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Best Practices and Outreach for Active Traffic Management

Final Report

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16. Abstract Continued growth in travel on congested freeway corridors and limited public funding for expansion and improvement projects are limiting agencies' abilities to provide sufficient roadway capacity in major metropolitan areas. Focusing on trip reliability, active traffic management (ATM)—widely deployed for decades in Europe but in its early stages in the United States—maximizes the effectiveness and efficiency of the facility and increases throughput and safety through integrated systems with new technology, including the automation of dynamic deployment to optimize performance quickly. This congestion management approach consists of a combination of strategies that, when implemented in concert, fully optimize the existing infrastructure and provide measurable benefits to the transportation network and the motoring public. These strategies include speed harmonization, temporary shoulder use, junction control, and dynamic signing and rerouting. By providing transportation agencies across the United States with crucial information on best practices for deployment and operation of ATM strategies, this project can have a positive impact on transportation networks where ATM is deployed. This report provides a summary of the research conducted during a project sponsored by the University Transportation Center for Mobility™ related to ATM. This document includes a literature review related to ATM, an inventory of ATM deployments both overseas and in the United States, a summary of best practices and general guidelines for the deployment of ATM, information on the development of an ATM website, and the delivery of a webinar to present the project results to increase the awareness of ATM within the transportation profession.					
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BEST PRACTICES AND OUTREACH FOR ACTIVE TRAFFIC MANAGEMENT

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Executive Summary

Since the 1980s, European countries have evaluated the effectiveness of measures designed to increase capacity and safety on motorways without having to widen them. These measures—called active traffic management (ATM)—include shoulder use, speed harmonization, queue warning, dynamic merge control, dynamic rerouting, and dynamic truck restrictions. ATM strategies can have a positive impact on transportation in the United States. This project contains crucial information on best practices for deployment and operation of ATM strategies.

The primary intent of this project was to develop general high-level guidelines for successful ATM deployment based on international and domestic experience. The project was also intended to increase the awareness of ATM as a feasible operational alternative through the development of a website to serve as a clearinghouse of ATM reports and resources and through the development and hosting of a webinar to share project results.

It is envisioned that state departments of transportation (DOTs) and their partnering agencies—including metropolitan planning organizations (MPOs), transit authorities, commuter organizations, toll authorities, and regional mobility authorities—will have an interest in the results for assessing the best approach for ATM deployment in their region.

Shoulder use for all vehicles allows all drivers to use the designated shoulder when open. Traffic control devices over or adjacent to the shoulder instruct drivers when driving on the shoulder is permitted. Transit-only shoulder use allows only transit vehicles to use the designated shoulder under specific conditions and driving regulations.

Many countries and several states in the United States deploy speed harmonization for weather-related conditions and congestion management. Speed harmonization is an operational strategy where agencies use an expert system to monitor data coming from field-deployed sensors on a roadway and proactively and automatically adjust speed limits when congestion thresholds are exceeded and congestion and queue formation are imminent.

Based on dynamic traffic detection, queue warning informs travelers of the presence of upstream queues, using warning signs and flashing lights. This strategy allows the traveler to anticipate a situation of emergency braking and limit the extent of speed differentials, erratic behavior, and queuing-related collisions.

Dynamic merge control closes specific lanes upstream of the interchange to manage access based on traffic demand. A typical U.S. application is a lane drop for one of the outside lanes or a merging of two inside lanes, both of which are static solutions. The intent is to provide dynamic priority access to the higher traffic stream.

Dynamic rerouting and traveler information consist of redirecting traffic to avoid unequal levels of service on parallel routes, providing users with viable route alternatives and helping reduce the impact of noncurrent congestion. A new direction can be suggested by dynamic message sign

while the standard routing remains, or if the hardware allows it, the standard routing may be substituted by the recommended one.

Dynamic truck restrictions require all truck traffic to use designated lanes during peak periods. The intent is to increase the homogeneity of speed on each lane and to minimize the disruption in traffic flow caused by heavy vehicles.

ATM has the potential to help transportation agencies operate existing facilities in the most efficient manner possible. Potential improvements can include:

- An increase in average throughput for congested periods;
- An increase in overall capacity;
- A decrease in primary accidents;
- A decrease in secondary accidents;
- A decrease in accident severity;
- An overall harmonization of speeds during congested periods;
- An increase in trip reliability; and
- The ability to delay the onset of freeway breakdown.

The project team developed a website for information dissemination regarding the subject of ATM. The first step in the development of the site was the generation of the graphic design for the site. It was the desire of the project team to create a site that was easy to navigate and reflective of the dynamic approach of ATM. With the assistance of the graphic design experts at TTI, the project team developed a banner for the website that incorporates a logo, a photograph of a dynamic speed display implementation, a search box, and links to the various sections for the website.

The ATM website is database driven to facilitate easy updating by staff when related documents, links, and information are available. The project team used Drupal® for developing the content portion of the website, which allowed the developers to create modules that provide various website features and also facilitate easy management of the large number of resource documents and components that are included in the ATM website. The ATM website includes several key sections to provide key information for users:

- a main page that provides a brief overview of Active Traffic Management and provides links to the main sections and a request for feedback from users if appropriate;
- a resources page that provides a variety of resources, including documents, presentations, references, related websites, and an inventory of ATM operational facilities in the United States and overseas;
- an ATM glossary that provides a list of commonly used terms related to ATM along with brief definitions for each; and
- a contact page with which users can provide feedback to the team regarding any aspect of the site.

One of the key objectives of this project was to reach out to the transportation community to share information related to ATM. The following sections highlight the activities undertaken to conduct a webinar to share the research results with agencies interested in implementing ATM in their jurisdictions.

The project team selected and confirmed the date for the webinar and scheduled the event with the Centra videoconferencing system to which TTI has access through Texas A&M University. The project team worked with the external advisory panel and other organizational and personal contacts to advertise and market the webinar. The webinar was hosted on Monday, December 19, 2011. Approximately 50 individuals registered for the webinar and participated in the event. Once the webinar concluded, the research team posted the slides to the website for the Transportation Research Board Joint Subcommittee on Active Traffic Management and a link to the presentation was then sent to the attendees for their personal reference.

It is the hope of the authors that by providing transportation agencies with information on practices for deployment and operation of ATM strategies as well as general guidance on implementation, this document can have a positive impact on transportation networks where ATM is feasible. Potential improvements can include an increase in average throughput for congested periods, an increase in overall capacity, a decrease in primary accidents, a decrease in secondary accidents, a decrease in accident severity, an overall harmonization of speeds during congested periods, an increase in trip reliability, and the ability to delay the onset of freeway breakdown. ATM has the potential to help transportation agencies address the ever-increasing challenge of doing more with less and operating existing facilities in the most efficient manner possible.

Chapter 1: Background

Document Overview

A 2006 Federal Highway Administration (FHWA)-sponsored International Scan Tour of Europe examined the congestion management programs of other countries that are either in the planning stages, have been implemented, or are operating on freeway facilities. This scan sought information on how agencies approach highway congestion and how they are planning for and designing managed lanes at the system, corridor, and project or facility level. The scan tour revealed a complete package of strategies that make up the broader concept of active traffic management (ATM). This approach to congestion management is more holistic and is considered the next step in congestion management of freeway corridors. The FHWA scan tour defined active traffic management as the ability to dynamically manage recurrent and non-recurrent congestion based on prevailing traffic conditions (1). Similarly, the Transportation Research Board Joint Subcommittee on ATM defines it as the ability to dynamically manage traffic flow based on prevailing traffic conditions (2). Focusing on trip reliability, ATM's goal is to maximize the effectiveness and efficiency of the facility under both recurring and non-recurring congestion as well as during capacity reductions involving incidents or road work. Through the flexible use of the roadway, ATM aims to increase system performance as well as traveler throughput and safety through the use of strategies that actively regulate the flow of traffic on a facility. ATM strategies can be automated, combined, and integrated to fully optimize the existing infrastructure and provide measurable benefits to the transportation network and the motoring public. These strategies include but are not limited to speed harmonization, temporary shoulder use, junction control, queue warning, ramp metering, lane restrictions, and dynamic rerouting and traveler information.

ATM is virtually in its infancy in the United States when compared to Europe. Only a handful of states have deployed some type of ATM strategy, and agencies are challenged with finding good guidance on deployment alternatives.

Scope and Purpose

The primary intent of this project was to develop general high-level guidelines for successful ATM deployment based on international and domestic experience. The project was also intended to increase the awareness of ATM as a feasible operational alternative through the development of a website to serve as a clearinghouse of ATM reports and resources and through the development and hosting of a webinar to share project results.

Intended Audiences and Uses

It is envisioned that state departments of transportation (DOTs) and their partnering agencies—including metropolitan planning organizations (MPOs), transit authorities, commuter organizations, toll authorities, and regional mobility authorities—will have an interest in the results for assessing the best approach for ATM deployment in their region. This project may also identify

research gaps that can be pursued in other avenues and with sponsoring agencies that have a vested interest in the subject.

Chapter Summary

The following chapters are included in this report:

- **Chapter 1—Background:** Provides the background, scope, and purpose of the project; identifies the intended audiences and uses for the project results; and gives a summary of the report components.
- **Chapter 2—Literature Review:** Details a comprehensive literature review that was performed on the subject of active traffic management, both internationally and domestically.
- **Chapter 3—Inventory of ATM Strategies:** Presents an inventory of active traffic management strategies and facilities in use around the United States and overseas.
- **Chapter 4—Best Practices and Guidelines:** Details the development of guidelines for successful ATM deployment based on the results of the literature review and inventory development. This chapter can also serve as a standalone document that transportation professionals can use to identify the most appropriate ATM strategy for their jurisdiction.
- **Chapter 5—Website Development:** Provides the philosophy and process for developing the ATM website and an overview of the information contained therein.
- **Chapter 6—Webinar Development and Hosting:** Describes the development and delivery of the ATM webinar.
- **Chapter 7—Final Remarks:** Provides a final comment on the project progress and products and highlights research gaps that should be addressed to enhance and support more widespread deployment of ATM.

Chapter 2: Literature Review

Traffic congestion is a problem found in industrialized countries worldwide, and every year the congestion problems grow. Since the 1980s, European countries, including Germany and the Netherlands, have started to evaluate the effectiveness of measures designed to increase capacity and safety on motorways without having to widen them. These measures include shoulder use, speed harmonization, queue warning, dynamic merge control, dynamic rerouting, and dynamic truck restrictions. All of these measures are grouped under one general name: Active Traffic Management.

ATM has proven effective in reducing congestion while requiring little to no geometric changes in the facilities. As explained later in detail, these measures can prove very efficient in managing congestion and safety on highways in the United States.

Shoulder Use

Shoulder use, also known as hard shoulder running (HSR), is a measure designed to temporarily increase the capacity of a facility by opening one or sometimes both shoulders to traffic. In some instances, only transit buses are allowed to use the shoulder lane. This section of the report investigates different shoulder use practices in both European countries and the United States.

Shoulder Use in England

In England, the Highways Agency implemented shoulder use on M42 as part of the pilot project for multiple traffic management measures including speed harmonization with camera enforcement, incident detection with queue warning, and traveler information (3). In the pilot project, temporary shoulder use was controlled by the traffic management center (TMC) and was exclusively applied between exits, making the shoulder operate like an auxiliary weaving lane. Enforcement was performed through a wide network of cameras with automatic number plate recognition. Loop detectors placed every 100 m (328 ft) in all lanes, including the shoulder, provided additional traffic data. The striping pattern for the shoulders on M42 was the same as that for a regular motorway without temporary shoulder use: a continuous line separating the shoulder from the other lanes. To avoid surprising drivers that enter the shoulder, the rumble strips that induce noise in the vehicle were reduced, and raised pavement markers were placed on both sides of the shoulder lane. Extra emergency refuge areas were placed at regular intervals (every 500 m [1640 ft] on the M42) to ensure safety for vehicles in distress during shoulder operation. Each refuge area was also equipped with loop detectors to elicit a quick response by the control center (3,4).

Overhead lane control signals were used to implement temporary shoulder use. When the shoulder was meant for emergency purposes only, a red cross was shown in the sign above the shoulder, while the other overhead signs were either blank (under normal conditions) or displayed a mandatory speed limit (under congested or incident conditions). When the shoulder was open to traffic, the mandatory speed limit was displayed on the shoulder overhead sign and a description of the situation was written on a dynamic message sign (DMS)—typically, “Congestion, Use hard shoulder,” as pictured in Figure 1. These lane control signals could also prove very useful during incidents to clear one lane and provide quicker access for emergency vehicles. The pilot project included other features that were added to the motorway including lighting and emergency phones at every emergency refuge area.

The Highways Agency expected that shoulder use alone would reduce the initial level of safety; therefore, a safety plan was assembled for the project. Each hazard that was found had a risk assessment and a mitigation plan implemented if necessary (3). According to a feasibility study by the British Department for Transport, data showed that safety was not reduced during the time the temporary shoulder use was in place; in fact, the tendency pointed to an improvement (5).



Figure 1. Example of operations under speed harmonization without shoulder use (left) and with shoulder use (right) (3).

The environmental impacts of implementing shoulder use are expected to be far lower than adding a new lane. Less construction is needed, especially if the shoulder pavement thickness is sufficient. Furthermore, loop detectors are already present on the entire motorway and the shoulder. The need for right-of-way is also reduced. The improvement in quality of flow reduces congestion and emissions per vehicle. However, the shoulder use might increase total emissions because of the added capacity. It has been recommended that if shoulder use is to be implemented on a wide scale, driver education and communication are necessary, with particular attention being paid to optimizing the efficiency and safety on the motorway (6).

The results of the M42 pilot project included a travel time decrease of 26 percent in the northbound direction and 9 percent in the southbound direction. Also, travel time reliability increased by 27 percent in the northbound direction and 34 percent in the southbound direction (5). Additionally, the M42 was able to carry significantly more vehicles. The before and after daily flow profiles are shown in Figure 2. During both peak periods, significantly more vehicles could use the M42 with four-lane operations (three lanes plus shoulder) compared to the original three-lane operation. In both cases, speed harmonization (variable mandatory speed limits [VMSL]) was available to further manage traffic (7).

