Advanced Highway Management Systems

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1 INTRODUCTION

1.1 Overview

Since the first applications in the United States and Europe in the 1960s, traffic management systems (TMSs) belong to transport agencies. They aim for

- enhancing the safety of travelers,
- improving the current capacity of the infrastructure by performance-enhancing measures at junctions and sections (supply management), and
- providing travel and roadway condition information to travelers to influence the traffic demand in space and time (demand management) on the basis of current and projected traffic, roadway, and weather conditions.

Advanced highway management systems (AHMSs) in reference to the general structuring of the ITS (Intelligent Transport System) as referred to in Intelligent Transport Systems: Overview and Structure (History, Applications, and Architectures). Additional applications related to highway traffic are addressed in chapters titled Road Traffic and Travel Information (Road Traffic and Travel Information (RTTI)), Logistics and Fleet Management (Logistics and Fleet Management), Tolling, Mobility, Pricing (Tolling, Mobility Pricing), and Emergency Services, eCall (Applications: Emergency Services and e-Call). AHMS is recognized as the collective measures and systems on roads with a minimum of separated two-lane roadways with grade-separated junctions.

1.2 Structure of AHMS

Consistent with other subsystems, the AHMS can be described using the three levels of the ITS architecture as

- functional level,
- system level, and
- institutional and procedural level.

The functional level includes the control strategies, the optimization criteria and control functions of one system element as well as the interaction with various system elements or other systems.

Figure 1 shows the major functional areas of AHMS at a glance:

- data collection,
- data processing and decision making in the control center, and
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- traffic monitoring, selection, implementation, and evaluation of operational measures.

The system level describes its physical infrastructure, including field devices, software, and interfaces and means, therefore, the system architecture in a narrow sense.

While the functional level principally represents the benefit, the system level represents the costs.

The institutional level describes the organizational arrangements as well as the responsibilities and competencies of the agencies responsible for the management and operation of the AHMS. In this chapter, the functional level is primarily considered.

1.3 Objectives and functions of AHMS

AHMS should make a positive contribution to reach the following goals:

- safety (reduction in accident number and consequences),
- mobility (increase in probability with which the expectable travel time is realized),
- economy (reduction in travel time and vehicle operating costs), and
- environmental compatibility (reduction in pollutant emissions and traffic noise),
The specific functions of AHMS to achieve these goals lie in the

- information distribution,
- lane use management,
- ramp management,
- traffic incident management,
- traffic surveillance monitoring, and
- traffic evaluation, management, and operation.

The infrastructure to support these functions may include

- communications infrastructure,
- surveillance and detection,
- traffic control and other field devices,
- computer systems and software,
- traffic monitoring and management systems,
- information systems,
- TMSs and centers, and
- telecommunications.

1.4 Future directions of road transport agencies

Highway operators and motorists continually face increased levels of highway congestion and operational inefficiencies. The major contributors are population growth, increased vehicle use, increase in travel during peak-commuting periods, and inadequate growth (if any) in roadway capacity. Funding for transportation improvements has not historically matched the growing use of and need for these improvements. Transportation are challenged with making the most efficient use of the infrastructure that is in place along with continuing to investigate new, low cost alternatives to major new highway construction. The future focus should lie on the operation on the transportation system, to modify their perspective from a construction mindset to an improvement in operations mindset, where their resources are allocated to provide an operational system that best meets the needs of the users and providers of service to that system. Specifically, these systems help improve safety and mitigate the impacts of congestion in an effort to improve traffic flow without having to add additional capacity (Jacobson, 2003).

Effective highway management system operation is critical to the safe and effective operation of the transportation network. Coordination and collaboration among operating agencies, emergency responders (e.g., police, fire, and medical), and service providers (e.g., towing and roadway maintenance) is also a key success factor. Automated control and decision-support systems can greatly reduce the load on highway management staffing. Therefore, controls and criteria have to be developed from the objectives and functions, as mentioned in Section 1.3, to implement, manage and coordinate operational strategies and control plans. While the goals of different operational strategies and associated control plans are the same, they differ in relevance and influence. They are evaluated differently on the social, facility, or user level. While these goals are important in the decision-making process of road transport agencies in order to get an optimized system solution from the perspective of a representative of the public interests, the individual’s safety, time, and travel time reliability are practically the only determining factors from the driver’s perspective. Therefore, a conflict results between “system optimum” and “user optimum,” which particularly occurs in route guidance. Assuming there is a need for the usage of AHMS and therefore a potential benefit, a high economic surplus benefit can generally be derived from the total cost of investment and operation, as numerous international example studies (Jones et al., 2011; Mirshahi et al., 2007) point out.

2 TRAFFIC FLOW ON HIGHWAYS

The traffic flow on highways can be described microscopically by observing the movements of individual vehicles and macroscopically by observing the traffic flow as a continuum over a section of roadway. The fundamental diagram in its presentation as a volume–speed diagram is of particular importance because it is used as the basis of analyzing the performance and evaluating the potential traffic operational strategies or improvements to road infrastructure. Resources to assess the flow of traffic on roadways include representatively: the American Highway Capacity Manual—HCM (TRB, 2010), the German “Handbuch für die Bemessung von Straßenverkehrsanlagen—HBS” (FGSV, 2001), and the Federal Highway Administrations Traffic Analysis Toolbox.

Congestion occurs when the traffic demand exceeds the capacity of a section of roadway, especially at bottlenecks. Bottlenecks on highways can have permanent physical or temporary operational impacts on travel that may include

- regular and permanent lane reductions or other changes in the cross section,
- suboptimal alignment (high slope, small curve radius),
- highly loaded junctions, whereby the traffic flow on the roadway is disturbed by increased merging and diverging processes,
- roadway construction and maintenance,
- toll stations,
- border crossings,
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Table 1. Performance indices for highways.

