Traffic Management Systems (TMSs) Actively Managing the Display of Queue Warning Messages

Transportation Management Center (TMC) Pooled-Fund Study[(1)]

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Presentation Outline

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TMSs Using Queue Warning Messages To Improve Safety

- Queuing conditions on freeway facilities present significant safety concerns:
  - Increased potential for rear-end collisions.
  - Introduction of shockwaves that disrupt traffic flow upstream of the queue.
- Traffic queues may be recurring or nonrecurring:
  - Bottleneck or roadway geometry (for example, reduction in number of lanes on a freeway).
  - Merge areas with heavy on-ramp traffic volumes.
  - Crashes.
  - Work zones (for example, reduced number of travel lanes, reduced speed limit).
- TMSs can provide warning messages to alert vehicles before they encounter unexpected, unstable traffic flow conditions.
- Drivers are less likely to need to take abrupt action (such as hard braking, abrupt lane changes, or running off the road) to prevent rear-end collisions.

TMS Requirements To Display Queue Warning Messages

The capabilities needed for a TMS to display warning messages associated with areas of unstable traffic flow may include the following:[2]

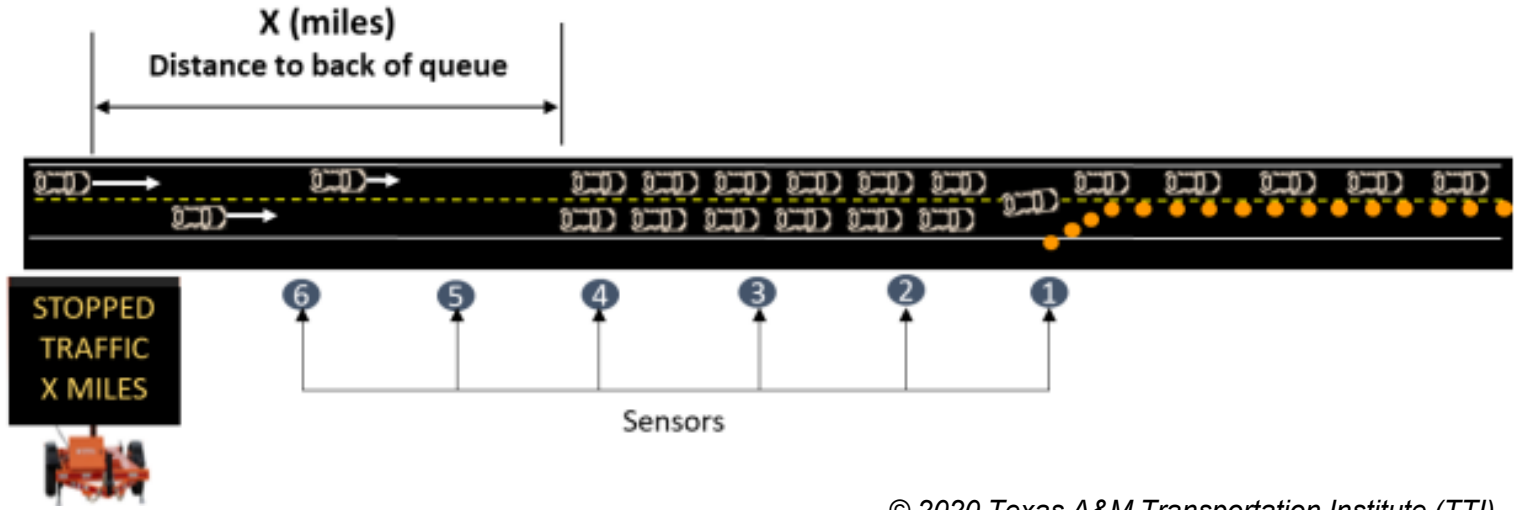
- TMS assets to monitor travel conditions—typically, including sensors to measure speeds, vehicle flows, or both—at multiple points upstream of a potential bottleneck location.
- TMS software to detect the presence of a queue and select appropriate warning messages based on message selection logic or an algorithm, potentially requiring operator approval and posting.
- Changeable message signs (CMSs) or portable changeable message signs (PCMSs) to provide warning messages to the drivers of approaching vehicles.

Data Sources

- Infrastructure or sensor data: Loop detectors, vehicle probes, microwave vehicle detection equipment.
- Probe or third-party traffic data: Toll tags, third-party vehicle probes, crowdsourced data.
- Connected vehicle data.

TMS Functions To Generate and Display Queue Warning Messages

- TMS uses data collected from traffic sensors to determine the changing location of the back of queue (BOQ) and potentially locate unstable traffic flow.
- TMS compares data collected to predefined thresholds to indicate when the display of a warning message may be warranted.
- TMS determines when to post messages, where, on what sign(s), and what the messages should say. Examples:
  - "Slow traffic X miles" or "Slow traffic ahead": Displayed when speeds begin to drop, and congestion builds or distance from the BOQ is sufficient to warrant a more cautionary message.
  - "Stopped traffic X miles" or "Stopped traffic ahead": Displayed when speeds drop to a specific threshold and congestion builds more significantly and/or distance from the BOQ is short enough to warrant a more urgent message.



Benefits of TMSs Displaying Queue Warning Messages (1/2)

- Agencies identify reductions in crashes, severity of crashes, and crash cost savings.
- Agencies often display queue warning messages in combination with other strategies to achieve greater benefits:
  - These messages are one of several strategies that improve safety and mobility associated with work zones.
  - These messages are one of several traffic management operational strategies (for example, lane use control, hard shoulder running, variable speed limits (VSLs)) that are used to manage corridors and improve safety and mobility.
- Agencies report few quantified benefits of these messages because displaying queue warning messages is a relatively inexpensive add-on to other strategies, but the messages are a useful tool.[3]

Example

Queue warning messages are sometimes used with VSLs. The queue warning messages may explain why speeds are being reduced. This combination results in safety and mobility benefits from smoother traffic flow with smaller speed differentials.