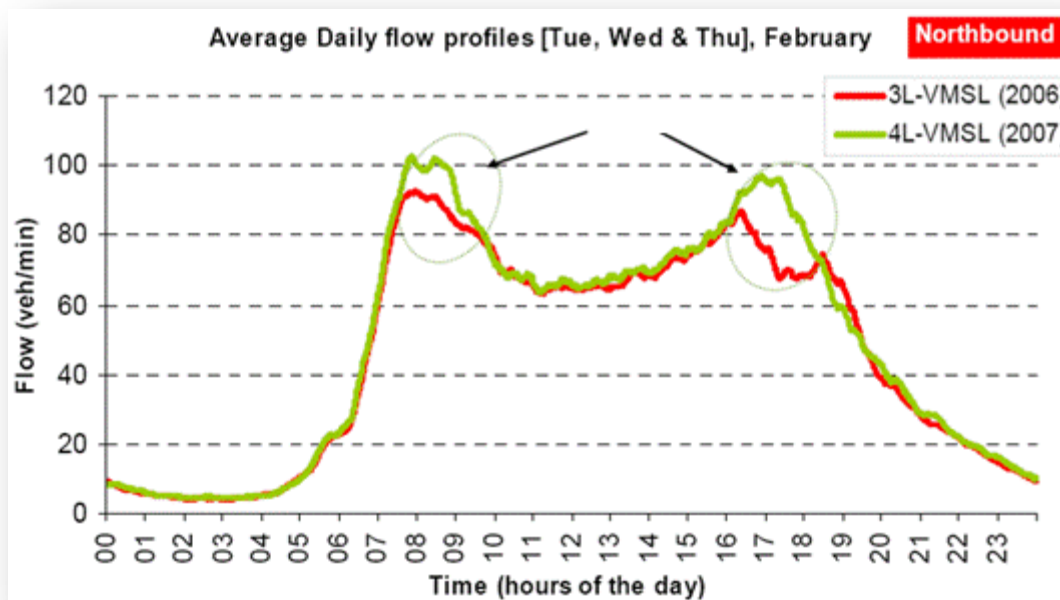


Figure 2. Before and after average daily flow profiles with and without shoulder use (7).

The cost of the M42 project was £5.6 million per km (£96.4 million total). Added to these costs was the cost of communication on the pilot program of £300,000 (plus value added tax [VAT]). In comparison, adding an extra lane in each direction would have had an estimated cost between £18 million and £25 million per km for a total of approximately £370 million (7).

Shoulder Use in Germany

In Germany, transportation agencies can use one of two ways to turn the right shoulder into a usable lane: they can restripe the shoulder as another lane with a broken line on the left side and a solid line on the right side, or, more commonly, they can stripe the shoulder lane with solid lines on both sides (8). Shoulder use is controlled by the state traffic center. When traffic volumes reach a trigger value established by traffic center personnel, the system suggests enabling shoulder use. An operator then checks the shoulder for obstacles using field cameras. If the shoulder is clear, the operator can allow traffic to use the shoulder. If an obstacle were to be detected later, the use of the shoulder would be stopped immediately (9).

The improvement in terms of added capacity is made obvious in the speed-volume diagram shown in Figure 3. It also shows the point at which shoulder use should be enabled—approximately 2,700 vehicles per hour (vph) (8).

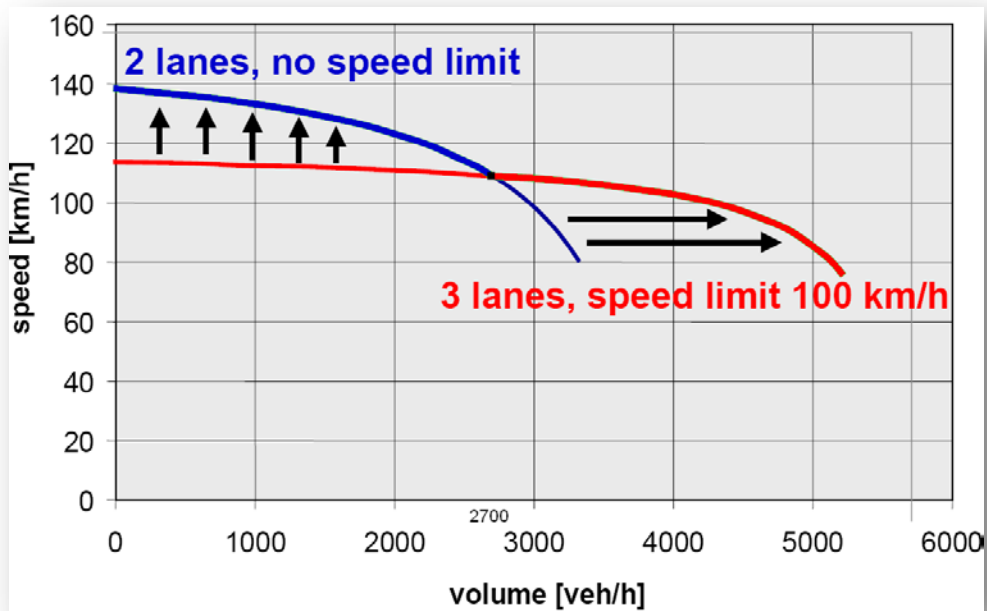


Figure 3. Speed/flow curves corresponding to both states of shoulder use (8).

The signing for shoulder running is usually a ground-mounted rotating sign. As shown in Figure 4, the sign has three faces with the following text: use hard shoulder, end use of hard shoulder, and leave hard shoulder. When shoulder use is active, a lower speed limit is also set for safety. When shoulder use is inactive, these signs are blank. The usual speed on the motorway is 120 km/h (75 mph), and the maximum speed allowed is 100 km/h (62 mph) when shoulder use is active, as seen in Figure 5 (8).

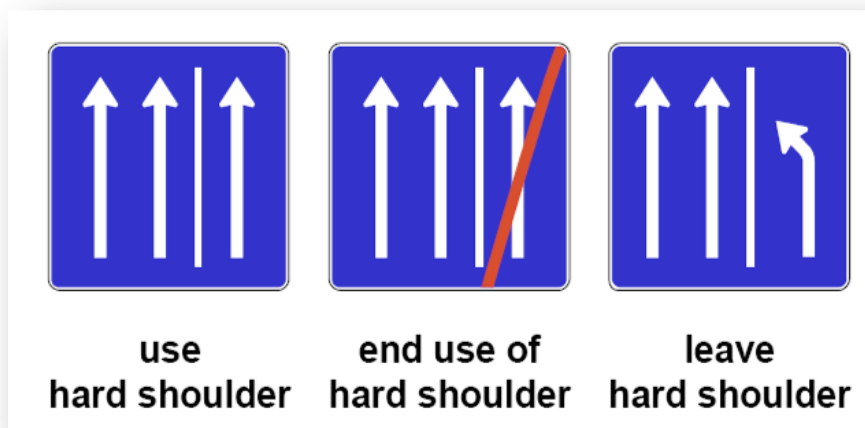


Figure 4. Forms of shoulder use sign (8).

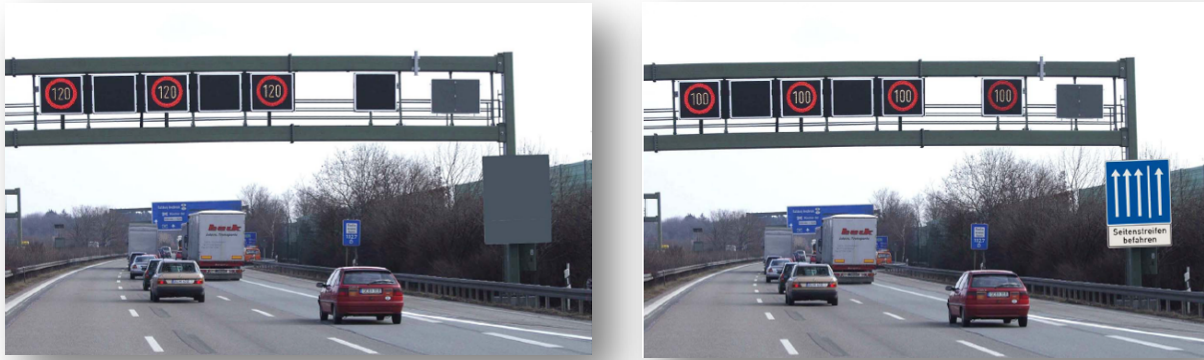


Figure 5. Hard shoulder for emergency only (left) and in use (right) (8).

The direction signing was designed to adapt to the enabling of shoulder use. This accommodation is commonly accomplished using rotating guide signs like those shown in Figure 6.

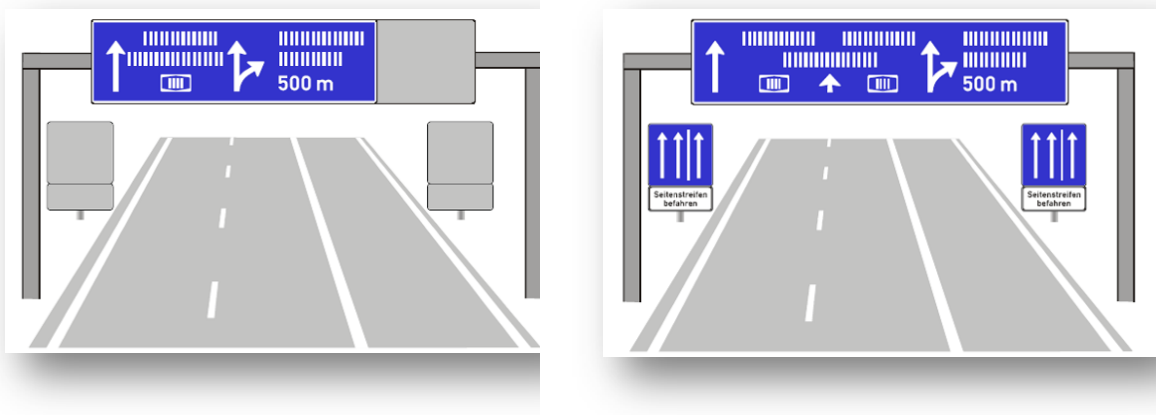


Figure 6. Direction signing without shoulder use (left) and with shoulder use (right) (8).

Safety evaluations for shoulder use were conducted by authorities, and no negative impact on safety was recorded. In fact, a reduction in congestion-related crashes was assumed. In terms of public opinion, a large majority of the traveling public is in favor of the measure, and positive feedback was received from users (9). Access to shoulders is not restricted to specific vehicles; trucks are allowed on the shoulders (10).

According to a study in Hessen, when driving on the shoulder is allowed on a three-lane motorway, the capacity is increased by 20 percent, allowing over 7,000 vehicles per hour without breakdown. Conversely, without shoulder use, breakdown would occur at approximately 5,850 vehicles per hour (9).

An economic analysis on the A5 showed that shoulder use saves 3,200 vehicle hours in congestion per day, which is equivalent to a savings of €48,000 per day or €10 million per year. Those savings do not include any environmental benefits as a result of improved traffic flow. The amount invested in making shoulder use operational was €25.7 million: €13 million for the traffic control system and €12.7 million for strengthening the shoulder (9).

Shoulder Use in the Netherlands

Since 1994, the Netherlands has focused on making the best use of the existing transportation infrastructure in a safe and efficient way. Rijkswaterstaat—the Dutch Department of Transportation, Public Works, and Water Management—has implemented two types of shoulder uses. The first type of deployment uses the right shoulder, designated as hard shoulder running or rush-hour lane. The second type of deployment uses a narrow left shoulder lane, called the plus lane. Standard shoulder widths are 1.25 m (4.10 ft) on the left shoulder and 3.0 m (9.85 ft) on the right shoulder. Since these widths are usually not chosen for shoulder use on either side, restriping is necessary most of the time. In 2006, 150 km (93.2 mi) of HSR/plus lanes were operational and another 235 km (146 mi) were planned for the future.

The plus lane is typically a 2.7 m (9.25 ft)-wide left lane striped just like a normal third lane (motorways in the Netherlands typically have two lanes). Its accessibility is determined by overhead lane control signs placed on regularly spaced gantries. When access to the plus lane is allowed, the speed limit is set to 70 km/h (44 mph) for all lanes (11). The safety issues caused by the narrower lane are reduced by this lower speed. This speed also allows a better quality of flow. However, because of the lost width on the lane, increased driver attention is required. For that reason, transportation professionals found that the maximum appropriate length for this type of measure is 8 km (5.0 mi). The increase in road capacity due to this measure was evaluated at 42 percent for a two-lane motorway, with an improvement in safety as well. Other plus lane restrictions are that neither trucks nor vehicles more than 2.0 m (6.7 ft) wide are allowed to use it (11).

Right shoulder use in the Netherlands is similar to right shoulder use in Germany. The typical width for a usable shoulder is 3.5 m (12 ft), but it can be smaller in given situations. For safety purposes, shoulder use also requires a lower speed limit (8, 11).

One key feature to enable a natural driving pattern on shoulders is to have variable route signs. The signs must adjust to the current width of the road in use and show arrows as if the shoulder were another general purpose lane. These signs can be either DMS or rotating guide signs (11).

Initially, HSR was only used in between junctions. This approach forced traffic to either merge into the two through lanes or exit at a junction. Current installations include acceleration and deceleration tapers, which allow continuous HSR use through a junction. Dynamic pavement markings are useful to signalize merging/exiting areas depending on the state of HSR. The use of HSR is deployed at the TMC in coordination with the national headquarters. Models are used to evaluate the benefits and possible problems or shifting of bottlenecks downstream of the HSR

section. Typically, once volumes reach 1,500 vehicles per hour per lane (vphpl), an operator at the regional TMC will inspect the shoulder for debris or stalled vehicles using the network of cameras. If the shoulder is clear, the TMC operator will enable HSR. Some motorway sections have HSR active for up to 8 hr daily, but 24-hr operation is not recommended (8, 11).

Initially, public reaction for shoulder use in the Netherlands was positive. However, stakeholders (e.g., fire brigade, police, emergency medical services, etc.) showed reluctance to the idea. Rijkswaterstaat found it necessary to communicate with stakeholders and to establish an incident management policy. Emergency refuge areas are placed along the shoulder every kilometer (11). In terms of safety, a significant improvement was observed on every section (11).

The ministry of transport made €380 million available for the construction of 150 km (93.2 mi) of HSR/plus lanes in 2003 (12).

The “flexroad” (dynamic cross sections) is a concept based on dynamic pavement markings that could allow modeling the cross section to demand in real time. Figure 7 shows two states of a section of the A44. This is achieved by devices that are incrustated into the pavement. These can be turned on or off to materialize different sets of pavement markings (13).



Figure 7. Left, a “flexroad” with its two possible cross sections on the A44. Right, an LED-based pavement device used for dynamic lane marking (8).

Overall, experience using shoulders for interim use has been positive in the United States, and more agencies are considering the strategy to address growing congestion on their urban freeway networks (14). In fact, several states have deployed temporary shoulder use for all vehicles on congested corridors with success. Another application that is much more difficult to research and document is the number of locations where an existing shoulder has been narrowed or taken away to allow for widening with an extra permanent travel lane. This method is more commonly used in roadway work zones to maintain the existing number of travel lanes during construction. However, it has been applied in some permanent forms as well (14).

Studies performed at the Texas Transportation Institute (TTI) showed reducing the lane width in order to add an extra traffic lane had a positive impact on all travel time, capacity, safety, and quality of operations. The increase in absolute number of crashes that could be expected due to the narrower lanes was offset by the additional capacity (15). Comments suggested that it is not so much the level of hazard that is increased when lanes become narrower, but that the driver's level of attention needs to be higher.

Speed profiles on narrow lanes were shown to be similar to those on regular lanes except in the case of level of service (LOS) F, where the speed was slightly lower (16). The same research study found that global accident rates could even be lower with narrow lanes if lane continuity and lane balance are respected. However, truck accident rates seem to be always higher on freeways with shoulder use and narrow lanes. It is recommended that narrow lanes be applied only to short sections for these reasons.

