Design Treatments to Reduce Nonrecurrent Congestion

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by

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ABSTRACT: Individuals and businesses rely on predictable travel times to ensure that people and goods arrive at their destinations on time; however, travel times are often unpredictable due to nonrecurrent congestion. Unlike recurrent congestion, which occurs on a daily basis during peak traffic periods, nonrecurrent congestion results from unpredictable causes of delay. The six key sources of nonrecurrent congestion considered in this research are:

- Traffic incidents
- Work zones
- Demand fluctuations
- Special events
- Traffic control devices
- Weather

Because of nonrecurrent congestion, travelers may find that the same trip requires substantially different travel times on different days, making it difficult to arrive at work on time, make deliveries on time, and plan efficient travel routes. This is frustrating to motorists and has substantial economic consequences to industries that depend on just-in-time deliveries.

A major research effort is under way in the United States and other countries to find ways to increase travel-time reliability and make travel times more predictable. As part of the Reliability area of the Strategic Highway Research Program (SHRP 2), which focuses on the need to increase travel-time reliability, SHRP 2 Project L07, *Identification and Evaluation of the Cost-Effectiveness of Highway Design Features to Reduce Nonrecurrent Congestion*, is identifying and evaluating a broad range of design treatments to reduce nonrecurrent congestion. These include innovative median treatments, shoulder treatments, ramp treatments, detour treatments, work zone treatments, treatments that address animal-vehicle collisions, and treatments that minimize the impact of severe weather events. This paper describes many of the treatments identified for evaluation in Project L07 and shows how they may be used to reduce nonrecurrent congestion.

INTRODUCTION

Individuals and businesses rely on predictable travel times to ensure that people and goods arrive at their destinations on time; however, travel times are often unpredictable due to nonrecurrent congestion. Unlike recurrent congestion, which occurs on a daily basis during peak traffic periods, nonrecurrent congestion results from unpredictable causes of delay, such as traffic incidents, work zones, demand fluctuations, special events, traffic control devices, and severe weather. Because of nonrecurrent congestion, travelers may find that the same trip requires substantially different travel times on different days, making it difficult to arrive at work on time, make deliveries on time, and plan efficient travel routes. This is frustrating to motorists and has substantial economic consequences to industries that depend on just-in-time deliveries.

Travel-time reliability is defined as "the level of consistency in travel conditions over time" and is measured by describing the distribution of travel times that occur over a substantial period of time.(*1*) While travel-time reliability is a relatively new concept in the transportation profession, it represents a key aspect of transportation system performance. Reliability is highly important because travelers must either build in extra time to their trips to avoid arriving late or suffer the consequences of being late. Because of the extra time required in planning trips, reliability influences decisions about where, when, and how travel is made. Due to the extra economic cost of unreliable travel, these costs need to be included in the project planning, programming, and selection processes.

A major research effort is under way in the United States and other countries to find ways to increase travel-time reliability and make travel times more predictable. As part of the Reliability area of the Strategic Highway Research Program (SHRP 2), Project L07, *Identification and Evaluation of the Cost-Effectiveness of Highway Design Features to Reduce Nonrecurrent Congestion*, is focusing on design treatments to reduce nonrecurrent congestion and improve travel-time reliability.(*2*) The objectives of SHRP 2 Project L07 are to (1) identify the full range of possible roadway design features used by transportation agencies on freeways and major arterials to improve travel time reliability and reduce delays due to key causes of nonrecurrent congestion, (2) assess their costs and operational and safety effectiveness, and (3) provide recommendations for their use and eventual incorporation into appropriate design guides.

This paper begins with a brief introduction to the causes of noncurrent congestion, the mechanisms by which they impact travel time, and treatment strategies that can be used to address each cause. The paper then describes several of the specific design treatments that are being evaluated in Project L07. Finally, the methods that will be used to evaluate the treatments are briefly presented.

CAUSES OF NONRECURRENT CONGESTION

There are six key sources of nonrecurrent congestion; each source impacts travel-time reliability in different ways and, therefore, can be addressed with a variety of design treatments. The six causes of nonrecurrent congestion addressed in this research are discussed below.(*3*)

Traffic Incidents

Traffic incidents include vehicle crashes, disabled vehicles, debris in the travel lane, and other unpredictable occurrences that interrupt the flow of traffic. Traffic incidents often reduce the capacity of the roadway by blocking one or more lanes or the shoulder. While the demand for the roadway does not change, the available lanes for those vehicles decreases, causing traffic to slow and creating delay for each motorist. The types of treatments that help reduce delay caused by traffic incidents are those that increase capacity to minimize the impact of the blocked lanes (such as opening an HOV lane or reversible lane), those that minimize the time that lanes are blocked (providing crash investigation sites or strategies that minimize response and clearance times), and those that reduce the frequency of incidents (truck escape ramps).