Benefits of TMSs Displaying Queue Warning Messages (2/2)

Agency	Facility	Benefit
Minnesota Department of Transportation (MnDOT)(4)	I–94 westbound near I–35 West, Minneapolis	• 56 percent decrease in crashes.[1] • 69 percent decrease in near-crashes.[1]
Pennsylvania DOT (PennDOT)(5)	I–78 reconstruction, Berks County between Fredericksburg and Allentown	• 12 percent decrease in crashes. • 23 percent decrease in injury or worse crashes. • 24 percent decrease in possible injury or worse crashes.
Texas DOT (TxDOT)(6)	I–35 widening, Central Texas	• 44 percent decrease in crashes.[2] • $1.36 million crash cost savings (over 216 nights).[2]

[1]MnDOT notes that these safety benefits pertain only to a specific crash type during a specific period and thus may be inflated.
[2]TxDOT I–35 widening project, which used portable transverse rumble strips in addition to warning messages.

Key Considerations

- Integration with TMSs and sources of data.
- Implications for TMC staff.
- Selection of queue warning messages.
- Prioritization of posting queue warning messages.
- Integration with operational strategies and other messages to manage traffic.

Integration of Queue Warning Messages With TMSs

- Determine, based on traffic condition, what queue warning messages a TMS may display:
  - What coverage and TMS assets are needed to monitor traffic conditions (e.g., type, spacing monitoring and data collected, ability to distinguish among lanes of traffic)?
  - Are permanent or portable CMSs available to display needed messages, and where are these CMSs located?
- Determine type and source of data (infrastructure or sensor data, probe or third-party traffic data, connected vehicle data) to collect and use to monitor traffic conditions.
- Determine the analytic requirements to display queue warning messages:
  - Algorithms to analyze traffic conditions, detect a queue, and select appropriate messages.
  - Need for additional software incorporated into the TMS's operating system to manage the process.
  - Business rules that accommodate other traffic management functions and TMC operator supervision.

Implications for TMC Staff

- TMC operator duties are supervisory in nature and generally incorporated into regular duties for monitoring the roadway system, as follows:
  - Confirm queue conditions to ensure a trigger is not a false positive.
  - Confirm posting of the queue message or override the message if a more urgent or alternative event must be communicated.
- TMC operator staffing level guidance is as follows:
  - Display of queue warning messages may only require modest time beyond regular operator duties; therefore, increased operator staffing is not likely to be needed.
  - Display of queue warning messages may require more TMC staff when used in conjunction with other traffic management strategies, as opposed to if only queue warning messages were being displayed.
  - Display of queue warning messages may require staff dedicated to work zone planning and contractor support to integrate equipment into an agency's TMS and TMC.

Selection of Queue Warning Messages

- Queue warning message display triggers and logic are based on defined speed thresholds.
- Thresholds can correspond to free-flow conditions, slow traffic conditions, or stopped traffic conditions. For example:[2]
  - Compare a freeway free-flow speed (v) to two speed thresholds: v1 for slow traffic and v2 for stopped traffic.
  - Set v1 to be 40 or 45 mph and v2 to be between 20 and 35 mph (typical).

Free Flow	Slow Traffic Message		Stopped Traffic Message	
v > v1	**v2 ≤ v ≤ v1**		**v < v2**	
Pre-queue: Default message for free-flow conditions	"Slow traffic X miles"		"Stopped traffic X miles"	
	"Slow traffic ahead"		"Stopped traffic ahead"	
Post-queue (optional): "Traffic delays possible for up to 5 minutes" (or similar)	***Near CMS***	***Far CMS***	***Near CMS***	***Far CMS***
	"Congestion: X miles"	"Congestion: Reduce speed"	"Stopped traffic ahead"	"Be prepared to stop"

Prioritization of Posting Queue Warning Messages

- Research recommends that queue warning messages should be displayed on a CMS whenever a TMS is able to detect the end-of-queue condition, and the CMS is not already displaying a higher priority message.(7)
- Agencies generally set queue warning message priority to "equal to adverse weather conditions and just below an incident or crash message" because queue warning is of immediate importance to drivers.(7)
- Michigan DOT notes that queue warning has the "highest priority" among other messages that may be posted on small CMSs.[1]

[1]Palmer, S. and J. Foley. 2018. "US 23 FlexRoute." Presentation. Jackson, MI: Michigan DOT University Region.

Integration of Queue Warning Messages With Operational Strategies and Other Messages To Manage Traffic

- Queue warning messages are often incorporated into how TMSs actively manage the use of other operational strategies, such as:
  - Dynamic lane use control.
  - Part-time shoulder use.
  - VSLs.
- Queue warning messages are integrated with these strategies through an agency's TMS operating system and share similar functions:
  - Collect and use the same or similar data.
  - Rely on algorithms to perform functions.
  - Require similar activities from operators.
  - Display messages as part of functions.

Examples of Agencies With TMSs That Display Queue Warning Messages

- MnDOT.
- PennDOT.
- Iowa DOT.