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Typical Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs of congestions per person/driver</td>
<td>Financial burden caused by congestions per person of the population per year/per driver per year</td>
</tr>
<tr>
<td>Delay caused by incidents and bottlenecks induced by</td>
<td>Increase in travel time caused by an incident or bottleneck</td>
</tr>
<tr>
<td>infrastructure or construction sites</td>
<td></td>
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<tr>
<td>Loss of time per person/driver</td>
<td>Increase of the average travel time per person year/per driver per year</td>
</tr>
<tr>
<td>Duration of congestion</td>
<td>Period of congestion (differentiated by causes)</td>
</tr>
<tr>
<td>Level of service (LOS)</td>
<td>A (best) to F (worst) based on measures of effectiveness</td>
</tr>
<tr>
<td>Percent of system congested</td>
<td>Percent of kilometers congested (usually defined based on LOS E or F)</td>
</tr>
<tr>
<td>Percent to travels congested</td>
<td>Percent of vehicle kilometers of person kilometers traveled</td>
</tr>
<tr>
<td>Delay caused by incidents</td>
<td>Increase in travel time caused by an incident</td>
</tr>
<tr>
<td>Travel time index</td>
<td>Amount of additional travel time</td>
</tr>
<tr>
<td>Travel time</td>
<td>Distance divided by speed</td>
</tr>
<tr>
<td>Travel-time reliability</td>
<td>Several definitions are used that include:</td>
</tr>
<tr>
<td></td>
<td>1. variability of travel times;</td>
</tr>
<tr>
<td></td>
<td>2. percent of travelers who arrive at their destination within an acceptable time;</td>
</tr>
<tr>
<td></td>
<td>3. range of travel times</td>
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Figure 2. Time losses on motorways due to congestion causes per year in Germany. (Reproduced with permission from Listl, 2008. © Gerhard Listl.)

- accidents,
- vehicle breakdowns, and
- weather-related damage or poor condition of road surfaces.

The traffic congestion is characterized by a decrease in speed and the resulting shockwave running or propagating upstream from the bottleneck and impacting traffic along the roadway. Traffic jams and the associated unstable flow of traffic typically increases the number and severity of crashes, increases travel time and travel time reliability, causes higher fuel consumption, increases vehicle operating costs, and increases vehicle emission.

The most important performance parameters are shown in Table 1.

In order to quantify the effects of different causes of congestion, agencies regularly monitor, evaluate, and report on the flow of traffic on roadways. As an example, Figure 2 shows the causes and impacts of congestion on motorways in Germany (Listl, 2008).
3 OVERVIEW OF HIGHWAY MANAGEMENT SYSTEMS

3.1 General approaches

Road transport agency initiatives aim to provide travelers with a safe, convenient, and reliable travel on the surface transportation system. This has required a paradigm shift for transport agencies, especially for countries that have a relatively high permitted speed or no speed limits, to shift their vision and strategic focus from increasing roadway capacity and delivering roadway projects to one that includes actively managing and operating roadways to ensure safe and reliable journeys. This requires agencies to establish and provide the resources for a strategic vision, policies, procedures, systems, and strategies to actively manage and operate roadways. Therefore, it is the agencies’ responsibility to

- actively manage and monitor decision-support systems,
- adjust system operation as needed, and
- take actions beyond the capability of automated operation of control plans and TMSs (such as communicating and coordinating with appropriate field personnel, emergency responders, and partner agencies) (Jacobson, 2003).

Road transport agencies in Europe have successfully demonstrated the benefits of actively managing and controlling traffic on the actual lanes of a highway, in addition to the highway ramps. Figure 3 depicts an example of such an active TMS on the motorway M42 in the United Kingdom.

The active management and control of traffic on highways allows transport agencies to proactively respond to current and expected future traffic and roadway conditions that may impact traffic operations, where planned and unplanned incidents may temporarily increase traffic demand, reduce the flow of traffic, or reduce the roadway capacity of the cross section. A scanning study in Denmark, England, Germany, and the Netherlands identified the following benefits of active traffic management approaches for highways (Mirshahi et al., 2007):

- increase in efficiency by 3–7%, with temporary hard shoulder use up to 22%,
- decrease in incidents, including the accidents, by up to 50%,
- harmonization of speed during peak traffic times,
- smaller time gaps by concurrent uniform driving behavior of traveler,
- increase in reliability of travel time of one trip, and
- delay of traffic collapse and guarantee of a stable traffic flow at a high load level.

3.2 Strategy planning and application

The day-to-day operation of TMSs and travel on the roadways requires the cooperation and collaboration of many agencies, service providers, and travelers. To effectively manage and operate these systems requires agencies to provide the resources necessary to develop and sustain the

![Figure 3. Example of an active traffic management system in the United Kingdom (Grant, 2008). (Reproduced from Grant, 2008. Image courtesy of David Grant and the UK Highways Agency.)](image-url)
operational policies and procedures and the infrastructure (i.e., control center, communications network, and traffic control devices). The management and collaboration in the development of the operational strategies and control plans is essential due to the number of local agencies and service providers (e.g., enforcement, emergency medical, towing, fire, and roadway maintenance) that may be located along the length of a road and are required to operate other roadways or provide support to these highways (Neudorff et al., 2003).

An operational strategy is considered a predefined action plan for taking measures and measure combinations for improving a problem situation (FGSV, 2003). In Europe, for example, the transport agencies cooperate in the development and use of operational strategies and control plans that may be used to manage and control traffic or to provide traveler or roadway condition information to motorists in highway corridors of the trans-European road network (TERN). Supporting the communication between partners, a web-based inter-regional strategy manager (ISM) was developed that assists in all processes of strategy development, monitoring and assessing traffic conditions, and evaluating the use of various operational strategies (Riegelhuth et al., 2010).

An essential requirement is the cooperation and participation of all institutions in the development and evaluation of these operational strategies. Because of the relevant administrative framework, a decentralized management approach has been formed in practice in which the competence and responsibility for the particular road network of each partner will be preserved.

In strategy management, two processes can be distinguished, the development of strategies (offline) and the implementation by an operator or a system (online). The active management and operation of a highway facility is critical to ensuring the implementation of the appropriate operational strategies and control plans in response to current and expected future travel conditions. To select and use the operational strategy that is most effective requires agencies to have deployed the electronic infrastructure necessary to monitor, evaluate, report on, and coordinate in response to current and projected traffic conditions with other agencies and service providers. The deployment of the operational strategies or measures necessary to actively manage and control specific highway segments is a strategic decision of the road transport agencies, where the responsible agency must determine whether it is in the public’s interest to make the initial investment and sustain its operation. Continuous monitoring and an assessment of the effects are important in order to make adjustments and to improve the effectiveness, if necessary (FGSV, 2003).

In Figure 4, the process of the planning and implementation of a traffic management strategy is depicted in a general way (FGSV, 2003).

### 3.3 Public–private cooperation

The institutions responsible for operating of AHMS are generally public authorities, where they control and influence road users through messages with different levels of obligation:

- managing and controlling traffic,
- providing information on traffic and roadway conditions, which is a sovereign task that can only be executed by the public agencies, and
- determining which traveler-related services and information may or may not be considered as a sovereign task.

