incident classification is regionally developed and differs from one TOC to another. However, the purpose and the basic criteria remain the same in every region, and incident classification system is an important input for every TIM program.

From disabled vehicles to major weather events or even terroristic attacks, the causes of traffic incidents are numerous. But it is the impact on traffic conditions that determines the classification or “rating” of traffic incidents. An incident rating system should classify incidents in terms of their potential to cause delays, fuel wastage, secondary accidents, and other adverse operational impacts. The following are the main problems and secondary effects associated with highway incidents:

- Traveler delay
- The serious risk of secondary crashes
- Danger posed to rescue and response personnel
- Reduction in productivity
- Increased fuel consumption
- Reduction in air quality
- Reduction in quality of life

Incidents can be classified in terms of their severity, nature of incident cause, time of occurrence and the number of agencies required to respond and clear incidents [21.]. Incident severity is the most often criterion used in incident rating, and it usually refers to the number of lanes and shoulders blocked and the delay caused due to a certain incident. If incidents are properly classified using the severity criterion, the level of incident impact prediction accuracy could be increased. This would positively affect the incident response time and total time needed for the recovery.

Previous studies that developed incident rating systems considered different variables that are directly related to the severity of the incident such as number of vehicles involved, lanes blocked, the time of the day, weather conditions, incident duration and number of service entities responding. The primary findings of several research studies were that the delay due to an incident is a function of the incident type. Cambridge Systematics developed an incident classification system using previous research findings. The large majority of the recorded incidents are categorized as vehicle disablements, referring to cars and trucks that have run out of fuel, have a flat tire, or simply have broken down and are abandoned by their drivers. Eighty percent of these disablements are moved to the shoulder, usually by their drivers, and then cleared in 15 to 30 minutes. Such incidents have no significant effect on traffic flow during off-peak hours, and are usually not included in traffic incident studies. During peak hours, however, they can cause up to 200 hours of delay to other vehicles. The remaining 20 percent of disabled vehicle incidents occur in the travel lane and result in one or more blocked lanes. According to a Cambridge Systematics study, these disablements are cleared in 15 to 30 minutes, but may cause up to 200 hours of delay to other drivers.

Table 2.1 represents the overall freeway capacity available based on the total number of lanes and number of lanes that are blocked due to an accident. For example, if a shoulder accident occurs and no lanes are blocked, 19 percent of the freeway capacity will still be lost due to rubbernecking of drivers passing by the incident site, and 81 percent of the overall freeway capacity will be available. Also, in the case when one lane out of two per direction is blocked, Table 2.1 shows that only 35 percent of capacity will be available instead of 50 percent as a value that would be expected. The additional capacity reduction of 15 percent is a consequence of drivers rubbernecking as they pass the incident site. Some recent studies show that losing one lane out of three causes more than a 33 percent reduction in capacity [67.], since in addition to physical reduction of capacity, the mere existence of the incident can further reduce the number of vehicles, i.e., capacity that can be served.

Table 2.1 Fraction of Freeway Capacity Available Under Incident Conditions [59.]

Number of Freeway Lanes in Each Direction	Shoulder Disablement	Shoulder Accident	Lanes Blocked		
			One	Two	Three
2	0.95	0.81	0.35	0.00	N/A
3	0.99	0.83	0.49	0.17	0.00
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.40	0.20
6	0.99	0.89	0.71	0.50	0.25
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	0.63	0.41

Only 10 percent of reported incidents are categorized as accidents, most of which are “minor collisions such as sideswipes and slow-speed rear-end collisions.” According to the study conducted by Sullivan [67.] about 40% of accidents occur in travel lanes, 10 percent on median shoulder, and the rest on the right shoulder. In 60% of accidents, drivers are able to move their vehicles onto the shoulder. An average accident lasts 45 to 60 minutes, and during congested periods such accident can induce up to 1,000 vehicle-hours of delay [Cambridge Systematics].

Major accidents constitute only 5-15 percent of all accidents and only a few of those are major incidents, such as hazardous materials incidents, that will cause major traffic disruptions both locally and regionally. The effects on traffic from catastrophic accidents can last from 12 hours up to a day, requiring the cooperation of multiple parties such as police, fire and rescue, ambulances, and tow truck operators. Table 2.2 includes the examples of these incident types, necessary clearance time and typical occurrence.

Table 2.2 Accident Impact - Summary of Previous Research Findings

<table>
<tr><th>Accident type</th><th colspan="2">Percentage</th><th>Duration</th><th>Delay [veh-hours]</th></tr>
<tr><td>One or two lanes closed</td><td colspan="2">40%</td><td>45-90 minutes</td><td>1,200-1,500</td></tr>
<tr><td>Major accidents</td><td colspan="2">5-15%</td><td>More than 60 minutes</td><td>2,500-5,000</td></tr>
<tr><td>HAZMAT</td><td colspan="2">Up to 5%</td><td>10-120 hours</td><td>30,000-40,000</td></tr>
<tr><td rowspan="2">Other</td><td rowspan="2">45-55%</td><td>70% on the shoulder</td><td>Up to 30 minutes</td><td>Minimal impact</td></tr>
<tr><td>30% on one or more lanes</td><td>60-90 minutes</td><td>1,000-1,500</td></tr>
</table>

A study conducted in Minnesota shows that 13 percent of all peak-hour crashes are the result of a previous incident. A study by the Washington State Department of Transportation further emphasizes this point. This study found that 3,165 shoulder collisions occurred on interstate, limited access, or other state highways during a period of seven years. The injury rates for shoulder collisions were much higher than the rates for all other accident categories [21.]. The severity of secondary crashes is greater than that of the original incident. This is the reason why it is very important to respond and clear incidents as soon as possible, since the longer the incident is in place, the greater the exposure to secondary crashes. A 1995 analysis of collision statistics in California show that secondary crashes represent an increase in collision risk of over 600% [21.].

Traffic incidents are divided into three general classes of duration, each of which has unique traffic control characteristics and needs [MUTCD, 2003].

- Major traffic incidents are typically traffic incidents involving hazardous materials, fatal traffic crashes involving numerous vehicles, and other natural or manmade disasters. These traffic incidents typically involve closing all or part of a roadway facility for a period exceeding two hours.
- Intermediate traffic incidents typically affect travel lanes for a time period of 30 minutes to two hours, and usually require control on the scene to divert road users past the blockage. Full roadway closures might be needed for short periods during traffic incident clearance to allow traffic incident responders to accomplish their tasks.
- Minor traffic incidents are typically disabled vehicles and minor crashes that result in lane closures for less than 30 minutes. On-scene responders are typically law enforcement and towing companies, and occasionally highway agency service patrol vehicles.

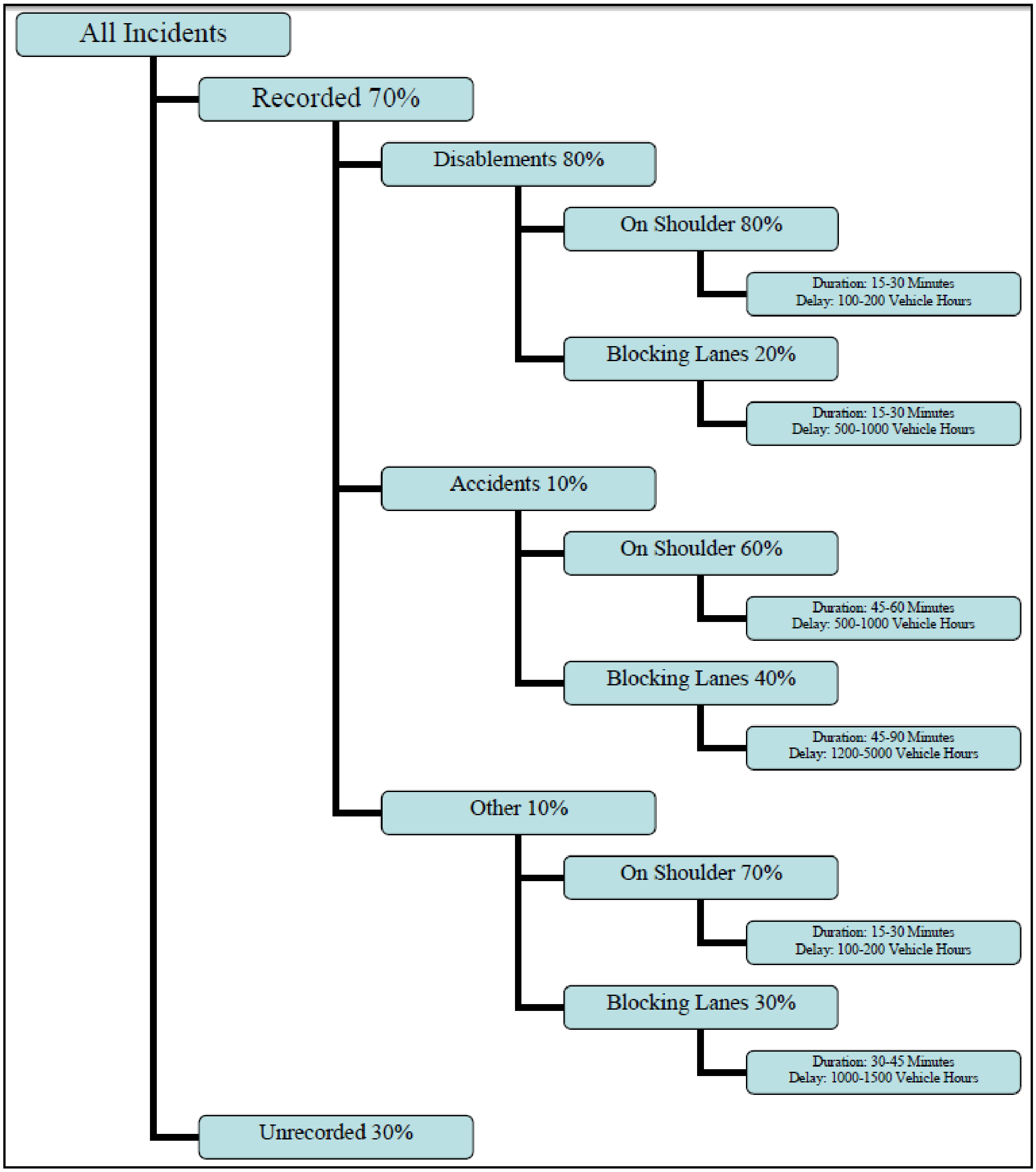

Figure 2.1 Profile of Reported Freeway Incidents by Type (11.)