In 2008, TTI and Parsons Brinckerhoff created guidelines for the New York State Department of Transportation (NYSDOT) to help in decision making for managed lane strategies. According to these guidelines, shoulder use is to be accompanied by speed harmonization and dynamic message signs over or next to the shoulder to indicate when the shoulder is in use. Once the shoulder has been checked to be clear of obstacles, an operator allows traffic to access the shoulder. The criteria to consider when converting a regular shoulder to a useable shoulder are (17):

- Essential criteria:
 - LOS E/F for at least 2 hr in at least one peak period;
 - length of facility sufficient to alleviate a series of bottlenecks, at least 3 mi;
 - low volume of entering/exiting vehicles if crossing multiple interchanges;
 - minimum shoulder width of 3.05 m (10 ft), with ability to add emergency refuge areas; and
 - pavement strength to accommodate increased traffic load.
- Desirable criteria:
 - active incident management;
 - existing intelligent transportation system (ITS)/sensors;
 - ability to deploy speed harmonization concurrently; and
 - low turning movements (for arterials).

The left shoulder, or inside shoulder, can also be removed to add a lane and increase capacity. This was done in both Texas and California. Crash data for Dallas, Texas, showed no statistical difference between accident rates per million vehicle miles traveled (MVMT) on sections with and without inside shoulders (18). In Los Angeles, California, the number of crashes dropped remarkably and remained low over time when inside shoulders were removed to increase capacity (19). Research studies have shown the severity of accidents are not made worse by removing the inside shoulder. A scanning/feasibility study on active traffic management conducted for the Washington State Department of Transportation (WSDOT) showed that shoulder use is an effective way to increase capacity and reduce congestion in a small amount of time. The cost of preparing a freeway for shoulder use was estimated at \$2.7 million per mile (20). Table 1 provides a summary of the advantages and disadvantages of shoulder use alternatives included in the WSDOT feasibility study.

Table 1. Advantages and disadvantages of shoulder use design alternatives (20).

Design Alternatives	Advantages	Disadvantages
Use of Left Shoulder	<ul style="list-style-type: none"> • Left shoulder not used as much for emergency stop or emergency enforcement • Least expensive if width is available • Trucks often restricted from left lane 	<ul style="list-style-type: none"> • Usually requires restriping • Sight distance problems with some median treatments
Use of Right Shoulder	<ul style="list-style-type: none"> • Often the easiest to implement 	<ul style="list-style-type: none"> • Right shoulder is preferred area for emergency stops and enforcement • Sight distance changes at merge and diverge areas of ramps
Use of Both Shoulders	<ul style="list-style-type: none"> • Not recommended • Use ONLY in extreme cases 	<ul style="list-style-type: none"> • Requires restriping • Safety concerns (no refuge) • Enforcement difficult • Incident response longer • Maintenance more difficult and more expensive

In the U.S., temporary shoulder use varies. On Massachusetts State Route 3 and I-93 and I-95 in the Boston area, all vehicles are permitted on shoulders in the peak periods only. Similarly, in Virginia on I-66, the shoulder carries general purpose traffic from 5:30 a.m.–11:00 a.m. (eastbound) and 2:00 p.m.–8:00 p.m. (westbound); however, during this time, the interior general purpose lane is open to high-occupancy vehicle (HOV) traffic only. I-66 uses extensive traffic signals and signage in order to communicate the active times of service. In the Seattle area, the right shoulder on the US 2 trestle near Everett is opened to all traffic in the eastbound direction during the afternoon peak period. A similar operation is provided on H1 in Honolulu in the morning peak on the right shoulder. A unique combination of strategies is operational on I-35W in Minneapolis where a segment has the left shoulder open during the peak periods. Known as priced dynamic shoulder lanes (PDSLs), transit and carpoolers use the shoulder for free, and MnPASS customers can use the shoulder for a fee (14).

A Special Treatment of Shoulders: Transit-Only Access

Another type of shoulder use involving transit-only use of the shoulder has proven successful in several North American cities in variable forms. Several states, including Florida, California, Georgia, and Ohio, are moving to enable this type of treatment. Among all bus bypass shoulder (BBS) projects, very few have been abandoned after implementation. Projects that were abandoned were usually replaced by dedicated bus lanes, indicating that these cities wanted to go further in improving transit performance.

The motivation behind this measure is to encourage transit use and fully utilize the capacity of the transportation system (21). The treatment is very popular with bus riders for apparent reasons. It has several advantages: travel time variability due to congestion is reduced, which helps schedule reliability; travel time is competitive compared to cars; has low deployment cost; is easy to implement; does not require extra right-of-way; and other vehicles' line of sight is not obstructed by the buses (22).

In Minneapolis, BBS has been proven to be both safe and effective. In fact, improvements were such that schedules had to be rewritten and unneeded buses were taken off route schedules due to increased efficiency (21). Perceived travel time savings range from 5 to 15 min for each passenger with an average of 7 min. The main factors impacting the ease of implementation are the width of the shoulder and the shoulder pavement thickness (**Error! Bookmark not defined.**).

For an arterial or freeway to qualify for BBS, the Minnesota Department of Transportation (Mn/DOT) established a list of criteria. Most importantly, the facility must experience "predictable congestion delays," in other words, the speed must drop below 56 km/h (35 mph) during the peak period or approaches to intersections must suffer continuous queues. Other criteria include the following: congestion delays must occur at least once a week, at least six transit buses must use the shoulder in a week, the delay savings must be greater than 8 min per mile per week, and the shoulder has to be at least 3.05 m (10 ft) wide (21).

Mn/DOT issued guidelines to transit bus drivers to ensure the safety of passengers and all other users of the facility. To avoid speed differentials with the main traffic, shoulder use is only allowed when the speed drops below 56 km/h (35 mph). Buses using the shoulder are not allowed to drive more than 24 km/h (15 mph) faster than main traffic, and the maximum speed on the shoulder is 56 km/h (35 mph) (21). Figure 8 illustrates the typical signing layouts used in Minnesota.

Other screening criteria for BBS treatments were also provided to the NYSDOT and were separated into essential and desirable categories as noted below (17):

- Essential criteria:
 - LOS D or worse for 2+ hr for at least one peak period, to have room for improvement of bus travel time reliability;
 - at least 3.05 m (10-ft) shoulder width (or parking lane space on arterials) available;
 - sufficient pavement strength to sustain bus load; and
 - minimum volumes: arterials 25 buses/hr, freeway 50 buses/hr.

- Desirable criteria:
 - travel time variability higher than 1 min per 3.2 km (2 mi);
 - acceptable changes for on-street operation;
 - few conflict points at junctions (less important); and
 - portion shared with multiple bus routes (less important).

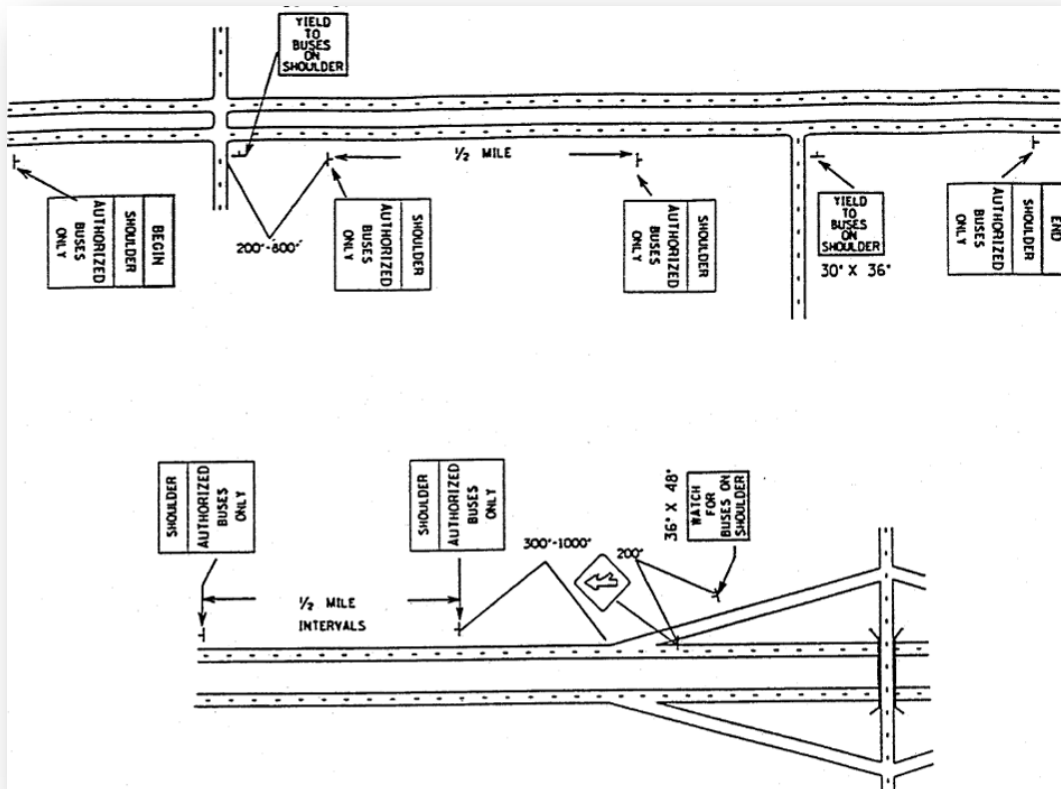


Figure 8. Typical signage for BBS as described by MnDOT (21).

In Virginia, the shoulder has a double use. During specific times of the day, the shoulders are allowed to be used by general traffic, and at other times, only HOVs of 2+ passengers are allowed to use the shoulders. The Virginia Department of Transportation (VDOT) assures this type of use of the shoulder has no significant impact on the number of crashes (23).

Speed Harmonization

The concept of speed harmonization, also called variable speed limits or dynamic speed limits, is already in place in many countries and several states in the United States. Agencies choose speed harmonization to solve very different problems. The two most cited purposes for deploying speed harmonization are for weather-related conditions and congestion management. Depending on the goals of the agency, the speed can either be mandatory or advisory.

Weather-Related Speed Harmonization

Weather-related speed harmonization is often used on roads where fog, ice, rain, or other factors often impact safety. Several northern European countries have witnessed disastrous pileups due to ice or heavy fog. Funding was made available in Finland for real-time driver information and speed control (24). In both Finland and Sweden, local weather stations collect weather conditions and pavement-embedded sensors measure pavement characteristics, allowing a system to post an accurate safe speed for all users. That speed is then displayed on a DMS with a message or pictograph of the reason for the new speed limit. In Finland, the Road Weather Information System (RWIS) uses the data from all weather stations to inform travelers of weather and road surface conditions in real time and with a short-term forecast. This practice has proven very useful to organize winter maintenance teams. Public acceptance of this type of speed harmonization is good; no marketing was needed because drivers easily understand the function of the system (25).

Sydney, Australia, implemented a fog warning system that includes advisory speeds. During fog, the advisory speed limit is continuously adjusted to the speed of the preceding vehicle within the speed limit (26).

In Denmark, studies found that a DMS indication of slippery road, fog, and other hazardous road conditions reduced the traffic mean speed by 1 to 2 km/h (0.62 to 1.24 mph). When the speed harmonization sign showed a speed limit of 80 km/h (49.7 mph) instead of 100 km/h (62.1 mph), the mean speed was reduced by 3.4 km/h (2.1 mph). In adverse road conditions, such as black ice, the speed limit was lowered from 120 km/h (74.6 mph) to 100 km/h (62.1 mph); mean speed dropped by 5.1 km/h (3.2 mph). The speed harmonization signs also reduced speed variance (27).

The Netherlands also deploys speed harmonization for weather conditions. Visibility sensors are used to measure the level of fog, and when visibility drops to 140 m (459 ft) or 70 m (230 ft), the speed limit is dropped to 80 km/h (49.7 mph) or 60 km/h (37.3 mph), respectively. After implementation of the speed harmonization during fog conditions, drivers reduced their speed by 8-10 km/h (5.0-6.2 mph) (28).

Congestion-Related Speed Harmonization

Congestion-related speed harmonization is used, as the name suggests, during periods with high traffic volumes or congested situations. It is believed that speed harmonization can be used to create a better uniformity in speeds and a sustainable traffic flow. The Netherlands was one of the first countries to utilize this strategy. The speed limit was set to a 1-min average of speeds across lanes. When deployed, this method yielded a high compliance rate, and the severity of shockwaves was significantly reduced (28). Figure 9 shows a typical speed harmonization sign in the Netherlands.



Figure 9. Speed harmonization in the Netherlands (13).

The motto for many agencies can be summarized as “drive slower, arrive faster.” The underlying idea of the motto is that a slower, more consistent flow is less likely to break down into congested flow, therefore improving travel times. Volumes and speeds are mainly measured through inductive loop detectors. The speed limit is changed automatically by using the information from the loops in a computer algorithm. By gradually reducing the speed as volumes are predicted to increase, this strategy allows a slight increase in capacity. In the case of the Netherlands, the increase was 5 percent. This strategy also avoids an abrupt transition into congested flow (25).

The M25 motorway was the first to introduce speed harmonization in Britain in 1995. Currently, 60 percent of motorists believe the plan is beneficial, and results show 6 percent fewer stop-and-go situations. This reduction has resulted in a decrease in emissions by 2 to 8 percent, a noise reduction around 0.7 decibels, 20 percent fewer property-damage-only crashes, and 10 percent fewer injury crashes (29, 30). Implementation has also resulted in an improvement in travel time reliability, a smoother flow, a better lane balance, and a calmer driving experience. Setting up gantries to support the speed displays as well as enforcement cameras has increased speed compliance even when no speed restriction is applied, resulting in increased travel times. A benefit/cost analysis on the portion of controlled highway was negative, but the implications of the operation were broader than the study accounted for and further analysis is needed (30).

In all of the European countries surveyed, the signing for speed harmonization and most other active traffic management tools like queue warning and shoulder use are placed on overhead gantries. These installations have the advantage of providing unobstructed visibility for every lane (31). In the Netherlands, the speed on the sign can be accompanied by flashers when there is a speed drop and red circles meaning the speed limit is enforced; however, all posted speeds are regulatory (28).

Facilities in Germany with speed harmonization had a 5 to 15 percent reduction in travel times, a 30 percent decrease in the number of crashes, and a 5 percent increase in capacity (10, 26). In Denmark, the implementation of speed harmonization resulted in speeds decreasing by less than 5 km/h and reduced speed variance. A survey showed that 46 percent of Danish travelers felt safer after the implementation (32).

A feasibility study in Washington predicted reductions in injury collisions of 30 percent and all other collisions by 16 percent. The study concluded that the benefits from reduced travel times and delays would exceed the cost of the program in anywhere from 4.5 years to as little as 1 year (20). A conceptual rendering of a WSDOT installation is shown in Figure 10.



Figure 10. Gantry concept for WSDOT, with an HOV lane on the left side (33).

