FINAL REPORT

Synthesis of Active Traffic Management Experiences in Europe and the United States

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Foreword

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16. Abstract

This synthesis report describes both US and European techniques in Active Traffic Management (ATM). The primary focus of this synthesis is on European experience, which in some cases dates back a number of years. This report provides a compilation of lessons learned, experiences, operational results, and benefits associated with active traffic management applications. The applications included for discussion are primarily those that include variable speed management (also called speed harmonization or lane control in Europe), shoulder or line management, junction control, and directional routing. The report concludes with a discussion of the potential benefits and challenges of a system-wide application of techniques to actively manage traffic and a listing of initial implementations of European strategies in the US.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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List of Abbreviations and Acronyms

ATM	Active Traffic Management
CCTV	Closed Circuit Television
DMS	Dynamic Message Sign
FHWA	Federal Highway Administration
GP	General Purpose
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
ITS	Intelligent Transportation System
LCD	Lane Control Display
LED	Light Emitting Diode
MUTCD	Manual on Uniform Traffic Control Devices
NTCIP	National Transportation Communications for ITS Protocol
O&M	Operations and Maintenance
PM	Preventive Maintenance
PS&E	Plans, Specifications and Estimate
SOP	Standard Operating Procedure
SOV	Single-Occupant Vehicle
TDM	Travel Demand Management
TMC	Traffic Management Center
TMS	Transportation Management System
UPS	Uninterruptible Power Supply
US	United States
VMS	Variable Message Sign
VSL	Variable Speed Limit

1.0 Introduction

1.1 Report Purpose

This synthesis report describes both US and European techniques in Active Traffic Management (ATM).

The primary focus of this synthesis is on European experience, which in some cases dates back a number of years. This report provides a compilation of lessons learned, experiences, operational results, and benefits associated with active traffic management applications. The applications included for discussion are primarily those that include variable speed management (also called speed harmonization or lane control in Europe), shoulder or line management, junction control, and directional routing. The report concludes with a discussion of the potential benefits and challenges of a system-wide application of techniques to actively manage traffic and a listing of initial implementations of European strategies in the US.

1.2 2006 Scan Tour Summary

In June 2006, a group of eleven US transportation professionals representing planning, design, and operations visited five European nations to study how they were addressing freeway congestion using dynamic or actively managed traffic management techniques. The trip was sponsored by the International Technology Scanning Program, a partnership of AASHTO, FHWA, and the National Cooperative Highway Research Program of TRB. The trip purpose was to examine congestion management programs, policies, and experiences from the perspectives of national, state, and local transportation agencies.

The scan team found that through the deployment of these specific traffic management techniques, agencies in Denmark, England, Germany, and The Netherlands exercise increased control over their roadway facilities and are able to better optimize their infrastructure investment to meet customer needs. Depending on the location and the combination of strategies deployed, specific benefits as a result of this congestion management approach include:

- An increase in average throughput for congested periods of 3 to 7 percent;
- An increase in overall capacity of 3 to 22 percent;
- A decrease in primary incidents of 3 to 30 percent;
- A decrease in secondary incidents of 40 to 50 percent;
- An overall harmonization of speeds during congested periods;
- Decreased headways and more uniform driver behavior;
- An increase in trip reliability; and
- The ability to delay the onset of freeway breakdown.

Nine key recommendations were identified by the scan team that would be applicable to congestion management in the United States. The following are the scan team's primary recommendations (Mirshahi, et al., 2007):

1. Promote active management to optimize existing infrastructure during recurrent and non-recurrent congestion.
2. Emphasize customer orientation and focus on trip reliability.

3. Integrate active management into infrastructure planning and programming processes.
4. Make operations a priority in planning, programming, and funding processes.
5. Develop tools to support active management investment decisions.
6. Consider public-private partnerships and other innovative financing and delivery strategies.
7. Provide consistent messages to roadway users.
8. Consider pricing as only one component of a total management package.
9. Include (ATM consideration) as part of the overall management of congested facilities.

2.0 What Is Active Traffic Management--Why and When is it Used?

Active Traffic Management is generally regarded as an approach for dynamically managing and controlling traffic demand and available capacity of transportation facilities, based on prevailing traffic conditions, using one or a combination of real-time and predictive operational strategies. When implemented together with traditional traffic demand management strategies, these operational strategies can help to maximize the effectiveness and efficiency of a roadway and result in improved safety, trip reliability and throughput. A truly active management philosophy dictates that the full range of available operational strategies be considered; including the various ways these strategies can be integrated together and among existing infrastructure, to actively manage the transportation system to achieve system performance goals. This includes traditional traffic management and ITS technologies commonly applied in the US, as well as new technologies and non-traditional traffic management technologies more commonly applied in other parts of the world.

Active management techniques are utilized throughout the world, but the focus of this synthesis is on those strategies utilized in Europe and the US. While the European and US strategies are different, in many cases they are complementary and may be combined to provide greater benefits than when implemented separately. The following sections describe strategies that are used in Europe and the US to enhance and support the management of roadway facilities either in an individual or combined manner to maximize efficiency and effectiveness of a single roadway facility or a larger roadway network.

2.1 European Traffic Management Strategies

The following list provides a high-level description of strategies currently being deployed in Europe to actively manage traffic:

- **Speed Harmonization/Lane Control**: utilizing regularly spaced, over lane speed and lane control signs to dynamically and automatically reducing speed limits in areas of congestion, construction work zones, accidents, or special events to maintain traffic flow and reduce the risk of collisions due to speed differentials at the end of the queue and throughout the congested area.
- **Queue Warning**: utilizing either side mount or over lane signs to warn motorists of downstream queues and direct through-traffic to alternate lanes – effectively utilizing available roadway capacity and reducing the likelihood of collisions related to queuing.
- **Hard Shoulder Running**: using the roadway shoulder (inside or outside) as a travel lane during congested periods to alleviate recurrent (bottleneck) congestion for all or a subset of users such as transit buses. Hard shoulder running can also be used to manage traffic and congestion immediately after an incident.
- **Junction Control**: using lane use control, variable traffic signs, and dynamic pavement markings to direct traffic to specific lanes (mainline or ramp) within an interchange area based on varying traffic demand, to effectively utilize available roadway capacity to reduce congestion
- **Dynamic Re-routing**: changing major destination signing to account for downstream traffic conditions within a roadway network or system.

- **Traveler Information**: providing estimated travel time information and other roadway and system conditions reports allowing travelers to make better pre-trip and in-route decisions.

2.2 US-based Traffic Management Strategies

The following list provides a high-level description of traffic management strategies that have been typically deployed in the US.

- **Ramp Metering**: controlling the flow of vehicles entering a travel stream (typically freeway or highway facilities) to improve the efficiency of merging, and reduce accidents.
- **Lane Management (or Managed Lane)**: improving or facilitating traffic flow in response to changing roadway conditions. Lane management includes controlling use of lanes by vehicle eligibility (carpool or transit), access control, and price.
- **Variable Speed Limits**: dynamically changing speed limit signs to adjust to changing roadway conditions, oftentimes weather related.
- **Shoulder Use:** use of the shoulder by time of day for transit or HOV, and in some instances general purpose traffic, to provide improved mobility along or within congested corridors.
- **Pricing**: managing traffic demand and flow using priced lane facilities, where traffic flow in the priced lane(s) is continuously monitored and electronic tolls are varied based on 'real-time' demand. Pricing of roadway facilities can collect a toll from all users of the facility. In the case of high occupancy toll (HOT) lanes, transit and carpools with a designated number of occupants are allowed to use the priced lanes for free or a reduced rate.
- **Traveler Information**: a variety of types of information provided to travelers (typically via variable message signs) to allow them to make informed travel decisions. Typical travel information includes travel times via alternative routes, and occurrence of incidents ahead.