In the field of road traffic and travel information (Road Traffic and Travel Information (RTTI)), private providers of information and navigation services also influence the traffic flow with a high penetration. They independently collect and process data, monitor travel conditions, and design and distribute traffic-related information. The associated problems and tasks particularly affect the route guidance and are well known (Section 3.4.8) (Hessen Mobil, 2013):

- From the perspective of the public agencies that are seeking a system optimum, information and recommendation of private service providers should not run contrary to the optimization of the overall traffic system. Therefore, the current public information and control strategies should be considered in the information and control strategies of private providers.
- Inconsistencies with the information of different providers should be avoided.
- Private information must not have a negative impact on the safety of road users.
- Sensitive areas of the network must be protected. This applies in particular to the minor road network in urban areas (see Urban Traffic Management).

One possibility to face this problem is through public–private partnerships (PPPs), which have been developed in different regions by road transport agencies and private companies about 10 years ago with the purpose of operating and financing traffic information centers. Examples in the United Kingdom are “Traffic Wales” or in Germany the “Traffic Information Agency Bavaria” and the “Traffic Information Centre Berlin.” Also in the United...
3.4 Operational strategies and measures

The following sections briefly introduce the scope of AHMS operational strategies and related measures. In the following, the aspects of objectives and approach, control criteria, conditions of application, data collection, and range of potential benefits are presented. Survey results about the effects are presented as far as available. Main sources are Jones et al. (2011) and Mirashi et al. (2007). Further sources are quoted in the text.

3.4.1 Ramp management and control

Ramp management and control systems attempt to prevent congestion or unstable flow of traffic on the main lanes of highways by controlling and disbursing the platoons of vehicles entering the highway. Having been operated without involvement of private information and navigation service providers, actually, a closer cooperation emerges at the level of data and information exchange.

States, PPP is implemented or planned, for example, the “Traveler Information and Traffic Management System” of the Pennsylvania Department of Transport. Having been operated without involvement of private information and navigation service providers, actually, a closer cooperation emerges at the level of data and information exchange.

Figure 4. Process of planning and deployment of traffic management strategies. (Reproduced by permission of FGSV Verlag GmbH, Köln.)
strategies may include permanent closing of closely spaced entrance ramps, temporary closure of ramps during peak travel periods or incidents, provision of interchanges or ramps dedicated to only buses, or dedicated lanes to bypass ramp meters. One of the challenges with any ramp control strategy involves the balancing of the delay that vehicles may encounter at the on-ramp or on the local street network in comparison to the improved safety, reduced travel time, and improved travel time reliability on the highway (Jacobson et al., 2006).

Fifty years of experience with ramp metering in the United States have shown reductions in total crashes from 15% to 50%, an increase in mainline speed from 8% to 60%, and an increase in vehicle throughput from 8% to 22%. The reduction in the average travel time by 10–18% in the Germany and in the United Kingdom has led to an increased reliability and improved the flow of traffic on the road network by up to 5%.

3.4.2 Junction control

Junction control systems reallocate the use of lanes on a highway at an interchange to safely and efficiently accommodate vehicles entering the highway at the crossing or merging with another highway. The closing of a lane on the highway to create a lane for the entering traffic from the on-ramp eliminates the immediate merging of traffic where the volume of entering vehicles will adversely impact travel on the main lanes of the highway. The use of junction control typically drops or eliminates an extra lane on a highway or the off-ramp at the interchange. Junction control is also used when two highways merge together, where the volume of traffic on one of the ramps requires two lanes and a lane can be temporarily closed on the other highway to accommodate the higher volume on the ramp (Fuhs, 2010).

The decision to use the junction control operational strategy depends on the number of lanes and traffic volumes on the two highways and the ramps connecting these two facilities. Junction control is used when the volume of the traffic on a ramp reaches a threshold where the merge with the main lanes will adversely impact the flow of traffic on that highway. In order to instruct road users, over-head lane control or assignment signs are deployed indicating not to use a lane (red cross displayed), change to indicated lane (orange diagonal arrow displayed), or permission to use the lane is granted (green arrow displayed). The use of variable or changeable message signs in conjunction with the over-head lane control signs is necessary to provide approaching motorists with roadway and traffic condition information they will be encountering (i.e., congestion, crash, and lower speeds), which may require lowering their speed or changing lanes. A pilot junction control test in the Netherlands reduced overall mean travel times from 7% to 8% and reduced vehicle delay of 4–13% for both traffic on the mainline and merging traffic from the ramp (Jacobson et al., 2006).

3.4.3 Speed harmonization

The objective of speed harmonization is to reduce the deviation of speed between vehicles on a highway in order to increase the safety and maintain stable traffic flow. The current and projected traffic volume, mean speed (if possible distinguished between cars and trucks), and speed deviation provide the basis for the algorithms that are used to monitor traffic conditions and determine when it is appropriate to implement the use of the speed harmonization control algorithm. Speed harmonization is mainly in operation on highway sections where unstable traffic flow occurs when the traffic volume exceeds the effective operating capacity of a section of highway.

The use of speed harmonization may be appropriate to implement at any point during a week, month, or year where traffic volumes or incidents (e.g., weather, crashes, planned special event, and roadway maintenance) create unstable traffic flow. Road users are informed with variable message signs (VMSs) of the roadway or traffic conditions requiring the implementation and compliance with the lower speed limits being displayed. The implementation of speed harmonization on congested roadways requires a gradual reduction in speeds upstream of the sections of the roadway where it is critical to maintain the posted speeds to ensure stable traffic flow to avoid forming a bottleneck or unstable flow of traffic. While some countries, for example, United Kingdom or Austria, use automated enforcement of the varying speed limits that are posted with automated number plate recognition systems, many countries have found motorists to voluntarily comply with varying speed limits if they are presented with timely and credible information on the conditions requiring the reduced speeds in order to maintain stable traffic flow.

Speed harmonization is positively affecting safety by reducing accidents by 20–30% in Germany. In the Netherlands, the decrease is 16%, and in Great Britain, there are 18% less accidents. Economic effects are the reduction in minor material damages by 3% and heavy damages by 27% in Germany. Speed harmonization is also improving the capacity on a section of highway in the range of 3–5%.