The criteria for speed harmonization suggested in a study by TTI and Parsons Brinkerhoff to the NYDOT were divided into the categories of essential and desirable. The criteria recommended were:

- Essential criteria:
 - LOS E or F for minimum of 3 hr for at least one peak period and at least 5 hr per day;
 - right-of-way for overhead gantries and DMSs;
 - at least one location every 2 mi where queues form and warning is warranted; and
 - at least five incidents related to queuing merging/diverging per week.
- Desirable criteria:
 - willingness to automate the deployment of strategy; and
 - existing ITS and connections to TMC.

In the United States, some locations that have implemented speed harmonization use a ground-mounted sign instead of a more expensive gantry. This approach has raised some concerns in the population, as the sign could be obstructed and drivers fined for speeding unknowingly (34).

Speed harmonization is commonly used with automated queue detection/warning and lane control signs. In the Netherlands and England, this function is part of incident detection and management programs respectively named motorway traffic management (MTM) and Motorway Incident Detection and Automatic Signaling (MIDAS). In Sweden, this type of system helped reduce serious accidents by 35 percent and secondary accidents 46 by percent, for an overall reduction of 23 percent. In Germany, accidents were reduced by 20 percent at the same time that they increased by 10 percent on a similar autobahn without speed harmonization (35).

Speed harmonization is also regularly used in combination with shoulder use. In all surveyed countries that implemented shoulder use, the use of the shoulder was only allowed at a speed below the standard speed limit. In Germany, for instance, the speed limit is changed from 120 km/h (74.6 mph) [or other posted limit] to 100 km/h (62.1 mph) (8).

Compliance and Enforcement

The success of speed harmonization is closely linked to the extent to which drivers comply with the signing. The experience in four countries (the Netherlands, Germany, Sweden, and Australia) led to the identification of basic guidelines for a speed harmonization strategy. Communication has to be of paramount importance and should aim at the jurisdiction, the police, the engineers, and especially the public. The strategy also has to be success oriented with a fair and reasonable plan for the majority of users. For instance, placing a 20-mph limit on a freeway to force a speed reduction is bound to fail and will reduce public confidence in traffic management strategies (26).

Travelers are usually not familiar with these new signs on the road and usually have plenty of unanswered questions regarding the signs. Thus, it is important that agencies communicate with the public and inform motorists of new measures and regulations as they are put in place. In many European Countries and Australia, a high emphasis on outreach and education helped bring better compliance.

Speed harmonization needs to be implemented in response to an actual situation. If users do not believe the system is legitimate, compliance rates will be low. Therefore, if the reason for the new speed limit is not apparent, it should be explained through appropriate signing. A report on speed harmonization on the M25 in England explains that in the beginning of the project, the speeds displayed had no connection to a congested situation or incident; therefore, the speed limits were largely ignored by the driving public (30).

When speed harmonization was used with hard shoulder running, the compliance rates on M42 in England showed that shoulder users tend to comply better with the speed limits (5). Compliance rates were seen as follows:

- On the main lanes:
 - 94 percent or better for speed limits of 43.5 (70), 37.3 (60), and 31.1 km/h (50 mph); and
 - 87 percent or better for speed limits of 24.9 km/h (40 mph).

- On the hard shoulder:
 - 98 percent for 31.1-km/h (50-mph) speed limit; and
 - 93 percent for 24.9-km/h (40-mph) speed limit.

In many situations, automated enforcement is used; however, police vehicles can also monitor speeds manually. Automated enforcement is used as a prevention method rather than a repressive or profitable measure. It is also an economic means of enforcement in terms of manpower and efficiency (26).

When enforcement is chosen to improve compliance, it is necessary to implement the enforcement using a phased approach. This approach includes education and communication to explain the importance of speed compliance. Enforcement may also be chosen to use average speed control between two distant gantries rather than spot speed control that is predictable even if the cameras are randomly set. In that case, speeders cannot simply slow down to pass the cameras and will be caught if their average speed is higher than the limit over the controlled stretch, which can be as long as 17 km (5).

Imposing variable speed limits on the driving population may lead to significantly lower compliance. Using automated speed enforcement cameras can be an effective solution to this problem. In France, an aggressive countrywide speed enforcement policy managed to reduce the number of speeders from 7 percent to fewer than 3 percent of all drivers in camera-enforced locations. Political support is strong: 86 percent of the population admits to reducing their speed because of the cameras, and 77 percent believe that the enforcement improves road safety (36). Figure 11 shows the typical signing and equipment used for speed enforcement in France.

Other Approaches to Improve Speed Compliance

Speed can also be reduced through the driver perception of risk. Narrower lanes and noise-inducing tactile strips (rumble strips) are approaches that result in the driver perception of risk. By applying these in the Netherlands, a speed reduction between 5 and 10 km/h (3.1 and 6.2 mph) was observed and the safety on the road was not compromised. There was a 35 percent reduction in crashes on trial roads, while control road crashes increased by 17 percent. These measures prove especially efficient on roads where the perception of risk is too low for users to decrease their speed (26).



Figure 11. A fixed enforcement camera and warning sign in France (36).

It is possible to inform drivers of their speed without taking action to force self-moderation. Using a DMS sign showing every driver's speed and whether he or she is driving too fast or too slow has been proven to be an efficient method that does not involve the presence of an authority. In Germany, this technique was used to encourage people to drive between 60 (37.3) and 80 km/h (49.7 mph); the number of speeders decreased from 38 to 11 percent, with an average speed reduction of 3 to 8 km/h (1.9 and 5.0 mph), and the number of vehicles going under 60 km/h (37.3 mph) slightly increased (25). In France, on the A7, an experiment was conducted whereby non-complying drivers had their plate number displayed on an overhead DMS with a notice of the violation, but no fines were issued. Their speed was determined on a stretch of 10 km (6.2 mi) delineated by two gantries that were equipped with automated vehicle identification (AVI). The results were promising, with 80 percent compliance at 110 km/h (68.4 mph) and a lower 50 percent at 90 km/h (55.9 mph).

Queue Warning

The basic principle of queue warning is to inform travelers of the presence of upstream queues, based on utilizing dynamic traffic detection and using warning signs and flashing lights. This strategy allows the traveler to anticipate a situation of emergency braking and limit the extent of speed differentials, erratic behavior, and queuing-related collisions. Figure 12 is an example of a queue warning installation in Germany. The pictogram warning can be turned on manually by a TMC operator or automatically when it is integrated into an incident management program such as MIDAS (England). The DMS signs on England's network are primarily used by the national traffic control center, but MIDAS can override the messages if deemed necessary (29).



Figure 12. Queue warning in Germany.

In the Netherlands, on heavily traveled routes with an average daily traffic (ADT) over 60,000 vehicles per day, “about 50 percent of the accidents are caused by severe disruptions in the traffic flow, caused themselves by accidents or queues” (13). The chance of having a queuing-related accident becomes virtually absent 20 min after deploying the warning. This statistic indicates the benefits of detecting these disruptions as quickly as possible.

Results on the A8 Autobahn between Ulm and Stuttgart in Germany showed that queue warning improves the quality of traffic flow, reduces speeds with closer headways, encourages more uniform driving speeds, and slightly increases capacity. Since drivers anticipate the risk of queues, accidents are less severe and less frequent. It was also noted that users are interested in knowing the location of the queue and what route they should take to avoid it (10).

When queue warning is included in a larger traffic management project that has lane control signals and variable speed limits with DMSs, it is possible to reduce the speed incrementally between gantries and evacuate traffic from one lane to provide access and shelter for emergency vehicles. This procedure, called automatic incident detection (AID) in the Netherlands, is illustrated in Figure 13. In Sweden, this type of system helped to reduce accidents by 23 percent overall; specifically, serious accidents decreased by 35 percent, and secondary accidents decreased by 46 percent. In Germany, accidents were reduced by 20 percent on an autobahn with queue warning, while they increased by 10 percent on a similar autobahn without queue warning (35).

Work zones also take advantage of queue warnings. Many agencies use mobile DMSs to warn approaching traffic of queues. The results have been very positive, with an example being in Belgium, where 60 percent of rear-end crashes were avoided (31). On some roads, like on both the inner and outer ring roads in Paris, France, congestion occurs so regularly that users are much

more interested in knowing the expected travel time to their exit than the presence of downstream queue (37).

A study in Washington found that queue warning could reduce congestion-related collisions by 15 to 20 percent and that the benefits were estimated to outweigh the cost within 1 to 3 years (20). The criteria assessment for queue warning made by the Texas Transportation Institute and Parsons Brinkerhoff for the New York State DOT are the following (17):

- Essential criteria:
 - LOS E/F for at least 2 hr per peak period;
 - presence of queues in predictable locations;
 - sight distance restricted by vertical grades, horizontal curves, or inadequate illumination;
 - right-of-way for overhead gantries and DMSs; and
 - at least five incidents related to queuing merging/diverging per week.
- Desirable criteria:
 - large mix of high-profile vehicles or inability to control speeds;
 - presence of speed harmonization on the facility;
 - willingness to automate the deployment of strategy;
 - existing and sufficient ITS; and
 - connection to a TMC that serves as the focal point for the system.

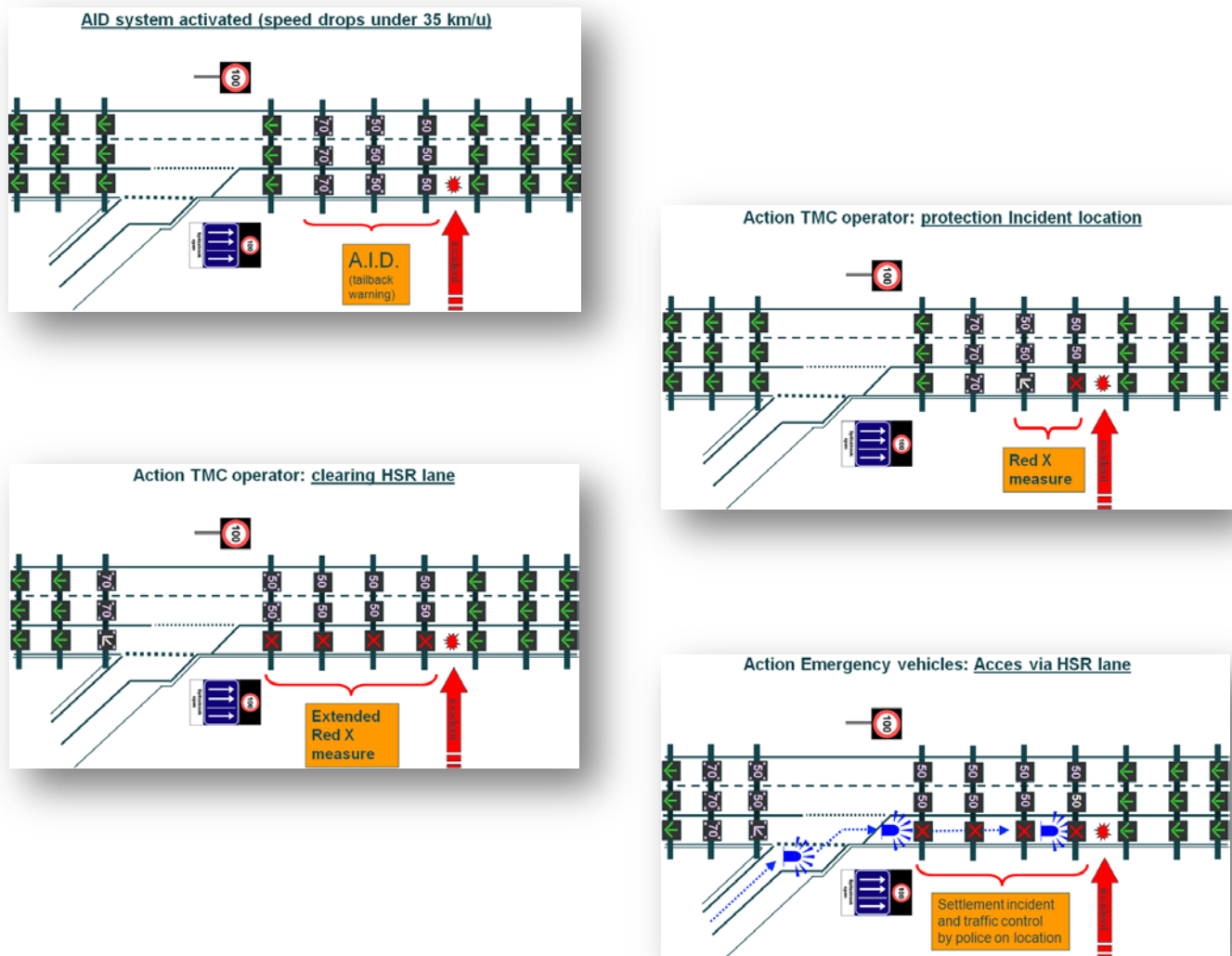


Figure 13. Four-step incident response protocol with shoulder use in the Netherlands (11).

Dynamic Merge Control

Dynamic merge control, also termed junction control, is used when the sum of both freeway general purpose lanes and merging lanes at an interchange is higher than the number of downstream general purpose lanes. A combination of ramp metering and lane control at ramps, dynamic merge control is used to dynamically meter or close specific lanes upstream of the interchange to manage access based on traffic demand (1). A typical U.S. application of this condition would be a lane drop for one of the outside lanes or a merging of two inside lanes, both of which are static solutions. Figure 14 illustrates the German approach, in which lane control signals are used to close the rightmost general purpose lane upstream of the on ramp to allow two ramp lanes to merge onto the motorway. The intent is to provide dynamic priority access to the higher traffic stream. Dynamic

merge control can be a permanent application, or it can be used temporarily until a downstream roadway is widened (35). It is a practical approach to handling varying demand on the main lanes and the merging lanes to effectively utilize existing capacity.

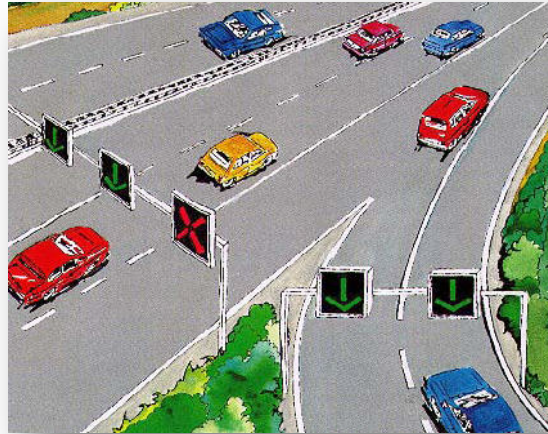


Figure 14. Dynamic merge control schematic (38).

In the Netherlands, a pilot test of dynamic merge control on the A1 showed promising results (28). In the state of Washington, this measure—if implemented—is expected to reduce collisions by 20 to 25 percent; the benefits of avoided collisions would most likely outweigh the primary cost in about 6 to 8 years (20). The criteria assessment for dynamic merge control made by TTI and Parsons Brinkerhoff for NYSDOT provided essential and desirable criteria, which included the following (17):

- Essential criteria:
 - high volume of entering traffic, at least 900 vph; and
 - available capacity in the upstream general purpose lanes to be borrowed with no worse than LOS E after implementation.
- Desirable criteria:
 - active incident management; and
 - existing ITS/sensors.