The following chapters describe the listed European and US management strategies in greater detail.

3.0 US Techniques

As noted previously, ramp metering and managed lanes comprise the primary types of techniques currently under operation in the US that can be managed actively, with many metropolitan areas employing both ramp metering and managed lane facilities. Ramp meters are stop-and-go traffic signals placed at an on-ramp to control the frequency at which vehicles enter the freeway traffic stream. Managed lane facilities can include high occupancy vehicle (HOV), high occupancy toll (HOT), transit only lanes, and express lanes. They can be concurrent, contraflow or reversible lanes, whether operated part- or full-time.

3.1 Ramp Metering

Ramp metering, which maintains smooth freeway mainline flow by breaking up platoons of entering vehicles and/or limiting vehicle entry at entrance ramps, has been proposed and implemented in a number of metropolitan areas in and outside the US to mitigate freeway congestion due to merging vehicles.

The primary objectives of ramp metering include managing traffic demand to reduce congestion, improving the efficiency of merging, and reducing accidents—all of which lead to improved mainline freeway flow. In some situations, high volume freeway mainline flow can accommodate disbursed merging vehicles, but often cannot handle groups of vehicles at once. Ramp meters may control ramp traffic based on conditions in the field or manually to optimize the release of vehicles entering the freeway facility.

Ramp metering that is operated at pre-determined fixed-times of day is typically not considered an active management technique – while its operation can be demand based (on historical demand data), it does not manage the demand in a real-time active manner[1]. Ramp metering that employs or is managed using an adaptive algorithm that is based on system-wide monitoring that controls the application of ramp metering *is* considered an active management technique. Ramp meters that are monitored, activated and adjusted based on traffic operations by staff at traffic management centers would be considered actively managed, regardless of the algorithm used by the specific ramp meter.

The success of early ramp metering applications in US cities such as Chicago, Los Angeles, Minneapolis and Seattle led to the implementation and expansion of ramp metering systems in many other metropolitan areas in the US including Phoenix, AZ; Fresno, CA; Sacramento, CA; San Francisco, CA; San Diego, CA; Denver, CO; Atlanta, GA; Las Vegas, NV; Long Island, NY; New York, NY; Cleveland, OH; Lehigh Valley area, PA; Philadelphia, PA; Houston, TX; Arlington, VA; Miami, FL; and Milwaukee, WI; as well as in cities in other countries including Sydney, Australia; Toronto, Canada; and Birmingham and Southampton, UK.

In 2000 an independent study on ramp metering was conducted in the Minneapolis-St. Paul area (Cambridge Systematics, 2001). The evaluation addressed traffic flow and safety impacts associated with turning off all 430 ramp meters for six weeks. Results released by the Minnesota Department of Transportation showed that without ramp meters there was:

[1] It could be argued that even though a ramp metering system is set to start and stop at the same time every day, if it is actively monitored by operators and adjusted to adapt to conditions, and/or if the overall ramp metering algorithm is proactive in nature, then it could be considered actively managed.

- A nine percent reduction in freeway volume.
- A 22 percent increase in freeway travel times.
- A seven percent reduction in freeway speeds, which contributed to the negative effect on freeway travel times. The reliability of freeway travel time was found to decline by 91 percent without ramp meters.
- A 26 percent increase in crashes, which was averaged for seasonal variations. These crashes broke down to a 14.6 percent increase in rear-end crashes, a 200 percent increase in side-swipe crashes, a 60 percent increase in "run off the road" crashes, and an 8.6 percent increase in other types of crashes.

While ramp metering is more prevalent in the US, it is also employed in Europe. Germany has noted that ramp metering effectively prevents the drop in traffic speeds normally associated with merges and allows for the harmonization of traffic flow on major controlled access roadways. Ramp metering was found to reduce crashes with person and property damage by up to 40 percent, with no negative effects on the adjacent roadway network. On highway A40, a test program from 1998–2002, showed a reduction in accidents of 55 percent, and a 65 percent reduction in severe accidents (translated from "Europe on Course—Telematics on German Roads" German Ministry for Transportation, Construction and Housing 2005).

3.2 Managed Lanes

A popular approach to mobility management in the US is managed lanes, which are defined as dedicated highway facilities or lanes in which operational strategies are implemented and managed. Many of the current strategies are not managed in real time, but with technology advances more real time applications are being considered and implemented. Managed lanes can facilitate traffic flow in response to changing conditions by controlling user eligibility, access and/or pricing. Traditional lane management strategies include high occupancy vehicle (HOV) lanes, high occupancy toll (HOT) lanes, express lanes and reversible lanes. Of the listed managed lane strategies, the only two that can currently be considered as "actively" managed are HOT lanes and express lanes that are dynamically priced.

This chapter includes a description of European traffic management techniques with specific examples from Germany, Denmark, the Netherlands, and the United Kingdom. Information, experience and data were highly variable in their availability and therefore, some management techniques are discussed in greater detail than others. All techniques described include a definition of the technique and an associated benefits assessment. When information was available for a given technique, information on operational and safety considerations was included as well.

The following European techniques are discussed:

- **Speed Harmonization/Lane Control:** dynamically and automatically reducing speed limits in or before areas of congestion, accidents, or special events to maintain flow and reduce risk of collisions due to speed differentials.
- **Queue Warning:** warning motorists of downstream queues and direct through-traffic to alternate lanes, to effectively utilize available roadway capacity and reduce the likelihood of collisions related to queuing.)

- **Hard Shoulder Running:** using the shoulder (inside or outside) as a travel lane during congested periods to minimize recurrent congestion. Hard shoulder running can also be used to manage traffic and associated congestion immediately after an incident.
- **Junction Control:** using variable traffic signs, dynamic pavement markings, and lane use control to direct traffic to specific lanes (mainline or ramp) based on varying traffic demand, to effectively utilize available roadway capacity and manage traffic flows to reduce congestion
- **Dynamic Re-routing:** changing destination signing to account for downstream traffic conditions
- **Traveler Information:** providing estimated travel time information and other conditions reports allowing for better pre-trip and in-route decisions

3.3 Speed Harmonization

Speed harmonization (also known as variable speed limits in the US) has been used in the Netherlands and Germany since the 1970s, where it is typically implemented on roadways with high traffic volumes, with a goal of improving traffic flow. In the Netherlands, speed harmonization has been used for many years for the purposes of creating more uniform travel speeds and managing traffic during adverse weather conditions. Lane control displays are used for mitigation of incidents, maintenance and construction. In Germany, approximately 200km (124 miles) of roadway are managed using speed harmonization and lane control. In Denmark, speed harmonization, also referred to as variable speed limits, is deployed to manage construction project-related congestion on the ring road around Copenhagen.

Source: Dutch Department of Transportation

Figure 1. Speed Harmonization Signing in the Netherlands

Figure 1 shows speed `harmonization signing in the Netherlands, while Figure 2 shows the Dutch signage application of the dynamic speed limit system in the Randstad area.