According to Manual on Classification of Motor Vehicle Traffic Accidents [21.], there are four categories of traffic accident severities:

- Severity 1 refers to a single or multiple car incident involving mechanical difficulties or slight vehicle damage and lasts no longer than 5-10 minutes. Vehicle remains operational or can be pushed to the nearest exit without endangering life and property of those involved. Very little or no debris is present and no towing response is necessary. Agency involvement beyond law enforcement may not be necessary. No injuries are reported.
- Severity 2 requires assistance in the form of towing and law enforcement and typically lasts from 15-40 minutes. Vehicles typically cannot move from the freeway to the nearest off ramp or crash investigation site under their own power. Debris or fluid might be seen, but no injuries are reported.
- Severity 3 involves assistance in the form of towing, law enforcement, fire, and EMS. It typically lasts from 20 minutes to one hour or more. Vehicles cannot move from the freeway without mechanical assistance. Debris, fluid, and potential fire hazard are present. Injuries or fatalities are possible.
- Severity 4 refers to incidents that last longer than one hour and may involve multiple disabled vehicles. There is a possible need for EMS, fire department, and towing. Debris that is present could require clean up. These incidents last longer than the previous severity types of incidents.

There are many different classifications of traffic incidents. Inside the U.S. this classification differs from one state to another. To develop the incident classification system for this paper the following incident types are considered:

- Moderate crashes
- Severe crashes
- Emergency incidents
- Major snowstorms

Table 2.3 Accident Impact – Summary of Previous Research Findings

Incident	**Examples**	**Clearance Time (hours)**	**Typical Occurrence**
Moderate Crashes	One or more lanes blocked with personal injuries	1	Daily
Severe Crashes	Hazardous material spills, overturned oversized loads, fire flammable materials	2-6	Monthly
Emergency Incidents	Minor or major earthquakes affecting bridge structures, plane crashes affecting major highway, hazardous material spills requiring the evacuation of people, forest fires requiring the closure of a major highway	24+	Rare
Major Snowstorms	Severe capacity restriction	2-8	Monthly

The classification used for the purpose of this paper [UDOT] is based on the level of closure due to the traffic incident:

- LEVEL 1: Not blocking any lane
- LEVEL 2: Blocking less than one half of through lanes
- LEVEL 3: Blocking at least one half of through lanes
- LEVEL 4: Blocking all lanes and shoulder, no passage possible or permitted

3. STAGES IN TRAFFIC INCIDENT MANAGEMENT PROCESS

Incident management entails an identifiable series of activities, which may be carried out by personnel from a variety of response agencies and organizations. These activities are not necessarily performed sequentially. The most detailed process of incident management is represented in the Freeway Management and Operations Handbook [1.]:

1. Incident detection is the process by which an incident is brought to the attention of the agency or agencies responsible for maintaining traffic flow and safe operations on the facility.
2. Incident verification entails confirming that an incident has occurred, determining its exact location, and obtaining as many relevant details about the incident as possible. Verification includes gathering enough information to dispatch the proper initial response. Incident verification is usually completed with the arrival of the first responders on the scene. However, when hazardous materials are involved, the verification process may be quite lengthy.
3. Motorist information involves activating various means of disseminating incident-related information to affected motorists. Motorist information needs to be disseminated as soon as possible, and beyond the time it takes clear an incident. In fact, it should be disseminated until traffic flow is returned to normal conditions. This may take hours if an incident occurs during a peak period, and has regional impacts.
4. Incident response includes dispatching the appropriate personnel and equipment, and activating the appropriate communication links and motorist information media as soon as there is reasonable certainty that an incident is present. Response requires preparedness by each responding agency or service provider. This is fostered through training and planning, both as individual, and collectively with other response agencies. Effective response mainly involves preparedness by a number of agencies (i.e., planned cooperatively) for a variety of incident types, so that response to individual incidents is coordinated, efficient, and effective.
5. Site management is the process of effectively coordinating and managing on-scene resources. Ensuring the safety of response personnel, incident victims, and other motorists is the foremost objective of incident site management. Effective incident site management can be facilitated by an incident command system (ICS). An ICS is a formalized system that fosters consistency in the way agencies and service providers function cooperatively at an incident scene.
6. Traffic management involves the application of traffic control measures in areas affected by an incident. As with each function of effective incident management, traffic control in the incident management context is rooted in planning. This includes ensuring the availability of traffic control equipment and materials, knowledge of available fixed traffic control resources, and alternate route planning.
7. Incident clearance is the process of removing wreckage, debris, or any other element that disrupts the normal flow of traffic, or forces lane closures, and restoring the roadway capacity to its pre-incident condition. At times, this may also include temporary or permanent repair to the infrastructure.
8. Incident Recovery consists of restoring traffic flow at the site of the traffic incident, preventing more traffic from flowing into the area and getting trapped in the upstream queue, and preventing congestion from spilling across the roadway network. Thus it encompasses the activities of site management, traffic management, and clearance. Resources including traffic operations centers and their operating staff can facilitate recovery by managing the network-wide effects of traffic incidents and thus hastening recovery.

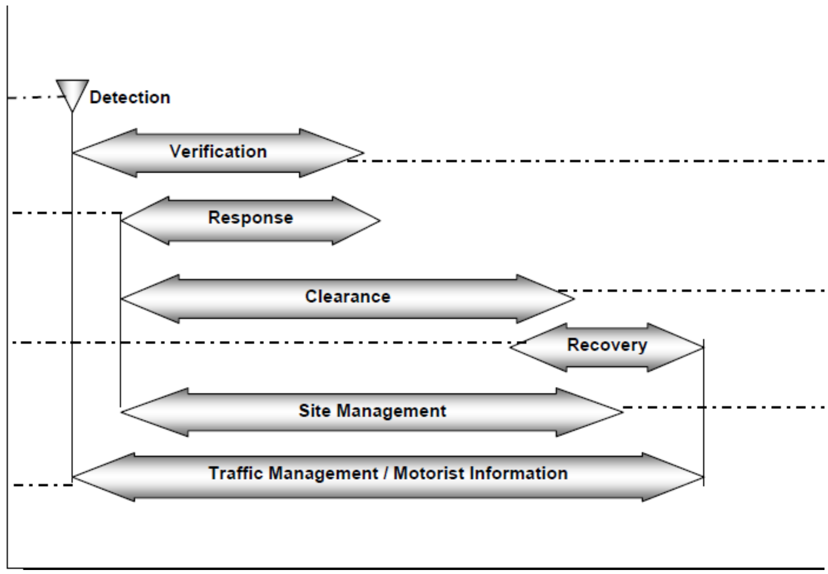

Figure 3.1 Timeline of Stages in the Traffic Incident Management Process [1]

3.1 Traffic Incident Management Area

A traffic incident management area is an area of a highway where temporary traffic controls are installed, as authorized by a public authority or the official having jurisdiction of the roadway, in response to a road user incident, natural disaster, hazardous material spill, or other unplanned incident. It is a type of Temporary Traffic Control (TTC) zone and extends from the first warning device (such as a sign, light, or cone) to the last TTC device or to a point where vehicles return to the original lane alignment and are clear of the incident [4.].

The primary functions of TTC at a traffic incident management area are to inform road users of the incident and to provide guidance information on the path to follow through the incident area. Alerting road users and establishing a well-defined path to guide road users through the incident area will serve to protect the incident responders and those involved in working at the incident scene and will aid in moving road users expeditiously past or around the traffic incident, will reduce the likelihood of secondary traffic crashes, and will preclude unnecessary use of the surrounding local road system. Examples include a stalled vehicle blocking a lane, a traffic crash blocking the traveled way, a hazardous material spill along a highway, and natural disasters such as floods and severe storm damage.

MUTCD Guidance [4.] for TTC zones is as follows:

- To reduce response time for traffic incidents, highway agencies, appropriate public safety agencies (law enforcement, fire and rescue, emergency communications, emergency medical, and other emergency management), and private sector responders (towing and recovery and hazardous materials contractors) should mutually plan for occurrences of traffic incidents along the major and heavily traveled highway and street system.
- On-scene responder organizations should train their personnel in TTC practices for accomplishing their tasks in and near traffic and in the requirements for traffic incident management contained in this manual. On-scene responders should take measures to move the incident off the traveled roadway or to provide for appropriate warning. All on-scene responders and news media personnel should constantly be aware of their visibility to oncoming traffic and wear high-visibility apparel.

- Emergency vehicles should be safe-positioned (see definition in *MUTCD Section 1A.13*) such that traffic flow through the incident scene is optimized. All emergency vehicles that subsequently arrive should be positioned in a manner that does not interfere with the established temporary traffic flow.
- Responders arriving at a traffic incident should estimate the magnitude of the traffic incident, the expected time duration of the traffic incident, and the expected vehicle queue length, and then should set up the appropriate temporary traffic controls for these estimates.

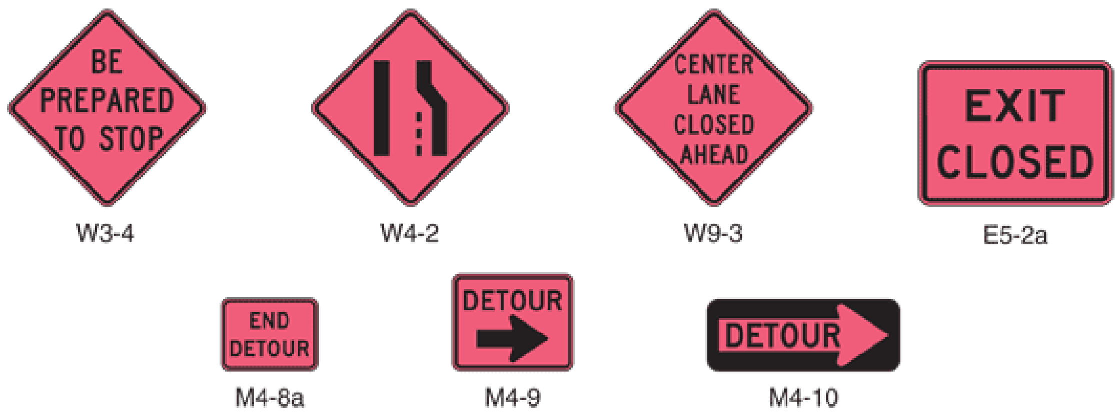

Figure 3.2 Examples of Traffic Incident Management Area Signs

While some traffic incidents might be anticipated and planned for, emergencies and disasters might pose more severe and unpredictable problems. The ability to quickly install proper temporary traffic controls might greatly reduce the effects of an incident, such as secondary crashes or excessive traffic delays. An essential part of fire, rescue, spill clean-up, highway agency, and enforcement activities is the proper control of road users through the traffic incident management area to protect responders, victims, and other personnel at the site. These operations might need corroborating legislative authority for the implementation and enforcement of appropriate road user regulations, parking controls, and speed zoning. It is desirable for these statutes to provide sufficient flexibility in the authority for, and implementation of, TTC to respond to the needs of changing conditions found in traffic incident management areas [4.].