Traffic incidents often cause a phenomenon referred to as rubbernecking, where drivers traveling in unaffected lanes slow to observe the incident. The delay caused by rubbernecking can be minimized with treatments that block the view of the incident (incident screens or extra-height median barriers).

Work Zones

Work zones are sections of the roadway, or roadside, on which construction, maintenance, or utility work activities take place. Work zones may involve a reduction in the number or width of travel lanes, lane "shifts," lane diversions, reduction or elimination of shoulders, or temporary roadway closures. Thus, work zones can cause delay by reducing the capacity of the traveled way. While long-term work zones are more predictable and can be planned for by familiar drivers, delay is often unavoidable. Strategies that find innovative ways of increasing capacity can be used to minimize delay. Construction management strategies that shift lane closures to non-peak periods and those that accelerate construction schedules (express lanes through work zones and temporary bridges) can also help minimize the time period over which delay is experienced.

Work zones may also cause delay as construction trucks and equipment continually enter and exit the work zone. This delay can be minimized by design considerations that facilitate the flow of construction machinery with minimal impact to traffic.

Demand Fluctuations

Demand fluctuation refers to the day-to-day variability in traffic demand that leads to higher traffic volume on some days than on others. Examples of occurrences that cause travel demand to fluctuate include Friday afternoon travel to weekend destinations (e.g., Cape Cod, recreational lakes, ski resorts), Sunday afternoon return travel from weekend destinations, holiday travel (e.g., Thanksgiving, Memorial Day), and Daylight Savings time changes (evening peak periods have been observed to be more congested immediately following the end of Daylight Savings). One design treatment that may be used to address demand fluctuations is shoulder-use lanes, where the shoulder may be opened to general-purpose traffic to accommodate travel demand surges. An operational strategy to address demand fluctuations is electronic toll collection. Some highway agencies have the flexibility to open up more electronic toll collection lanes in response to a surge in travel demand.

Special Events

Special events include such occasions as major sporting events, festivals, and concerts. Most special events create a short-term increase in demand. When this demand exceeds capacity, delays can be experienced. Some special events may reduce capacity by closing lanes, such as for parades, runs, or biking events. Treatments that provide short-term increases in capacity, such as reversible lanes, can minimize the delay this causes for traffic. Special events may also be managed with lane closures, detour routes, restricted turning movements at intersections, or special ramp treatments.

Traffic Control Devices

Intermittent disruption of traffic flow by malfunctioning or poorly timed signals, or by railroad grade crossings, contributes to congestion and travel-time variability. Delay caused by malfunctioning traffic signals may be addressed by implementing temporary traffic control devices or turn restrictions. Delay caused by poorly timed signals can obviously be addressed with signal timing improvements or traffic signal upgrades.

Weather

Reduced visibility and/or roadway surface friction can affect driver behavior and, as a result, traffic flow. Drivers usually lower their speeds and increase their headways when poor weather conditions are present. Snow and ice storms may result in a greater number of collisions as well. They may also cause unexpected drifts of snow along the roadway or force roadway closures. While winter weather cannot be controlled, its effects can be minimized with automated anti-icing or deicing systems, snow fences, and design strategies that facilitate faster snow and ice removal. Other weather events include blowing sand and fog, which reduce visibility and may lead to collisions. Devices that detect these problems and communicate visibility problems to drivers can reduce incidents and help keep traffic flowing more smoothly. Some weather events require evacuations, such as hurricanes, floods, wild fires and mud slides. Treatments that increase capacity for evacuation plans can minimize delays experienced by motorists exiting the affected area.