MnDOT Queue Warning Messages (1/3)

- MnDOT developed and deployed TMS assets to display queue warning messages in the Twin Cities Metro Area for the following locations:
  - I–35 West southbound approaching Highway 62 at the southern edge of Minneapolis.
  - I–94 westbound near I–35 West (2016–2018).
  - I–94 westbound near I–35 West, 0.75-mi upstream (2018–2022, during corridor reconstruction).
- I-35 West location: MnDOT used the distance between consecutive vehicles in a lane (headway) to detect the presence of a queue and display the "Slow traffic ahead" message for all queues.(8)
- I–94 locations: MnDOT used crash prediction algorithms, along with traffic speed and headway data, to determine if a message should be displayed:(4)
  - Assumed a subset of congestion events lead to queue-related, crash-prone conditions.
  - Included two operator overrides to limit message overexposure to drivers.
  - Attempted to distinguish among differing conditions in four lanes at the second I–94 location and used separate algorithms for left- and right-side lanes with mixed results.(9)
- The queue warning algorithms ran on a server housed at the University of Minnesota, which was polled by the TMS every 30 s to determine message display.

MnDOT Queue Warning Messages (2/3)

- MnDOT currently displays queue warning messages at one location:
  - Highway 52 Northbound approaching the Lafayette Bridge, which crosses the Mississippi River into downtown St. Paul.
  - Exiting traffic can cause backups and large speed differentials between the center lane and left- and right-side lanes after crossing the bridge.
- Overhead CMS suggests lane assignments and displays a “Stopped traffic ahead” queue warning message, based on downstream speed data in each lane.
- TMC operator time used to provide oversight of message posting is incidental to normal as part of duties monitoring traffic conditions and managing the TMS.
- Crashes are reduced, but attributing these reductions to queue warning is hard because signing and striping improvements were also made.

MnDOT Queue Warning Messages (3/3)

Queue warning is a standard message displayed with work zones, particularly in the Minneapolis-St. Paul region:

- Uses existing CMS or PCMS if signs are unavailable due to construction.
- Displays a "Stopped traffic ahead" message in advance of work zones when certain average speed thresholds are met.(10)
- Connects to the TMS and is managed through TMS software at the TMC.
- Requires half the time of one senior engineer at the TMC, who:
  - Reviews plans for work zones.
  - Determines which work zones need integration with TMS software to enable queue warning.
- Requires roughly 0.5 full-time equivalent (7 to 8 staff total) on an ongoing basis to support integrating contractor equipment that enables the display of queue warning messages.

PennDOT Queue Warning Messages (1/3)

- PennDOT considers the display of queue warning messages anywhere concerns exist about recurring or nonrecurring traffic queues leading to crashes.
- PennDOT displays queue warning messages along nearly 30 corridors, as of early 2024; most of these corridors experience queuing conditions on a temporary basis due to work zones.
- PennDOT uses vehicle probe data, rather than traditional traffic detection equipment, along with "Vehicle Probe Data-Driven Queue Protection Corridors":[5]
  - Certain corridors also use crowdsourced location and vehicle speed data from users of the PennDOT mobile application (511PA) to detect slowdowns.
  - One managed corridor (I-76 in Montgomery County) also uses remote traffic microwave sensors (including automated VSLs).
- PennDOT calculates the distance to the location of the slowdown based on detection or probe data and the upstream CMS and then:
  - Governs the posting of automated warning messages using set business rules, typically in response to computed vehicle speed differentials.
  - Provides an alarm to TMC operators.

PennDOT Queue Warning Messages (2/3)

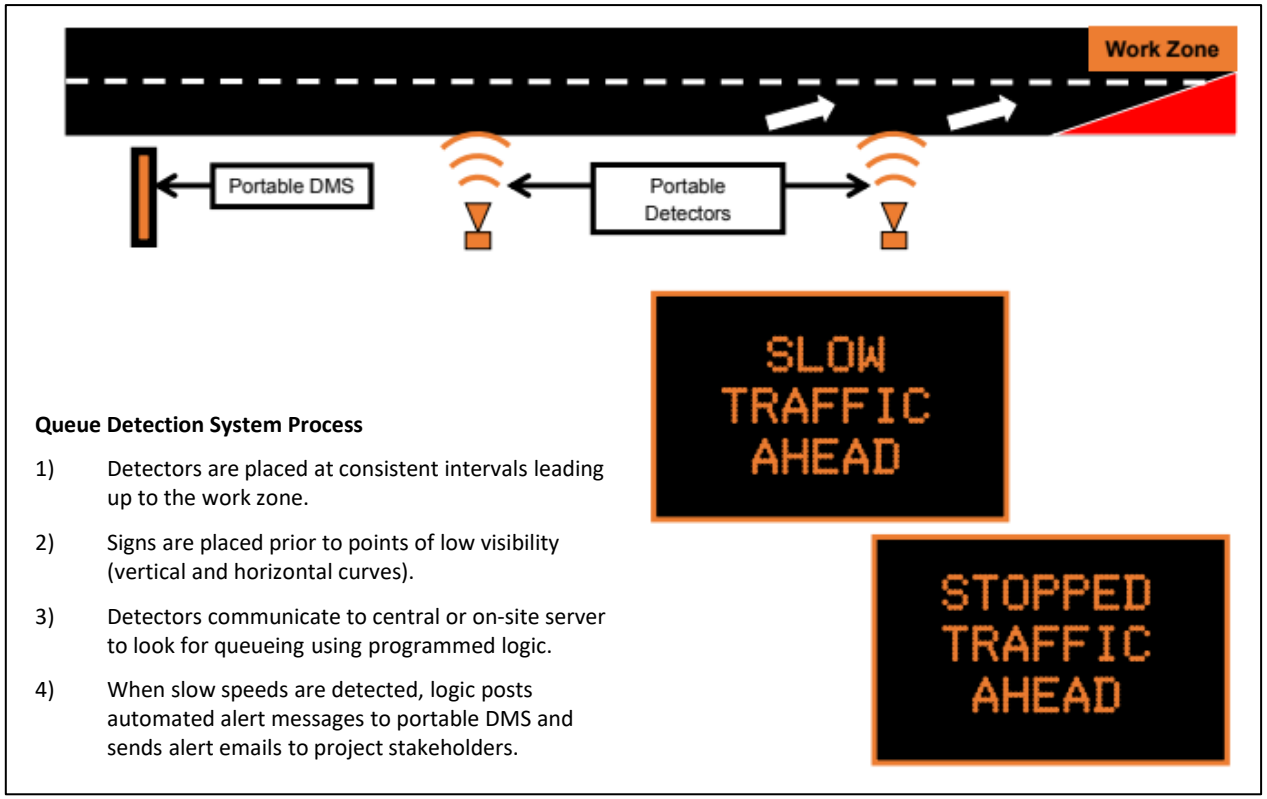
- General criteria to select work zones for the display of queue warning messages is as follows:
  - Work zone has limited access route or “higher average daily traffic route equivalent.”
  - Project duration is 6 mo or greater (with some exceptions).
  - Work zone has access to permanent or portable CMSs that are on the statewide network or have compatible modems.
- Collaboration among district traffic staff that develop work zone traffic management plans and central office staff that manage the TMS includes:
  - Identifying relevant devices and locations.
  - Confirming desired messages.
  - Establishing a geofence around the area where queue warning messages will be displayed along the corridor.
- Designs are underway for TMS upgrades to display queue warning messages along other corridors (like the I–76 managed corridor) as part of larger freeway management upgrades in the Philadelphia and Pittsburgh regions.