3.4.4 Temporary use of the hard shoulder

Temporary hard shoulder use increases the number of lanes of travel on a highway to maintain stable flow of traffic during periods of higher traffic demand or incidents.
reducing or impacting traffic on other travel lanes. Information on traffic volumes, speeds, and incidents can be used to detect and predict stable and unstable traffic flow conditions that would be mitigated through the temporary use of a hard shoulder for travel. All temporary hard shoulder use applications in Europe and the United States first implemented speed harmonization where all lanes on the highway were operating at a lower speed before opening and using a hard shoulder for traffic either upstream of an interchange or on a lane of a highway that continues through downstream interchanges. In addition to first lowering the travel speed, it is necessary to ensure the clearance from obstacles on the hard shoulder with usage of video monitoring systems. Messages on VMS and other types of changeable signs inform road users of the opening or closing of the hard shoulder, the conditions warranting compliance with lower speeds and use of the hard shoulder lane, as well as display a speed limit for harmonizing traffic flow and lane control signs (i.e., green arrows) reinforcing to motorists that the lanes are open for travel.

The temporary use of hard shoulders and speed harmonization has a strong positive effect on safety by decreasing the number of crashes and significantly reducing the severity of property damage and personal injury crashes that occur by 25% in Germany. A reduction in travel time and travel time reliability by 30% led to positive economic effects in Germany in addition. The use of speed harmonization and hard shoulder running on the M42 in England realized 25–30% improvements in travel time and travel time reliability. The capacity increased by up to 25% in Germany and in the Netherlands.

### 3.4.5 Managed lanes

Managed lanes use operational strategies to actively manage and control traffic on specific lanes or an entire roadway. The use of managed lanes requires agencies to actively monitor and evaluate current and projected traffic and roadway conditions in support of the implementation of the appropriate operational strategies and control plans appropriate for a particular time period and section of roadway. While lane control strategies applying only one operational strategy (i.e., tolls, open or closed (reversible) lanes, trucks only) managed lane operational strategies actively using one or more operational strategies or measures.

Managed lane operational strategies use pricing, vehicle type, or access control in support of balancing current and projected traffic demand with the number of lanes available and the roadway conditions. High occupancy vehicle (HOV) lanes are an example of a managed lane operational strategy where access and occupancy are used to manage and operate the use of a lane. Over the past 40 years, over 4000 lane miles of HOV lanes have been developed in the United States where occupancy, or the number of people in a vehicle, provides an incentive for vehicles to use a congestion-free lane on a highway where the other lanes are congested (Fuhs and Obenberger, 2002). The deployment of ITS technologies has allowed agencies in the United States to improve the use of HOV lane performance by integrating pricing with occupancy to actively manage and operate these lanes.

The combined use of pricing and occupancy allows more vehicles to use the lane in off-peak commuting periods or when there are no incidents on the roadway and raises the price required for vehicles to use these lanes, which limits the number of toll paying vehicles when the HOV demand is high. Figure 5 demonstrates the range and complexity of using different combinations of managed lane operational strategies.

It shows that the flexibility-managed lanes provide agencies to actively manage and control traffic based on current and projected traffic conditions to optimize the performance of the lanes by varying occupancy or the price charged to use a lane to ensure a congestion-free trip (FHWA/TRB, 2003).

#### 3.4.6 Reversible lanes

Reversible lane operational strategy involves a lane assignment that is dependent on current traffic demand and, as a result, makes a better use of the existing road space, by switching the direction of travel on a lane or roadway. The primary control criterion is the traffic volume per direction of travel. Reversing specific lanes or an entire roadway requires the roadway's cross section to be able to accommodate traffic traveling in the opposite direction. Depending on the type of facility, a buffer (e.g., traffic cones) or physical barrier may be required, if the facility is not built specifically to adapt regular switches in traffic. Clearly, changing the direction of the traffic stream based on projected or historical traffic demands (e.g., a.m. or p.m. peak travel period) during the day, or for major events, allows the use of this measurement. The required data are traffic volume per direction and per lane as well as the mean speeds. In order to advise the road user, permanent lane assignment lights are used, as already mentioned in Section 3.4.2, as well as VMS indicating current lane assignment.

#### 3.4.7 Emission monitoring and dependent traffic control

Emission monitoring and dependent traffic control is aiming for a reduction in air pollution.
Traffic monitoring, traffic control and operational strategies, and traffic performance criteria can be set to account for the following:

- vehicle emissions [e.g., NO₂ (nitrogen dioxide), PM10 (particulate matter)],
- actual and forecasted traffic volumes, and
- meteorological data (average wind speed, average wind direction, thermal spreading conditions).

The emission-based traffic control is regularly integrated in the speed harmonization systems (Section 3.4.3). Conditions where emissions monitoring may be appropriate include sections of highways where traffic is identified as the main cause of emissions, locations where poor air spreading conditions exist (e.g., street canyons and valleys), or facilities impacted by adverse climatic conditions (e.g., frequent inversions) occur.

Traffic-related data and VMS are required in support of implementing speed harmonization strategies (Section 3.4.3) in support of achieving reductions in emission. The provision of additional traffic and roadway condition information may be necessary to achieve desired levels of acceptance by road users and achieve the desired reductions in speed to reduce vehicle emissions. The ASFINAG in Austria, where five emission-dependent speed reduction systems are running, has surveyed the impact of these measures with the following results:

- reduction in NOₓ emissions from 2.0% to 11.0% and
- reduction in PM10 emissions from 1.7% to 3.9%.

### 3.4.8 Route guidance

Route guidance attempts to mitigate the impacts of congestion by the issuance of advisory information and messages that have the potential to influence changes in a person’s travel route, time, or mode. Even minor changes in traffic demand may have a positive or adverse impact on the flow of traffic on a route, so these messages should be displayed to motorists on all routes within a corridor or meshed network where traffic may divert. Even a 5–10% shift in the number or the time of the departure of trips has the potential to significantly improve travel times and travel time reliability and increase safety on these routes. The monitoring and use of operational strategies and the issuance of supporting traveler and roadway condition information should be based on and occur only after evaluating the impacts these messages may have on motorists and traffic flow. It is worth mentioning that fully automated operation of route guidance systems has not been implemented area-wide in practice.

The use of messages that are intended to provide information to allow motorist to consider other route choices should be based on the conditions specific to each road section, all other roadways in the corridor or network, time of day, and other factors. The traffic volume data and mean speeds on the main routes and alternative routes have to be acquired to assess when conditions may be appropriate for displaying various messages for different traffic and roadway conditions. Messages displayed on VMS provide road users with additional information about
3.4.9 Traveler and traffic information

3.4.9.1 Congestion warning. Warning of road users with up-to-date roadway and traffic condition information is intended to alert them of changing conditions that may require action. The objective of this measure is to warn motorists in advance of changing traffic conditions and reduce their travel speeds to prevent rear-end collisions before encountering unexpected locations of unstable traffic flow. Road users are being warned when the sensors detect that the mean traffic speed and the speed differences between measurement points exceed defined threshold values. Messages warning travelers are applicable in advance of the bottlenecks on highways, construction or maintenance work sites, lane drops, curves, or changes in the grade of the roadway. The type of messages that may be displayed on VMS could include variable speed limits, congestion warnings, closed lanes, and lane restrictions (e.g., trucks in two right lanes, no passing).