In general, the European experience has been that at least one lane control display should be visible at all times for maximum effectiveness. In the Netherlands, gantries supporting speed controls are typically spaced an average of every 1,600 feet. In Germany, overhead sign bridge spacing is every 3,300 feet (1 km), but varies with installation and can extend farther, depending on sight distance. In addition to sight-distance and geometric considerations, cost may ultimately play a role in the spacing of lane control displays. Gantry spacing for the UK M42 motorway pilot project that implemented a combined speed harmonization and hard shoulder running installation was approximately every 1,600 feet (500 meters). Future UK managed motorway installations may ultimately consider a minimum spacing of approximately 2,600 feet (800 meters) and a maximum spacing of 3,300 feet (1000 meters) (UK Highways Agency Interim Advice Note 87/07, 2007).

Source: Stoelhorst and Havermans Centre for Transport and Navigation, 2008

Figure 2. Dynamic Speed Limits in Randstad Area

Lane control displays provide the flexibility to help manage incidents or address maintenance activities. When congestion is present, the speed limit is dynamically adjusted and displayed. When an incident occurs, a lane may be closed by showing a red 'X'. Advance notice of an incident is usually provided by indicating to motorists that they should switch out of that lane. This is typically done by using a diagonal arrow pointing to a neighboring lane. In the Netherlands, when an incident occurs, they use a cocked arrow, followed by a red "X" to move drivers out of the lane. On the M42 motorway in the UK, lane control displays are typically enabled for four gantries upstream from the closure or incident, with the first indication being a reduction in standard operating speed, the second a further reduction in speed, and the following two gantries using cocked arrows to move drivers out of a closed lane(s).

Critical to success of speed harmonization is the traveler's trust in the real-time operation of the system, including how it is being operated, its reliability, and the sense that it is being implemented for a valid purpose that will result in true safety and travel time benefits. Hence traveler information and in many cases queue warning are treated as crucial components for maximizing effectiveness of this technique. Operating the system on a 24/7 basis also generates public trust in the system whenever conditions warrant, and these conditions do not necessarily mean 24/7 staffing of the operation center.

Benefits Assessment

Germany has perhaps the longest history of speed harmonization projects, dating back to the 1970's. Their experience has shown that speed harmonization results in lower accident rates and typically results in a modest (5-10 percent) increase in roadway capacity. This is accomplished in part because the variable speed limits decrease the likelihood of severe congestion by increasing the stability of traffic flow (translated from "Europe on Course—Telematics on German Roads" German Ministry for Transportation, Construction and Housing 2005).

When implemented in Germany on the A5 motorway between Bad Homburg and Frankfurt/West, speed harmonization was associated with a 27 percent reduction in accidents with heavy material damage and a 30 percent reduction in personal injury crashes (Sparmann, 2006). In Bavaria, accidents were reduced by up to 35 percent, with 31 percent fewer crashes involving injuries (translated from "Europe on Course—Telematics on German Roads" German Ministry for Transportation, Construction and Housing 2005).

In the Danish case, as a result of the traffic management applications implemented (speed harmonization, lane management and variable message system)—traffic loads on the surrounding streets were less than expected and accidents did not increase appreciably during the re-construction of the M3 Motorway, even though the existing roadway lanes were narrowed during the construction period (Wendelboe, 2008).

England has also applied speed harmonization, known locally as Variable Mandatory Speed Limits (VMSL). On M-42, speed harmonization with hard shoulder running resulted in a seven percent increase in capacity and less overall congestion over the 12-month study period. Statistically valid safety analysis requires three years of data, but the initial results are encouraging (Mott MacDonald Ltd., 2008).

Additionally, a number of countries have documented a reduction in vehicle emissions after the implementation of speed harmonization. In The Netherlands, local traffic emission reductions of NOx were in the 20 to 30 percent range and PM10 was reduced by approximately 10 percent in the four test locations. In the UK, initial results found that vehicle emissions were reduced between four and 10 percent depending on the pollutant, and fuel consumption was also reduced by four percent (Mott MacDonald Ltd., 2008).

Operations

In the UK, speed harmonization has been applied to the six-lane M42 motorway (three lanes in each direction) in the West Midlands near Birmingham. In locations where hard-shoulder running is also applied to the outside shoulder, speed harmonization is included for the hard shoulder lane as well. Speed harmonization in the three-lane sections is automatically activated based upon flow and speed thresholds, though operators may adjust the operation if required. In general, speeds are adjusted approximately three gantries (approximately 1,500 meters or nearly 1 mile) back from the area of reduced speeds or an incident.

Speed harmonization with hard shoulder running (four lanes) is also based on predefined flow and speed thresholds. However, activation is not automatic, since operators need to ensure that the hard shoulder running lane is not blocked by debris or stopped vehicles. When activated, the speed limit is 50 mph or less (Mott MacDonald Ltd., 2008).

Operations for the Washington State Department of Transportation (WSDOT) speed harmonization/queue warning system will be similar to the UK M42 motorway system in that the over-lane speed and lane control signs are automatically activated based on identified thresholds. Under normal congested conditions reduced speeds will be shown on the over-lane signs and reduced speed warnings and information will be provided via side-mount signs and traditional VMS approximately two gantries (1 mile upstream) from congested conditions. The gantry immediately preceding the back of the queue will display the lowest designated speed on the over-lane signs. Over-lane signs on subsequent gantries within congested conditions will be turned off and the shoulder-mount and traditional VMS will provide regulatory and informational messages as necessary. Under incident conditions that include a lane blockage, approximately four gantries upstream from the lane blockage will be employed to first reduce traffic speeds and then divert traffic from the blocked lanes.

Operations for the Minnesota Department of Transportation (MnDOT) intelligent lane control and variable speed limit system are generally similar to those discussed for the WSDOT system. Under normal congested conditions, two gantries prior to congested conditions will be engaged and five gantries prior to a blocking incident will be engaged, with the first two gantries displaying speed reductions and the remaining three displaying lane control information (Kary, 2009).

Enforcement and Compliance

Enforcement of the speed harmonization system's reduced speeds in the Netherlands and England is automated. The automated speed enforcement system in the Netherlands measures average speeds over a two to three km (1.2 to 1.8 miles) section of the highway. In England, digital cameras are being used to record the license plates of violators who do not comply with the reduced speeds shown on the over-lane signs. Not all digital cameras are actively monitored at any one time, but the randomness of monitoring helps promote widespread respect among motorists. The threshold for what constitutes a speed offense is also random, based on the number of observed offenses so that only the worst offenders are cited.

Thus far, England's experience on M42 near Birmingham illustrates high compliance with the posted speed limits using the Association of Chief Police Officers (ACPO) thresholds for enforcement. This threshold T is defined as being 10 percent higher than the posted speed S plus two mph, or:

$$T = 1.1 \times S + 2$$

Speed data were collected from January 2006 to September 2007 at 12 locations in each direction and analyzed applying the above thresholds for compliance with the posted speed limit. For speed limits of 50, 60, and 70 mph, compliance was 94 percent or better in all cases. For 40 mph posted speed limits, compliance was 84% or better. On the hard shoulder running lane, compliance was 97 percent or better at a 50 mph speed limit and 93 percent or better at a 40 mph speed limit (Mott MacDonald Ltd., 2008).

During the M42 pilot project study, surveys were performed to determine public awareness of signs and information. Each survey was split into two populations: local users and long distance users. Both groups had high (over 90 percent) awareness of the signs in the study section. However, they noted that some driver education is still necessary, particularly with the 'lane ahead closed' sign indicating that the lane was closing and drivers should therefore change to a neighboring lane. During 2007, a total of 25 percent of local users did not know the meaning of the sign (Mott MacDonald Ltd., 2008).