DESCRIPTION OF TREATMENTS

The research in SHRP 2 Project L07 has identified approximately 50 design treatments to address nonrecurrent congestion. These treatments have been identified through extensive literature review and from discussions with highway agencies. The treatments have been classified into two major categories: directly design-related treatments and indirectly design-related treatments. The directly design-related treatments are highway design features or function through changes in highway design features (e.g., shoulder widening). The indirectly design-related treatments have secondary implications related to highway design (e.g., ramp metering). This paper focuses on those treatments that are *directly* related to geometric design. The treatments, and their application to nonrecurrent congestion, are discussed in the next section. While the treatments are not easily categorized, as many of them have overlapping characteristics and objectives, they have been organized into the following categories in this paper:

- Median treatments
- Shoulder treatments
- Ramp treatments
- Detour treatments
- Work zone treatments
- Treatments that address animal-vehicle collisions
- Treatments that minimize the impact of severe weather events

Median Treatments

Median crossovers are typically used on divided facilities to provide access to cross streets and driveways. However, median crossovers can be an important element of an incident management strategy. For example, they improve the accessibility to an incident scene by allowing emergency vehicles (as well as law enforcement and maintenance services) access through designated breaks in the freeway median. Median crossovers are also a key element of contraflow plans for hurricane evacuation. Along with entrance and exit ramps, they serve as the termination points and regulate the volume of traffic that can enter and exit a contraflow segment.

To address recurring congestion, *moveable traffic barriers* are often used to change the direction of traffic flow in a center lane to better respond to peak hour demand. However, moveable traffic barriers can be a useful tool in nonrecurrent congestion. For example, if a crash were to occur, the direction of traffic flow in a center lane could be changed to facilitate moving traffic around the crash, thereby reducing delays experienced by motorists. Also, moveable barriers have been shown to facilitate efficient use of nonpeak periods for construction, while protecting both the construction worker that must stand only feet from vehicles traveling at high speeds, as well as protecting vehicular traffic from potential hazards within the work zone. Anticipated lengths of construction periods have also been shown to be reduced when moveable traffic barriers have been used to temporarily delineate work zone areas.

Movable cable median barriers can provide a temporary access point for relieving nonrecurrent congestion on a divided facility. The specially designed wire cable barrier system, illustrated in Figure 1, is constructed such that the cables can be detached from the posts individually and the posts can be removed from their base. This deconstruction can be done over a short segment of the length of the cable to provide a temporary median opening should an incident occur that would require access by emergency vehicles or the rerouting of traffic. This treatment is particularly useful in environments where the available right of way on either side of a median barrier has the potential to be completely constrained by a traffic incident or routine roadway maintenance. By providing a cable median barrier that can be removed in a relatively short period of time, potential bottleneck situations can be averted. An added benefit over traditional median openings is that the location of an access point along a movable cable barrier is dynamic and can be placed at any point along the segment that is most useful in alleviating the congestion.


Figure 1. Movable cable barrier on a 2+1 roadway in Sweden.

Controlled or gated turnarounds include the provision of manually operated or automatic gates at emergency median crossovers on freeway facilities. The gated turnarounds provide the benefits of median crossovers by improving access to an incident site by emergency vehicles, while at the same time preventing unauthorized use of the emergency median crossover.

Extra-height median barriers (EHMB) consist of an above-standard-height median barrier, either through design of the barrier itself, or the addition of hardware at the top of the barrier to extend its height. EHMBs are most commonly used to redirect tractor-trailers and other large vehicles on impact or to reduce (or eliminate) headlight glare from traffic in the opposing direction of travel. In nonrecurring congestion, an EHMB can be used to reduce "rubbernecking" by blocking the view of incidents in the opposite direction of travel. By reducing or eliminating the ability for motorists to see across the median, these barriers can prevent motorist slowdowns in reaction to congestion, or an incident, thereby preventing this secondary type of congestion.

Mountable or traversable medians on divided arterials include flush or painted medians, two-way left-turn lanes (TWLTL), and raised (but traversable) medians. The main objective of installing a traversable median section on a divided arterial is to provide emergency vehicle access while mitigating some of the safety concerns associated with undivided roadways. Providing a traversable median section within a longer divided highway segment can allow emergency responders to reach a crash site more quickly by providing access across the median. Under certain circumstances, such as a roadway closure due to an incident, traversable median sections can also provide vehicles with an alternate travel route, or the ability to turn around.