Dynamic Rerouting and Traveler Information

When the main road is congested, rerouting traffic on a parallel road to relieve further congestion can be an efficient strategy. Providing rerouting and traveler information in a dynamic manner is a critical component of a successful ATM system. The intent is to provide users with viable route alternatives, and the approach can be especially beneficial in helping reduce the impact of noncurrent congestion (1). When considering dynamic rerouting and traveler information, there are two signing strategies that can be applied: substitution and addition. In the substitution

strategy, rotating panels on guide signs turn and indicate the suggested secondary route. The problem encountered with this method is that the first route is no longer displayed, and some mid-trip destinations may be missed. In the addition strategy, orange arrows show the recommended diversion route while keeping the original signing. In both cases, full-matrix DMSs can be used to display any of the strategies (39).

One scenario proposed for WSDOT, pictured in Figure 15, shows two separate approaches to signage for dynamic rerouting. A study on dynamic rerouting and traveler information in Copenhagen, Denmark, suggested that more travelers followed the alternative route (up to 12 percent of the time), as the displayed travel time between the original and alternate route increased. The relatively low portion of route changers may be due to erratic displays on the DMS at the time of deployment. Surveys conducted showed that 80 percent of the driving public was in favor of this system (32).



Figure 15. Two types of rerouting by WSDOT (20).

In the Netherlands, rerouting information is displayed using full-matrix DMSs that provide useful information for drivers to make the appropriate decision based on their needs. These signs are usually set at entrances of cities. Evidence indicates that the use of these signs has helped reduce congestion. For instance, after implementation on the Amsterdam ring road, congestion dropped by 25 to 33 percent. Drivers give more credit to the provision of accurate information (62 percent) on DMSs than on radio (52 percent) (13). In normal conditions, 8 to 10 percent of drivers are reacting to the information. This trend can have a major effect on roadway operations and recurrent congestion (28). Figure 16 shows a DMS showing two routes to Schiphol and a notice that both routes are congestion free. For important interchanges like the one depicted in Figure 17, the amount of information to deliver for every possible route is too important for textual signing; therefore, a graphical approach is chosen.



Figure 16. Route information in the Netherlands (13).

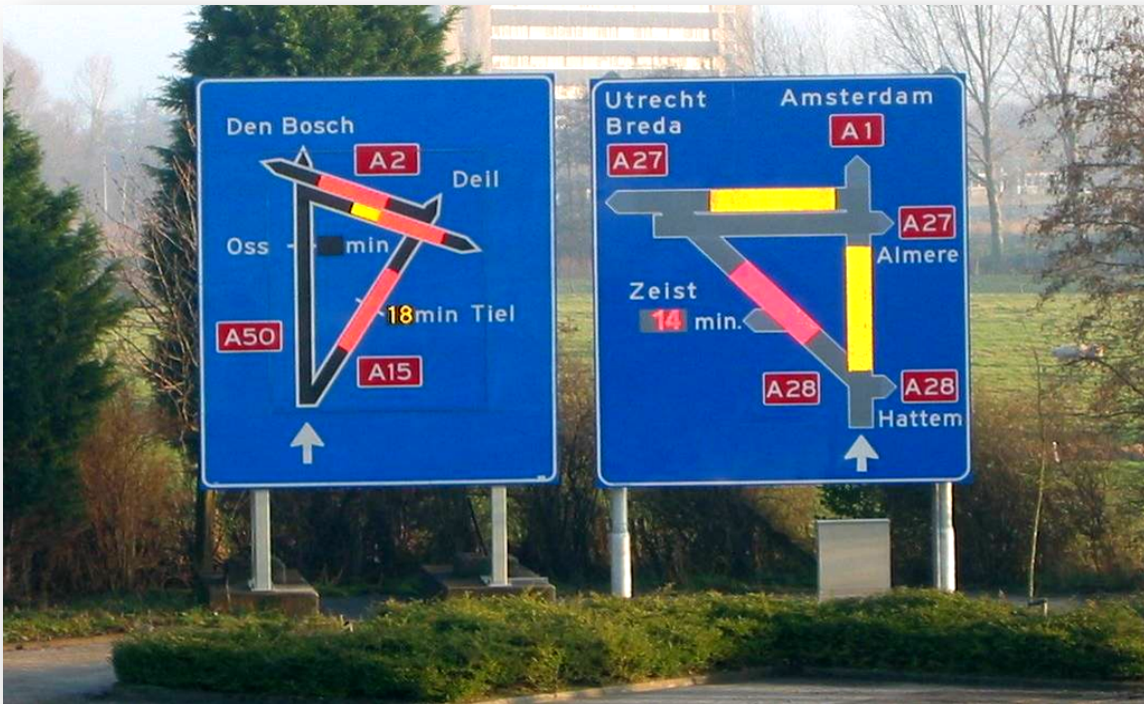


Figure 17. Graphical route information in the Netherlands (13).

In England, an expert system in the TMC computes the remaining capacity on a facility and the anticipated demand for the duration of an incident. If the anticipated delay exceeds a set threshold,

the demand on alternate routes and the presence of road works, weather problems, or special events are evaluated before communicating the alternate route to the traffic (29).

Some general criteria assessment for dynamic rerouting provided to NYSDOT include the following (17):

- Essential criteria:
 - level of service E/F for 2 hr or more in at least one peak period;
 - at least three incidents per week resulting in severe congestion;
 - the presence of a viable parallel and comparable corridor to accept rerouted traffic no farther than 2 mi from the primary corridor;
 - available capacity on the parallel facility; and
 - available right-of-way for overhead gantries to provide routing information.
- Desirable criteria:
 - existing ITS/sensors; and
 - concurrent implementation of speed harmonization.

Dynamic Truck Restrictions

Restricting trucks to the right lane has several benefits. The treatment can increase capacity by up to 3 percent, the speed of the left lane can be higher, and safety is improved since no trucks are changing lanes. Eventually, the flow becomes more stable and homogeneous (40). However, it is important to note that in Europe, trucks do not have the same speed limit as cars, and in most countries, the difference between the two limits is 20 to 30 km/h (12.4 to 18.6 mph). Trucks are also instructed to drive on the rightmost lane except for when passing, which when combined with the mandatory speed differential is often a restriction to the right lane itself (41). Although most drivers agree with the measure, the trucking industry is not very supportive.

In the Netherlands, until the dynamic aspect was introduced recently as a test, the restriction took place at fixed times of the day, mainly during peak hours. The dynamic restriction is activated when necessary and is displayed on overhead gantries. The approval rates for the dynamic variation are better among truck drivers, and fewer violations have been reported (13). Figure 18 shows an example of dynamic truck restriction in the Netherlands. Some sections where speed harmonization is present also have dynamic truck restrictions that are implemented at the same time as the speed harmonization. The combination of these two strategies has been shown to reduce accidents enough to pay for itself in 3 years (39).

Depending on the location, truck restrictions might not be a solution for a congestion problem. In England, a section of the M5 that regularly experienced congestion with up to 30.6 km (19 mi) of queue was used as a pilot scheme for truck restrictions. The restriction applied to towing vehicles, buses, and heavy goods vehicles (HGVs). Although the right lane usage by trucks increased from 84 to 91 percent, the levels of congestion were not significantly affected, as the congestion was mainly due to car traffic (42).



Figure 18. Dynamic truck restriction in the Netherlands (41).

Chapter 3: Inventory of ATM Strategies

An inventory of active traffic management practices was constructed to capture how the different agencies in Europe and in the United States managed to implement the different ATM strategies. For each of the different strategies, specific points of interest were determined to describe what choices the different agencies had made and what their reasons were. The inventory was completed using information from a comprehensive literature review and email correspondence with the people who participated in the different applications of the strategies.

The questions that were asked for each application of a strategy included situation aspects, design aspects, performance measures and results, public support, and cost aspects. In many cases, the lack of available information and time constraints did not allow all questions to be answered. The questions used in the interviews and email correspondence for this effort are included in following sections. The specific ATM operational strategies included in the inventory, which is housed on the website developed as part of this project and discussed in Chapter 5, are the following:

- temporary shoulder use,
- speed harmonization,
- queue warning,

- dynamic merge control,
- dynamic rerouting, and
- dynamic truck restrictions.

Interview Questions Related to Temporary Shoulder Use

Following are the interview questions regarding temporary shoulder use:

1. What facilities have had shoulder use either in the past or currently?
2. What was the intent of the implementation (goals and objectives)?
3. Were other operational strategies evaluated prior to identifying shoulder use as the alternative to deploy?
4. What are the specifics of that operation?
 - a. Facility name/number, city
 - b. Date implemented
 - c. Date terminated (if applicable)
 - d. Length of implementation
 - e. Allowed vehicles
 - f. Operating partners
 - g. Conditions associated with implementation: Is this an interim treatment until future widening occurs? Are speeds restricted or other conditions changed from the prior condition?
5. Operational hours (part-time vs. permanent)?
6. What is the maximum speed allowed for the shoulder lane?
7. What are the geometric features of the implementation?
 - a. Cross-sectional details, including shoulder width
 - b. Treatment at interchanges
 - c. Handling of inlets (if applicable)
 - d. Handling of existing rumble strips (if applicable)
 - e. Guardrail and fixed-object shielding/adjustments (if applicable)
8. What traffic control devices are part of the implementation?
 - a. Pavement markings
 - b. Overhead signs and signals
 - c. Ground-mounted signs
9. What are the ITS-related elements of the implementation?
10. What performance measures are associated with the facility, and how are they used?
 - a. Specific measures of effectiveness?
 - b. Who is responsible for monitoring?
11. What were the costs associated with implementation?
12. How is the facility enforced?
 - a. Who is responsible?
 - b. What are the related fines?
 - c. What is the enforcement approach?
13. How is the facility maintained?

- a. Who is responsible?
 - b. Other specifics?
14. How are incidents within the facility handled?
 - a. Who is responsible?
 - b. What is the average response time?
 - c. Are there unique strategies deployed here that are not deployed elsewhere in the region?
 15. What is the overall evaluation of the implementation?
 - a. Overall safety experience (crashes/severity)
 - b. Operational experience (travel speeds/delay)
 - c. In-service compliance rates
 16. What, if any, liability issues or concerns posed a problem with the implementation of shoulder operations?
 17. Were there impacts with oversized and/or over-width vehicles? How were they addressed?
 18. Was there a public outreach or education component to the deployment?
 19. Was any legislation required to enable the strategy?
 20. Are there any issues with compliance or return to traditional operations on adjacent sections or on other local facilities that do not permit emergency shoulder/breakdown lane use as peak period travel lanes?

Interview Questions Related to Speed Harmonization

The following questions related to speed harmonization were used in the interviews:

1. What facilities have had speed harmonization use either in the past or currently?
2. What was the intent of the implementation (goals and objectives)?
3. Were other operational strategies evaluated prior to identifying speed harmonization as the alternative to deploy?
4. What are the specifics of that operation?
 - a. Facility name/number, city
 - b. Date implemented
 - c. Date terminated (if applicable)
 - d. Length of implementation
 - e. Operating partners
 - f. Conditions associated with implementation: Is this an interim treatment until future widening occurs? Are other operational strategies deployed in conjunction with the speed harmonization?
5. Operational hours (part-time vs. permanent)?
6. Operation: automated or manual control?
7. Is the same speed applied on all lanes, or do speeds vary across lanes?
8. Is the indicated speed advisory or compulsory?
9. What is the maximum speed allowed on the facility?
10. How is speed changed (minimum speed, increments)?
11. How often can speeds be changed, and how much can they be changed at once?
12. How long does it take for traffic to adjust its speed to the newly posted limit?

13. Is speed harmonization run with another ATM measure(s)? If so, which one(s)?
14. What traffic control devices are part of the implementation?
 - a. Overhead signs and signals
 - b. Explanatory signs
 - c. Ground-mounted signs
15. What are the ITS-related elements of the implementation?
16. What performance measures are associated with the facility, and how are they used?
 - a. Specific measures of effectiveness?
 - b. Who is responsible for monitoring?
17. What were the costs associated with implementation?
18. How is the facility enforced (speed)?
 - a. Who is responsible?
 - b. What are the related fines?
 - c. What is the enforcement approach?
19. How is the facility maintained?
 - a. Who is responsible?
 - b. Cost? Source of funding?
 - c. Other specifics?
20. What is the overall evaluation of the implementation?
 - a. Overall safety experience (crashes/severity)
 - b. Operational experience (travel speeds/delay)
 - c. In-service compliance rates
21. What, if any, liability issues or concerns posed a problem with the implementation of speed harmonization?
22. Was there a public outreach or education component to the deployment?
23. Was any legislation required to enable the strategy?
24. Are there any issues with compliance or return to traditional operations on adjacent sections or on other local facilities?

Interview Questions Related to Queue Warning

Following are the interview questions related to queue warning:

1. What facilities have had queue warning either in the past or currently?
2. What was the intent of the implementation (goals and objectives)?
3. Were other operational strategies evaluated prior to identifying queue warning as the alternative to deploy?
4. What are the specifics of that operation?
 - a. Facility name/number, city
 - b. Date implemented
 - c. Date terminated (if applicable)
 - d. Length of implementation
 - e. Allowed vehicles
 - f. Operating partners

- g. Conditions associated with implementation: Is this an interim treatment until future widening occurs? Are speeds restricted or other conditions changed from the prior condition?
- 5. Operational hours (part-time vs. permanent)?
- 6. Was queue warning used at the same time as another ATM measure(s)? If so, which one(s)?
- 7. What traffic control devices are part of the implementation?
 - a. Pavement markings
 - b. Overhead signs and signals
 - c. Ground-mounted signs
- 8. What are the ITS-related elements of the implementation?
- 9. What performance measures are associated with the facility, and how are they used?
 - a. Specific measures of effectiveness?
 - b. Who is responsible for monitoring?
- 10. What were the costs associated with implementation?
- 11. How is the facility maintained?
 - a. Who is responsible?
 - b. Cost? Source of funding?
 - c. Other specifics?
- 12. What is the overall evaluation of the implementation?
 - a. Overall safety experience (crashes/severity)
 - b. Operational experience (travel speeds/delay)
 - c. In-service compliance rates
- 13. What, if any, liability issues or concerns posed a problem with the implementation of queue warning?
- 14. Were there impacts with oversized and/or over-width vehicles? How were they addressed?
- 15. Was there a public outreach or education component to the deployment?
- 16. Was any legislation required to enable the strategy?
- 17. Are there any issues with compliance or return to traditional operations on adjacent sections or on other local facilities?