3.2 TOC Functions

In the early 1990's, the Utah Department of Transportation (UDOT) began plans to develop **Commuter Link**, an Advanced Traffic Management System. By providing real-time information, travelers have an opportunity to adjust their route, time of travel, or mode of travel to avoid delays. This system, started as a regional coordination of signals across jurisdictional boundaries within the Salt Lake Valley, has grown to include over 600 traffic signals, 1400 detector stations, 250 closed circuit television cameras (CCTV), 70 VMS and a wide range of ancillary transportation management systems such as 511, a website, HAR, RWIS, etc. To support this system, UDOT has installed its own dedicated fiber optic communication network.

The application of ITS technologies has decreased congestion and delays without the need to increase the existing capacity of roadway networks. The Commuter Link has resulted in the reduction of freeway delays, traffic signal stops, intersection delays, and has increased peak-hour freeway speeds, thus saving over 100 million annually and reducing carbon monoxide emissions. ITS deployments have proven to be a cost effective tool with benefit/cost ratios ranging annually from 8:1 to 20:1. ITS in Utah is funded primarily through federal, state, and local participation, and the success of the Commuter Link ITS is due in part to public agencies working together for a seamless transportation system.

The nerve center of Commuter Link is the Utah Department of Transportation Traffic Operation Center (TOC). Information gathered by Commuter Link is brought together at UDOT's Traffic Operations Center (TOC). Using advanced technologies such as cameras and traffic and weather sensors, operators in the TOC can monitor traffic, detect accidents/problems, and take actions necessary to return traffic flow to normal. Basic TOC functions include the following:

- Traffic monitoring: Observing real time traffic conditions
- Traffic management: Dealing with "normal" traffic conditions
- Incident management: Detection, response and clearance
- Involvement in other processes and procedures

Traffic monitoring is related to constant observations of real-time traffic conditions. To provide this service, TOC uses CCTV to control traffic. Information is also collected from smaller traffic control centers and UTA's three radio control centers. The purpose of monitoring traffic is most importantly having a constant insight of the actual state of traffic, and then using the collected data for further traffic management under "normal" conditions and in the case of incident occurrence.

The term "traffic management" primary relates to dealing with everyday traffic conditions. This includes both peak and off-peak day periods. Data collected through traffic control and monitoring system are used to direct the travelers in the optimal way to their destinations and help them avoid long delays. Using data from traffic monitoring provides knowledge about real-time traffic and helps traffic management decision making. Traffic management is accomplished through the use of the systems of ramp metering, VMSs, traffic signals and their coordination, and advanced traveler information technologies. The final results of successful traffic management are reduced congestion and improved safety and efficiency of transportation system.

Incident management represents managing traffic under special conditions related to unplanned events that could seriously disrupt normal traffic operations. System used to provide this TOC service are the same as in the case of "regular" previously mentioned traffic management. The only difference is that incidental situations are difficult to predict, sometimes they are not easily detectable, and time for decision making certainly needs to be shorter than in the case of everyday traffic management to prevent or minimize possible negative consequences. The accent is on optimization of response time and time necessary to clear the incident site so that traffic can go back to its normal state. TOC functions could also be a part of other planning, design, public transit operations, maintenance, and many other activities in the transportation system. All TOC functions are goal oriented. The main goals of TOC operations and functioning are defined as following:

- To improve highway safety
- To improve the efficiency of Utah's highways
- To provide timely and accurate real-time traffic information
- To facilitate cooperative public and private partnerships that integrate transportation services
- To provide customer service directly to the public on the operation of the transportation system

4. TRAFFIC INCIDENT MANAGEMENT TOOLS

TIM tools presented in this section are used as traveler information systems or traffic management systems in congested conditions. The main focus is on variable message signs, since some of the studies used to support decisions about message display are 30-40 years old and human factors' research relevant for the usage of these signs is still not updated. Other traveler information strategies that have a significant impact during TIM procedures are also described: 511 calls and Highway Advisory Radio. At the end of this section, basic research findings about ramp meters are presented.

4.1 Variable Message Signs

Variable message signs (VMS) are traffic control devices used for traffic warning, regulation, routing, and management, and are intended to affect the behavior of drivers by providing real-time traffic-related information. VMSs are playing increasingly important roles in attempts to improve highway safety, operations, and use of existing facilities. The first set of VMS design guidelines was written in 1978, and it was focused on the recommended content in VMS messages, the manner in which messages should be displayed, and the location where messages should be displayed. Later updates of this document included maintenance, improvement of target value, motorist reception, operational procedures, and policies. The main challenge addressed in all these documents is the design and display of VMS messages.

Section 2A.07 of the Manual on Uniform Traffic Control Devices [4.] defines VMS as "traffic control devices," and says that a VMS "shall conform to the principles established" in the MUTCD related to the use of signs within the right-of-way of all classes of public highways, and to the extent practical, the design and applications prescribed in sections 6F.02 and 6F.52. Section 2E.21 of the MUTCD specifies that "changeable message signs shall display pertinent traffic operational and guidance information only, not advertising."

NTCIP 1203 v02 defines the user needs and features, functional requirements, and standardized design elements for variable message signs. VMS include all types of signs that can change state.

Table 4.1 Classification of VMS

VMS with fixed number of messages	VMS with unlimited number of messages	Matrix technologies
Fold-out Rotating drum Neon or blank-out signs	Character matrix Line matrix Full matrix	Reflective disk matrix Shuttered fiberoptic signs Light-emitting diode (LED) signs Hybrid VMS

Portable VMS provide great flexibility and are usually applied in construction and maintenance conditions. They are usually diesel or solar-powered and use wireless (cellular) communications to a central management point, making them a very attractive and flexible tool. Portable changeable message signs are usually located at the side of the road and do not sit as high as an overhead sign, which can impair driver visibility. Most are 3-line, 8 or 9- character signs, and although most have the capability of displaying multiple phases, they tend to be used with simple short messages to allow drivers to read and comprehend the message. The MUTCD states that no more than two phrases shall be used to display a message.

VMSs should be installed at locations where drivers have the opportunity to take some action in response to messages displayed [9.]:

- Upstream from major decision points (exit ramps, freeway-to-freeway interchanges or intersections)
- Upstream of bottlenecks, high accident areas, and/or major special event facilities (stadiums, convention centers)
- Where regional information concerning weather conditions is crucial

4.1.1 Applications and Design

In the most recent Changeable Message Signs Operations and Messaging Handbook [9.] published by the Federal Highway Administration, VMS are defined as "programmable traffic control devices that can usually display any combination of characters to present messages to motorists." The reason VMS are applied instead of static guide signs is to present real-time traffic information. VMS can be permanently installed above the roadway or driven to a desired location as portable devices. Portable VMS are much smaller than permanent and are oftentimes used in highway work zones, when major crashes or natural disasters occur, or for special events. The information presented on VMS must be consistent and compatible with static signs used on the freeway. VMS manage traffic by displaying three types of messages:

1. Early warning messages give drivers advanced notice of slow traffic, queuing ahead, new detours, changes in lane patterns, special speed control measures and are effective in reducing secondary crashes.
2. Advisory messages provide drivers with useful information about a specific problem along their routes, so they can change their speed or take an alternative route before they reach the problem area.
3. Alternative route messages influence drivers to travel to their chosen destinations by using routes different than originally intended. Alternative routes are designated by the transportation agency and MUST be used in the cases of road closures due to construction, crash, or natural disaster.

VMS display real-time information about traffic conditions, which is why they represent a direct link with the drivers. Since only a few seconds are available to communicate the message, VMS messages should be standardized and consistently applied. Reading times for VMS messages are longer than in the case of static guide signs, because drivers are less familiar with them, so exposure time of the VMS message is the factor that controls the maximum length of the displayed message. That is why very often a trade-off must be made and some useful information must be omitted from the message to stay within the maximum length requirement. Another factor that reduces the amount of information communicated via VMS is the legibility distance – the distance from which the driver can see, understand, and respond to a message, taking the possible bad weather conditions into consideration. Factors that are likely to enhance understanding of the VMS messages are as follows:

- Simplicity of words
- Brevity
- Standardized order of words
- Standardized order of message informational units
- Understood abbreviations when abbreviations are needed
- Standardized applications of messages

The messages displayed on VMS should represent what actually happens with traffic, and as traffic conditions change, VMS messages should follow those changes. If VMS messages are not changed in a timely manner, the drivers might start questioning the message credibility, and their confidence in VMS would decrease. VMS messages are changed manually, by system operators who must type in all the new messages before they are displayed, or automatically, in systems developed with computer assigned message design and display. A good message is efficient, brief, and to the point. Regardless of how well a message is designed, VMS must provide timely, reliable, accurate, and relevant information and they must be operated properly to be effective. Factors that may decrease VMS system credibility are inaccurate information, not current information, irrelevant information, obvious information, repetitive information, trivial information, erroneous information, and poor design.

The most important issue related to VMS application is message design. Display and design of VMS messages should be consistent with recommendations based on human factor research. Many traffic operations center (TOC) managers don't have the access to research reports that could assist them in VMS designing and operating, so they often display as much information that can fit on a VMS without recognizing that the messages exceed drivers' capability to read and comprehend them. Every TOC should have VMS message design and operations policies and procedures in a form of written document. The process of message design and establishment of a message objective should be completed before VMS are purchased, to avoid the lack of VMS space, lower target value, and legibility.

Table 4.2 The Application of Permanent VMS

Application	**Examples**
Non-recurrent problems	Caused by random, unpredictable incidents such as crashes, stalled vehicles, spilled loads; or caused by temporary, preplanned activities such as construction, maintenance, or utility operations.
Environmental problems	Caused by acts of nature such as fog, floods, ice, snow, etc.
Special event traffic problems	Problems associated with special events (e.g., ballgames, parades, etc.).
Special operational problems	Operational features such as high occupancy, reversible, exclusive or contra-flow lanes and certain design features such as drawbridges, tunnels, ferry services.
Recurrent problems	In a limited number of cases, caused by daily peak period traffic demands exceeding freeway capacities. In some cases, limits-of-congestion messages are displayed; in other cases, travel time messages are displayed.

4.1.2 Operating Fundamentals of VMS

It is very important that TOC has operations policies, procedures, and guidelines in written form. Operations policies are guiding principles that are considered to be prudent and that influence the actions taken by the managers of TOC. Operations procedures and guidelines outline and describe day-to-day operation of the VMSs. These documents in written form may support manager's decisions about displaying certain VMS messages.