Shoulder Treatments

Shoulder improvements for vehicle breakdown and storage include stabilizing an unstabilized shoulder, paving an unstabilized shoulder, paving a stabilized shoulder, adding a shoulder where none exists, and widening an existing shoulder. The objectives for an improved shoulder related to nonrecurrent congestion include:

- Provide a clear, paved recovery area to help reduce crashes, and potentially reduce the onset of nonrecurrent congestion near an incident site.
- Remove a disabled vehicle from the main travel lanes to minimize/eliminate potential nonrecurrent congestion.
- Provide easy access to emergency vehicles resulting in quicker clearing of an incident site.
- Provide latest technology/ITS capabilities to monitor and provide help for disabled vehicles
- Provide safe refuge to disabled vehicles.

Continuous and paved shoulders can also be used as an emergency travel lane (see "shoulder-use lanes," which is discussed next).

Shoulder-use lanes refer to the use of a shoulder in any of the following ways:

- As an added lane for use by traffic during peak periods
- To temporarily route traffic around an incident or work zone
- To provide access for emergency vehicles or tow trucks to the scene of an incident

While shoulder-use lanes are often used as a treatment to add capacity in recurring congestion situations, shoulder-use lanes have clear application in nonrecurrent congestion as well. Shoulder-use lanes can be used to restore lost capacity by routing traffic around a lane blockage (e.g., incident or work zone). They can also be used to reduce the duration of an incident by allowing emergency vehicles and tow trucks to use the shoulder to access an incident site more quickly.

Alternating shoulders is a treatment that is used in work zones where limited roadway width is available. In particular, it is most often used when one side of a divided roadway is shut down for a work zone, and traffic is moved over to the other side of the divided roadway, resulting in two-way traffic operations on that side. Rather than provide a full shoulder for one direction of travel and provide little or no shoulder for the opposing direction of travel (i.e., the crossover traffic), a full shoulder is provided for one direction for some distance and then the full shoulder is shifted to the opposite direction for some distance.

Alternating shoulders provide at least some shoulder or refuge for disabled vehicles in both directions of travel. Thus, alternating shoulders may prevent nonrecurrent congestion due to a disabled vehicle blocking a through lane.

Portable incident screens consist of a portable screening device, typically placed at the roadside to block motorists' view of a roadside incident. The primary objective of a portable incident screen is to reduce rubbernecking and secondary incidents/congestion caused by the presence of an incident or a work zone. A secondary objective found in the literature is that of preventing motorists from throwing objects at construction personnel in work zones.

Vehicle turnouts are essentially short sections of shoulder provided on routes without sufficient shoulder to allow a vehicle to be safely removed from the travel way. On rural, two-lane highways in areas where highway alignment does not provide opportunities for safe passing, and where passing lanes are not feasible, vehicle turnouts allow slow moving vehicles to momentarily pull out of traffic to allow faster moving vehicles to pass. In these areas, slow moving vehicles may be a significant source of nonrecurrent congestion. In urban and suburban areas, turnouts allow disabled vehicles that might otherwise be blocking a lane, or part of a lane, to be removed from the travel lanes. Minor crashes and breakdowns are sources of nonrecurrent congestion that can be minimized by allowing the vehicles a safe place to pull over. Vehicle turnouts may be used as accident investigation sites.

A *bus turnout* (or bus pullout) is a designated paved area to the side of the main travel lanes for buses to stop to pick up and drop off passengers. Turnouts often include tapers or acceleration/deceleration lanes, the bus bay area, and a passenger waiting area. Bus turnouts are intended to reduce disruptions to traffic flow due to bus stops along major roadways. They improve passenger safety during boarding and de-boarding and can reduce the potential for rear-end crashes. They also provide a safe place for passengers to wait that is offset from the main travel lanes.

Crash investigation sites are paved areas outside of the traveled way (or on an adjacent roadway) to which crash-involved vehicles can be moved and at which crash investigations can be conducted. An example of a crash investigation site is presented in Figure 2. Crash investigation sites are provided to minimize the effect on traffic congestion of "rubbernecking" that occurs if crash investigations are conducted on the roadway shoulder. During a crash investigation, the vehicles involved in the crash and at least one police vehicle with flashing lights are typically present. When such vehicles are parked on the roadway shoulder, passing vehicles may slow due to their drivers' curiosity to see what is happening, leading to a disruption of traffic flow and resulting congestion. However, if the crash-involved vehicles are moved from the roadway to an off-roadway location as soon as possible after the crash, the resulting congestion can be minimized.

Figure 2. Aerial view of a crash investigation site within a freeway interchange in Chicago.