Capital, Operations and Maintenance Costs

Capital costs of speed harmonization can vary considerably by installation. This variance in cost is a result of the overall infrastructure approach to gantry/sign-bridge placement distances (1/4, to ½ to ¾, to 1 mile spacing), the number of lanes being spanned, the type of roadway that gantries/sign-bridges are being place on (at-grade or structure), the application of over lane, variable message and side mount signage, and the need for new or additional ancillary equipment (power, fiber optics, data feed, etc).

As an example of the difference in capital costs due to infrastructure, the M42 project in the UK is estimated in USD equivalent (USD equivalent based on 2008 exchange rates) per mile costs of approximately $18 million per mile (UK Department for Transport, 2008), which also includes the costs related to hard shoulder running. Whereas, the conceptual cost estimates for the Washington State speed harmonization/queue warning system were projected to range between $2.4 and $5.5 million per mile depending on the roadway segment (WSDOT, Active Traffic Management Conceptual Design and Cost Estimates, 2008). WSDOT developed an average conceptual cost estimate for a three-lane section of approximately $3.2 million per directional mile and approximately $4.0 million per directional mile for a five-lane section. It is important to note that the WSDOT costs do not include implementation of hard shoulder running.

As is demonstrated by the information above, capital costs for these systems can vary dramatically depending on the desired system, the inclusion of shoulder operations, signage requirements, gantry/sign bridge spacing, upgrades to ancillary equipment, and associated emergency refuge areas if desired. Therefore, it is critical to develop the overall system concept first and then determine the system requirements and operational approach to fully understand and estimate system costs. Operation and maintenance cost variances are due to the level to which existing traffic management systems are already employed along the roadway, the operational philosophy employed for the proposed speed harmonization system and finally the integration of speed harmonization facilities and operations into an existing traffic management center.

Queue Warning

A key component of Germany's speed harmonization system is the addition of queue warning. A congestion pictograph or icon is displayed on both sides of the gantries to alert motorists of congestion ahead (Figure 3). Alternatively, the pictograph may be displayed on an overhead DMS. The value of the system lies in being able to reduce the occurrence of incidents caused by the congestion.

Queue warning systems are very frequently combined with speed harmonization systems given the large number of design elements they have in common. The Dutch system also incorporates queue warning in their speed harmonization system; motorists are alerted of downstream queues with flashing lights in addition to variable speed signs. As a result, there are few examples of queue warning systems

Source: Hessen, Germany

Figure 3. Queue Warning—Side-Mount Congestion Icons

operating in the absence of other traffic management strategies, which makes separate quantification of benefits and costs difficult.

Benefits Assessment

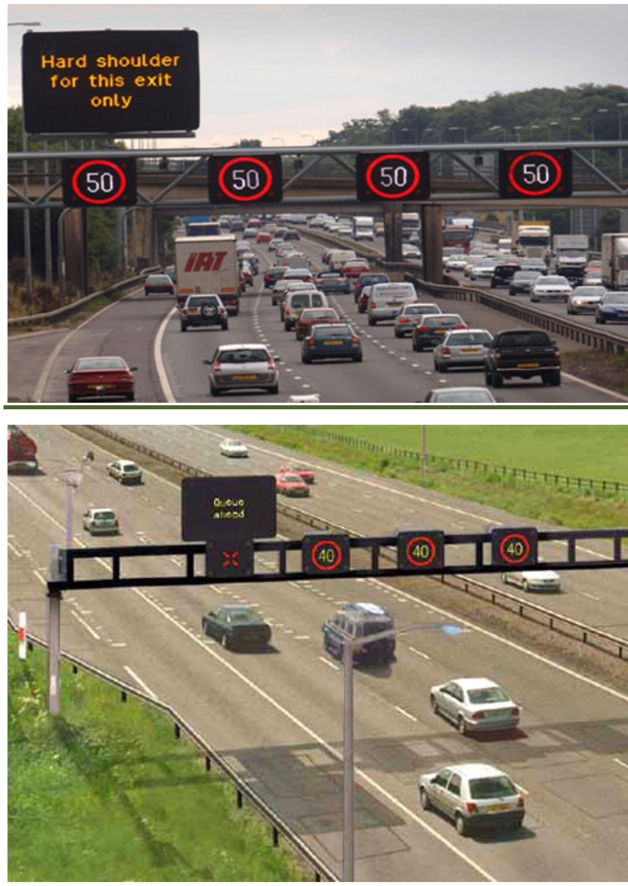
In Germany, the pilot project queue warning system was implemented on the A8 motorway between Stuttgart and Ulm. Positive results measured from the pilot included fewer accidents and reduced accident severity, a considerable reduction of high travel speeds, harmonization of all driving speeds, closer headways and more uniform driver behavior, and a slight increase in capacity, when compared to other motorways. In general, motorists were found to drive with greater caution due to the increased awareness of oncoming risks and downstream queuing. The result of this successful pilot has been its broader implementation across Germany and the inclusion of this strategy in the overall approach to managing congestion (Sparmann, 2006).

The Dutch have reported benefits of congestion warning (queue warning) in combination with speed harmonization in terms of a 15 to 25 percent decrease in primary accidents and a 40 to 50 percent decrease in secondary accidents from their safety assessments in 1983 and 1996, as well as an increase in throughput of four and five percent (Middelham, 2006).

3.4 Hard Shoulder Running

In Germany, hard shoulder running (also called temporary shoulder use) is applied with speed harmonization typically to address recurrent congestion and bottlenecks, but can also be deployed for non-recurrent congestion or incidents. This strategy allows for additional capacity during congestion and has been in use since the 1990s.

The Netherlands started using hard shoulder running in 2003 as part of a larger program to improve use of the existing infrastructure. The system on the M42 motorway in England utilizes the availability of the shoulder for travel rather than for emergency refuge only (Figure 4). To ensure its safe operation, additional emergency refuge pull-outs are spaced approximately every 1600 feet (0.31 miles) with emergency call boxes (Figure 5). Temporary shoulder use is almost universally deployed in conjunction with speed harmonization.



Source: UK Highways Agency

Figure 4. Hard Shoulder Running When Active and Inactive

Benefits Assessment

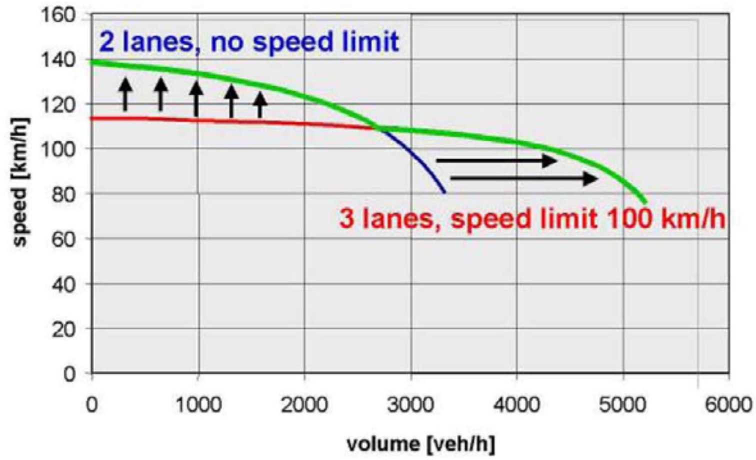
In the Netherlands, implementing temporary shoulder use has had an overall capacity increase of seven to 22 percent by decreasing trip travel times from one to three minutes and increasing traffic volumes through the area up to seven percent during congested periods (Taale, 2006). In Germany, this technique has demonstrated a 20 percent increase in rush-hour capacity and reduced air and sound pollution along Munich area freeways (translated from “Europe on Course—Telematics on German Roads” German Ministry for Transportation, Construction and Housing 2005).