PennDOT Queue Warning Messages (3/3)

- Requirements for display of queue warning messages:[5]
  - Statewide or regional TMS.
  - Vehicle probe data subscription ingested into the TMS.
  - Networked permanent or portable CMS that communicates back to the TMC.
  - Probe data road segmentation tool to calculate travel times.
  - TMS software module functioning at the corridor level to associate devices to ingested data.
  - Business rules engine that maps data and operator inputs to CMS messages.
- Role of a TMC operator:
  - Mostly supervisory.
  - Incorporated into duties to monitor traffic conditions, alerts, and facilitate traffic management decisions or incident or event response.

Iowa DOT Queue Warning Messages[1]

- Iowa DOT regularly displays queue warning messages in advance of work zones on freeways and ramps.
- Iowa DOT integrates assets used to manage and monitor traffic impacted by work zones with the TMS.
- TMS assets include both portable and permanent changeable message signs (if available), detectors, and cameras.
- Messages are displayed based on speed thresholds; typically, 45 mph indicates a slowdown, and 35 mph indicates stopped traffic ahead.
- TMC staffing levels did not increase to monitor travel conditions and display queue warning messages, as procedures are the same as the procedures used for verifying detected incidents and coordinating responses.



[1]Interview with Iowa DOT, February 2024.

Lessons Learned in Displaying Queue Warning Messages

- Many State DOTs have successfully deployed the use of queue warning messages in work zones and along freeway corridors.
- The display of queue warning messages does not add significant costs to managing and operating TMSs, which use existing assets to display queue warning messages on permanent or portable CMSs.
- The most common sources of data to detect unstable traffic flow or queues are sensors, third-party sources, or crowdsourcing (for example, mobile device applications).
- The display of queue warning messages typically does not increase the number of operators managing and operating a TMS.
- The display of queue warning messages is highly automated, with operators generally performing a supervisory role as a part of regular duties to monitor the roadway system.
- An agency may need staff or contractor support to integrate field devices deployed to monitor traffic conditions and display messages into a TMS to monitor traffic conditions for select work zones.
- The display of queue warning messages enhances the effectiveness of other operational strategies by providing a rationale related to downstream traffic conditions (slowed or stopped traffic).[1]

[1]Palmer, S. and J. Foley. 2018. "US 23 FlexRoute." Presentation. Jackson, MI: Michigan DOT University Region.

Additional Information on Other TMS Practices

- National Operations Center of Excellence (NOCoE) TMS portal.(10)
- TMC Pooled Fund Study (PFS) website.(1)

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Speaker's Notes

Speaker's Notes (1/26)

None.

Speaker's Notes (2/26)

This presentation is organized as follows:

1. TMSs displaying queue warning messages – we cover how TMSs use queue warning messages to address safety, TMS requirements to display queue warning messages, and TMS functions to generate and display those messages.
2. Benefits – we review some of the quantified benefits of TMSs displaying queue warning messages.
3. Key observations and key considerations – we highlight some overarching findings from the state of the practice and important considerations related to TMSs and TMC operators for agencies considering using the display of queue warning messages.
4. Agency practices and examples – we summarize three state DOT examples to explore implementation and outcomes.
5. Lessons learned – we identify several lessons learned from the agencies investigated and industry practice overall.
6. Resources and references – the presentation concludes with some additional resources and references from the research.

Speaker's Notes (3/26)

Queuing conditions on freeway facilities present significant safety concerns.

- Increased potential for rear-end collisions.
- Introduction of shockwaves that disrupt traffic flow upstream of the queue.

Traffic queues may be recurring or nonrecurring.

- Bottleneck or roadway geometry – such as near heavily used off-ramps (especially those that queue back onto the mainline) - recurring.
- Merge areas with heavy on-ramp traffic volumes - recurring.
- Reduction in number of lanes on a freeway - recurring.
- Recurring traffic queues may occur during certain times of the day (e.g., during morning and evening peak periods) or certain times of year (e.g., Friday afternoons in the summer or on routes leading to recreational areas).
- Crash - nonrecurring.
- Reduction in roadway capacity and travel speed due to a work zone - nonrecurring.