VMS are tools used to help manage traffic on a roadway system. The TOC managers must select determine when and how to use VMS to accomplish traffic management tasks. Determination of VMS involves six basic considerations, and within each of these steps, several factors must be addressed:

1. Determine the purpose for using a VMS
2. Determine which VMS(s) is (are) appropriate to use
3. Determine what to display on the VMS
4. Determine how long to display the message (s)
5. Resolve any message signing conflicts that exist
6. Display and verify VMS message

4.1.3 Issues and Principles of Message Design

The VMS message design process was initially designed at the New Jersey DOT, and it begins with the development of base VMS message using guidelines of acceptable words and message terms for incidents or roadwork events. The base VMS message is the sum total of all the information that drivers need to make fully informed driving decisions. In most cases base VMS message must be shortened because it exceeds either the amount of information that drivers can read and comprehend or the space available on VMS. The maximum length of a VMS message depends on the sight distance from which drivers can adequately view the message and on their perception and information processing capabilities. Factors that affect sight distance are the type of sign, the sun position, roadway geometric design, travel speed, and environmental conditions at the VMS location. In cases where portable VMS are used, it may be necessary to reduce the number of units of information because of the sight distance restrictions related to vertical grades and horizontal curves. After the maximum number of units that may be displayed is determined, guidance should be provided to shorten the base VMS message so that the maximum length is not exceeded but the essential meaning of information is kept. Consistency of information and format should be provided. This process should prove that drivers will be able to read and understand the messages. The underlying objective is to keep messages as complete and concise as possible.

Message content refers to specific information displayed on VMS. The key elements are answers to the questions about what is happening ahead and what driver should do. The content must provide information relevant to the wants of the motorist. If an incident has occurred, the first information drivers are interested in is location. If the incident is near, they will want to change their primary route. If the incident is far, they might not be affected. The next important information is the level of incident impact on the roadway network, which can be expressed in terms of lanes closed if the information about delay is not prepared by TOC operators. At the end of the VMS message should be the “advice” such as REDUCE SPEED, EXIT, TAKE OTHER ROUTES etc. In order for drivers to follow the advice presented on the VMS, the message should include the reason for the given recommendation such as MAJOR INCIDENT, ROADWORK, AVOID 20 MINUTE DELAY, etc.

Message length refers to number of words or number of characters and spacing in a VMS message. Several factors may require the length of the message to be reduced:

- Reading time is the time that the driver has to read and comprehend the message content. It is affected by VMS legibility zone and the amount of activity in the traffic stream (reading signs, adjusting vehicle speed, lane positioning, etc.).
- Message familiarity because unfamiliar or unusual messages may increase the reading time. This factor varies from location to location.
- Driver workload refers to the fact that drivers must pay attention to more than one task while driving, which increases the reading time.

- Reading the VMS message requires longer time because the entire message must be read to properly understand the meaning.
- Message length should not exceed eight words (excluding prepositions), or it will result in some drivers slowing to read the message.
- The complexity of driving situation due to extremes in geometrics, heavier traffic volumes, increased traffic conflicts, or weather conditions could increase drivers' workload and visibility and thus decrease the time available to read the VMS message. When reducing the length, the message designer should take care not to lose the intent of the message. Also the philosophy "if it fits on the VMS, the message is OK" should be avoided, because the designed message might be longer than necessary.

Message load is the amount of the information expressed in the VMS message, usually in terms of units of information (informational units).

Unit of information (informational unit) is the answer to a question a driver might ask. It represents each data item that a driver could use to make a decision. Each answer is one unit of information [9.]. Unit of information usually contains up to three words, at times up to four. The concept of informational unit is presented in Table 4.3.

Table 4.3 Examples of the Units of Information in VMS messages

UNITS OF INFORMATION

Question		Answer		Info Unit
1. What happened?	• •	ACCIDENT	• •	1 unit
2. Where?	• •	AT EXIT 12	• •	1 unit
3. What effect on traffic?	• •	MAJOR DELAY	• •	1 unit
4. Who is advisory for?	• •	NEW YORK	• •	1 unit
5. What is advised?	• •	USE ROUTE 46	• •	1 unit

Research and experience indicate that no more than four units of information should be in a VMS message when traffic speeds are 35 mph or more. When operating speeds are less than 35 mph, no more than five units of information should be displayed. In addition, no more than three units of information should be displayed on a single message phase. Normally only one unit of information appears on each line of the VMS. However, a unit of information may be displayed on more than one line. A sign line should not contain more than two units of information. In a case when all informational requirements are met but VMS message exceeds the allowed length, tradeoffs must be made to determine which message parts should be omitted.

Message format refers to the order and arrangement of the units of information on a VMS. Order of information in the VMS message must be as expected from drivers. If the order of information is wrong, it may cause driver confusion and increase the reading time. For the appropriate order of VMS message parts, refer to the VMS Operations and Messaging Handbook 2004 (Tables 8-1 to 8-8).

Message design process begins with a base VMS message that is then reduced. The base VMS message is the sum total of all the information that drivers need to make a fully informed driving decisions. It will normally exceed the maximum amount of informational units that should be displayed, and so must normally be reduced in length and content. Three elements should be initially included in a base VMS message:

- Problem
- Location of problem
- Recommended driver action

It is not always possible to provide information about each of these elements because some state policies do not allow the VMS operator to post diversion messages. Instead of “Problem” and “Action,” more useful information could be posted, taking into account sign space and sign legibility. The base VMS message will differ depending upon whether the VMS is on the same freeway and relatively close to the incident/roadwork, same freeway but relatively far from the incident/roadwork, or different freeway than the incident/roadwork.

Table 4.4 Possible Base VMS Message Elements

Message Element	Incidents			Roadwork	
	Lane(s) Closed	Freeway Blocked[A]	Freeway Closed	Lane(s) Closed	Freeway Closed
Incident/ Roadwork Descriptor	X	X	X	X	X
Incident/Roadwork Location	X	X	X	X	
Lanes Closed (Blocked)	X	X	X	X	X
Closure Descriptor			X		X
Location of Closure			X		X
Effect on Travel	X	X	X	X	X
Audience for Action	X	X	X	X	X
Action	X	X	X	X	X
Good Reason for Following the Action	X	X	X	X	

In 2001, Dudek [9.] developed a VMS message design process that recognizes that there are variations to the message elements that can be used effectively in a VMS message. Message display is a dynamic process in which messages on a particular VMS can change as conditions change after an incident occurs. VMS message designers and VMS operators should be aware of the totality of information needed by motorists to make fully informed and rational decisions. VMS message designers and VMS operators should be aware that if the totality of driver information needed cannot be displayed in a message, the message length, in most cases, must be reduced. VMS message designers and VMS operators should be aware of the amount and type of information needed by drivers that cannot be displayed.

4.1.4 Maximum Message Length and Viewing Distance

All highway signs must display a message such that the driver is able to detect the sign, read and understand the message, and make the appropriate decision based on the information displayed. Initiating a control response and completing the required maneuver could also be the actions included in driver’s reactions to a VMS message. The amounts of time required for each of these actions generate the adequate VMS reading distance. Various factors have an impact on the maximal length of a VMS message:

- Driver’s perception/reaction time
- Obstructions between the driver and VMS
- Available reading distance

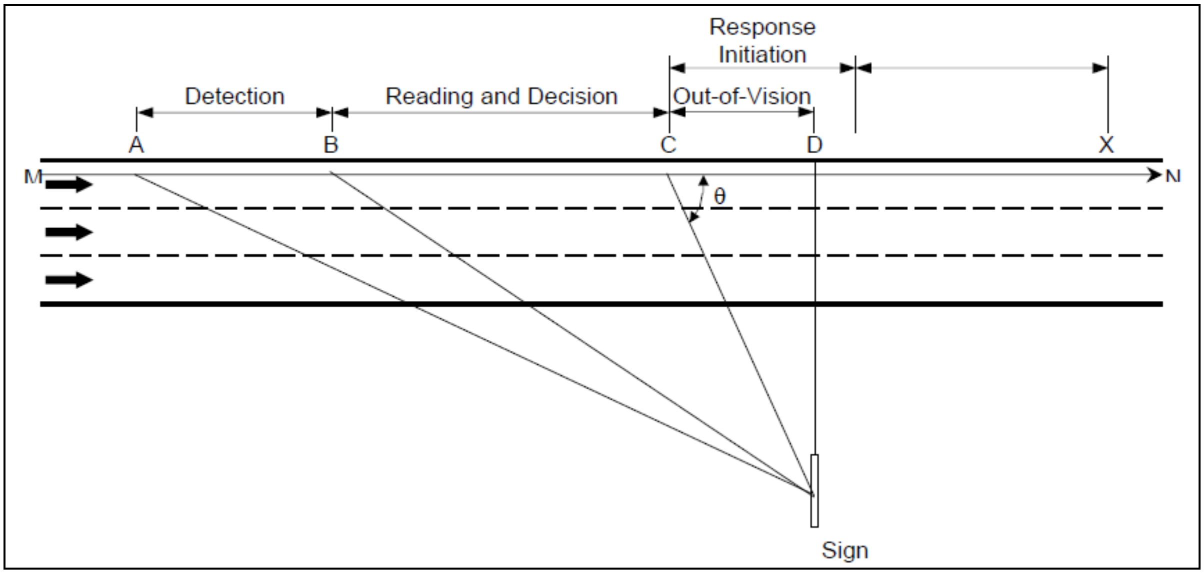

Figure 4.1 Sign Detection, Reading, Decision, Response Initiation, and Response Relationship

In cases where VMS does not require that a driver initiate and complete a maneuver prior to reaching the sign, the only elements that are relevant for maximum message length analysis are detection distance, reading and decision distance, and out-of-view distance. Distances traveled during each of these three components are mainly governed by the speed of the vehicle. Important definitions for this analysis are as follows:

- The minimum required visibility distance refers to a distance that a driver needs to detect the VMS.
- The minimum required legibility distance refers to a distance from a VMS where a driver needs to begin reading a VMS.