As described in the Scan Report (Mirshahi et al., 2007), temporary addition of a shoulder lane allows congested roadways to have higher throughput at reduced speeds, as indicated in Figure 6. However, the key to hard shoulder running is that the segment must extend through the roadway bottleneck. If it does not extend beyond the bottleneck, traffic is simply fed at a greater rate into the segment that is already over capacity, thereby compounding the congestion.

Source: Mirshahi, et al., 2007

Figure 5. Emergency Pull-Outs Associated with Hard Shoulder Running

Operations



Source: Lemke and Irzik, 2006)

Figure 6. Speed-Volume Relationship of Temporary Shoulder Use

In the UK the Highways Agency currently activates their speed harmonization system whenever hard shoulder running is in effect. The addition of the shoulder as a travel lane tends to increase speeds on neighboring lanes due to the sudden reduction in traffic density. There is some debate about whether or not there needs to be a limit imposed on the speeds during shoulder operating periods. Nonetheless, a conservative approach may be prudent for the initial implementation until post-implementation studies can be performed and analyzed.

The hard shoulder running implementation in the UK currently only extends between major freeway interchanges (or junctions, as they are called in the UK). There is consideration underway of extending hard shoulder running through junctions where right-of-way and other considerations allow, but this approach has not yet been implemented. The initial plan calls for these through-junction lanes to be permanently open, as opposed to dynamic opening and closure as in traditional hard shoulder running (UK Highways Agency, 2008).

Safety and Design Considerations

Safety is generally the greatest concern when implementing shoulder-running strategies, since use of the roadway outside shoulder as a travel lane results in the loss of a continuous emergency refuge area for disabled vehicles and during incidents. Depending on the length of the hard shoulder running section, European examples suggest that the provision of infrequent paved emergency refuge areas or pull-outs should be considered during analysis and design of the affected segment. Alternative refuge areas would be outside of the shoulder area and would provide a designated place for stalled or disabled vehicles while allowing use of the hard shoulder as a travel lane (Figure 5). In England, the alternative refuge areas are spaced every one-third or one-fourth mile. Alternatively, Germany does not generally include refuge areas. Very short segments may not require a refuge area.

Pavement markings for the hard shoulder vary by installation and country as well. In Germany, the outside edge is not striped, which makes the lane appear more like a shoulder. However, in the Netherlands, the outside edge has a solid stripe, except in the emergency refuge area locations where it is dashed. This makes the shoulder appear more like a travel lane. Dynamic lane markings such as lighted pavement markers could be used to assist in delineating the travel lanes for motorists, especially for dynamic changes in ramp exits as shown in Figure 7.

Another safety issue relates to impediments in the shoulder (i.e., stalled vehicles or other debris) that needs to be cleared before opening the lane to use. The English approach requires a visual inspection of the shoulder before it is opened. This requires some intervention on the part of operators, which means that the system cannot be automatically engaged. Verification that the lane is clear of obstacles is completed via CCTV cameras for the M42 motorway system and for shoulder operation in Germany. Clearly, this requires strategic camera placement to ensure the affected shoulder is clear and can be opened for hard shoulder running.

Source: The Netherlands

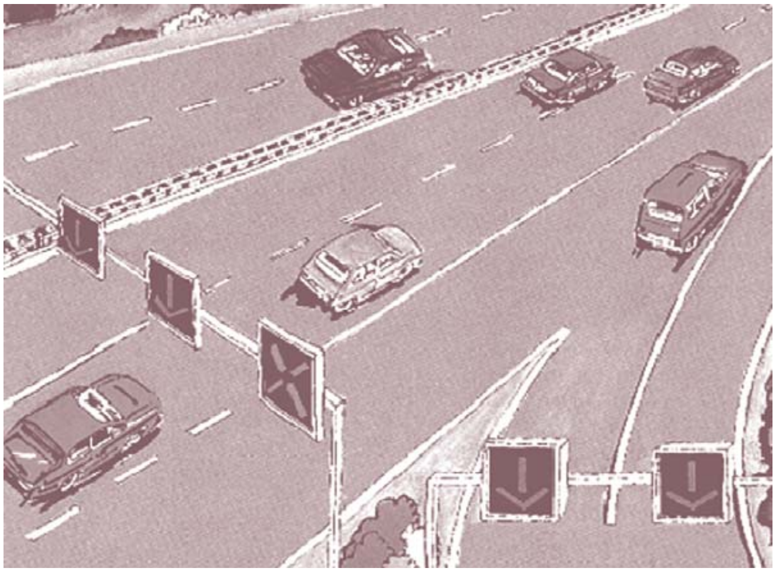
Figure 7. Junction Control at an Exit with Hard Shoulder Running

In Germany, the Netherlands, and the UK, temporary shoulder use is typically implemented in conjunction with speed harmonization. In the Netherlands, additional traffic management and ITS treatments are used along with hard shoulder running to help mitigate any adverse safety consequences. These include (Helleman, 2006):

- Overhead lane signs;
- Emergency refuge areas with automatic vehicle detection (in-pavement loop detectors);
- Speed reduction during times of temporary shoulder use;
- Variable route signs at junctions;
- Advanced incident detection;
- CCTV surveillance;
- Incident management; and
- Roadway illumination.

3.5 Junction Control

A method to dynamically change lane allocation at an interchange is called Junction Control. It can be used at freeway off-ramps or on-ramps (Figure 7 and Figure 8); particularly for high volume ramps often associated with major freeway-to-freeway interchanges. The rationale for use is that in some traffic conditions or at certain times of day, it may be more effective to use existing downstream or upstream lanes for one type of movement or for traffic coming from the main lanes while at other times of day it may be more effective to use the through lanes for the ramp movement. For example, when ramp volumes are relatively light or mainline volumes are very heavy, it might be most effective to have an entrance ramp merge into the right lane. However, there may be times that the volume on the ramp is extremely high while the mainline volumes are low. In this case, traffic merging from the on-ramp will have to find gaps in the



Source: Germany

Figure 8. Junction Control On-Ramp Schematic

mainline traffic, despite the mainline traffic being relatively light. The delay caused by hesitation and time required to find a gap may be disruptive to ramp capacities and flows and thus, create a situation with higher rear-end collision potential on the ramp. Junction control is used to “close” the right lane of the mainline upstream of the ramp through the use of lane control signs in order to give ramp traffic a near free-flow onto the mainline. Junction control provides priority to the facility with the higher volume and gives a lane drop to the lesser volume roadway.

Junction control can also be used at off-ramps, especially when hard shoulder running is used, to dynamically create a two lane off-ramp with a freeway drop lane and an option lane. Junction control is only advantageous at on-ramps when the mainline has spare capacity (giving priority to a higher merge volume). Similarly, junction control at an off-ramp is only desirable if an exit ramp has available width to accommodate an additional exit lane (giving priority to a higher exiting volume and/or downstream merging volume).

Benefits Assessment

In the Netherlands, a pilot junction control project at the Diemen interchange resulted in a reduction of overall mean travel times of seven and eight percent and reduced vehicle delay of four and 13 percent for both mainline and merging traffic, respectively (Helleman, 2006).

Operations

Junction control has been applied in Germany, typically at merge points or entrance ramps where there are a lower number of travel lanes downstream of the merge point. This requires the installation of lane control signals over the upstream and merging travel lanes, dynamically providing priority to the facility with the higher volume (Tignor, et al., 1999). The noted examples do not typically employ dynamic lane markings to match the changed merge conditions communicated by overhead signs, although this dual approach has been applied in the Netherlands.