Speaker's Notes (3/26) (continued)

TMSs can provide warning messages to alert vehicles before they encounter unexpected, unstable traffic flow conditions. Consequently, drivers are less likely to need to take abrupt action (such as hard braking, abrupt lane changes, or running off the road) to prevent a rear-end collisions.

Given the safety benefits of TMSs displaying queue warning messages, it becomes important to understand the role of TMSs and traffic management center (TMC) operations staff in supporting the deployment and management of queue warning messages on freeways. This includes the actions, decisions, information needs, capabilities, and resources that TMSs and operators may need to support using queue warning messages on freeways.

Speaker's Notes (4/26)

The capabilities needed for a TMS to display warning messages associated with areas of unstable traffic flow may include:(2)

- TMS assets to monitor travel conditions, typically including sensors to measure speeds and/or vehicle flows at multiple points upstream of a potential bottleneck location (e.g., on the approach to a work zone lane closure). Common sources are from loop detectors or microwave vehicle detection equipment. Probe data (e.g., from toll tags or third-party vehicle probes) or crowdsourced data may supplement or substitute for fixed roadway/roadside sensor data. Connected vehicle data is not regularly being used in the display of queue warning messages because of limited CVs on roadways currently.
- TMS software to detect the presence of a queue and select appropriate warning messages based on some message selection logic/algorithm, potentially requiring operator approval and posting.
- Changeable message sign(s) or portable changeable message sign(s) (PCMS) to provide warning messages (e.g., slow/stopped traffic ahead) to the drivers of approaching vehicles.

Overall, displaying queue warning messages does not present significant implications on agency TMSs, as they often rely on existing traffic monitoring sensors. Permanent or portable CMS are used to display the messages. Queue verification may use existing CCTV cameras, viewable at a TMC.

Speaker's Notes (4/26) (continued)

New deployments may require additional sensors to ensure adequate granularity of data to determine queue characteristics. Lane-by-lane data may be important when speed characteristics vary cross the roadway, which is common at high-volume interchanges or freeway exit ramps. Some systems can augment sensors or solely operate with third-party traffic data. Work-zone based deployments typically require temporary, portable sensors and CMS that require integration into an existing communication network and integration with the TMS (unless they operate independently, without remote, supervisory control).

Speaker's Notes (5/26)

Data collected by traffic sensors determine the location of the changing location of the back of queue (BOQ) of stopped vehicles and potentially the location of unstable traffic flow. The sensors capture vehicle speeds and/or lane occupancy at defined upstream locations. (Lane occupancy is typically not determined by sensors for the display of queue warning messages in work zones.) Typical required spacing is one-half to one mile, with potentially closer spacing near the queue generation point, if known (e.g., in the case of recurring bottleneck or ramp-caused queue or work zone). Data is averaged over defined time intervals like one minute and compared against pre-defined thresholds that would warrant a warning message. An algorithm determines when to post messages, where and on what sign(s) to post them, and what they should say.

Two common examples for slow or stopped traffic are shown on the slide.

Speaker's Notes (6/26)

Agencies identify reductions in crashes, severity of crashes, and crash cost savings.

Agencies often use the approach in combination with other strategies resulting in aggregate benefits:

- One of several strategies that improve safety and mobility associated with work zones.
- One of several traffic management operational strategies (for example, lane use control, hard shoulder running, variable speed limits [VSL]) to manage corridors and improve safety and mobility.

Example: Queue warning messages are sometimes used with VSL. The queue warning messages may explain why speeds are being reduced. The combination results in safety and mobility benefits from smoother traffic flow with smaller speed differentials.

Agencies report few quantified benefits though, because displaying queue warning messages is relatively inexpensive to add on to other strategies. FHWA reports that the incremental cost of including CMS on gantries provided for variable speed limits and dynamic lane use control signs to provide queue warning messages is relatively small.

Speaker's Notes (7/26)

Shown are a few examples of quantified safety benefits of displaying queue warning messages. We'll hear more later about the details of the Minnesota DOT and Pennsylvania DOT examples.

Between 2016 and 2018, MnDOT, in conjunction with the University of Minnesota (UMN), operated a prototype system to display queue warning messages at two locations along I–94 westbound near I–35W in Minneapolis. The application used crash prediction algorithms along with traffic speed and headway data to determine if a message should be generated and posted. The first I-94 prototype concluded after two years because a reconstruction project corrected the cause of the queuing. UMN performed an evaluation of the deployment that showed a 56% decrease in crashes and 69% decrease in near-crashes, with the system providing warnings to drivers in those events approximately 35% of the time. However, MnDOT notes there is some concern that the safety benefits may be overstated, as the results pertain only to a specific crash type during a specific time period.

PennDOT's reconstruction of 40 miles of I-78 in Berks County between Fredericksburg and Allentown displayed queue warning messages in the work zones. Preliminary crash data collected six months before and six months after queue warning deployment showed a 12% decrease in crashes, a 23% decrease in the number of injury or worse crashes, and a 24% decrease in possible injury or worse crashes.

Speaker's Notes (7/26) (continued)

TxDOT used the display of queue warning messages upstream of nighttime lane closures during the widening of I-35 in Central Texas consisting of portable radar speed sensors, portable transverse rumble strips, and PCMS. A study estimated that displaying queue warning messages reduced crashes 44 percent compared to not displaying them. Over 216 nights of construction, this equated to 5.7 fewer crashes and a crash cost savings of $1.36 million. Crashes that did occur were less severe. Note, of course, that these benefits also include the use of the portable transverse rumble strips.