Congestion warning has positive effects on safety by decreasing the numbers of primary accidents by 15–25% and secondary accidents by 40–50%. The reliability of the highway network has improved by an increased capacity of 4–5%. Both positive results were gained in the Netherlands.

3.4.9.2 Weather condition warning. Adverse weather conditions warning alerts motorists of the importance to reduce their speed of travel and adapt to changing traffic and roadway conditions due to detected or projected adverse weather conditions. Environmental data (i.e., road surface wetness, darkness, and fog density), roadway conditions (i.e., temperature of road or bridge surface), and the exact location of these conditions allows agencies to advise approaching motorists of the actions they should take or alter them to these expected conditions. The conditions and messages may include fog, snow, sand, flooding, rain, and high winds that have the potential to cause crashes or adversely impact the flow of traffic. VMS should display messages pertaining to the changing condition and, if necessary, a gradual reduction in speed for vehicles upstream of any queue that may be formed due to the slower speeds that may be required for a safe travel through the section of roadway impacted by the adverse conditions.

3.4.10 Road works management

Road works for maintenance and construction of the roadway usually results in a temporary reduction in the number or narrowing of travel lanes or a hard shoulder. Road works management is critical to ensuring the safety of workers and motorists traveling through work sites and has a high economic relevance. Road works management aims to minimize or ideally avoid any congestion or delays related to road work sites and to reduce accidents and safety risks for road users. According to Figure 2, more than a third of the travel time losses on highways are caused by road works.

The term road works management includes in a comprehensive understanding all phases and activities of planning, tendering, approval to the setting, operating, and clearing of a road work site. Effective road works management is characterized by a coordinated approach of all participants, primarily road construction administrations, road traffic agencies, police, and information and service providers. Ideally, there exists an IT-based planning and management system to support decision making (BASt, 2011).

Road works planning should be carried out on the basis of an assessment of the traffic impacts of different work zone and traffic control layouts, construction and traffic staging plans, capacity reserves and deficits, or monetarily rated congestion costs. Software-based traffic analysis methods are available for impact evaluation. Figure 6 shows an example of a user interface showing input and output data for a planning tool for short- and long-term road works on highways.

The evaluation of impacts on traffic should include the construction work site, work zone traffic control, roadway, and any adjoining roadway that may be adversely impacted by the project. The following information and data are necessary for this assessment (BASt, 2011):

- expected traffic volume on the relevant road works sections and potential alternative routes,
- information about road works at the same time on the road section upstream and downstream and on possible alternative routes,
- capacity of the possible road works site layouts, and
- capacity of sections of alternative routes.

Very important in this assessment is the potential to require certain construction activities during off-peak travel periods, limit the length of time required to temporarily close a lane, and consider options to use the entire cross section of the roadway (e.g., hard shoulders and narrower lanes). In order to support a safe traffic flow upstream or at road works site, existing section control systems...
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1. Enter construction site with number, version, name and position in the network
2. Enter road work period, in case of short-term road work with time
3. Choose layout
4. Add comment on chosen layout
5. Enter speed limit within the construction site area
6. If the box opposite direction is ticked the impact of the road works on the traffic flow of the opposite direction is calculated
7. Output of the calculated impact of the road works during complete construction time with parameters duration and length of congestion as well as the loss of travel time
8. Description of congestion information (quantity, stating of the congestion message with date and time)

Figure 6. User interface of a congestion prediction tool for road works. (Reproduced with permission from Dempe, Keiner, and Listl, 2011. © Gevas Humberg & Partner.)

should be operated, if available, or mobile TMSs should be considered (e.g., monitoring, surveillance, portable VMS, and portable highway advisory radio) (Section 3.4.9). These systems are also important for the purpose of data collection and continuous monitoring of layout and traffic flow. Another important component of a road works management system is the preparation of information for road users and different devices and applications (Road Traffic and Travel Information (RTTI)).

3.4.11 Traffic incident management

Unpredictable accidents or breakdowns can have serious negative effects on traffic flow. Particularly critical are incidents that lead to capacity reductions due to blocked lanes or roadways. Especially at high traffic volume, minor incidents for even short durations can adversely impact the flow of traffic and could cause congestion. Congestions due to accidents have the potential to adversely impact the local economy, especially if a roadway must be closed or travel is impacted for an entire peak travel period or a portion of the day. Therefore, the rapid solving of incidents is of great importance. Often, the highway patrol is confronted with a decision of removing a crash scene as quickly as practical to maintain the capacity of the affected road sections or minimizing the costs of damage to the involved vehicles and the roadway. While the material damage to vehicles can roughly be estimated by the officer, the economic damages...
that result from time losses to vehicles traveling on the roadway cannot be calculated by the police (Listl, 2008).

Basiclly, there is the possibility to provide the highway patrol with a decision-making tool similar to the layout planning tool for road works sites (Section 3.4.10). By means of such a traffic analysis tool to assess the length and time of a queue or jam lengths, time to clear the incident, travel time delays, and the resulting economic costs, when an accident occurs, the effects of different combinations of possible traffic lane blockages (number and duration) can be evaluated for every road section and for different hours of a day and traffic levels (morning rush hour traffic, evening rush hour traffic, and normal daily traffic). The evaluation results should support the officer in charge in deciding on the type of lane closures to allow for traffic safety, recovery, gathering of evidence, and clearing. Input data are limited to typed reference time graphs of traffic demand and capacity on open road section as well as the remaining capacity after lane closure.

The management and the quick clearance of traffic incidents usually requires intensive coordination among different emergency responders (e.g., medical and fire), service providers (e.g., towing, traveler information, and media), and agency staff (e.g., traffic control and roadway maintenance). The organizational and operational structures for proactively responding to and managing the impact of traffic incidents may not exist on all segments of the roadway network in a manner as that for road works management (Section 3.4.10). There is need for optimization in this area, which is limited, however, by agency resources, insurance, or criminal law boundary conditions.

3.5 System integration

The overlap of coverage area, functions provided, need to share information between different systems and the need for service providers and others to obtain information or data typically drives the need for integrating systems.