3.6 Dynamic Re-routing

Dynamic re-routing involves directing motorists to take an alternate controlled access route within a regional freeway network, using either full-matrix dynamic message signs or rotational prism guide signs. The signs change with traffic conditions to provide information regarding queues, major incidents, and alternate routes.

In Germany, the use of dynamic re-routing information is a critical component of their ability to meet their national goal, which is to serve 80 percent of all trips on the motorway network using real-time traffic and traveler information by 2010. In the Netherlands, dynamic route information has been provided since 1990, currently utilizing over 100 gantries to display informational panels across the country on major motorways. Figure 9 shows a dynamic route sign in the Netherlands (Middelham, 2006).

Source: Middleham, 2006

Figure 9. Dynamic Route Information in The Netherlands

A hybrid sign can also be used for dynamic re-routing. A static sign comprises the major portion of the sign, but the route shields and destinations are changeable within the fixed sign panel, such that they can direct motorists to take the alternate route. These hybrid signs are typically located over the affected lanes approaching an interchange. For the normal "through" route, the shields and destinations are deactivated (changing the shield and destination part of the panel to background blue or in the case of US implementation, green) or displaying route closure notification in the same space. Meanwhile, the exit or diverging ramp sign includes the alternate route shield with downstream destinations. Algorithms are applied to properly display the route diversion on all affected downstream signs, and can be automated or manually activated from a traffic control center. Dynamic re-routing typically addresses only the most prominent or strategic routes within a freeway network. Dynamic re-routing may also be employed with junction control to help manage traffic in a variety of contexts. For example, if junction control is used to provide additional exit lanes and reduce through lanes at a particular junction, dynamic re-routing could be used to divert through traffic to parallel routes. Similarly, junction control can also support dynamic re-routing by providing additional capacity to a particular movement that has been targeted for re-routing.

Benefits Assessment

The ability of this technique to divert up to 40 percent of through-traveling vehicles was shown on Nuremberg area freeways in Germany, leading to reduced travel times and emissions (translated from "Europe on Course—Telematics on German Roads" German Ministry for Transportation, Construction and Housing 2005). The Dutch have estimated a five percent improvement in overall system performance associated with dynamic re-routing (Middelham, 2006).

Compliance

The driver compliance rate increased on German freeways when a reason for the re-routing was given in addition to the alternate route information (translated from "Europe on Course—

Telematics on German Roads" German Ministry for Transportation, Construction and Housing 2005). Assessment studies completed by the Dutch indicate that between eight and 10 percent of drivers comply with the changed route information (Middelham, 2006).

3.7 Traveler Information

The Germans, Danes, and Dutch successfully employ traveler information to increase roadway efficiency and performance. In Germany, the traffic management centers (TMC) serve a critical role in disseminating information to roadway users about incidents, congested conditions, and other events or situations that may impact operations. The TMCs use the traffic data to change speed, lane usage, and route guidance information. One of the methods of informing drivers is to use rotational prism guide signs that change with traffic conditions.

In Denmark, the Traffic Information Center (TIC) was established in 1982 in a joint effort with a private company to provide traffic reports on morning radio news programs. The TIC covers all of Denmark and operates 24 hours a day, seven days a week. Traffic-related data is acquired from a number of sources, such as law enforcement, counties, municipalities, private citizens, private companies, transportation agencies, traffic reporters, road sensors, monitoring cameras, and weather stations. The TIC disseminates information in a variety of ways to reach the largest number of potential users.

Benefits Assessment

Traffic information systems in Germany have proved effective, especially when integrated with other traffic management systems (translated from "Europe on Course—Telematics on German Roads" German Ministry for Transportation, Construction and Housing 2005).

3.8 Summary

There are a number of traffic management techniques that can be applied on a spot basis, a roadway basis and on a system-wide basis to positively affect overall roadway and system operations. The application of combined set of traffic management techniques at the system-wide level is a considerable undertaking, but one that can yield considerable operational benefits and system-wide efficiencies.

All countries discussed in this report have or are implementing or expanding a variety of traffic management techniques. However, the UK is perhaps approaching the concept of traffic management on a system-wide, multimodal basis most fully by embarking on their managed motorways approach, which strives to manage the entire roadway system and other modes interfacing with the roadways as efficiently and effectively as possible using multiple management strategies. In this sense, the UK is approaching the concept of Integrated Corridor Management that has recently been discussed in the US, in which management strategies are applied to an entire travel corridor (freeway, ramp systems, transit facilities and parallel arterials) to best utilize all transportation facilities, regardless of facility type or jurisdiction, within a travel-shed.

4.0 System Level Applications

This chapter examines benefits at the corridor and system level, reporting on identified or potential synergistic relationships between any of the European- or US-based traffic management techniques. System level applications will examine the following contextual settings:

- Overall roadway management including all access connections to the system;
- Spot roadway management strategies that function to improve overall flow in the system;
- Incremental implementation of synergistic applications; and
- How these systems could be adapted to existing ITS and traffic operations investments commonly found on US freeways based on a phased approach.

4.1 Overall Roadway Management

The intent of this chapter is to document cases where synergistic relationships between traffic management strategies have been found; however, performance monitoring data regarding these strategies to date has been limited. Because this data is rarely stratified by strategy, being able to use it to estimate an individual strategy's contribution to system level benefits is even more challenging. Nonetheless, research has shown that these strategies are rarely implemented in isolation, and a number of them are clearly complementary. While most of these strategies have some form of relationship with all of the others, there are some that stand out most clearly as complementary and/or supportive to a particular technique. Figure 10 indicates typical complementary and/or supportive strategies for each of the six European traffic management techniques. Note that while one technique may support another, the reverse is not always true. For example, while speed harmonization may be a critical supportive strategy for implementing hard shoulder running; hard shoulder running is not critical to the success of speed harmonization applications.

Technique \ Complementary and/or Supporting Techniques	Speed Harmonization	Queue Warning	Hard Shoulder Running	Junction Control	Dynamic Re-Routing	Ramp Metering	Traveler Information	Incident Response
Speed Harmonization		x					x	
Queue Warning	x				x		x	
Hard Shoulder Running	x	x		x	x	x	x	x
Junction Control	x		x		x	x	x	x
Dynamic Re-Routing		x	x	x			x	
Ramp Metering		x					x	

Source: Parsons Brinckerhoff, 2009

Figure 10. Relationships Between ATM Strategies

A brief discussion of how these techniques could be applied in a synergistic manner is provided below. Not all combinations of complementary and/or supporting techniques are discussed, but the write-up provides a general idea of how certain strategies can work together.

Speed harmonization, for example, is often implemented in tandem with queue warning. Queue warning complements speed harmonization because in addition to warning drivers of downstream queues, it communicates the reason why speeds are being lowered. In Germany, a congestion pictograph or icon is displayed on both sides of the overhead gantries to alert motorists of queues or congestion ahead. The value of the system lies in warning drivers of downstream queues so they take appropriate actions (e.g., slow down or change lanes), thereby reducing the occurrence of primary and secondary collisions caused by the congestion. In the

Netherlands, motorists are alerted of queues with flashing lights surrounding the variable speed limits, and speed harmonization is activated with variable speed limit signs.

Queue warning is valuable in that it warns drivers of downstream queues so they take appropriate action to slow down or change lanes, reducing the occurrence of primary and secondary collisions caused by congestion. Queue warning can be supported by the implementation of speed harmonization to further enforce the need to reduce speeds.