Speaker's Notes (8/26)

Next, we'll review several important considerations for agencies implementing the display of queue warning messages.

- Integration with TMSs and sources of data.
- Implications for TMC staff.
- Selection of queue warning messages.
- Prioritization of posting queue warning messages.
- Integration with operational strategies and other messages to manage traffic.

Speaker's Notes (9/26)

There are several important considerations with respect to TMS equipment and integration, as well as the source of data used to detect a queue.

First, an agency must determine the extent the display of queue warning messages uses elements of an existing TMS. It is possible for displaying queue warning message to function separately from a TMS but this approach would forgo the benefits of leveraging existing equipment, communications, and ability to remotely supervise the application. A common exception is standalone work zones that use the display of queue warning messages, where it may be too costly or impractical to integrate with a TMS.

When integrating with a TMS, new deployments may require additional sensors to ensure adequate granularity of data to determine queue characteristics. Lane-by-lane data may be important when speed characteristics vary cross the roadway, which is common at high-volume interchanges or freeway exit ramps. Some systems can augment sensors or solely operate with third-party traffic data. Work-zone based deployments typically require temporary, portable sensors and CMS that require integration into an existing communication network and integration with the TMS (unless, as mentioned, they operate independently, without remote, supervisory control).

Speaker's Notes (9/26) (continued)

A related decision is the source of data to input the queue warning message display algorithm. This is largely driven by availability and quality to satisfy the requirements of the decision-making process. Where available, reliable, and sufficiently robust, probe data or third-party data can provide a good option that doesn't require the need for potentially additional infrastructure. But existing sensors, perhaps with some with modest addition (e.g., microwave detection) could be a viable solution. It's also possible to combine infrastructure data with probe or third-party data. Generally, CV data is not currently a viable option.

An agency will also need to develop or procure software, potentially a module of existing TMS software, to drive the queue warning message logic. Business rules should support the entire application, including addressing issues of criteria for use (e.g., 24/7, congested conditions only, seasonal, etc.) and the role of TMC operators in terms of functions like supervision and message display overrides.

Speaker's Notes (10/26)

The implications for TMC staff for TMSs displaying queue warning messages include their duties and staffing levels. Neither of these are significantly affected beyond baseline operations, because queue warning messages typically function with a high degree of automation.

A TMC operator typically performs a supervisory role as a part of their regular duties to monitor the roadway system for incidents, congestion, or other events. The operator may confirm queue conditions to ensure a trigger is not a false positive and confirm posting of the queue message or override the message if a more urgent or alternative event needs to be communicated.

Increased TMC operator staffing levels are unlikely to be needed given modest increment beyond regular duties that queue warning presents.

However, when queue warning is one element of a TMS, the implications for TMC staff are more significant but reflect the integrated nature of managing a corridor using multiple strategies, such as lane-use control, part-time shoulder use, and/or variable speed limits—along with queue warning.

Beyond TMC operators, an agency may need staff dedicated to work zone planning and contractor support to integrate their equipment into an agency's TMS and TMC if regularly deploying queue warning messages in work zones.

Speaker's Notes (11/26)

Queue warning message display triggers and logic are based on defined speed thresholds, typically free flow conditions, slow traffic conditions, and stopped traffic conditions. Generally, all TMSs follow some variation of comparing freeway free-flow speeds (v) to two speed thresholds: v1 for slow traffic and v2 for stopped traffic. Agencies typically set v1 to be 40 or 45 mph and v2 to be between 20 and 35 mph. The table illustrates some examples.

Speaker's Notes (12/26)

Research related to CV applications including CV-based queue warning concluded that queue warning messages should be displayed on a CMS whenever a TMS is able to detect the end-of-queue condition is detected, and the CMS is not already displaying a higher priority message. Since a queue warning message is of immediate importance to drivers, its priority compared to other messages is generally "equal to adverse weather conditions and just below an incident or crash message."

For Michigan DOT's Flex Route systems, particularly US 23 Flex Route—an eight-mile, four-lane bidirectional facility with part-time shoulder use, dynamic lane control, variable speed advisories, and queue warning—the agency notes that queue warning has the "highest priority" among messages it posts on small CMS mounted on periodic overhead gantries.

Speaker's Notes (13/26)

Queue warning messages are often incorporated into TMSs that dynamically manage recurring and non-recurring congestion based on prevailing and predicted traffic conditions. Integrated strategies can include dynamic lane use control, part time shoulder use, variable speed limits, and ramp metering. These individual strategies generally share the same TMS elements, which include vehicle traffic detection equipment, CMS, and communication equipment.

Queue warning messages are integrated with these strategies through an agency's TMS operating system and share similar functions including collecting and using the same/similar data, relying on algorithms to perform their functions, requiring similar activities of operators, and displaying messages as part of their functions.

Speaker's Notes (14/26)

We have three state DOT examples of using TMSs to actively display queue warning messages: Minnesota, Pennsylvania, and Iowa.

Minnesota DOT piloted several permanent uses of queue warning messages between 2016 and 2022 based on research and testing performed by the University of Minnesota. It currently has one permanent location on a highway heading into St. Paul and regularly uses queue warning as a standard feature of its work zones.

Pennsylvania DOT refers to the display of queue warning messages as "Vehicle Probe Data-Driven Queue Protection Corridors" and has about 30 currently in operation around the state, mostly for work zones that integrate with a TMS and are managed through a TMC.

Iowa DOT also regularly uses queue warning in intelligent work zones, integrating the equipment into a TMS and supervising operation at a TMC.