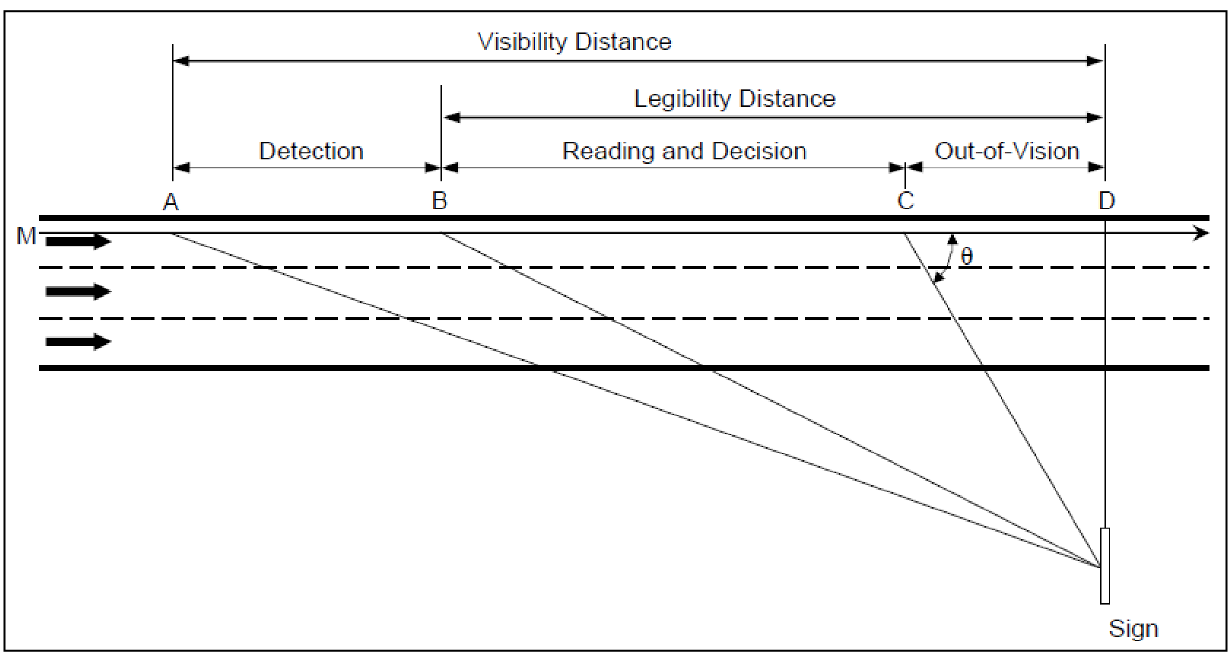

Figure 4.2 VMS Detection, Reading, Decision, and Out-of-Vision Relationships

For permanently mounted overhead VMSs, these relationships are the same, except for the fact that the angle θ is vertical rather than horizontal. The factor that dictates the available reading time for drivers is the minimum required legibility distance, taking the obstructions between the drivers and VMS into consideration. The higher the vehicle speed, the minimum legibility distance required is greater.

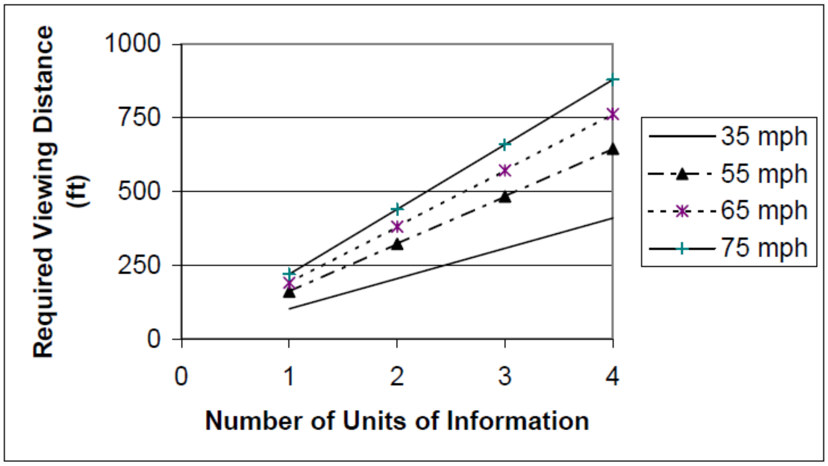

Figure 4.3 Required Message Viewing Distance for VMS mounted over the Travel Lanes

For VMSs positioned off to the side of the roadway additional sight distance is required to read the message. The greater the lateral offset between the driver and the center of the VMS is the greater the additional sight distance is needed.

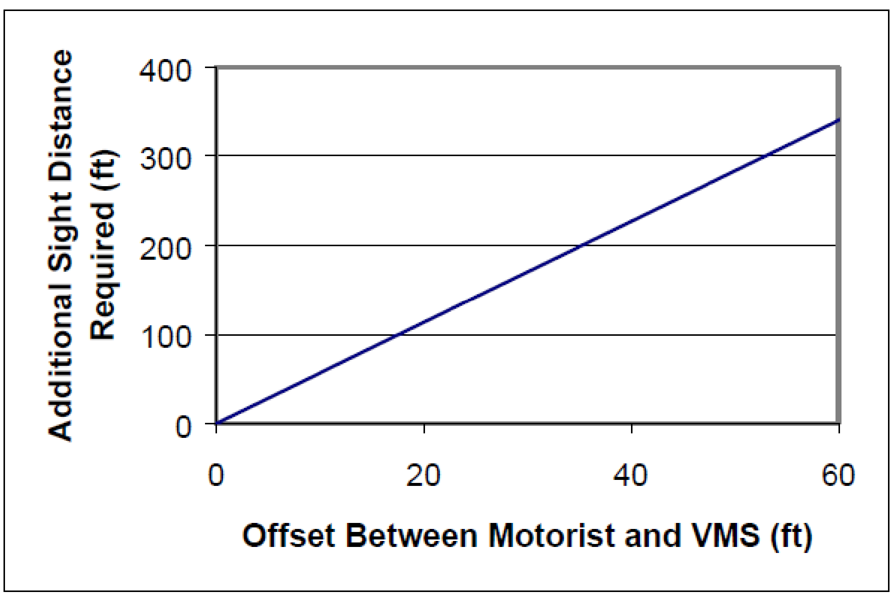

Figure 4.4 Additional sight distance required for lateral VMS offset

VMS legibility distance is the maximum distance at which drivers can first correctly identify letters and words of a VMS message. However, the maximal legibility distance is not always available, and that decreases the available reading time and requires shorter VMS messages. The maximal legibility distance is often reduced due to the following:

- Lightning conditions
- Position of the sun
- Rain and fog
- Vertical alignment
- Horizontal alignment
- Sight obstructions
- Trucks in the traffic stream

VMS legibility depends on design characteristics of the sign: type of display technology, height and width of the characters, the stroke width of the characters, and the type of font displayed. Smaller characters yield shorter distances. Legibility distances proposed for use in VMS message design presented in Table 10 include standard font (all uppercase), 18-inch character heights, 13-inch (approximate) character widths, and about 2.5-inch stroke (pixel) widths. Character heights on VMSs used on freeways and other high-speed highways should not be less than 18 inches (4).

Table 4.5 Suggested VMS legibility distances for use in message design (ft)

Condition	Light-Emitting Diode[A]	Fiberoptic	Incandescent Bulb	Reflective Disk
Mid-Day	800	800	700	600
Washout	800	800	700	400
Backlight	600	500	400	250
Nighttime	600	600	600	250

[A] Valid only for the newer aluminum indium gallium phosphide (or equivalent) LEDs

Table 4.6 Maximum number of units of information in VMS message (base maximum message length)

	Light-Emitting Diode [A]			Fiberoptic			Incandescent Bulb			Reflective Disk		
	0-35 mi/h	36-55 mi/h	56-70 mi/h	0-35 mi/h	36-55 mi/h	56-70 mi/h	0-35 mi/h	36-55 mi/h	56-70 mi/h	0-35 mi/h	36-55 mi/h	56-70 mi/h
Mid-Day	5 units	4 units	4 units	5 units	4 units	4 units	5 units	4 units	3 units	5 units	4 units	3 units
Washout	5 units	4 units	4 units	5 units	4 units	4 units	5 units	4 units	3 units	4 units	3 units	2 units
Backlight	4 units	4 units	3 units	4 units	3 units	2 units	4 units	3 units	2 units	2 units	1 unit	1 unit
Nighttime	4 units	4 units	3 units	4 units	4 units	3 units	4 units	3 units	3 units	3 units	2 units	1 unit

[A] Valid only for the newer aluminum indium gallium phosphide (or equivalent) LEDs

The presence of vertical curves usually affects portable VMSs positioned on the shoulder of the roadway. When actual operating speeds that are higher than the design speed of a vertical curve (non-freeway applications) can sometimes result in less reading time for the VMS message. In the case of vertical curve design speeds 45 mph and above, no reductions of unit information is required for LED VMSs. Vertical curve design speeds lower than 45 mph require the reduction of number of information units to account for lower legibility. For the required reduction of the number of units of information in the VMS message due to vertical curve refer to the VMS Operations and Messaging Handbook (2004).

If a permanent VMS is properly located, horizontal curvature will not impact the viewing distance and unit information reductions will not be necessary. The reductions are deployed in cases when portable LED VMSs are used. For the required reduction of the number of units of information in the VMS message due to horizontal curve, refer to the VMS Operations and Messaging Handbook (2004).

Rain and fog deteriorate the amount of light that is coming from the VMS and thus reduce the contrast between the sign legend and its background, decreasing drivers' capability to read the message properly.

The percentage of trucks in the traffic stream also impacts the visibility of VMS messages. As the percentage of trucks increases, and the design speed decreases, the percentage of drivers able to fully read a VMS message decreases. For the percentage of drivers able to fully read a VMS message with maximum base number of units of information, and for different types of highways, refer to the VMS Operations and Messaging Handbook 2004 (Tables 7-14 to 7-17).

4.1.5 Long Messages and Priority Reduction Principles

It is usually necessary to reduce the base VMS message because it is too long to be displayed in its primary form. Message length can be reduced by omitting unimportant word or phrases and using abbreviations. Approaches used are as follows:

1. Initial Reduction Approach
    a. Omitting unimportant words/phrases
    b. Omitting evident or redundant information
    c. Combining base VMS message elements
2. Secondary Reduction Approach
    a. Reducing the number of destinations in the "Audience for Action" message element
3. Priority Reduction Principles: Information units are eliminated starting with the lowest priority

In the case of splitting the message and displaying it on a VMS in sequences, the following principles should be deployed:

- No more than two phases should be used.
- Each phase must be understood.
- Compatible units of information should be displayed on the same phase.
- A message line should not contain portions of two different units of information.
- No more than three units of information should be displayed on a single phase at high freeway speeds.