Hard shoulder running is frequently implemented in conjunction with both speed harmonization and queue warning, as well as with junction control because they share the common need of addressing recurring congestion in bottleneck locations. Limited data from the UK indicates how these techniques can build upon each other. Transportation professionals in the UK believe that using speed harmonization and queue warning is important in order to maintain safety during hard shoulder running operations. Since hard shoulder running removes the shoulder for use as a breakdown lane, having a robust incident management program in place to monitor and respond to incidents as soon as possible is essential. Where hard shoulder running begins or terminates at a ramp junction, junction control is often required to maintain lane continuity and safe operations.

Junction control may be enhanced when supported by ramp metering, particularly when used at freeway on-ramps. If the control strategy has changed a junction from an add-lane to a merge condition, ramp metering would be especially beneficial to break up platooning vehicles from entering a ramp and facilitate the merge condition. Dynamic re-routing can support junction control as well in that if the control strategy reduces capacity of one movement (e.g., the through movement) in favor of another movement (e.g., the exiting movement), then it may be beneficial to re-route some through movement traffic to alternate routes so as to not experience undue congestion.

Dynamic re-routing is highly dependent on traveler information (including queue warning) to not only direct drivers to the desired alternative parallel route, but to also inform them as to why they are being encouraged to reroute. Information could include projected travel times via alternative routes and reasons for the delay on the primary route, e.g., “accident ahead.” Junction control can also support dynamic re-routing by providing additional capacity to a particular movement that has been targeted for re-routing.

Ramp metering can be enhanced by queue warning and traveler information when used to address mainline congestion. These techniques can provide the driver with information on why the ramp meter rate is operating in a given manner, which can lead to more acceptance of the meter and higher compliance.

4.2 Spot Roadway Management Strategies

In many urban roadway networks, overall system capacity is governed by localized constraints, or “bottlenecks,” at a limited number of locations. Addressing these bottlenecks can make a significant improvement in overall system performance and reliability. Often times these bottlenecks cannot be physically expanded due to either prohibitive costs or environmental concerns. These conditions can also be present during construction where detours do not offer the capacity, performance or operational safety of the final roadway configuration.

Because traffic management techniques are generally less expensive than the physical expansion of facilities, it can more feasibly be used as a means of addressing these conditions. For example, various traffic management strategies have been applied in Denmark as a way of maintaining traffic flow during construction

Hard shoulder running is one of the more effective traffic management techniques that can provide additional capacity on an as-needed basis to address bottleneck issues. For hard shoulder running to be truly effective, it needs to extend through the bottleneck location upstream of typical queues. Otherwise it is simply moving the bottleneck to a new location.

4.3 Incremental Implementation

It is important to consider the environment within which potential traffic management techniques will be implemented; for example, are ramp metering, service patrols, existing VMS, managed lanes, or other more US-based techniques already a part of the freeway management system? While these more traditional elements can be integrated into many traffic management techniques or strategies, careful consideration should be given to implementing traffic management techniques that lend themselves to being actively managed when the more basic traffic management systems are not in place. This is particularly relevant when considering the overall operation of the system and the demands it may place on existing traffic management center facilities and staffing requirements.

It is important to consider the overall system and plan for the best combination of traffic management techniques for the region or area under consideration. Many logical and synergistic combinations of techniques lend themselves to incremental implementation that improves effectiveness. The benefit of this is that it allows agencies to implement some applications sooner rather than later, building users' experience and trust in the general traffic management concept prior to implementation of supporting techniques. Examples of techniques that have been implemented incrementally include speed harmonization, followed by hard shoulder running in the UK on the M42. Speed harmonization produces clear benefits to safety and operations – the inclusion of hard shoulder running in select locations increases the system's ability to decrease congestion and improve overall operations and throughput. The European experience is filled with examples where an initial corridor was fully instrumented and monitoring demonstrated proven effectiveness before wider system applications occurred. This approach also allowed agencies to 'learn from their mistakes" in refining the applications in order to improve performance and lower their investment costs.

The deployment of traffic management techniques that will be managed actively should be done considering logical operating segments within the system under consideration. Logical starting and stopping points based on travel patterns, freeway geometrics, observed operations of recurrent congestion or persistent queuing, and areas with higher than expected crash rates provide insight into areas where initial investigation and consideration of active management techniques may be warranted.

4.4 Adaptation to Existing US ITS and Traffic Operations Investments

Much of the following discussion is based on work conducted by the Washington State Department of Transportation. This dialog is illustrative of similar adaptations occurring in other states as of 2010.

Integration with Current ITS Infrastructure

Current traffic management systems require a variety of instrumentation and communication investments to make the system functional. Some of this equipment is multi-purpose serving a number of traffic management techniques (e.g., in-road or other forms of vehicle detection, CCTV, VMS, communications network/equipment, etc). In many cases new or augmented equipment specific to the desired traffic management technique would be required (e.g., variable speed limit signs for speed harmonization). If existing equipment, detection, or traffic management systems are in place, their functionality should be reviewed to determine if they can be used for both the original intent as well as the proposed traffic management technique(s) to obtain the greatest benefit from existing system investments. The traffic management system will be relying on accurate, reliable and continual input for the various traffic management application algorithms – maintaining a high level of reliability on detection is crucial.

The variable message signs used to support these techniques are similar to sign technology used elsewhere by state DOTs. However, the purpose and application of the VMS signs is different than what has been typically used, due to the over lane positioning of the speed harmonization signs, their size, mounting maintenance and access requirements. Once again, it will be important to assess the existing system capabilities, the requirements of the new system, and their subsequent integration. For example, some transportation management system software can communicate with NTCIP signs, making integration much easier than if proprietary communication protocols are used.

Institutional Issues

Institutional issues are challenges that can prevent proper implementation of active traffic management techniques, but instead of being attributed to technology or engineering, these issues are caused by regulatory, legal, financial, management, organizational, human, or physical resource concerns and constraints and can even vary by state and locale.

Institutional issues differ between Europe and the US in various respects. European agencies may be subject to less liability due to legal statutes; they are perhaps more attuned to experimenting because there is limited funding and few geometric options to widen or otherwise add capacity through expansion or new routes; and for many applications they have a longer (and successful) track record in active traffic management accepted by their political and public stakeholders.

- Legal statutes and case law may limit US agencies' interest in such concepts as hard shoulder running, since the effective pavement, when not traveled on, is supposed to provide a safe refuge for emergency parking. Many European freeways do not traditionally have paved shoulders on one or both sides of the mainline lanes. Providing 'hard' shoulders that are able to take all types of vehicle loads as traveled lanes during peak periods improves capacity and mobility while not adversely impacting safety if the shoulder is able to be adequately monitored.

- Transportation policies within the US tend to favor more capital investment in the "hard" side road system, while operational investments in some European countries are the primary (and in many cases only) form of investment occurring outside maintenance needs. The institutional arrangements within Europe reflect both federal and regional provinces in the decision making roles, not unlike the federal/state/local relationships in the US.
- The Netherlands countrywide investment in active traffic management, currently underway on all motorways, dates back more than 20 years to much earlier demonstrations that provided insight into successful deployment under specific conditions. Institutionalizing a network approach came from these corridor demonstrations. Adjacent countries have now borrowed such experiences and system approaches from each other and share common implementation schemes. As noted above, within the US most agencies have focused more on rehabilitation and expansion projects with less comparative investment in operations. And similar to the European experience, just as much downstream time from initial US applications of actively managed traffic techniques to widespread adoption may be required.