To accomplish this integration—there are different levels as pointed out—institutional, functional, and technical (Section 1.2). The following aspects should be taken into account: at the functional level, the control strategies and required commands have to be coordinated in terms of an overall operational concept and strategy in order to avoid operational and tactical problems and incompatibilities between individual systems. Data sources and data transmission paths must be shared at the technical level. In case of separated centers or users of information, they have to be linked. At organizational level, the exchange of information has to be defined. Decision-making responsibilities, policies, procedures, protocol and day-to-day operations, and coordination requirements have to be developed and adopted.

Combination of integrated AHMS may involve

- speed harmonization and congestion warning,
- speed harmonization along a road section and merging aids,
- route guidance and road traffic information in meshed networks and in corridors,
- route guidance and dynamic use of the hard shoulder, and
- junction control with speed harmonization, ramp management, and adaptive traffic signal control in the minor network (Urban Traffic Management).

Owing to the differing competence of the individual system elements, cooperation between agencies is necessary. The institutional system architecture in Figure 7 assumes a decentralized cooperation that does not affect the existing responsibilities of the concerned institutions (Section 3.2). Strategy planning and implementation should be carried out in accordance to Figure 4. All participating institutions have to be informed about the current and projected traffic and the current state of operation. These are, besides the highway agencies and dedicated agencies for the minor road network, also the affected emergency services (control center of the municipal police, the highway patrol, and emergency services) and ideally private information and navigation service providers.

3.6 Standardization

In order to ensure interoperability of technology used for data collection, data processing, and displays of AHMS, appropriate technical solutions exist in the form of regulations, policies, standards, specifications, protocol, and guidelines. Collectively, they provide a framework for planning, developing, integration, managing, and facilitating the day-to-day operation of systems and the exchange of information between other systems and users. These standards will ensure a systems functions and interfaces will operate as designed and, thus, ensure that systems from different agencies and producers are comparable in operation with each other. The aim of standardization of AHMS is to offer the road users a unified communication system in order to increase the comprehensibility and acceptability of the displayed information.

Exemplary regarding the standardization is the United States, having created a national ITS system architecture in 1994, which will continuously be adapted to developments in the functional, technical, and institutional fields (USDOT, 2013). This architecture naturally also includes
the AHMS applications and its interfaces with other ITS. Similar architectural concepts also exist in other countries, such as Japan. In Europe, the standardization is experiencing new impulses by the Directive on the Framework for the Deployment of Intelligent Transport Systems in the Field of Road Traffic (The European Parliament and the Council of the European Union, 2010).

Significant achievements have also been realized with the development and adoption of industry standards to support the operation and sharing of information between a wide range of ITS devices. Substantial standards efforts continue in the United States, Europe, and other countries in support of ensuring the ITS devices that will be manufactured to support the integrated operation and sharing of information.

4 PLANNING, IMPLEMENTATION, AND QUALITY ASPECTS

The planning and development of AHMS is encouraged to follow a process consistent with an industry accepted or endorsed systems engineering process. The concepts are generally oriented toward the step-by-step process that is shown in Figure 8. The planning of the operational strategies (Section 3.2) at the beginning has a central importance, because its quality has a decisive influence on the benefit (see also Section 1.2).

The AHMS’s operational concept and supporting architecture should be developed following this type of process. This technical concept and its resulting cost have been updated with increasing depth of planning. Generally, sponsors, for example, the responsible government department, only approve facilities with a benefit surplus or a benefit-cost ratio of higher than 1.0 for implementation. Therefore, a substantiated ex-ante evaluation of systems requirements, functions, services provided, or operations should be considered and quantified (e.g., by macroscopic or microscopic simulation, in addition to a cost forecast).

The system design, operational strategies, and services that will be provided should be complemented by appropriate reports, procedures, plans, maps, and tables. After implementation and a certain operation time that allows the road user to get used to the control measure, a proof of effectiveness has to be provided. The parameters basing the ex-ante evaluation have to be determined empirically with the data collection infrastructure for a statistically significant period of time. Unstability, caused by the usage of different methods (simulation in the ex-ante forecast and empiricism in the ex-post evaluation), has to be taken into account for the evaluation of the degree of the achievement of objectives.

For continuously ensuring the quality, monitoring has become an essential part of the system (Quality Management in ITS). Generally, an incident and error detection is implemented in central routines but increasing complexity of the system technology, the processes of data merging and processing, from the detection to activation of measures, as well as moving toward strategies require a more comprehensive quality approach, beginning in the planning phase (Busch, 2009).
Figure 8. Planning process of AHMS.
The implementation of a quality concept for AHMS ought to be a software-supported benchmarking system that prepares and displays automatically the results for the functional areas. Input parameters of the benchmarking system are measured values of the traffic and environmental data, error logs, system, and status data. According to Busch et al. (2006), the software architecture of the benchmarking system requires results in five monitoring modules (Figure 9).

5 CURRENT DEVELOPMENTS

5.1 Overview

The active management and control of traffic on highways is considered to be a conventional ITS measure. However, new developments are being initiated in some areas. They provide new technology and automate the functions and operation of an AHMS, apply new approaches of active traffic management, and optimize the cooperative acting of collective and individual traffic control. Additionally, the development and integration of technologies into automobiles has the potential to substantially increase the amount and quality of data that is available, where this information could be used to enhance the management and operation of the AHMS and the associated roadway network. The most important areas of current activity are described in the following sections.

5.2 Data collection

The usage of vehicle-generated traffic data or floating car data (FCD) for the identification and evaluation of traffic and roadway conditions and environmental conditions and for traffic control measures has become a main theme of research and development in recent years (In-Vehicle Sensors),

- on one hand, in order to improve data collection by measuring directly section-related journey time and speed or environmental data and
- on the other hand, in order to integrate measured and aggregated parameters into control strategies.

Previous approaches in projects and field trials have not led to the dissemination as expected. Mainly based on the rapidly growing fleet numbers, it currently appears that FCD is being used more intensively by highway agencies as a source of data for operational strategies and measures.

Another currently discussed data collection method, also regarding privacy protection, is the usage of Bluetooth sensors on highways (Data Acquisition by Roadside Detection) in order to use this data, in particular, for traffic information and route guidance. The road transport agency in Bavaria, Germany, proposes one of the first area-wide FCD and Bluetooth installations for incident detection and section- or route-related journey time measurement but continues to deploy high precision local sensors for vehicle measurement and classification (Listl and Singer, 2012).