Table 4.7 Information priority order for incidents

Message Elements For Lane Closure Incidents	Message Elements For Freeway/Expressway Closure Incidents
1. Incident Descriptor (Problem)	1. Closure Descriptor (Problem)
2. Incident Location	2. Location of Closure
3. Lanes Closed (Blocked)	3. Speed Reduction Action (if needed)
4. Speed Reduction Action (if needed)	4. Diversion Action
5. Diversion Action (if needed)	5. Audience for Action (if needed)
6. Audience for Action (if needed)	6. Effect on Travel (if needed)
7. Effect on Travel (if needed)	
8. Good Reason of Following Diversion Action (if needed)	

Table 4.8 Information priority order for roadwork

Message Elements For Lane Closure for Work Zones	Message Elements For Freeway Closure for Work Zones
1. Roadwork Descriptor 2. Roadwork Location 3. Lanes Closed 4. Speed Reduction Action (if needed) 5. Diversion Action 6. Audience for Action (if needed)	1. Freeway Closure 2. Location of Closure 3. Speed Reduction Action (if needed) 4. Diversion Action 5. Audience for Action (if needed)

After the message reduction approaches and requirements have been applied to the base VMS message and the message still has more units of information than should be displayed to drivers at the prevailing freeway speed, then the priority reduction principles discussed in this section should be applied. There is a priority of information that motorists need in order to make driving decisions when incidents occur or lanes are closed due to roadwork. The information needed by motorists in order of priority for incidents and roadwork is shown in Tables 4.7 and 4.8. Although the incident descriptor and the roadwork descriptor are useful to motorists, these message elements can be replaced with the lanes closed message element. When the number of information units exceeds the maximum that should be displayed under prevailing speeds and the initial reduction approaches and the secondary reduction approach have been applied, then the message designer must begin eliminating informational units. This is done by eliminating units of information starting with the lowest priority (*4*).

4.1.6 Dynamic Features on VMSs

Dynamic features on VMS messages are either flashing words or phrases of the message or parts of a split message in sequences. Messages with flashing words or phrases are displayed to attract the attention of drivers and emphasize the importance of the message. The effect that flashing has on drivers while traveling on a freeway is not fully known. The results of a single-task study shows that in a laboratory setting, flashing one-phrase, three-line messages increase the average reading time while not significantly affecting message comprehension. In contrast, for the driving simulator studies, the results indicate that unfamiliar drivers would have difficulty in understanding all parts of the entire message when it is flashed, while no differences were found between the flashing and static messages. Further research should be conducted to resolve this disagreement. Flashing one-line of three-phase messages significantly increase average reading time during both the laboratory and the driving simulator studies, while comprehension levels are lower. This implies that VMS messages should not be displayed with single flashing lines. Some VMSs operate as they have a two-phase message, but with information on two lines constant and redundant between two phrases. The results of the studies conducted in this area strongly imply that alternating line messages should not be displayed due to the increase of reading time and split subject preferences.

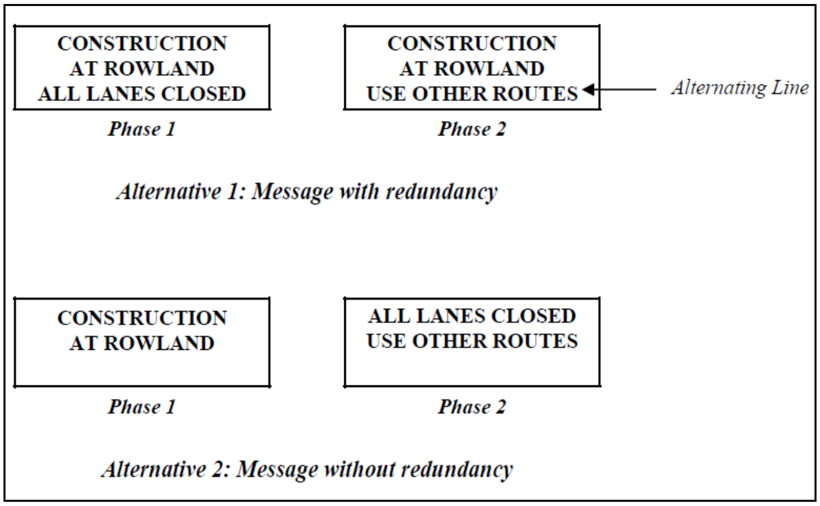

Figure 4.5 Two alternatives of a two-phase VMS message

4.2 The 511 Service

Operational 511 service is a part of a larger traveler information system (ATIS) that provides information to travelers via multiple media – web sites, television stations, and other technologies. To achieve useful and comprehensive 511 service, deployers need to be concerned with data acquisition, data quality, and system integration. It must be recognized that 511 is a service, and that it operates in an overall business environment created by the travel information market and the lead coordinating, or facilitating, agency.

Information content for 511 service can be broken into two main types: basic and optional. Basic content comes in three general categories:

1. Roadway (Highway and Arterials) – Information associated with particular roadways in a 511 service area
2. Transit or Public Transportation – Information associated with transit services (bus, rail, etc.) in a 511 service area
3. Weather – Information associated with observed and forecasted weather and road surface conditions that may impact travel in the 511 service area

In each of these content categories, the guidelines provide general principles or philosophies and specific guidelines on the type of information that should be provided to callers. The key concept in 511 service planning is that 511 systems must be designed to provide information beyond a single agency, mode, or content type. While content is organized in different types and categories, one principal carries throughout all content: provide sufficient “context” for an unfamiliar user of the service.

4.2.1 Roadway Content (Highways and Arterials)

As the primary means of travel in the United States, roadways (highways and arterials) and information about major roadways should be a principal part of 511 system. The core of many existing telephone-based traveler information services is highway conditions reporting. As these systems migrate to 511 access and new systems are established, the following guidance should be considered.

While not applicable in all areas, regional overviews can provide the caller with general high-level information about a region, helping to determine if the caller should seek additional detailed information by going to the routes/corridor and continuing through the content. Regional overviews, summaries, or floodgate messages allow users to get important information quickly, (i.e., incidents or service disruptions that may impact one's trip) without going through the menu system. Upon hearing the overview, the caller would be able to select the specific route or segment to obtain detailed information. Thresholds for determining what content is placed in a regional overview should be determined regionally.

Content should be route/corridor based, and 511 service should provide information that is retrievable by route number and/or name. In certain circumstances, if one or more roads run parallel, it may be acceptable to provide information on a corridor basis. However, providing information on major roadways on a broad geographic basis (e.g., "roads in the northwest portion of the state will be…") is not recommended. When a route/corridor is operated by multiple agencies, these agencies should work together to provide an integrated description of conditions.

Limited access roadways and the National Highway System (NHS) should be covered by the basic 511 highway/roadway – related content – with 40% of the nation's travel, including 75% of truck traffic and 90% of tourist traffic, the 160,000 mile National Highway System should be the focus of the basic 511 content. Limited access roadways that are not part of the NHS, likely to exist in urban areas, should also be part of the basic content.

Segment specification is left to the implementer, but should follow logic with segments defined between major towns, landmarks, roadways, or by weather differences. In urban areas, segments should be defined between major interchanges and will generally be smaller in length than non-urban segments. Once the 511 service knows the specific section of highway that the caller is interested in, it then provides the caller with a report of the relevant basic content. In non-urban areas, long routes should be sub-divided into segments.

Urban areas need more details given the increased traffic volumes and congestion levels, and the fact that even minor events could have large impacts to travel. Thus, greater content detail is recommended in urban areas. Whether the information provided to the caller is a human recorder message or synthesized or digitalized speech, this information should be stored and automatically provided to callers. There need not be any direct contact between callers and human operators to provide basic highway content. For each segment, specific types of content should be provided including the following:

- Construction/maintenance project
- Road closures and major delays
- Major special events
- Weather and road surface conditions

For each of these highway content types, it is necessary to provide details that enable callers to assess travel conditions and make travel decisions associated with a route segment:

- Location
- Direction of travel
- General description and impact
- Days/hours and duration
- Travel time or delay
- Detours/restrictions/routing advice
- Forecasted weather and road surface conditions
- Current observed weather and road surface conditions

The fundamental structure of telephone system design matches highways very well. Telephone systems are usually accessed through a “menu tree” that is navigated by voice commands or by touching a phone’s keypad. Eventually, callers reach their desired destination in the system and either get a recorded or digitalized voice message. When seeking highway information, callers will first find the specific highway or corridor for which they desire information, unless a regional overview is available and selected. Callers will then find the specific segment of highway or corridor that they are interested in, especially if it is a lengthy road.

The fundamental structure of a 511 telephone system design matches public transportation operations. Telephone systems are usually accessed through a “menu tree” that is navigated by voice commands or by touching a phone’s keypad. Eventually, callers reach their desired destination in the system and get either a recorded or digitalized voice message or possibly a live operator. In complex or large areas, the 511 service area may be segmented in sub-areas to simplify agency identification. Sub-areas may be dealt with by using voice recognition as described in San Francisco above.

Some content topics have been demonstrated to provide value to callers, but are recognized as difficult to uniformly implement. As services improve and evolve toward the long-range vision, these items should be incorporated into the service if not done so at the outset. Particularly in urban areas, estimated travel times across a route segment have proven highly desirable by callers. Travel times could be provided in absolute terms (“segment travel time is 24 minutes”) or in terms of delay from normal conditions (“segment travel time is delayed five minutes”). In the case of absolute travel times, it is recommended that travel times given do not exceed the speed limit travel time. In urban areas, multi-segment or corridor travel times are also acceptable.

Observed or measured weather information may, when combined and processed with other road and weather data, form the basis in predicting and providing callers with segment or route specific weather-related travel conditions.

4.2.2 Transit Content

In many cases, public transportation operators already have established methods of communicating to the public about their services, including websites and customer service centers accessible by telephone. If properly utilized and coordinated with these existing communications methods, 511 can assist public transportation operators in serving their customers better and even attracting new customers. Public transportation operators could take many different approaches to implement their portion of 511 services.

Information about all transit agencies in the area should be available. Often, one or two dominant public transportation agencies exist in the area, but many more exist that collectively provide a region’s public transportation system. All these operators should be accessible via 511. In complex or large geographic areas, it may be necessary to subdivide areas before identifying specific agencies. The San Francisco Bay area does not use sub-regions, which is one of the benefits of having a voice recognition system. The system asks callers to say the name of the transit agency they want, and if the caller does not know, then the system asks the caller to say the name of the city or county into which they are traveling. The 511 system returns with the agencies serving the city/county. If the caller still does not know which agency to say, the system takes the caller to the menu of the predominant local transit agency for the selected city or county.

The 511 service works in conjunction with transit customer service centers, and it is not intended to replace operators, but to provide compatible and supplemental information, usually in the form of recorded scripts. Further, the vision is that the callers would have direct access to customer service via 511, and how this occurs is an agency decision.