Interview Questions Related to Dynamic Merge Control

The interview questions related to dynamic merge control were as follows:

- 1. What facilities have had dynamic merge control either in the past or currently?
- 2. What was the intent of the implementation (goals and objectives)?
- 3. Were other operational strategies evaluated prior to identifying dynamic merge control as the alternative to deploy?
- 4. What are the specifics of that operation?
 - a. Facility name/number, city
 - b. Date implemented
 - c. Date terminated (if applicable)
 - d. Length of implementation
 - e. Operating partners

- f. Conditions associated with implementation: Is this an interim treatment until future widening occurs? Are speeds restricted or other conditions changed from the prior condition?
- 5. Operational hours (part-time vs. permanent)?
- 6. What are the maximum speeds allowed for the ramp and facility?
- 7. Are there any geometric specifics related to this merge control (shoulder use)?
- 8. What traffic control devices are part of the implementation?
 - a. Pavement markings
 - b. Overhead signs and signals
 - c. Ground-mounted signs
- 9. What are the ITS-related elements of the implementation?
- 10. What performance measures are associated with the facility, and how are they used?
 - a. Specific measures of effectiveness?
 - b. Who is responsible for monitoring?
- 11. What were the costs associated with implementation?
- 12. How is the facility maintained?
 - a. Who is responsible?
 - b. Cost? Source of funding?
 - c. Other specifics?
- 13. How are incidents within the facility handled?
 - a. Who is responsible?
 - b. What is the average response time?
 - c. Are there unique strategies deployed here that are not deployed elsewhere in the region?
- 14. What is the overall evaluation of the implementation?
 - a. Overall safety experience (crashes/severity)
 - b. Operational experience (travel speeds/delay)
 - c. In-service compliance rates
- 15. What, if any, liability issues or concerns posed a problem with the implementation of dynamic merge control?
- 16. Were there impacts with oversized and/or over-width vehicles? How were they addressed?
- 17. Was there a public outreach or education component to the deployment?
- 18. Was any legislation required to enable the strategy?
- 19. Are there any issues with compliance or return to traditional operations on adjacent sections or on other local facilities?

Interview Questions Related to Dynamic Rerouting

Below are the interview questions regarding dynamic rerouting:

1. What facilities have had dynamic rerouting either in the past or currently?
2. What was the intent of the implementation (goals and objectives)?
3. Were other operational strategies evaluated prior to identifying dynamic rerouting as the alternative to deploy?
4. What are the specifics of that operation?

- a. Facility name/number, city
- b. Date implemented
- c. Date terminated (if applicable)
- d. Length of implementation
- e. Concerned vehicles (all, just passenger cars, trucks, etc.)
- f. Operating partners
- g. Conditions associated with implementation: Is this an interim treatment until future widening occurs? Are other operational strategies deployed in conjunction with the dynamic rerouting?
5. Operational hours (part-time vs. permanent)?
6. Operation: automated or manual control?
7. Is there any communication between authorities to ensure continuity of service?
8. What is the maximum speed allowed on the facility?
9. Is dynamic rerouting deployed with another ATM measure(s)? If so, which one(s)?
10. What traffic control devices are part of the implementation?
 - a. Overhead signs and signals
 - b. Explanatory signs
 - c. Ground-mounted signs
11. What are the ITS-related elements of the implementation?
12. What performance measures are associated with the facility, and how are they used?
 - a. Specific measures of effectiveness?
 - b. Who is responsible for monitoring?
13. What were the costs associated with implementation?
14. How is the facility maintained?
 - a. Who is responsible?
 - b. Cost? Source of funding?
 - c. Other specifics?
15. What is the overall evaluation of the implementation?
 - a. Overall safety experience (crashes/severity)
 - b. Operational experience (travel speeds/delay)
 - c. In-service compliance rates
16. What, if any, liability issues or concerns posed a problem with the implementation of dynamic rerouting?
17. Was there a public outreach or education component to the deployment?
18. Was any legislation required to enable the strategy?
19. Are there any issues with compliance or return to traditional operations on adjacent sections or on other local facilities?

Interview Questions Related to Dynamic Truck Restrictions

The dynamic truck restriction questions used in the interviews were as follows:

1. What facilities have had dynamic truck restrictions either in the past or currently?
2. What was the intent of the implementation (goals and objectives)?

3. Were other operational strategies evaluated prior to identifying dynamic truck restrictions as the alternative to deploy?
4. What are the specifics of that operation?
 - a. Facility name/number, city
 - b. Date implemented
 - c. Date terminated (if applicable)
 - d. Length of implementation
 - e. Allowed vehicles
 - f. Operating partners
 - g. Conditions associated with implementation: Is this an interim treatment until future widening occurs? Are speeds restricted or other conditions changed from the prior condition?
5. Operational hours (part-time vs. permanent)?
6. What is the maximum speed allowed for trucks/other vehicles?
7. What is the triggering condition to the restriction (queue? distance to perturbation?)?
8. Is the response automated or manual?
9. How is the restricted length determined?
10. Is the dynamic truck restriction run with another ATM measure(s)? If so, which one(s)?
11. What traffic control devices are part of the implementation?
 - a. Pavement markings
 - b. Overhead signs and signals
 - c. Ground-mounted signs
12. What are the ITS-related elements of the implementation?
13. What performance measures are associated with the facility and how are they used?
 - a. Specific measures of effectiveness?
 - b. Who is responsible for monitoring?
14. What were the costs associated with implementation?
15. How is the facility enforced?
 - a. Who is responsible?
 - b. What are the related fines?
 - c. What is the enforcement approach?
16. How is the facility maintained?
 - a. Who is responsible?
 - b. Other specifics?
17. What is the overall evaluation of the implementation?
 - a. Overall safety experience (crashes/severity)
 - b. Operational experience (travel speeds/delay)
 - c. In-service compliance rates
18. What, if any, liability issues or concerns posed a problem with the implementation of dynamic truck restrictions?
19. Were there impacts with oversized and/or over-width vehicles? How were they addressed?
20. Was there a public outreach or education component to the deployment?
21. Was any legislation required to enable the strategy?

22. Are there any issues with compliance or return to traditional operations on adjacent sections or on other local facilities?

Chapter 4: Best Practices and Guidelines

After reviewing the literature and assessing deployments from across the United States and Europe, the research team developed high-level general guidelines for the deployment of ATM. Included in these guidelines are a brief description of each operational strategy, data needs, essential and preferable elements, key factors, and potential impacts and benefits. This chapter also can serve as a standalone document that transportation professionals can use to identify the most appropriate ATM strategy for their jurisdiction. Those ATM operational strategies included in the guidelines are shoulder use, speed harmonization, queue warning, dynamic merge control, dynamic rerouting, and dynamic truck restrictions.

Guidelines for Shoulder Use

Shoulder use, also known as hard shoulder running, is a dynamic measure designed to adapt roadway capacity to high traffic flow on a temporary basis. By allowing vehicles on the left or right shoulder under reduced speed limits, it is possible to serve a higher number of vehicles and avoid congestion, totally or partially, during peak hours. The decision to implement shoulder use on a segment is made by the operator in the traffic management center, although the need to open the shoulder is based on volume considerations. Two approaches to temporary shoulder use are allowing all vehicles to use the shoulder or allowing only transit vehicles to use the shoulder.

- *Shoulder use for all vehicles* allows all vehicles on the roadway to utilize the designated shoulder when open. Traffic control devices over or adjacent to the shoulder instruct drivers when driving on the shoulder is permitted.
- *Transit-only shoulder use*, also known as a bus bypass shoulder or bus on shoulder (BOS), allows only transit vehicles to utilize the designated shoulder under specific conditions and driving regulations. This measure allows more reliable transit schedules during congestion and does not require extensive changes on the road. The bus drivers are instructed to use the shoulder under specific circumstances to ensure the safety of the operation and all the freeway users. They are typically allowed on the shoulder when the speed drops below 35 mph. The measure can also be applied to parking lanes on arterials.

Data Needs

At a minimum, the following data needs are necessary for successful implementation of temporary shoulder use:

- traffic volumes,
- travel speeds,
- incident presence and location, and
- shoulder availability.

Essential and Preferable Elements

General criteria for shoulder use for all vehicles include the following:

- Essential elements:
 - LOS E or F for at least 2 hr per day;
 - facility segment under consideration at 3 mi in length;
 - no expected bottleneck downstream of the shoulder use segment;
 - low volumes entering and exiting the facility, especially if going through interchanges;
 - minimum shoulder width of 10 ft;
 - available right-of-way for emergency refuge areas and acceleration/deceleration tapers;
 - and
 - sufficient pavement strength on the shoulder to bear the traffic.
- Preferable elements:
 - active incident management;
 - connection to a TMC that serves as the focal point for the system;
 - existing sensors and ITS; and
 - presence of speed harmonization on the facility.

General criteria for shoulder use by transit vehicles only include the following:

- Essential elements:
 - predictable congestion delays, LOS D for 2 hr per day;
 - minimum 10-ft shoulder width available;
 - sufficient pavement strength to sustain bus load; and
 - minimum service of 50 buses/hr (freeway) or 25 buses/hr (arterial).
- Preferable elements:
 - travel time variability higher than 1 min per 2 mi;
 - few conflict points at interchanges;
 - portion shared with multiple bus routes; and
 - acceptable changes for on-street operation (arterial).

Key Factors

The following are key factors that can help facilitate successful deployment:

- Temporary shoulder use is typically implemented in conjunction with speed harmonization.
- When implemented with speed harmonization, speed limit signs and lane control signals need to be visible to all vehicles; therefore, the signs should be placed on gantries over every lane of traffic. During normal operation, i.e., when the use of the shoulder is prohibited, all the signs—including the sign over the shoulder—are blank.
- Either the left or right shoulder can be used for the application, depending on the facility conditions. It is not recommended to apply shoulder use on both left and right shoulders of a facility at the same time.
- To ensure the safety on the shoulder, video cameras should be placed regularly to allow operators to check for obstacles before opening the shoulder to traffic and monitor

operations while shoulder use is permitted. To avoid having stranded vehicles on a used shoulder, emergency refuge areas should be located at regular intervals along the shoulder with proper signing.

- Overhead guide signs should adapt to the current used width of the roadway. In other words, when the shoulder is open to traffic, guide signs should provide information to the shoulder lane as if it were a permanent travel lane. This can be accomplished with DMSs.
- When acceleration and deceleration tapers are needed, additional tapers should be placed on the right side of the shoulder since the original tapers are usually on the shoulder. The additional tapers are meant to be used only while traffic circulates on the shoulder.

Potential Benefits and Impacts

The following are potential benefits and impacts of speed harmonization, depending on local conditions and deployment approach:

- increased throughput,
- increased capacity,
- increased trip reliability, and
- delayed onset of freeway breakdown.

Guidelines for Speed Harmonization

Speed harmonization, also called variable speed limits or dynamic speed limits, is an operational strategy where agencies use an expert system to monitor data coming from field-deployed sensors on a roadway and proactively and automatically adjust speed limits when congestion thresholds are exceeded and congestion and queue formation are imminent. The intent of the strategy is to adapt the speed limit to obtain a consistent and homogenous traffic flow and delay the onset of breakdown. The measure is used mainly in Germany, the Netherlands, and Great Britain. Two common purposes for deploying speed harmonization are for weather-related conditions and congestion management:

- *Weather-related speed harmonization* is often used on roads where fog, ice, rain, or other factors often impact safety. When weather conditions deteriorate to the point that hazardous conditions are impending, the operating agency reduces the speed limit to one that helps minimize the likelihood of incidents.
- *Congestion-related speed harmonization* is used during periods with high traffic volumes or congested situations. When volumes and/or speed exceed a predetermined threshold, the operational strategy is deployed. The intent is to foster better uniformity in speeds and a sustainable traffic flow.

In both cases, the decrease of the speed limit is intended to alert drivers of changing conditions downstream. Ideally, these changes are automated and do not require intervention from any operator. The speed limit changes in increments of 5 or 10 mph to progressively decelerate the flow of traffic. Depending on the goals of the agency, the speed can either be mandatory or advisory.

Data Needs

At a minimum, the following data are necessary for successful implementation of speed harmonization:

- weather conditions,
- pavement conditions related to weather,
- traffic volumes,
- travel speeds, and
- incident presence and location.

Essential and Preferable Elements

General criteria for speed harmonization include the following:

- Essential elements:
 - LOS E or F for 3 hr during the peak hour and 5 hr per day;
 - right-of-way available for overhead gantries and DMSs at regular intervals;
 - at least one location where queues regularly form and warning is warranted; and
 - at least five incidents related to queuing merging/diverging per week.
- Preferable elements:
 - willingness to automate the deployment of the strategy; and
 - existing ITS and connections to the TMC.

Key Factors

The following are key factors to consider that can help facilitate successful deployment:

- The success of speed harmonization is closely linked to the extent to which drivers comply with the signing, so it is important that agencies communicate with the public and inform motorists of new measures and regulations as they are put in place.
- Speed harmonization needs to be implemented in response to an actual situation. If users do not believe the system is legitimate, compliance rates will be low. Therefore, if the reason for the new speed limit is not apparent, it should be explained through appropriate signing.
- Speed limit signs have to be visible to all vehicles; therefore, the signs should be placed on gantries over every lane of traffic. DMSs should be placed regularly to either give explanation for the lower speed limits or warn about extraordinary events.

Potential Benefits and Impacts

The following are potential benefits and impacts of speed harmonization, depending on local conditions and deployment approach:

- increased throughput,
- decreased primary incidents,
- decreased incident severity,
- more uniform speeds,

- decreased headways,
- more uniform driver behavior,
- increased trip reliability,
- delayed onset of freeway breakdown,
- reduced traffic noise,
- reduced emissions, and
- reduced fuel consumption.

Guidelines for Queue Warning

The basic principle of queue warning is to inform travelers of the presence of upstream queues, based on utilizing dynamic traffic detection and using warning signs and flashing lights. This strategy allows the traveler to anticipate a situation of emergency braking and limit the extent of speed differentials, erratic behavior, and queuing-related collisions. Queue warning can be used on its own with DMSs placed on overhead gantries that show the symbol or word when a queue is close. It can also be included with speed harmonization and lane control signals to provide incident management capabilities. The system can be automated or controlled by a TMC operator. Work zones also benefit from queue warning with portable DMS units rightfully placed upstream of expected queue points.

Data Needs

At a minimum, the following data are necessary for successful implementation of queue warning:

- traffic volumes,
- travel speeds, and
- incident presence and location.

Essential and Preferable Elements

General criteria for queue warning include the following:

- Essential criteria:
 - LOS E/F for at least 2 hr per peak period;
 - presence of queues in predictable locations;
 - sight distance restricted by vertical grades, horizontal curves, or inadequate illumination;
 - right-of-way for overhead gantries and DMSs; and
 - at least five incidents related to queuing merging/diverging per week.
- Preferable criteria:
 - large mix of high-profile vehicles or inability to control speeds;
 - willingness to automate the deployment of strategy; and
 - existing ITS and connections to TMC.

Key Factors

The following are key factors to consider that can help facilitate successful deployment:

- Queue warning can be more effective when deployed in conjunction with speed harmonization.
- When implemented with speed harmonization, the queue warning pictograms and/or flashing lights need to be visible to all vehicles. During normal operation, all the signs are blank. The signage should also be consistent and uniform to clearly indicate congestion ahead.
- An expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention is optimal.