My fellow presenters will discuss each in more detail. Up first we have [to be confirmed].

Speaker's Notes (15/26)

MnDOT has experience since 2016 with displaying queue warning messages associated with recurring congestion conditions on freeways in the Minneapolis-St. Paul metro region—initially through several prototypes developed by the University of Minnesota.

Deployed in 2016 and no longer in operation, MnDOT developed and deployed TMS assets to display queue warning messages to display queue warning messages on I-35W southbound as traffic approaches a split with Highway 62. The roadway geometry and traffic movements created recurring conditions during peak periods where the lanes of Highway 62 would often back up onto the free-flowing lanes of I-35, creating problematic speed differentials and increasing the likelihood of crashes. The system used five sets of high-resolution vehicle detectors to calculate vehicle headways (gaps) and therefore the presence of a queue. The TMS responded unselectively to all queues that would form and a "SLOW TRAFFIC AHEAD" message would be posted on overhead lane control signs.

Speaker's Notes (15/26) (continued)

Advancing this initial prototype, the University of MN (UMN) developed a more sophisticated algorithm based on the theory that not all congestion events are dangerous, but there are certain traffic conditions that are crash prone regardless of whether they result in standing queues or not, such as isolated, fast-moving shockwaves. By studying queue conditions and data, a crash prone condition methodology was developed and applied to an algorithm that triggered the display of queue warning messages based on computed likelihood of a crash. Two overrides could be applied at the system control layer to limit possible overexposure to drivers, one related to time so no posting takes place at certain times of day to avoid erroneous alerts, and one related to congestion so no posting takes place when vehicles are already traveling slowly. The application of this methodology on I–94 westbound near I–35W in Minneapolis was described earlier when citing the observed benefits of this deployment. A second I-94 location 0.75 mile upstream used during corridor reconstruction attempted to distinguish among differing conditions in four lanes and used separate algorithms for left- and right-side lanes. However, it achieved mixed results and was no longer warranted once reconstruction was completed and the queueing issue largely corrected.

All three prototype displays of queue warning messages on I-35W and I-94 were integrated with the MnDOT Regional Transportation Management Center (RTMC) TMS software. The actual algorithms used to identify which queue warning messages to display ran on a server housed at UMN. The TMS software would poll the UMN server every 30 seconds for possible messages to post (in other words, messages were not pushed to the TMS software). Some delay was incurred from the queue warning trigger/message generation and a separate traffic operations system that controls the refreshing of CMS.

Speaker's Notes (16/26)

The only display of queue warning messages on a permanent basis as of late 2024 is along Highway 52 northbound approaching the Lafayette Bridge that crosses the Mississippi River into downtown St. Paul. As traffic prepares to exit after crossing the bridge, backups can occur, and a large speed differential between the center lane and left and right-side lanes contribute to queue related safety risks. Along with signing and striping improvements along the bridge, in 2021 MnDOT installed a full color overhead sign about one mile upstream suggesting lane assignments and a "STOPPED TRAFFIC AHEAD" queue warning message.

Early evidence suggests some reduction in crashes, but it is not known whether the reduction is attributable to the queue warning, the signing and striping improvements, or both.

The system uses both microwave vehicle detection equipment and loop detectors downstream of the sign and an analytic methodology adapted from MnDOT's temporary work zone TMSs that display warning messages by examining speeds in each lane (rather than an average) to determine when to activate the overhead sign. When there is no queue, the sign displays no message. Operator commitment at the RTMC is simply incidental to normal duties to monitor traffic conditions and manage the TMS.

Speaker's Notes (17/26)

MnDOT regularly uses TMS assets to support work zone management during maintenance and construction projects. Queue warning is a standard feature of these work zones. In the Metro Region around Minneapolis-St. Paul, existing CMS are used to display a "STOPPED TRAFFIC AHEAD" message in advance of select work zones when certain average speed thresholds are met based on data from existing vehicle detection equipment. These applications are connected to the TMS and managed through the TMS software housed at the TMC. If the TMS and signs become unavailable due to the construction, MnDOT will deploy PCMS and integrate them with the TMS software. In Greater Minnesota (outside the Twin Cities region), districts decide whether to require a contractor to use TMS assets to support work zone management.

A senior engineer at the TMC spends roughly half their time on planning and managing work zones, which includes reviewing upcoming work zones and understanding which ones need integration with TMS software to enable queue warning. Throughout MnDOT, approximately 7 to 8 staff work on integrating contractor equipment to enable the use of displaying queue warning messages, totaling roughly 0.5 fulltime equivalent.

Speaker's Notes (18/26)

PennDOT displays queue warning messages using its TMS in several contexts. At the statewide level, it refers to these applications of queue warning as "Vehicle Probe Data-Driven Queue Protection Corridors," because the concept uses probe data rather than traditional traffic detection equipment to detect the presence and location of the queue. One exception is the 12-mile I-76 managed corridor in Montgomery County that also uses remote traffic microwave sensors that provide per-lane speed, volume, and occupancy data at approximately half-mile increments, along with probe data, as inputs into queue warning algorithms. The managed corridor also includes automated variable speed limits.

As of early 2024, PennDOT displays queue warning messages along nearly 30 corridors, most of which experience queuing conditions on a temporary basis due to work zones. The display of queue warning messages can be used anywhere there are concerns about recurring or non-recurring traffic queues leading to crashes. In all cases, the function of and implications on the TMS and TMC resources are largely the same.