Experience shows that access to 511 can increase the number of callers seeking public transportation information. If 511 were merely designed as a shorter number to access the service center, this could significantly increase the number of calls to the customer service center. However, 511 systems can and should be designed to provide automated messages that will answer many callers' questions prior to seeking assistance from customer service center operators. Ideally, thoughtful design will reduce the number of calls fielded by operators and allow them to handle only the calls that require their expertise, and increase the total number of calls successfully managed. The 511 service must work in concert with the existing transit information call centers for it to be useful to the operating agencies.

To ensure information quality and agency autonomy, any information provided via 511 for particular public transportation operator must be provided or quality-checked by that operator.

For each public transportation agency, the 511 system should have at least a single automated report that provides the following:

- A brief description of the agency's operations
- Major service disruptions, changes, or additions
- Where appropriate, an option to be transferred to the agency's customer service center
- Other "broadcast" information at discretion of agency
- Agencies may add more "layers" to reports at their option
- Weather or road surface conditions that could impact travel along the route segment

In addition, in the case of large or complex 511 service areas, the service area can be subdivided for navigating and providing transit reports. Each agency in the service area should be accessible.

4.2.3 Weather Content

Weather information is a basic component of 511 information provision, and it is recommended that deployers provide travelers with whatever weather information is available that may affect travel. This includes weather information provided by the National Weather Service and private sector weather forecasts, as well as roadway weather or surface conditions, both observations and forecasts, which can be provided by mobile and stationary sensor data information gathered by maintenance and operations personnel. The basic principle for providing weather information is simple: if weather will impact people's trips, then they should be alerted to that actuality or possibility. It is recommended that deployers provide the most appropriate transportation information in the shortest amount of time.

Travelers need prioritized hazard information for the impacts of both current and changing weather conditions, and if there is weather forecasted along the route that will impact the travel. These reports should be segmented by route or trip where appropriate. This also includes the weather impact on transit operations – on guideways, railways, pathways – and related passenger information such as wind chill effects on those waiting at bus stops.

Weather information on a 511 system can range from a regional alert (hurricane, winter storm, etc.) to a route specific observation or alert (low visibility, icy pavement, high winds, etc.). Deployers should include any available weather-related information that could impact a person's travel and attempt to package and deliver the information in a consistent manner. The two keys to weather are relaying and providing navigational references to aid the traveler.

When weather conditions are the cause of accidents, incidents, and delays, it is recommended that this be noted on 511. For example, there is a ten-minute delay at the bridge crossing due to high winds. This is at the heart of weather information provided on 511. In other words, it is not direct weather that is important to 511, it is the related impact that is important. This is why future generations of 511 will include weather in the context of travel rather than simply providing the "data."

Weather information should be presented with a navigation reference, such as road segment, cities/towns, milepost, exits, major intersection/interchange to major intersection/interchange, landmarks, and rest areas.

Recommendations for implementation of 511 weather information are detailed below:

- Format for Depicting Road Conditions – The society of Automotive Engineers (SAE) ATIS standard/message sets are appropriate for sharing and presenting weather information on 511. The ATIS and Traffic Management Data Dictionary (TMDD) – standards for center to center communication – committees coordinate message set structures and coding to ensure commonnality. Many of the elements come from National Transportation Communications for ITS Protocol (NTCIP), Environmental Sensor Stations (ESS), or from TMDD when they do not come directly from the ATIS standard. Still to be worked on as of this document's publication date by the SAE ATIS standards team are more "FORECAST" type messages to deal with predicted weather conditions.
- Observed vs. Forecasted – 511 users want to get more timely, accurate, and relevant (e.g., location or route specific) forecasted information than they might on the nightly news or radio. There is a need for route specific weather forecasts, and the operational weather community is working on providing this data. It is recommended that a 511 deployer include weather conditions and forecasts likely to impact the ability to travel. One way to accomplish this is through "Nowcasting," a zero to three-hour statement of what is happening and the changing conditions that are important to travelers.
- Short, Live Update Frequently – It is recommended that weather condition information on 511 be updated frequently so that the information presented is the best available at the time. Weather forecasts and current conditions are available through a variety of means (RWS, radar, etc.) and in a number of time frames. Weather conditions may be slow, moderate, or fast changing and a 511 deployer needs to convey the impact of these changes to travelers. Thus, 511 deployers must be cognizant of the time frame in which weather conditions and forecasts may be ascertained and the resultant impact on travelers.
- Road Surface Conditions – Road conditions can change swiftly. Atmospheric and pavement sensor data can provide indications of conditions affecting traffic flow and roadway safety (e.g., low visibility, slippery pavement). Environmental sensor station (ESS0 data are typically collected by road weather information systems (RWIS) deployed by maintenance managers. These managers can supplement observed data from ESS with information on maintenance operations to provide data on actual surface conditions. Route-specific road condition data are currently provided, through traveler information websites, by 39 state agencies. Deployers of 511 systems should coordinate with state and local agencies to access existing data from advanced road condition reporting systems.
- Metropolitan Rural Differences – In non-urban areas, it is important to provide weather information on road segments before logical decisions point along a route. If there is snow in the pass and chains are sequined, this needs to be conveyed to travelers well in advance so that they may put on chains, use an alternate route or delay passage. In urban areas, segments are more proximate to other areas and there is more information available on many segments that are relatively close to one another.

4.2.4 Optional Content

The 511 service can provide additional content beyond the basic content described in the previous section. As long as quality basic content is provided, providing optional concept will benefit callers. Based on local demographics or geography, some of these optional content categories would be expected by local callers. Implementers should factor these expectations into their service planning process. In providing additional content implementers have essentially two choices:

- Providing a richer set of basic services, for instance, more highway routes added to the basic system, more detailed content on public transit services, improved accuracy, timeliness or availability of information, improving quality instead of quantity.
- Providing additional categories included in 511 services that are not part of the basic content package, for instance, tourist information, special events, parking, local information/points of interest, interregional information, driving directions, public transportation trip itinerary planning, multimodal routing and trip planning, incident reporting, carpools and vanpools, reservations and purchases, personalized services, customer feedback, and caller reports.

4.2.5 Content Quality and Consistency Issues

The accuracy, timeliness, and reliability of information on 511 is an important issue for the 511 community and users as well. In an increasingly advanced information society, callers are generally accustomed to high quality information. 511 content must be no different. In 2001, ITS America, in its national consumer research on 511, determined that "those surveyed said that if they used 511 and found the information to be inaccurate in their first few uses, they would be unlikely to give the service another chance." Therefore, 511 implementers must focus on the following five quality parameters:

- Accuracy – Reports are recommended to contain information that matches actual conditions.
- Timeliness – Closely related to accuracy, information provided by 511 is recommended to be timely to the greatest extent possible in accordance with the speed of changing conditions.
- Reliability – Often, transportation management systems are staffed during normal working hours, but travelers use highways 24 hours a day, seven days a week. In fact, often the most challenging travel conditions are at nighttime and on weekends. Methods must be developed to provide callers with a reliable stream of information 24/7.
- Consistency of Presentation – It is recommended that reports use the same, or similar, terminology to describe conditions. Lack of consistent terminology leads to misunderstanding and confusion among callers, and consistent terminology will make the system more usable as users move from system to system. The use of existing and evolving standards for messages, such as the TMDD and SAE J2354, enable this consistency.
- Relevancy – The information that is provided needs to be relevant to the callers given their locations, modal choices and/or actions they may need to take as a consequence of weather and road conditions or service disruptions.

The quality of basic content will largely determine the success of 511. This is why the information is recommended to be tailored to the travelers' needs along their routes. It is recommended that 511 services give callers the ability to gauge the quality of the reported information to enable them to properly weigh the information in their decision-making. However, no specific quality parameters are in the existing 511 service implementation guidelines, mainly because of the experience and user feedback and objective analysis/requirements that are needed prior to determining optimal quality parameters, and because the focus on information quality should lead to quality services.

While the concept of dialing an easy to remember telephone number and providing quality information to the traveling public is easy to grasp, the complexities of the systems behind the service, or the total lack of relevant technologies to assist in providing the service, could present a problem in building the entire 511 system. The deployment of roadside detectors, wireless communication devices, and other systems is key to the development of a nationwide 511 service. In fact, many states are presenting 511 as the "face of ITS" to elected officials and the public and are using 511 as a way to increase the coverage area of detection and systems. The more detection and base-level of technological investment there is, the better the 511 service, and more consistent the level of information provided, can be. If every state or region has a similar level of detection and integrated networks for collection, then the products could also be similar.

4.2.6 Emergency Alert Messages

Broadcast or floodgate messages can be a critical tool for disseminating information to the traveling public during a major incident, be it weather, event, or security-related. Broadcast messages can be implemented in various ways, but the two basic types are uninterruptible and interruptible – meaning a caller can override or terminate the message.

In times of emergencies, uninterruptible broadcast messages can deliver a brief, important message at/or after the greeting of a 511 service and terminate the call, thus creating a 511 system that has short call durations and disseminates the most critical information to callers and nothing else. This will alleviate some of the peak capacity issues that deployers are experiencing. The uninterruptible message relating to a lesser service disruption with a large impact requires callers to hear the whole message before they may continue to additional selectable information. Other forms of the message type are broadcast by service, mode of geographic area. Interruptible messages can be placed in the same areas of the system, but are typically used for less important information.

Virginia DOT found that 511 is a welcome asset during incident and traffic management situations. The 511 service is being used in conjunction with permanent and portable VMSs to relay critical information to travelers during major incidents, typically hazardous material spills that can close an interstate. Because VMSs are limited to three lines of text on three panels, multiple detour listings and descriptions of complex situations are generally not possible. The VMSs convey the necessary information as they normally would in these situations, but they also prompt travelers to dial 511 for additional information. In one situation, VDOT used VMS up to 100 miles from an incident to alert drivers to dial 511 where they received information about up to three detours depending on their desired destinations. VDOT has documented that by using the VMS and 511 together, call volumes to the service double almost immediately.

The AMBER Alert is a child abduction response system that uses radio, television, VMSs, and emergency broadcast systems to disseminate information about kidnapping suspects and victims soon after the crime is committed. The system is designed to solicit aid from the public to look for victims by providing known details such as descriptions of vehicles and individuals. In recent months, 511 services have become an additional tool for disseminating AMBER Alert information quickly and completely. In fact, many states have realized a significant increase in unsafe driving from the amount of information displayed on the message boards, which seems to be supported by University of Minnesota research that recommended changes to the Minnesota AMBER Alert messages on its VMSs, including referring drivers to other information sources to retrieve more detailed information. As a solution, Utah DOT is using less detailed AMBER Alert messages on its VMSs and prompting drivers to dial 511 where they can receive accurate information about the solution. This process was recognized by the AMBER Alert representatives in Utah with the designation of the 511 system as a "certified" source of AMBER Alert information.