5.3 Active traffic management

In the field of active traffic management, there are some interesting approaches, with research, testing, and initial deployments being conducted in Europe and the United States to enhance the management of travel demand and
control of traffic. The project Spitsmijden in the Netherlands is aiming at making road users avoid traffic peak hours by creating financial incentives. The incentives are to support a time shift of the journey start time or a modal shift to public transport in order to obviate congestion of highways and city ring roads. The project results in the test field Nord-Brabant in the metropolitan areas Eindhoven and ’s-Hertogenbosch have shown that, having completed the project already, a permanent modification in behavior occurred in time setting of journey and choice of transport (Spitsmijden, 2012).

A further approach in the highly transit traffic-affected German highway network aims, in particular, at guiding truck traffic that searches for parking slots along highways and optimizing the use of truck parking slots. The system concept consists of the redesign of parking spaces in order to park a higher number of trucks in a row or side by side. Special detection and control methods have been developed for entering and leaving these compact parking systems. The truck driver in the parking zone is informed by displaying the leaving time in order not to block other trucks. A further element in the system is the display of free parking spaces on VMS along the road that are to support the truck driver’s choice of rest area considering the remaining driving time. Currently, several pilot installations are scientifically surveyed regarding the effects on the traffic (Kleine and Lehmann, 2011).

An evolving practice and leading edge application in the United States involves the use of speed harmonization, traveler and roadway condition information (e.g., queue warning), and lane control in Seattle Washington. The Active Traffic Management System that the Washington Department of Transportation deployed on I-5 in 2010 is for monitoring varying speeds on the freeway to notify drivers in advance of encountering slower vehicles, queues from forming, and the number and frequency of crashes. Another example involves combining the use of tolls and occupancy to actively manage the travel demand and operation of managed lanes [e.g., HOT (high occupancy toll) lanes or express lanes] (Section 3.4.5). The Katy Freeway (located in Houston Texas) was converted from an HOV lane to a HOT lane when the freeway was reconstructed to provide two lanes in each direction of travel. The Katy Freeway HOT lanes have an operating surplus of over $5,000,000 per year by allowing vehicles with three or more passengers to use the facility for free and charge a fee for vehicles with only one or two passengers.

5.4 Cooperative systems

New perspectives and potentials, in particular, for the highway traffic, lie in a cooperative operation in which intelligent equipped vehicles communicate with the infrastructure (v2i—vehicle to infrastructure) or among each other (v2v—vehicle to vehicle communication). An overview of the current international movement is provided by a study of the University of California (Shladover, 2012). From the responsible road operators’ point of view, cooperative systems must contribute, apart from improvements of the actually available traffic flow data (Section 5.2), to the enhancement of harmonization of the collective and individual guiding strategies and to increase the traffic safety with warning of danger areas (Riegelhuth, 2010). For example, information on congestion and dangerous road or weather conditions (e.g., icing, rainfall, and fog) is transmitted from one vehicle to the following suitably equipped vehicles or to VMS. The other way round, information on short-term road works or accidents and vehicle breakdowns can rapidly be transmitted with position and time to the vehicle. The technical implementation of cooperative systems requires an intelligent and standardized data network that continuously links vehicle- and infrastructure-based telematics.

In order to generate added value for the road user from cooperative compared to autonomous driver assistance systems, the following boundary conditions must be clarified (Riegelhuth, 2010):

- Car manufacturer have to develop technical components in such a way that v2v communication is not restricted to the own vehicle fleet.
- The type of data and the time at which the data is processed in the control system must be determined. This is, in particular, a challenging task for the v2i communication as the road operator has to ensure absolutely reliable content for mandatory signs or incident warning.

The currently intensive standardization discussion on these and other topics is handled by the Technical Committee 204 “Intelligent Transport Systems” of the International Standardization Organisation (ISO) in the following working groups (WGs):

- WG 11 Route guidance and navigation systems,
- WG 14 Vehicle/roadway warning and control systems, and
- WG 18 Cooperative systems.
There exists an intensive collaboration with other Technical Committees worldwide such as the European Technical Committee 278.