PennDOT developed a queue warning "corridor module" that can use traditional traffic detection and/or probe data from an API to feed a queue warning algorithm that dynamically posts messages within defined corridors. PennDOT also uses crowdsourced location and vehicle speed data from users of the agency's mobile app, 511PA to detect slowdowns along specific corridors in the state. The module works by calculating the distance between the location of the slowdown based on detection or probe data and the upstream CMS. A set of business rules governs the posting of automated warning messages, typically in response to computed vehicle speed differentials, and provides an alarm to operators in a TMC.

Speaker's Notes (19/26)

Typically, the new display of queue warning messages originates in the PennDOT Districts, and its most prevalent use is to mitigate the impacts of work zone related congestion. The basic requirements are:

- Use on a limited access route or "higher average daily traffic route equivalent."
- Project duration of 6 months or greater (with exceptions considered on a project-by-project basis).
- Access to permanent or portable CMS that are on the statewide network or have modems that are compatible.

The PennDOT District Traffic Unit responsible for the work zone makes a request to the Traffic Systems and TSMO Performance Unit in the Central Office, which manages the TMS software. The two groups undertake requirements gathering and planning. This exercise includes identifying relevant devices and locations, confirming desired messages, and establishing a geofence around the area where queue warning messages would be displayed along the corridor. Turnaround time for implementation is approximately one to two months.

In addition to the 12-mile I-76 managed corridor, PennDOT is designing others with multiple traffic management strategies that include queue warning; for example, I-476 west of Philadelphia, from I-95 north to Villanova, and along the I-376 Parkway East from Pittsburgh to Monroeville.

Speaker's Notes (20/26)

PennDOT's use of queue warning messages requires:

- Statewide or regional TMS.
- Vehicle probe data subscription ingested into the TMS.
- Networked permanent and/or portable CMS that communicate back to the TMC.
- Probe data road segmentation tool to calculate travel times.
- A TMS software module functioning at the corridor level to associate devices to ingested data.
- Business rules engine that maps data and operator inputs to CMS messages.

PennDOT's use of queue warning messages is designed to be automated. The role of the TMC operator is largely supervisory and incorporated into their ongoing duties to monitor traffic conditions, alerts, and facilitate traffic management decisions or incident/event response. Under certain conditions or in an emergency, there may be a need to override the business rules, depending on the context or severity of the scenario. PennDOT has continued to evaluate and adjust its business rules and the priority of queue warning messages relative to others posted to a CMS, based on feedback from operators. PennDOT believes that managing the display of queue warning messages does not add any substantive time or duties to its TMC operators once they are trained on the relevant procedures. At the managerial level, resources are required to contribute to new project corridor set up and go-live.

Speaker's Notes (21/26)

Iowa DOT regularly displays queue warning messages in advance of work zones on freeways and ramps. Iowa DOT requires TMS assets used to manage and monitor traffic impacted by work zones to be integrated with the TMS software in its TMC. TMS assets used to support monitoring traffic and displaying messages in advance of work zones includes both portable and permanent CMS (if available), detectors, and cameras. Contractor-provided equipment is subject to this requirement. Iowa DOT may supplement detection with third party traffic data. TMC operators monitor both permanent and temporary TMS assets. Messages are displayed depending on speed thresholds, typically 45 mph or less for slowdown and 35 mph or less for stopped traffic ahead messages. The thresholds are adjustable. Integration into the TMS software also allows operators to determine if a false positive occurs and to correct for it and communicate with field staff to let them know something may need to be adjusted.

Even with over 40 active intelligent work zones in recent years (not all with queue warning), Iowa DOT reports no increase in TMC staffing levels, but at times and depending on location, there is an increase in activity level. Monitoring by TMC staff is no different than the procedures operators follow for incident detection and coordinating response and simply requires "vigilance." The display of queue warning is covered by Standard Operating Procedures.

Speaker's Notes (22/26)

Many state DOTs have successfully deployed the use of queue warning messages in work zones and along freeway corridors. A number of applications in work zones function independently of an agency's TMC and do not integrate with a TMS. In some cases, these systems may connect to existing CMS, but are automated through local control. However, there are also good examples of agencies that use components of an existing TMS and integrate with a TMC. Typically, these uses of queue warning messages are enabled by additional software incorporated into the TMS.

Displaying queue warning messages does not add significant costs to managing and operating TMSs, which use existing assets to display queue warning messages on permanent or portable CMS. New equipment may be necessary when sensor coverage is insufficient for the message display decision-making algorithm or if additional CMS are needed at critical locations upstream of the queue source to warn drivers at the appropriate juncture or junctures.

The most common sources of data to detect unstable traffic flow or queues are sensors, third-party sources, or crowdsourced (for example, mobile device applications).

The display of queue warning messages typically does not increase the number of operators managing and operating a TMS.

Speaker's Notes (22/26) (continued)

Displaying queue warning messages is highly automated, with operators generally performing a supervisory role as a part of their regular duties to monitor the roadway system. The level of operator focus may increase with the volume of queue warning deployments, especially if they are regularly used for work zones. Generally though, the demands on a TMC operator's time do not warrant an increase in staffing.

An agency may need staff or contractor support to integrate field devices deployed to monitor traffic conditions and display messages into an agency's TMS to monitor traffic conditions for select work zones.

The display of queue warning messages enhances the effectiveness of other operational strategies by providing a rationale related to downstream traffic conditions (slowed or stopped traffic). For example, when variable speed limits are activated on Michigan DOT's US 23 Flex Route, the use of queue warning messages are also considered. Messages are posted to the CMS stating that slowed or stopped traffic is XX miles ahead, justifying the need of speed limits to be lowered upstream.(8)

Speaker's Notes (23/26)

None.

Speaker's Notes (24/26)

None.

Speaker's Notes (25/26)

None.

Speaker's Notes (26/26)

None.