4.3 Highway Advisory Radio

Highway advisory radio (HAR) is another type of traveler information system. Highway users receive the information through the radio receivers in their vehicles. The instruction to tune the vehicle radio to a specific frequency in order to hear the relevant information is displayed via roadside or overhead signs. Both live and prerecorded messages are broadcast.

The most important advantage of HAR is that it can reach more travelers than VMS because it communicates not only with the drivers at a particular point, but in the entire broadcast area. Another advantage of HAR over VMS is that HAR can deliver a greater amount of information.

The disadvantages of HAR are restriction to low power, often poor signal quality due to the impact of outside factors such as weather, and the requirement that a driver takes an action. All these disadvantages may often discourage drivers to use HAR.

Typically, HAR has been implemented using 10-watt AM transmitters, and this technology has proven to be effective. The application of digital HAR field systems eliminated many limitations of traditional dial-up systems, and improved quality of messages broadcast to the travelers. Digital systems offer increased speed of message updating, centralized management of multiple stations, enhanced reliability, superior radio quality, ease of operation, and automated event logging.

HAR messages can be broadcast in point or wide-area coverage. In a point broadcast, a single transmitter is used to broadcast to a given area. This type of coverage is applicable at diversion points in areas of recurring congestion to notify motorists of queues and congestion. Wide-area broadcast transmits a signal to a larger coverage area using multiple synchronized transmitters. It is used when a single message is applicable to a large coverage area and the coverage area is sufficiently large for a driver to hear the longer message. Synchronization is difficult to accomplish technically, and studies have proven that drivers prefer brief, specific messages.

In areas where the coverage is limited, the application of portable and mobile HAR systems is possible. These systems can be implemented in route guidance strategies at the decision points before the alternate routes to increase drivers' confidence in alternate route instructions.

HAR messages can be disseminated through centralized or distributed recording, storage, and playback. The centralized alternative considers transmission lines for audio connectivity and time synchronization with selected transmitters, while messages are created and stored at a central operations center. This type of architecture is subject to single point failures at the central operations center. The second alternative is distributed recording, storage, and playback where all system functionality is remote to the field HAR station. A distributed storage system is inherently more robust and less vulnerable to single point failures than a centralized system.

The signage indicating HAR frequency is typically installed throughout each zone. These signs usually include flashing beacons that are activated only when a message of some predetermined level of importance is being broadcast. The system is continuously broadcasting "default" messages during non-congestion periods, and alerting drivers to an emergency message by turning on the flashing beacons. This prevents the drivers from hearing the same message more times than needed, which could negatively impact system credibility. VMS messages could also be used to alert drivers to the broadcast of HAR message.

One way to overcome the need for HAR signing and manual tuning to the HAR frequency is to use automatic highway advisory radio (AHAR). The AHAR transmitter sends out a leading message, which is picked up by a special in-vehicle receiver when the vehicle enters the AHAR zone. The message automatically tunes the radio to the AHAR station and mutes any regular radio broadcast until the AHAR transmission is complete. A form of AHAR has been implemented in Europe via the "Radio Data System [RDS] Traffic Management Channel [TMC]." This system relies on a silent data channel broadcast via FM from existing radio stations.

Urban areas typically present a unique set of challenges to HAR application. Tall buildings present an obstacle to uniform transmission since the FCC restricts antenna height to approximately 50 feet. High-power electric lines can incur on the transmission and negatively impact broadcast quality. Messages are broadcast in the field from transmitters that play stored messages. These messages are transmitted to the field from a central location, which can be a traffic control center or any telephone. In its simplest form, no central system is needed, only an analog phone line to the transmitter so an operator can record a message in the transmitter for broadcast. This is labor intensive if an agency maintains a number of transmitters and traffic conditions change throughout the day. Its advantage is that it is inexpensive, and messages can be sent to a transmitter from anywhere a phone exists, even from a cell phone. Alternatively, a central message distribution system is used to record new messages, store pre-recorded messages, and distribute messages to the transmitters (simultaneous if necessary). This is typically a PC-based system with security access control.

4.4 Ramp Metering

The primary goal of ramp control and management is to connect functionally different roadways in a manner that will decrease traffic delay for the users. Close spacing, short acceleration distances, and constantly increasing congestion are some of the most serious problems in ramp design. From the aspect of incident management, the role of ramps is important simply because they are directly connected to two facilities, and the consequences of an incident in the ramps' area can cause greater delays comparing to other roadway segments. Typical ramp management strategies are ramp metering, ramp closure, special ramp treatments, and ramp terminal treatments [4.]. Many freeway activities are related to or dependent upon ramp management. This section is focused on ramp metering as an element of traffic incident management.

Ramp metering is the use of traffic signals deployed on a ramp to control the rate at which vehicles enter a freeway, thus making the traffic flow on the freeway more consistent, and allowing more efficient use of existing freeway capacity. Several ramp metering aspects must be considered before making decisions about the implementation of ramp meters:

- Metering Strategy – The control decision made that best addresses the specific goals and objectives of the metering system.
- Geographic Extent – The area that will be covered by ramp metering and whether the ramp meters in that area will be operated in an isolated manner or as part of a larger system of meters.
- Metering Approaches – Local or system-wide and pre-timed or traffic responsive.
- Metering Algorithms – The specific logic and calculations used to select or determine a metering rate.
- Queue Management – How the metering rate will be affected by ramp queues and how the agency will keep queues at a manageable and acceptable level.
- Flow Control – How traffic will be released from the meter, one at a time or two at a time in one lane or multiple lanes.
- Signing – How drivers will know that a ramp meter is on or off.

Ramp metering strategies have been the subject of several research studies both in the United States and in Europe. One of the first applications of mathematical programming to the problem of on-ramp control was by Wattleworth in 1965. This early formulation was based on a static model of traffic behavior, whereby the flows at any cross-section in the system could be expressed as the sum of the flows entering the freeway upstream of that location, scaled by a known proportion of vehicles that did not exit at any upstream off-ramp. This density-less model allowed the formulation of a linear program, since it avoided the important non-linearity in freeway traffic behavior – the relationship between flow and density also known as the fundamental diagram.

Many later contributions have built upon the original formulation by Wattleworth. Yan and Kreer proposed a quadratic cost to replace Wattleworth's liner maximization of on-ramp flows, in order to achieve a more equitable distribution of the control effort. Chen suggested the use of Total Travel Distance as the objective. Wang and May discussed several more enhancements, and extended the model to consider the effect of voluntary diversion to surface streets. Later authors furthered extended the model to capture the entire corridor, which comprises both the freeway and an alternative parallel route that allows drivers some flexibility in their choice of freeway access points. Payne and Thompson considered "Wardrop's first principle" as dictating the selection of routes by drivers, coupled with an on-ramp control formulation similar to Wattleworth's, and solved it with suboptimal dynamic programming algorithm. Iida posed a similar problem and employed a heuristic numerical method consisting of iterated solutions of two linear programs.

Another more recent enhancement has been the consideration of dynamic models. Most problem formulations using dynamic models have reverted to the simpler situation, where the effect of on-ramp control on access point selection is not considered. In these cases, the numerical method used to solve the resulting nonlinear optimization problem is gradient-based, and therefore provides only local solutions.

The ramp metering strategy extensively used by Caltrans is percent occupancy metering. This scheme utilizes occupancy measurements taken upstream of the on-ramp, in order to set the metering rate. Another strategy, Alinea, tested in Paris for the first time, tends to sustain near maximum flow downstream of the on-ramp by regulating the downstream occupancy to a target value set a little below the critical occupancy at which congestion first appears. The Alinea control strategy uses an integral of occupancy error between the set point occupancy and the actual downstream occupancy to compute the desired ramp metering rate. In the case where highways do not have loop detectors downstream of the ramps, Alinea can be adjusted to use the upstream detector – which as the simulation results have shown is preferred during congestion.

Based on the simulation and testing of these two ramp metering strategies, University of California Berkeley developed a new technique for generating optimal coordinated ramp meter plans. The design of this new and predictive coordinated strategy is based on avoiding the loss of travel time related to off-ramp blockage using the asymmetric cell transmission model. This solution requires only going through a single linear program to find the metering rates. After testing this technique in Pasadena, California, travel time savings of 8.4% were predicted. This research has shown that minimizing total travel time is equivalent to maximizing a weighted sum of flows. The advantage of this technique over many other predictive on-ramp metering designs is that it requires only solving a single linear program, which can be done with extreme efficiency using any modern LP solver. This solution takes on-ramp storage constraints into account.
Finally, the optimal solution is near global if slowly varying on-ramp flows are imposed, with respect to a cost function that is quantitatively similar to total travel time. This technique is envisioned as part of a larger and more robust traffic-responsive control structure on the complete freeway network. Perhaps the most important conclusion coming from the existing literature for other researchers is the efficiency of microsimulation tools such as VISSIM for different ramp metering strategies evaluation [61.].

Ramp metering reduces stop-and-go driving behavior, resulting in fewer rear-end collisions. Ramp meters also break up platoons entering a freeway, resulting in fewer side-swipe and merge-related collisions. During periods of severe weather, ramps may be closed to prevent motorists from accessing freeways that are impassable. Ramp-arterial treatments, such as signal timing improvements, may also improve safety by containing vehicle queues to the ramp, preventing queues from spilling back onto the freeway or adjacent arterial.

5. CONCLUSIONS

TIM programs address issues that are of vital concern: congestion and travel delay, public health and safety, energy savings, public safety resources, and responders' safety. Decision makers in most TOCs still do not have TIM procedures determined, usually because the cost-benefits of TIM investments are unknown.

Traffic incidents account for about one quarter of all congestion on U.S. roadways. For every minute that a freeway lane is blocked during a peak travel period, four minutes of travel delay results after the incident is cleared [16.]. Reduced incident-related travel delay is a key benefit of TIM programs. By reducing travel delay, fuel consumption, emissions, and secondary incidents, TIM programs benefit both the national and regional economy. TIM also decreases costs for highway users and makes the roads safer for them.

The future goals of TOCs should be to expand TIM programs to coordinated networks of freeways and arterials, in order to decrease travelers' delay even more. Using traveler information technologies to reroute drivers from a freeway incident decreases costs on their original route but also tends to increase delay on the arterial network. This brings out the question about the optimal number of drivers we need to reroute. VMS will have the greatest role in this matter, after the human factors are investigated and drivers' reaction and response to VMS messages are considered. This is still entirely new area of research, and some of the studies dealing with the problem of human response to VMSs were performed 30-40 years ago.

From the standpoint of performance measures of the current TIM programs, it is undeniable that all time periods relevant for an incident – detection, response, clearance, and recovery – are optimized by implementation of different TIM tools and strategies, and thus lead to time and cost savings for both users and stakeholders.

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