Potential Benefits and Impacts

The following are potential benefits and impacts of queue warning, depending on local conditions and deployment approach:

- decreased primary incidents,
- decreased secondary incidents,
- decreased incident severity,
- more uniform speeds,
- decreased headways,
- more uniform driver behavior,
- increased trip reliability,
- reduced traffic noise,
- reduced emissions, and
- reduced fuel consumption.

Guidelines for Dynamic Merge Control

Dynamic merge control, or junction control, is used to dynamically meter or close specific lanes upstream of the interchange to manage access based on traffic demand (1). It is an operational treatment that addresses the geometric condition when the sum of both freeway general purpose lanes and merging lanes at an interchange is higher than the number of downstream general purpose lanes. A typical U.S. application of this condition would be a lane drop for one of the outside lanes or a merging of two inside lanes, both of which are static solutions. The intent is to provide dynamic priority access to the higher traffic stream. Dynamic merge control can be a permanent application, or it can be used temporarily until a downstream roadway is widened (35). It is a practical approach to handling varying demand on the main lanes and the merging lanes to effectively utilize existing capacity.

Data Needs

At a minimum, the following data are necessary for successful implementation of dynamic merge control:

- maximum capacity of upstream general purpose lanes,
- traffic volumes on general purpose lanes and merging ramps,
- travel speeds on general purpose lanes and merging ramps, and
- incident presence and location.

Essential and Preferable Elements

General criteria for dynamic merge control include the following:

- Essential criteria:
 - significant merging volumes (>900 vph);
 - available capacity on general purpose lanes upstream of the interchange that can be borrowed with no worse than LOS E after implementation; and
 - non-simultaneous peak traffic upstream on the general purpose lanes and merging lanes.
- Preferable criteria:
 - active incident management in the corridor;
 - existing ITS and connections to the TMC; and
 - combination with shoulder use.

Key Factors

The following are key factors to consider that can help facilitate successful deployment:

- Effective dynamic merge control uses lane control signals on the main lanes and merging lanes of a freeway to dynamically adapt to varying demand. It is important that these signs be installed on gantries that are sufficient enough to ensure advance warning to roadway users.
- An expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention is optimal.
- To handle emergencies, a bypass lane for emergency vehicles, transit, or other identified exempt users is optimal.
- Dynamic merge control can be implemented in conjunction with temporary shoulder use as long as the overhead gantries with appropriate signing and lane control signals are part of the implementation.

Potential Benefits and Impacts

The following are potential benefits and impacts of dynamic merge control, depending on local conditions and deployment approach:

- increased throughput,
- increased capacity,
- decreased primary incidents,
- more uniform speeds,
- more uniform driver behavior, and
- increased trip reliability.

Guidelines for Dynamic Rerouting and Traveler Information

Dynamic rerouting and traveler information is the practice of redirecting traffic to avoid unequal levels on service on parallel routes. The intent is to provide users with viable route alternatives, and the approach can be especially beneficial in helping reduce the impact of noncurrent congestion. A new direction can be suggested while the standard routing remains, or if the hardware allows it, the standard routing may be substituted by the recommended one. Both of these strategies require some sort of DMS, either a full-size sign or smaller ones embedded into common route signs. When the main road is congested, rerouting traffic on a parallel road to relieve further congestion can be an efficient strategy. The implementation can be automated but needs to include detailed information about both roads, such as short-range expected volumes, construction, or special events.

When considering dynamic rerouting and traveler information, there are two signing strategies that can be applied: substitution and addition.

- *Substitution:* In the substitution strategy, rotating panels on guide signs turn and indicate the suggested secondary route. The problem encountered with this method is that the first route is no longer displayed, and some mid-trip destinations may be missed.
- *Addition:* In the addition strategy, orange arrows show the recommended diversion route while keeping the original signing. In both cases, full-matrix DMSs can be used to display any of the strategies.

Data Needs

At a minimum, the following data are necessary for successful implementation of dynamic rerouting:

- traffic volumes,
- travel speeds,
- weather conditions,
- incident presence and locations, and
- conditions and availability of alternate routes.

Essential and Preferable Elements

General criteria for dynamic rerouting and traveler information include the following:

- Essential elements:
 - LOS E or F for 2 hr per day;
 - at least three incidents per week resulting in severe congestion;
 - viable parallel corridor to accept rerouted traffic no farther than 2 mi from primary corridor;
 - available capacity on parallel route; and
 - available right-of-way for overhead gantries if necessary.

- Preferable elements:
 - existing ITS and connections to the TMC; and
 - combination with speed harmonization and temporary shoulder use.

Key Factors

The following are key factors to consider that can help facilitate successful deployment:

- The implementing agency needs to make a commitment to providing alternate route information to roadway users in response to non-recurrent congestion.
- Dynamic rerouting and traveler information can be more effective when deployed in conjunction with speed harmonization and temporary shoulder use.
- The agency needs to ensure that there is an adequate installation of sign gantries along the facility at critical locations to ensure that sufficient advance notice of alternate routes is provided.
- Dynamic rerouting and traveler information is most effective when connectivity to adjoining TMCs exists to coordinate alternate route information based on roadway conditions and special events in adjoining regions. Coordination with local communities to minimize the impact of alternate route information on the arterial network is also important.

Potential Benefits and Impacts

The following are potential benefits and impacts of dynamic rerouting and traveler information, depending on local conditions and deployment approach:

- increased throughput,
- decreased primary incidents,
- decreased secondary incidents,
- more uniform driver behavior, and
- increased trip reliability.

Guidelines for Dynamic Truck Restrictions

Dynamic truck restrictions require all truck traffic to use designated lanes in a dynamic manner during peak periods. The intent is to increase the homogeneity of speed on each lane and to minimize the disruption in traffic flow caused by heavy vehicles. The dynamic nature of the treatment allows for more flexibility in application as opposed to static restrictions. The activation of the signs indicating the presence of restrictions is usually automated and is triggered by real-time traffic volumes. The signs should be placed on overhead gantries for visibility.

Data Needs

At a minimum, the following data are necessary for successful implementation of dynamic truck restrictions:

- traffic volumes, including truck volumes;
- travel speeds;

- weather conditions; and
- incident presence and locations.

Essential and Preferable Elements

General criteria for speed harmonization include the following:

- Essential elements:
 - significant proportion of truck traffic;
 - available right-of-way for overhead gantries; and
 - no left side exits in the controlled section.
- Preferable elements:
 - existing ITS and connections to the TMC; and
 - combination with speed harmonization

Key Factors

The following are key factors to consider that can help facilitate successful deployment:

- Agencies will need to seek enabling legislation and related laws to allow dynamic truck restrictions.
- An expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention is ideal. It is very important that this expert system be reliable and accurate in order to gain the trust and acceptance of system users.
- The installation of sign gantries needs to be sufficient to ensure that at least one sign displaying the restrictions is visible at all times.

Potential Benefits and Impacts

The following are potential benefits and impacts of dynamic truck restrictions, depending on local conditions and deployment approach:

- increased throughput,
- increased capacity,
- more uniform speeds,
- more uniform driver behavior,
- increased trip reliability,
- reduced emissions, and
- reduced fuel consumption.

Chapter 5: ATM Website Development

The project team developed a website for information dissemination regarding the subject of ATM. The following sections describe the development process undertaken during the project.

Graphic Design

The first step in the development of the site was the generation of the graphic design for the site. It was the desire of the project team to create a site that was easy to navigate and reflective of the dynamic approach of ATM. With the assistance of the graphic design experts at TTI, the project team developed a banner for the website that incorporates a logo, a photograph of a dynamic speed display implementation, a search box, and links to the various sections for the website. The banner is shown in Figure 19.



Figure 19. ATM website banner.

Database Development

The ATM website is database driven to facilitate easy updating by staff when related documents, links, and information are available. The project team used Drupal® for developing the content portion of the website. Drupal® is an open-source content management platform that is a powerful tool for website development (43). It allowed the developers to create modules that provide various website features and also facilitate easy management of the large number of resource documents and components that are included in the ATM website. Figure 20 is a screen shot of one of the Drupal® input screens used by the project team to import data.

Website Sections

The ATM website includes several key sections to provide key information for users. The first section is a main page that provides a brief overview of Active Traffic Management. It also provides the links to the main sections and a request for feedback from users if appropriate. A screen shot of the main page is shown in Figure 21.

Content management Site building Site configuration User management Reports Help 0 / 1 Log out Beverly Kuhn

ATM Active Traffic Management
TEXAS TRANSPORTATION INSTITUTE

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Assessment Strategy for the M1 HOV Pilot

[View](#) [Edit](#)

Title: *
Assessment Strategy for the M1 HOV Pilot

Authors:

Resource Type:
Report

Publisher:
Highways Agency

Pages:
10

Report Number:


Abstract:
High Occupancy Vehicle (HOV) Lanes have been used successfully in other countries (primarily in the USA, and also in Spain and Australia). To date, HOV lanes have only been implemented in the UK on short sections of dual carriageway (in Leeds and South Gloucestershire) and the Highways Agency is looking to pilot an HOV lane on the strategic road network.

Publication Date:
06 2005
Format: 08 2011

Figure 20. Website development input screen.

ATM Active Traffic Management
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ATM - Dynamic Speed Display

About Active Traffic Management

This site is about [Active Traffic Management \(ATM\)](#). This site is intended to provide information on active traffic management operational strategies from overseas and across the United States, including ATM projects, ongoing and completed research, information on meetings and other events related to ATM. The site will also have links to key related Internet sites, and information on the TRB Joint Subcommittee on Active Traffic Management.

This site continues to evolve and grow. We welcome and encourage your comments and feedback. Should you have any questions, please don't hesitate to contact us.


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Please send comments, suggestions, and queries to the TTI Webmaster:
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(979) 845-1713 (979) 845-9356 (FAX)

Figure 21. ATM website main page.

A major section of the website is the Resources page. This page provides a variety of resources, including documents, presentations, references, related websites, and an inventory of ATM operational facilities in the United States and overseas. These resources are organized in several subsections to make navigating this section logical and easy. These resources provide a wealth of information to users on ATM deployments, research and articles about the various strategies, and the latest information on the subject. A screen shot of the main resources page, with links to the various subpages, is shown in Figure 22.

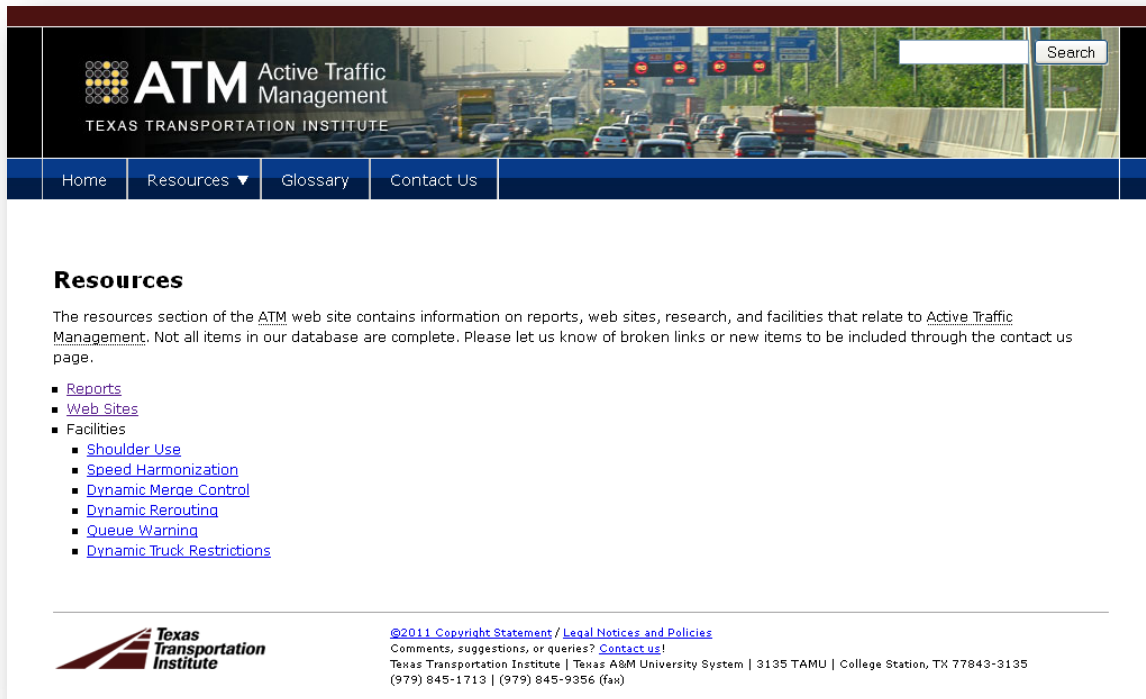


Figure 22. ATM website Resources page.

Another key section on the website is the ATM glossary. This page provides a list of commonly used terms related to ATM along with brief definitions for each. A shot of the Glossary page is shown in Figure 23.

The final section of the website is the Contact page. On this page, as shown in Figure 24, users can provide feedback to the team regarding any aspect of the site. The intent of this page is to provide users with an opportunity to alert the project team of problems, suggestions for improvements, or any other issue that might need addressing.

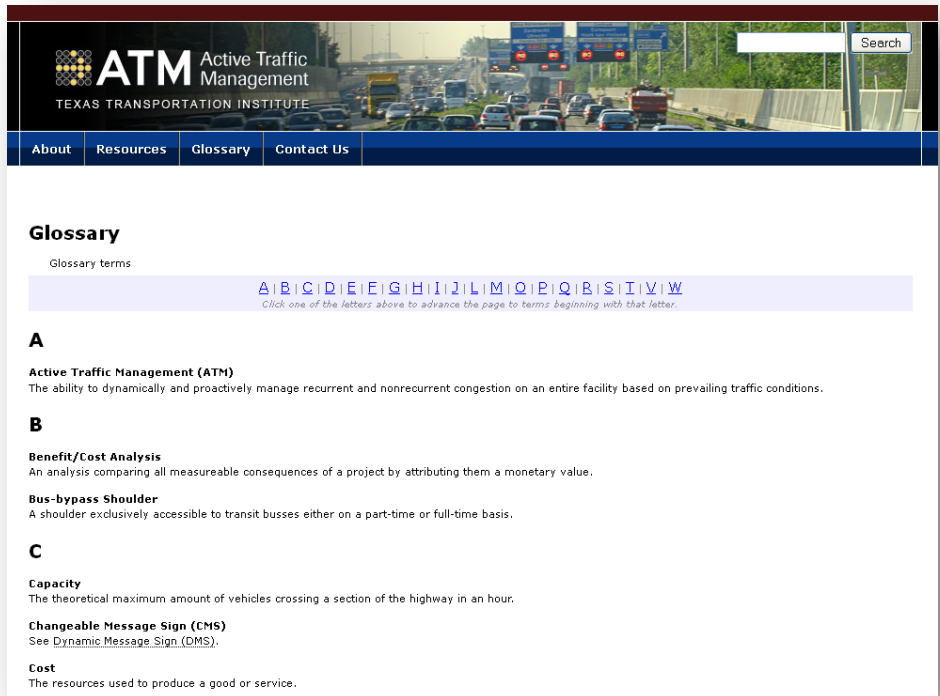


Figure 23. ATM website Glossary page.