Ramp Treatments

Ramp widening, which consists of widening either entrance or exit ramp terminals, focuses on providing solutions to problems at the ramp/arterial intersection, on the freeway (e.g., exit ramp traffic queuing onto the freeway mainline), or on freeway ramps. Ramp widening provides space on the ramp that previously did not exist, whether in the form of additional lanes, wider shoulders, or wider lanes. Nonrecurrent congestion caused by special events at nearby stadiums, concert halls, or arenas may be reduced by ramps that have been modified to provide additional storage capacity. For exit ramps, ramp widening can reduce queuing on the mainline freeway; for entrance ramps, ramp widening can reduce queuing on arterials near the facility that feed the freeway.

Wider ramps can also minimize the consequences of incident-related nonrecurrent congestion by providing additional space for emergency and law-enforcement vehicles to maneuver and reach incidents that occur on or near a ramp. Easier access to the incident results in shorter response and clearance times, which reduces congestion and potential secondary incidents caused by congestion.

Ramp closure is a method of managing traffic patterns on and surrounding freeway ramps. Closures may be implemented with the use of automatic gates, barriers, gates that need to be moved manually, or physically removing a ramp altogether. Temporary ramp closures are often applied in the following nonrecurrent congestion situations:

- *During construction and maintenance* – Ramp closures can reduce the potential conflicts between workers and vehicles, and they may reduce the construction time as maintenance and construction activities can proceed without consideration being given to impacts on the traffic stream.
- *To manage special events* – For ramps in proximity to special event venues, a ramp closure plan is appropriate for managing traffic during the times that traffic volumes are affected by those periodic events. By managing these ramp closures with enforcement personnel, special access can be granted and ramp re-opening can be determined and implemented as the situation justifies.
- *When severe weather conditions threaten safety* – Temporary ramp closures are often required in response to severe weather conditions, such as snow and ice or flooding. This treatment is also applicable to flooding zones. In regions that are susceptible to hurricanes and similar catastrophic weather events, evacuation procedures may also require the closure of ramps in order to effectively move traffic in a contraflow direction.
- *To manage a severe incident on or near the ramp* – Temporary ramp closures may be used to manage traffic around a severe incident on a ramp or on the freeway downstream of the ramp. Closing the ramp can also allow easier access for emergency vehicles responding to the incident.

Ramp terminal traffic control includes installation of signals, a roundabout, or turn lanes; improved signal timing; or any other changes to signing, striping or signals used at the ramp terminal to control the movement of traffic. It may also include manual traffic control by law enforcement, most commonly during a special event. Many ramp terminal treatments are implemented to prevent traffic stored on the ramp from queuing back onto the freeway. These queue spillbacks can block a travel lane and, potentially, lead to freeway crashes. Figure 3 illustrates an interchange in Maryland involving a roundabout where a freeway ramp intersects with an arterial. The intersection frequently experienced long queues on the freeway ramp that extended back towards the freeway mainline. To address the problem, a traffic signal was installed at the roundabout that was linked to a detector on the ramp. As long as the queue does not extend to the detector, the signal is a flashing yellow. The default signal operation is flashing yellow. However, when the queue extends back to the detector, the signal changes from flashing yellow to solid yellow and then transitions into a full signal. In full-signal operation, the traffic on the ramp gets free-flow access to the roundabout and traffic on the arterial is stopped. Once the queue on the ramp has dissipated, the signal transitions back to flashing yellow.

Improved signing, striping, and signal timing can have a direct effect on reducing nonrecurrent congestion. In addition, ramp terminal signals can be coordinated with other arterial signals along the corridor in an adaptive or responsive system, allowing the signal timing at the ramp to adapt to changing traffic patterns associated with both planned and unplanned congestion-causing events. The use of variable lane control signs and other ITS elements employed at the ramp terminal may assist law enforcement in manual traffic control during nonrecurrent congestion events such as special events.

Figure 3. Aerial image of the Maryland roundabout (left), and photo showing the signalized arterial leg of the roundabout (right).

Ramp turn restrictions are turn restrictions that are implemented at the ramp/arterial intersection to better manage traffic entering or exiting the ramp facility. The objective of ramp turn restrictions is to limit access to a ramp or arterial. Ramp turn restrictions may be used to address nonrecurrent congestion by:

- Preventing ramp queues from extending onto a highway through lane, thus preventing a lane blockage on the highway and, potentially, a rear-end collision;
- Preventing turn-lane queues from extending onto the arterial system, thus preventing a lane blockage on the arterial and, potentially, a rear-end collision;
- Effectively managing increased traffic due to special events;
- Rerouting traffic around a work zone or major incident.