Because many of these strategies are relatively new to the US, some institutional issues may need to be worked out. Even inter-agency and intra-agency issues can present implementation obstacles. The difficulty with institutional issues is that there are no consistent approaches to resolve them. Some general institutional issues that can impact implementation of a wide variety of actively managed techniques in the US include the following:

- **Priority**: for traffic management techniques to operate successfully and reach their full potential, the techniques must be given priority for funding, programming and maintenance.
- **Continued Funding for Operations and Maintenance**: sustained funding is essential to operate and maintain a safe and effective traffic management strategy. Operational funding provides the necessary staff to monitor, control, and adjust a system. Maintenance of a system is also necessary for proper operations, and the threshold for maintenance reliability may need to be much higher for passive in-field systems that are predicated on public respect to be effective. Any expansion of a traffic management system will also require sufficient and ongoing funding. Some delivery strategies, including design-build-finance-operate-maintain procurements, have been employed to assure the level of maintenance required in European examples.
- **Continued Funding for Electronic Equipment**: electronic components used in these systems have a shorter life cycle than typical components in highway transportation. A program for preservation is needed in addition to an on-going maintenance program.
- **Continuous Staffing for Traffic Management Center Operations**: staffing hours at a TMC may need to be expanded in order to safely and effectively operate traffic management systems in an active manner. A benefit-cost analysis should be undertaken to determine if the collision and congestion reduction benefits of implementing a traffic management technique will off-set the expected capital and operations and maintenance costs.
- **System Monitoring and Evaluation**: the use of effective monitoring and data collection allows implemented traffic management systems to be evaluated and improved. This

would typically coincide with a performance monitoring program with set objectives and thresholds in order to effectively determine if the system is meeting its goals.

- **High Quality System Information**: providing accurate and reliable information to the system is essential for the safe and effective implementation and operation of any management technique. This is necessary to earn drivers' trust and compliance for the systems. Accordingly, the algorithms behind the strategies must operate in real-time, with abilities for the system to self regulate with minimum operator oversight except to confirm specific pre-set actions.
- **Public Education**: increasing US driver familiarity with actively managed traffic techniques and systems, their purposes, and congested freeway safety requires an ongoing public information campaign.

Speed harmonization and hard-shoulder running may face additional institutional considerations in the US, such as the following:

- **Coordination with Enforcement and Emergency Response Agencies**: for successful operation, the proposed management techniques should be discussed with the enforcement/public safety entities (e.g. state patrol) and other key stakeholders such as emergency responders. These agencies must understand the overall function of the management techniques and collaborate with the operating agency on enforcement protocols. Enforcement protocols and understanding are important for the implementation of a speed harmonization system due to the variable nature of the speeds over a length of roadway; enforcement may want to focus on more obvious or blatant speed violations. For hard shoulder running, enforcement must be vigilant due to the safety issues and emergency responders must understand how using the shoulder as a travel lane will affect their response times.
- **Enforcement Plan for Traffic Management Techniques**: without enforcement, some of the traffic management techniques and strategies may not be as successful. It is vital that appropriate warnings and enforcement actions are taken for motorists who disregard the regulatory signing. Enforcement may add a cost component to implementation and operation. Public outreach efforts must work to reinforce the strategies and help foster public trust in the system. As an example, motorists need to learn that when the signs show a reduced speed limit that there is a good reason to slow down. With hard shoulder running, it is important that motorists understand when this technique is operational and when it is not. As such, appropriate warnings and actions must be taken for those who are not compliant.

Suggestions to Address Institutional Issues

Reaching solutions to a range of institutional issues, which allows for the successful implementation of a variety of traffic management techniques and systems, requires collaborative planning and development. To effectively implement traffic management techniques that are actively managed in the US the following actions are suggested (WSDOT ATM Concept of Operations Report, 2008):

- **Provide Continuous Operations**: providing continuous hours of operations of most techniques that will be actively managed is recommended, especially for speed harmonization and queue warning. This will provide necessary activation and monitoring of the system. By operating the system any time it is needed, stakeholder acceptance and public trust is created. Additionally, some legal liabilities may be reduced.

- **Outreach to Stakeholders and Public**: informing stakeholders and the public regarding the purposes, benefits, operation and performance outcomes of traffic management strategies will also build trust in the investments.
- **Outreach to Government Officials**: continued support of traffic management techniques and systems will require early involvement with key officials and stakeholders. Various elected and appointed public officials should be informed about the techniques and benefits, especially before including these techniques in funded programs and project budgets.
- **Coordinate with Law Enforcement and Key Partnering Agencies**: law enforcement needs to be involved with the design and intended operation of actively managed traffic management systems in order to determine how the system can accommodate enforcement and how officials should enforce it. Other agencies may also be interested in how potential management techniques could affect traffic on their transportation networks as well.
- **Create a Concept of Operations Plan**: for the purposes of design, outreach, and operations, a concept of operations plan will be required to provide clarity into how a system will operate. This plan also includes ITS integration and determining operational responsibilities.
- **Integrate with ITS Infrastructure**: creating and implementing a plan for integration with ITS architecture will define the roles of individual traffic management techniques and ITS.
- **Improve Analysis and Review**: proper monitoring of a operational network and comprehensiveness of a network model are beneficial for monitoring techniques and predicting the effect of proposed techniques.
- **Obtain Approval for Experimental Traffic Control Devices**: as traffic management techniques that are dynamically managed are new to the United States and frequently rely on signage and control procedures that are not currently described in the MUTCD, steps for experimental approval should be taken when a project timeline is set in order to ensure approval when the system will be activated.
- **Collaborate with Other States and Partnering Agencies**: several locales in the US are investigating and implementing the discussed traffic management techniques. Working with these states in gaining lessons learned can provide shared insight into how to address institutional and engineering issues.
- **Coordinate with TDM Efforts**: often times personnel charged with developing TDM policy are compartmentalized from operations staff who would be implementing the traffic management techniques. Coordinating these and other congestion management tools so as to provide a holistic approach is likely to produce more effective results.

5.0 Initial US-Based Implementation of European Traffic Management Strategies

As of early 2010, a number of US states and locales were moving forward with the study and implementation of various traffic management strategies. This list is not exhaustive and includes the following:

5.1 Under Study

- Colorado DOT is evaluating a speed harmonization system for I-70.
- Florida DOT is exploring hard shoulder running and variable speed limits on a portion of I-75.
- MTC and California DOT (Caltrans) are considering variable speed limits on I-80 in the Bay Area.
- North Carolina DOT is examining hard shoulder running options along portions of I-77 and I-485 in the Charlotte area.

5.2 Implementation

- California DOT (Caltrans) has implemented in-pavement dynamic lane controls on the expanded I-15 managed lanes in San Diego and is implementing dynamic lane operations on northbound SR-110 at the I-5 freeway interchange in Los Angeles.
- Minnesota DOT, as part of their priced dynamic shoulder lane project, is now operating variable speed controls and queue warnings in a three-mile segment of I-35W as part of their Urban Partnership grant, and an extension of the system is planned. They are studying the implementation of a similar approach for portions of I-94 between Minneapolis and St. Paul.
- Texas DOT tested dynamic re-routing and dynamic queue warning using portable solar-powered monitors, signs and cameras as part of a reconstruction of two converging interstates in Hillsboro, helping drivers avoid sudden queues.
- Virginia DOT is implementing a variable speed limit on I-95 to address construction related closures associated with the Telegraph Road interchange reconstruction.
- Washington State DOT is constructing a variable speed limit/queue warning system on approximately eight miles of I-5 as it approaches Downtown Seattle in the northbound direction. They are also proceeding with the design and construction of a similar system on I-90 and SR 520 across Lake Washington as part of their Urban Partnership grant. All systems are anticipated to be operational by 2010.

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