Figure 24. ATM website Contact page.

Chapter 6: ATM Webinar Development

One of the key objectives of this project was to reach out to the transportation community to share information related to ATM. The following sections highlight the activities undertaken to conduct a webinar to share the research results with agencies interested in implementing ATM in their jurisdictions.

Develop Webinar Material

During this task, the project team took the material developed in the literature review, inventory, and best practices and guideline document to create a webinar for information dissemination. The team developed webinar materials that allowed attendees to obtain the maximum benefit out of the research presented in the products. The material was suitable to be presented in a two-hour webinar and consisted of a slide presentation. The title slide for the webinar presentation is displayed in Figure 25.

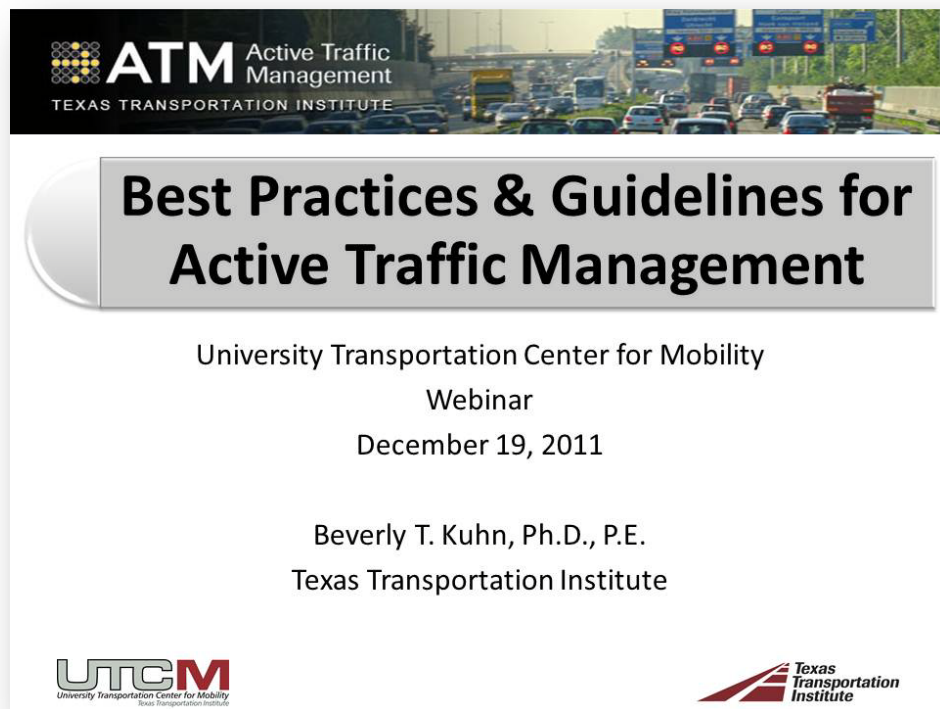


Figure 25. ATM webinar title slide.

Plan, Schedule, and Conduct Webinar

The project team selected and confirmed the date for the webinar and scheduled the event with the Centra videoconferencing system to which TTI has access through Texas A&M University. The project team worked with the external advisory panel and other organizational and personal contacts to advertise and market the webinar. The webinar was hosted on Monday, December 19,

2011. Approximately 50 individuals registered for the webinar and participated in the event. Once the webinar concluded, the research team posted the slides to the website for the Transportation Research Board Joint Subcommittee on Active Traffic Management, as shown in Figure 26. A link to the presentation was then sent to the attendees for their personal reference.

The screenshot shows a website page with a red header bar. The main heading is "TRB Active Traffic Management Joint Subcommittee". To the right of the heading is a search box with the text "Search this site". Below the heading is a navigation menu with links: "ATMJS Home", "What We Do", "Subcommittee Meetings & Documents", "Announcements", "[Untitled]", "Upcoming Events", "FileCabinet", "Contact Us", "My Page", and "Sitemap".

The main content area features an announcement titled "Best Practices and Guidelines for Active Traffic Management - A UTCM Webinar" posted on Dec 19, 2011 10:01 AM by Beverly Kuhn, with an update on Dec 19, 2011 10:02 AM. The announcement text describes the focus on trip reliability and active traffic management (ATM) in Europe and the United States, listing strategies such as speed harmonization, temporary shoulder use, junction control, and dynamic signing and re-routing. It also mentions that the webinar provided an overview of ATM, operational strategies, and general guidelines.

On the left side, there is a section titled "Join Our Subcommittee" with text about membership and contact information for Beverly Kuhn. Below this is a large "33" indicating "33 days until TRB 91st Annual Meeting". At the bottom left, there is a "Recent site activity" section listing "UTCM-ATM Webinar-2011.pdf" posted on Dec 19, 2011 10:01 AM by Beverly Kuhn (version 1).

Figure 26. ATM Joint Subcommittee website announcements page.

Chapter 7: Final Remarks

It is the hope of the authors that by providing transportation agencies with information on practices for deployment and operation of ATM strategies as well as general guidance on implementation, this document can have a positive impact on transportation networks where ATM is feasible. Potential improvements can include an increase in average throughput for congested periods, an increase in overall capacity, a decrease in primary accidents, a decrease in secondary accidents, a decrease in accident severity, an overall harmonization of speeds during congested periods, an increase in trip reliability, and the ability to delay the onset of freeway breakdown. ATM has the potential to help transportation agencies address the ever-increasing challenge of doing more with less and operating existing facilities in the most efficient manner possible.

References

1. Mirshahi, M., J. Obenberger, C. Fuhs, C. Howard, R. Krammes, B. Kuhn, R. Mayhew, M. Moore, K. Sahebjam, C. Stone, J. Yung. *Active Traffic Management: The Next Step in Congestion Management*. Report No. FHWA-PL-07-012. Alexandria, VA: American Trade Initiatives for Federal Highways Administration. 2007.
2. TRB Joint Subcommittee on Active Traffic Management—AHB20(5). *Definition of Active Traffic Management*. Unpublished Committee Document. Washington, DC: Transportation Research Board. 2009.
3. Grant, D. *M42 Active Traffic Management Pilot Project*. Unpublished Presentation to Planning for Congestion Management Scan Team. London, England: Highways Agency, Department for Transport. June 2006.
4. *Active Traffic Management (ATM) Project M42 Junctions 3A-7*. London, England: Highways Agency, Department for Transport. <http://www.highways.gov.uk/knowledge/tcc/atm/index.htm>. Accessed May 2011.
5. *Advanced Motorway Signaling and Traffic Management Feasibility Study*. London, England: Department for Transport. 2008.
6. *M42 Active Traffic Management Results—First Six Months*. London, England: Highways Agency, Department for Transport. 2007.
7. *4-Lane Variable Mandatory Speed Limits—12 Month Report*. London, England: Highways Agency, Department for Transport. 2008.
8. Lemke, K. and M. Irzik. *Temporary Use of Hard Shoulders—Experiences and Economic Assessment*. Presentation to Planning for Congestion Management Scan Team. Bergisch Gladbach, Germany: Federal Highway Research Institute, Traffic Planning, Highway Design, and Safety Analyses Section. June 2006. Original photos courtesy of Autobahndirektion Sudbayern (South Bavaria).
9. Riegelhuth, A. and A. Pilz. *ERP Achievements and Results in Traffic Management—Temporary Hard Shoulder Use in Hessen—Experiences and Strategic Planning*. Hessen, Germany: Traffic Centre Hessen (CENTRICO). June 2007.
10. Kuhn, B. *PCM International Scan Tour—Germany*. Frankfurt, Germany: Unpublished Personal Notes. June 2006.
11. Helleman, B. *Hard Shoulder Running (HSR) in The Netherlands*. Presentation to Planning for Congestion Management Scan Team. Rotterdam, The Netherlands: Ministry for Transport, Public Works, and Water Management, Directorate-General of Public Works and Water Management, AVV Transport Research Centre. June 2006.
12. *Rush Hour Lanes*. Ministry of Transport, Public Works and Water Management, www.verkeerenwaterstaat.nl, 04/17/2003, accessed 10/31/2005.
13. Middelham, F. *Dynamic Traffic Management*. Presentation to Planning for Congestion Management Scan Team, Rotterdam, The Netherlands: Ministry of Transport, Public Works, and Water Management, Directorate-General of Public Works and Water Management. AVV Transport Research Centre. June 2006.
14. Kuhn, B. *Efficient Use of Highway Capacity Summary*. Report No. FHWA-HOP-10-023. College Station, TX: Texas Transportation Institute, The Texas A&M University System. 2010.
15. McCasland, W.R. Use of Freeway Shoulders to Increase Capacity. In *Transportation Research Record 966*. Washington, DC: Transportation Research Board, National Academies of Science. 1978.
16. Curren, J. *Use of Shoulder and Narrow Lanes to Increase Freeway Capacity*. NCHRP Report 369. Washington, DC: Transportation Research Board. 1995.
17. Ungemah, D. and B. Kuhn. *Strategy Screening Criteria for Managed Use Lane Projects*. Report for New York State Department of Transportation. College Station, TX: Texas Transportation Institute and Parsons Brinckerhoff. July 2008.
18. *Summary of Accident and Vehicle Breakdown Data Related to Inside Shoulders, Houston, Texas*. College Station, TX: Texas Transportation Institute, The Texas A&M University System. 1986.

19. Urbanik, T., and C. Bonilla. California Experience with Inside Shoulder Removals. In *Transportation Research Record 1122*. Washington, DC: Transportation Research Board, National Academy of Science. 1987.
20. *Active Traffic Management Feasibility Study*. Report to Washington State Department of Transportation, Urban Corridors Office. Seattle, WA: PB Americas, Carter + Burgess, EarthTech, Inc., and Telvent Farradyne. 2007.
21. *Guidelines on Shoulder Use by Buses*. Minneapolis, MN: Minnesota Department of Transportation, Metro Division. 1997. http://www.dot.state.mn.us/metro/teamtransit/docs/bus_only_shoulder_guidelines.pdf. Accessed 2011.
22. Martin, P. *Bus Use of Shoulders*. TCRP Synthesis 64. Washington, DC: Transportation Research Board. 2006.
23. Thomsom, R. "Virginia Extending Shoulder Use on I-66." In *The Washington Post*. Washington, DC: August 8, 2008. http://voices.washingtonpost.com/getthere/2008/08/to_accommodate_increased_traff.html. Accessed June 2011.
24. Miles J. and W. Broeders. *Evaluation of the Finnish AINO Programme 2004-2007*. Helsinki, Finland: Ministry of Transport and Communications. 2007.
25. *FHWA Scanning Report on Traffic Management and Traveler Information Systems*. Report No. FHWA-PL-98-010. Alexandria, VA: American Trade Initiatives for Federal Highway Administration. 1997.
26. Coleman, J., J. Paniati, R. Cotton, R. Covey, D. Graham, J. McCauley, G. Mortford, J. Paniati, M. Parker, H. Pena, M. Robinson, W. Taylor. *FHWA Study Tour for Speed Management and Enforcement Technology*. Report No. FHWA-PL-96-006. Alexandria, VA: American Trade Initiatives for Federal Highway Administration. 1995.
27. Rämä, Pirkko. *Effects of weather-controlled variable message signing on driver behavior*. VTT Publications No. 447. Helsinki, Finland: Technical Research Centre of Finland, VTT Building and Transport. 2001.
28. Kuhn, B. *PCM International Scan Tour—Netherlands*. Rotterdam, Netherlands: Unpublished Personal Notes. June 2006.
29. Kuhn, B. *PCM International Scan Tour—England*. London, England: Unpublished Personal Notes. June 2006.
30. *M25 Controlled Motorways Summary Report, Issue 1*. London, England: Highways Agency, Department for Transport. 2004.
31. Steinke, D., L. Sanderson, J. Byrnes, J. Conrad, R. Forrestel, K. Harrington-Hughes, K. Kobetsky, S. Lanford, K. Snyder-Petty, D. Testa, and J. Wilkerson. *Methods and Procedures to Reduce Motorist Delays in European Work Zones*. Report No. FHWA-PL-00-001. Alexandria, VA: American Trade Initiatives for Federal Highway Administration. 2000.
32. Kuhn, B. *PCM International Scan Tour—Denmark*. Copenhagen, Denmark: Unpublished Personal Notes. June 2006.
33. *Smarter Highways*. WSDOT Website. <http://www.wsdot.wa.gov/smarterhighways/vsl.htm>. Accessed June 2011.
34. "Missouri Activates Variable Speed Trap Program." On *theNewspaper.com*. <http://www.thenewspaper.com/news/23/2386.asp>. May 2008.
35. Tignor, S., L. Brown, J. Butner, R. Cunard, S. Davis, G. Hawkins, E. Fischer, M. Kehril, P. Rusch, and S. Wainwright. *Innovative Traffic Control—Technology and Practice in Europe*. Report No. FHWA-PL-00-021. Alexandria, VA: American Trade Initiatives for Federal Highway Administration. 1999.
36. Njord, J., J. Peters, M. Freitas, B. Warner, K. Allred, R. Bertini, R. Bryant, R. Callan, M. Knopp, L. Knowlton, C. Lopez, and T. Warne. *Safety Applications of Intelligent Transportation Systems in Europe and Japan*. Report No. FHWA-PL-06-001. Alexandria, VA: American Trade Initiatives for Federal Highway Administration. 2006.
37. "Good Traffic Management Techniques Know No Bounds." In *TranScan*, No 3. Washington, DC: National Cooperative Highway Research Program, TRB. 2001.

38. Bolte, F. *Transport Policy Objectives: Traffic Management as Suitable Tool*. Presentation to Planning for Congestion Management Scan Team. Bergisch-Gladbach, Germany: Federal Highway Research Institute (BASt). 2006.
39. Jarema, F., C. Dahlin, R. Gillmann, M. Hallenbeck, D. Huft, R. Reel, and R. Tweedie. *FHWA Study Tour for European Traffic-Monitoring Programs and Technologies*. Alexandria, VA: American Trade Initiatives for Federal Highway Administration. 1997.
40. Toole, O. *Trucks on Motorways in the Netherlands—A Survey of the Role of Trucks in Traffic Flow*. Presentation to Planning for Congestion Management Scan Team. Ministry for Transport, Public Works, and Water Management, Directorate-General of Public Works and Water Management, AVV Transport Research Centre. June 2006.
41. McCarthy, K. *Trucks-Speed Limits and Lane Restrictions*. OLR Research Report No. 2005-R-0814. 2005.
42. *M5 Junctions 19 to 20 Pilot Scheme—Advisory Restrictions for Towing Vehicles*. London, England: Highways Agency, Department for Transport. 2005.
43. Drupal Website. <http://drupal.org>. Accessed July 2011.



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