A *truck runaway ramp* (or truck escape ramp) is typically a long sand- or gravel-filled lane adjacent to a roadway that is designed to slow or stop heavy vehicles that have lost control or are unable to stop due to brake failure on a downgrade. Truck runaway ramps reduce crashes involving heavy vehicles on or near downgrades by providing a path for out-of-control trucks to come to a safe stop away from other traffic. Crashes involving heavy vehicles often cause significant nonrecurrent congestion because they are typically more severe, can involve several vehicles, and often block multiple lanes of travel. Truck runaway ramps reduce nonrecurrent congestion by preventing such heavy vehicle crashes.

Detour Treatments

Detour routes are designated roadways set up to carry traffic along a secondary route to bypass a congested location on the primary route. Events that require traffic to be detoured from a primary route can be either planned events (such as special events or work zones) or unplanned events (such as major crashes, severe weather, or emergencies). *Improvements to detour routes* are intended to improve the capacity of the corridor strained by the addition of rerouted traffic volumes, and to provide an incentive for drivers to use the detour route to ease congestion on the primary route. Secondarily, improvements to detour routes may also improve the safety of these routes. Improvements may include:

- Providing additional lanes using existing pavement surface for traffic through the use of shoulders or on-street parking areas
- Providing additional surface area with new pavement to increase the number of usable lanes
- Restriping or resigning routes to accommodate additional volumes
- Retiming signalized intersections to give additional green time to directions of travel with increased volumes
- Accommodating trucks and other large vehicles that may not have used the detour route previously (increasing weight limits of bridges, increasing turning radii, etc.)
- Improving the road surface, limiting access, improving sight distance, and other improvements that may allow a higher speed limit

Temporary bridges are bridges that are constructed for temporary use, often during the construction of a permanent bridge. A temporary bridge is typically used to reduce the traffic operational impact of removing an existing bridge from service, and to accommodate normal traffic demands while permanent facilities are being constructed. In some cases, temporary bridges may be built to provide emergency access when a previously existing structure is no longer in use, or to provide construction vehicles with alternative access to constructions sites, minimizing the impact they have on the existing bridges and traffic patterns.

Temporary bridges may help decrease the construction time required for the permanent bridge by diverting traffic away from the bridge work zone. Once construction is complete, temporary bridges may be removed, or may remain in service for emergency vehicles, bicyclists, and/or pedestrians. Since bridges provide access over rivers, highways, railroad tracks, and other features that can only be crossed in limited locations, the removal of a bridge forces traffic to divert to alternate routes. These detour routes can sometimes be several miles long, creating significant increases in travel times for drivers.

Work Zone Treatments

Reduced construction duration is a treatment category that encompasses innovative techniques that can be implemented to reduce the duration of a work zone or other construction project. Such techniques may include total road closures, night work, and the use of innovative construction materials. Treatments to reduce construction duration facilitate highway maintenance and construction in a manner that reduces the impact of the work zone on operations and safety.

In many construction or maintenance operations, vehicles carrying materials must access the work site from the traveled way of a roadway. Poorly marked or controlled access points can result in substantial delays to traffic as work vehicles slow to enter the work site and may not be able to accelerate to prevailing speeds before entering the traffic stream when leaving the work site. *Improved work site access treatments* allow work vehicles to enter and leave the work site more quickly and safely.

Treatments that Address Animal-Vehicle Collisions

Wildlife barriers are used to reduce the potential for animal-vehicle collisions by preventing animal crossings at undesirable locations. Wildlife barriers include wildlife fencing and boulders in the right-of-way. Wildlife fencing, illustrated in Figure 4, is one of the most commonly applied measures to separate wildlife from motorists. However, large boulders have been placed in the right of way, outside of the clear zone, as an alternative to wildlife fencing. Large boulders are thought to make it hard for animals, especially ungulates, to walk across an area.

Figure 4. Wildlife fence in Wyoming. (4)

Since a large proportion of animal–vehicle collisions occur on two-lane rural highways, the potential for congestion due to animal-vehicle collisions is relatively high on these routes. The lack of alternative route in remote areas also creates a potential for extensive delays. Thus, wildlife barriers reduce the potential for nonrecurrent congestion due to animal-vehicle collisions.