GLOSSARY

See also http://onlinepubs.trb.org/onlinepubs/circulars/ec133.pdf.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Congestion</td>
<td>The travel time or delay in excess of that normally incurred under light or free-flow travel conditions.</td>
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<tr>
<td>Corridor</td>
<td>A broad geographical band that follows a general directional flow connecting major sources of trips that may contain a number of streets, highways, and transit route alignments.</td>
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<tr>
<td>Event</td>
<td>An occurrence, which includes all types of incidents, emergencies, and disasters (natural or human caused), that affects the transportation system and requires actions to maintain the safety and mobility of the system.</td>
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<tr>
<td>High occupancy toll (HOT)</td>
<td>Limited-access, normally barrier-separated highway lanes that provide free or reduced cost access to qualifying HOVs and also provide access to other paying vehicles not meeting passenger occupancy requirements.</td>
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<tr>
<td>Incident</td>
<td>Any nonrecurring event that causes a reduction in roadway capacity. Such events include traffic crashes, disabled vehicles, spilled cargo, and adverse weather conditions.</td>
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<tr>
<td>Incident management</td>
<td>Detection and verification of a traffic incident and the systematic, planned, and coordinated use of human, institutional, electrical, mechanical, and technical resources to reduce the duration and impact of incidents and improve the safety of motorists, crash victims, and incident responders. These resources are also used to manage the affected flow until full capacity is restored.</td>
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<tr>
<td>Institutional integration</td>
<td>Coordination among various agencies and jurisdictions to achieve seamless operations and/or interoperability.</td>
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<tr>
<td>Intelligent transportation system (ITS)</td>
<td>The application of advanced electronics, computers, communications, and sensor technologies—in an integrated manner—to increase the efficiency and safety of the surface transportation network.</td>
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<tr>
<td>Interoperability</td>
<td>The ability of two or more systems or components to exchange information and to use the information that has been exchanged.</td>
</tr>
<tr>
<td>ITS architecture</td>
<td>A framework within which interrelated systems can be built that work together to deliver transportation services.</td>
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<tr>
<td>Maintenance</td>
<td>The preservation (scheduled and corrective) of infrastructure.</td>
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<tr>
<td>Managed lanes</td>
<td>Highway facilities or a set of lanes where operational strategies are proactively implemented and managed in response to changing conditions.</td>
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<tr>
<td>Objectives</td>
<td>Specific, measurable statements related to the attainment of goals.</td>
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<tr>
<td>Operational integration</td>
<td>The implementation of multiagency transportation management strategies, often in real time, that promote information sharing and cross-network coordination and operations among the various transportation networks in the corridor–regions and facilitate management of the total capacity and demand of the corridor–region.</td>
</tr>
<tr>
<td>Operations</td>
<td>All decision making and actions necessary for the proper functioning of a system, such as information gathering (from a variety of sources), synthesis and processing, and dissemination and distribution of the decisions and information to traffic control equipment, other agencies and decision makers (including those associated with maintenance activities), and the public.</td>
</tr>
<tr>
<td>Performance measurement</td>
<td>A process of assessing progress toward achieving predetermined goals.</td>
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<td>Term</td>
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<tr>
<td>Procedural integration</td>
<td>The legislative, policy, planning, programming, and budgeting environment in which the transportation infrastructure functions.</td>
</tr>
<tr>
<td>Road works management</td>
<td>Strategies implemented for managing traffic during construction as necessary to minimize traffic delays, maintain or improve motorist and worker safety, complete roadwork in a timely manner, and maintain access for businesses and residents.</td>
</tr>
<tr>
<td>Systems engineering</td>
<td>A process incorporating a set of management and technical tools to analyze problems and provide structure to projects involving system development. A requirements-driven process in which user requirements are the overriding determinant of the system design, component selection, and implementation.</td>
</tr>
<tr>
<td>Transportation demand management (TDM)</td>
<td>Programs designed to reduce vehicle demand on the transportation system during the peak hours through various means, such as the use of transit and of alternative work hours.</td>
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<tr>
<td>Active traffic management</td>
<td>The practice of dynamically managing recurrent and nonrecurrent congestions based on prevailing traffic conditions. Focusing on trip reliability, it maximizes the effectiveness and efficiency of the facility, and increases throughput and safety through the use of integrated systems with new technology, including the automation of dynamic deployment to optimize performance quickly and without the delay that occurs when operators must deploy operational strategies manually.</td>
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<tr>
<td>Congestion warning</td>
<td>The display of warning signs and flashing lights along a roadway to alert that congestion and queues are ahead.</td>
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<tr>
<td>Junction control</td>
<td>A variation of the temporary hard shoulder used in Germany. Typically, it is applied at entrance ramps or merge points where the number of downstream lanes is fewer than the number of upstream lanes. Lane control signals are installed over both upstream approaches before a merge. They provide priority to the facility with the higher volume and give a lane drop to the lesser volume roadway or approach.</td>
</tr>
<tr>
<td>Ramp metering</td>
<td>Procedures used to reduce congestion by managing vehicle flow from local-access on-ramps. The entrance ramp is equipped with a traffic signal that allows vehicles to enter the freeway at predetermined intervals.</td>
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<tr>
<td>Route guidance</td>
<td>The provision of route information on overhead sign gantries along a roadway in response to recurrent and nonrecurrent congestions. The signs provide en route guidance information to motorists on queues, major incidents, and appropriate routes.</td>
</tr>
<tr>
<td>Speed harmonization</td>
<td>The practice of using an expert system to monitor data coming from field-deployed sensors on a roadway and automatically adjust speed limits when congestion thresholds are exceeded and congestion and queue formation are impending. Sign gantries that span the facility provide speed limits and additional information, depending on roadway conditions.</td>
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<tr>
<td>Temporary hard shoulder use</td>
<td>The practice of opening up the hard shoulder next to the outside lane of traffic for temporary use to address capacity bottlenecks on the freeway network during times of congestion and reduced travel speeds. Travel on the hard shoulder is permitted only when speed harmonization is active and speed limits are reduced. Signs indicate when travel on the hard shoulder is permitted. Also known as hard shoulder running or a rush-hour lane.</td>
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<td>Term</td>
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<tr>
<td>Truck restrictions</td>
<td>Any restrictions along a roadway on the operation of trucks or heavy goods vehicles. Examples include restricting trucks to specific lanes, prohibiting them from using particular lanes, limiting their operating speed, or prohibiting their use of the entire facility during specific periods of the day.</td>
</tr>
<tr>
<td>Variable message sign</td>
<td>A permanently installed or portable electronic traffic sign used on roadways to give travelers information about roadway conditions, including traffic congestion, crashes, incidents, work zones, speed limits, alternative routes, or special events on a specific highway segment. It can be changed or switched on or off as required and can be used to provide roadway lane control, speed control, and operational restrictions.</td>
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<tr>
<td>Variable speed limits</td>
<td>Speed limits that change based on road, traffic, and weather conditions.</td>
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<tr>
<td>Capacity</td>
<td>The maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental, and control conditions; usually expressed as vehicles per hour, passenger cars per hour, or persons per hour.</td>
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<tr>
<td>Demand</td>
<td>The number of users desiring service on the highway system, usually expressed as vehicles per hour or passenger cars per hour.</td>
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<tr>
<td>Density</td>
<td>The number of vehicles on a roadway segment averaged over space, usually expressed as vehicles per kilometer or vehicles per kilometer per lane. Also see Pedestrian density.</td>
</tr>
<tr>
<td>Downstream</td>
<td>The direction of traffic flow.</td>
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<tr>
<td>Entrance ramp</td>
<td>A ramp that allows traffic to enter a freeway.</td>
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<tr>
<td>Exit ramp</td>
<td>A ramp for traffic to depart from a freeway.</td>
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<tr>
<td>Flow rate</td>
<td>The equivalent hourly rate at which vehicles, bicycles, or persons pass a point on a lane, roadway, or other trafficway; computed as the number of vehicles, bicycles, or persons passing the point divided by the time interval (usually &lt;1 h) in which they pass; expressed as vehicles, bicycles, or persons per hour.</td>
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<tr>
<td>High occupancy vehicle (HOV)</td>
<td>A vehicle with a defined minimum number of occupants (&gt;1); HOVs often include buses, taxis, and carpools, when a lane is reserved for their use.</td>
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<tr>
<td>Travel speed</td>
<td>The average speed, in kilometers per hour, of a traffic stream computed as the length of a highway segment divided by the average travel time of the vehicles traversing the segment.</td>
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<tr>
<td>Travel time</td>
<td>The average time spent by vehicles traversing a highway segment, including control delay, in seconds per vehicle or minutes per vehicle.</td>
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<tr>
<td>Volume</td>
<td>The number of persons or vehicles passing a point on a lane, roadway, or other trafficway during some time interval, often 1 h, expressed in vehicles, bicycles, or persons per hour.</td>
</tr>
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</table>

See also Terminology of the *PIARC ITS Handbook*.

See also Glossary of the *Highway Capacity Manual HCM*.
REFERENCES