Wildlife passages are used to reduce the potential for animal-vehicle collisions by providing a means for animals to cross the roadway safely at selected desirable locations. Wildlife passages include long tunnels, long bridges, underpasses, and overpasses. Long tunnels and bridges are primarily constructed because of the nature of the terrain (e.g., through a mountain, across a floodplain), but in some cases they are constructed to avoid areas that are ecologically very sensitive and where no alternatives are available. Animals can move freely across the tunnels or bridges, and because the animals are physically separated from traffic, animal-vehicle collisions are eliminated. Wildlife underpasses and overpasses are used to provide habitat linkages for various species and to provide for safe crossing of the roadway. Wildlife fencing is sometimes used to direct animals to these overpasses or underpasses. As with wildlife barriers, wildlife passages reduce the potential for nonrecurrent congestion due to animal-vehicle collisions. This is especially true on rural two-lane roadways where alternative routes are lacking and, therefore, the potential for extensive delays may be high.

Treatments that Minimize the Impact of Severe Weather Events

A *snow fence* is a structure or vegetative planting used to trap and control the blowing and drifting of snow before it reaches the roadway. There are two types of snow fences – snow fences that trap snow upwind of the area to be protected (referred to as collector-type snow fences) and snow fences that deflect snow around the protected area (referred to as deflector-type snow fences). Figure 5 illustrates a deflector-type snow fence.

Figure 5. Deflector-type snow fence. (5)

Snow fences reduce the potential of winter-related crashes caused by blowing snow and the snow that is deposited on the roadway. By keeping the roadway clear of snow and ice and by improving visibility, snow fences allow drivers to travel closer to their desired speeds rather than being limited due to wintery conditions. Also, by reducing the need for winter maintenance activities, motorist delays due to snow removal activities are reduced. Snow fences also have the potential to reduce delays from road closures due to severe winter weather conditions.

Anti-icing systems involve the proactive application of chemicals to a roadway surface before a winter storm. In contrast to deicing, which involves the reactive application of chemicals to a roadway surface during or after a storm (when snow and ice may have already formed), anti-icing helps prevent snow and ice from bonding to the pavement. Anti-icing systems have the potential to reduce nonrecurrent congestion by reducing the potential for weather-related crashes.

EVALUATION OF TREATMENTS

In the next phase of the research in Project L07, a traffic operational assessment of each design treatment will be conducted to determine the effects of that treatment (or combinations of treatments) on reliability. The traffic operational assessment is intended to develop quantitative estimates of reliability measures. Most of the estimates will be based on formal analyses, while some estimates will be based on engineering judgment.

Ultimately, the research will produce a design guidebook that will include:

- Description of highway design treatments to reduce nonrecurring congestion;
- Geometric design guidelines for implementing the treatments;
- Procedures for quantifying the traffic operational performance of treatments;
- Estimated traffic safety performance of treatments, presented in a manner compatible with the HSM;
- Selection procedure for treatments, including a life-cycle cost analysis procedure; and
- Examples of actual treatment installations.

The design guidebook will present practical guidance for highway agencies on the application of design treatments to address nonrecurrent congestion and improve travel-time reliability.

SUMMARY

Nonrecurrent congestion, which varies from day to day and one incident to the next, creates unreliable travel times that frustrate motorists and interrupt the efficient production and delivery of goods. The key sources of nonrecurrent congestion are:

- Traffic incidents
- Work zones
- Demand fluctuations
- Special events
- Traffic control devices
- Weather

A wide range of geometric design treatments are available for use by highway agencies on freeways and major arterials to improve travel-time reliability and reduce delays due to the key causes of nonrecurrent congestion. These include innovative median treatments, shoulder treatments, ramp treatments, treatments for detours, work zone treatments, treatments that reduce animal-vehicle collisions, and treatments that address severe weather events.

Each of the treatments has been described in this paper and their role in reducing nonrecurrent congestion discussed. Over the next two years, research for SHRP 2 Project L07, *Identification and Evaluation of the Cost-Effectiveness of Highway Design Features to Reduce Nonrecurrent Congestion*, will be gathering cost, traffic operational, and safety data and evaluating the cost-effectiveness of each of the treatments. The research will also prepare a design guidebook that will provide guidance on the use and application of each of the treatments.

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