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]

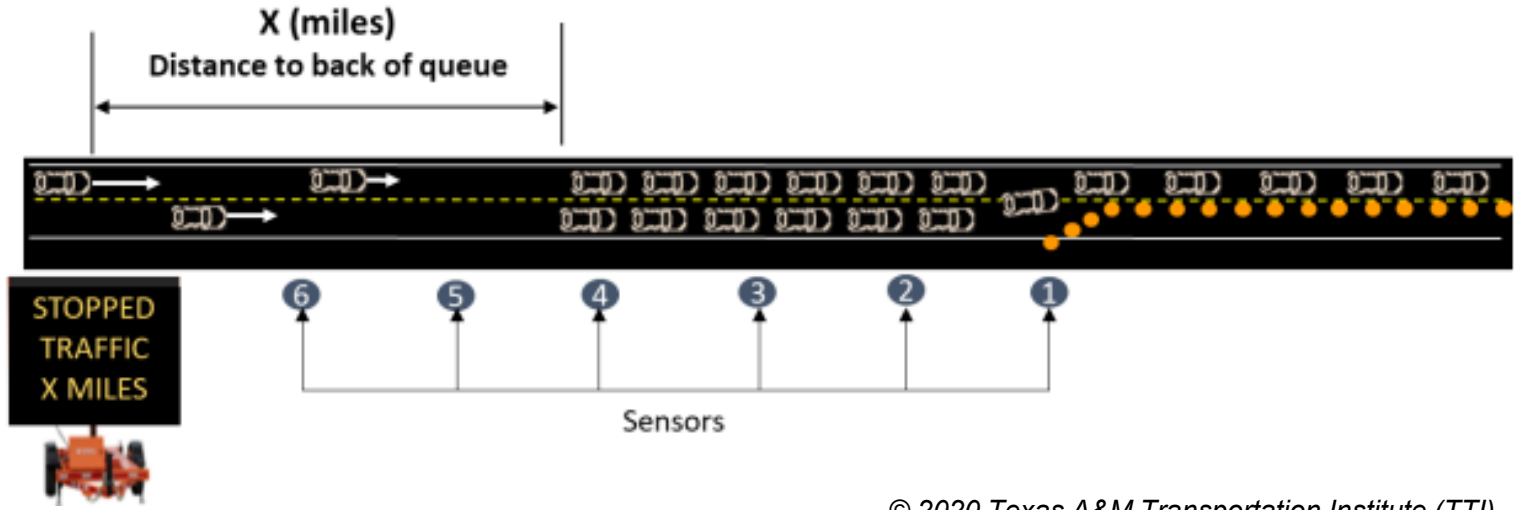
- TMS assets to monitor travel conditions—typically, including sensors to measure speeds, vehicle flows, or both—at multiple points upstream of a potential bottleneck location.
- TMS software to detect the presence of a queue and select appropriate warning messages based on message selection logic or 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)

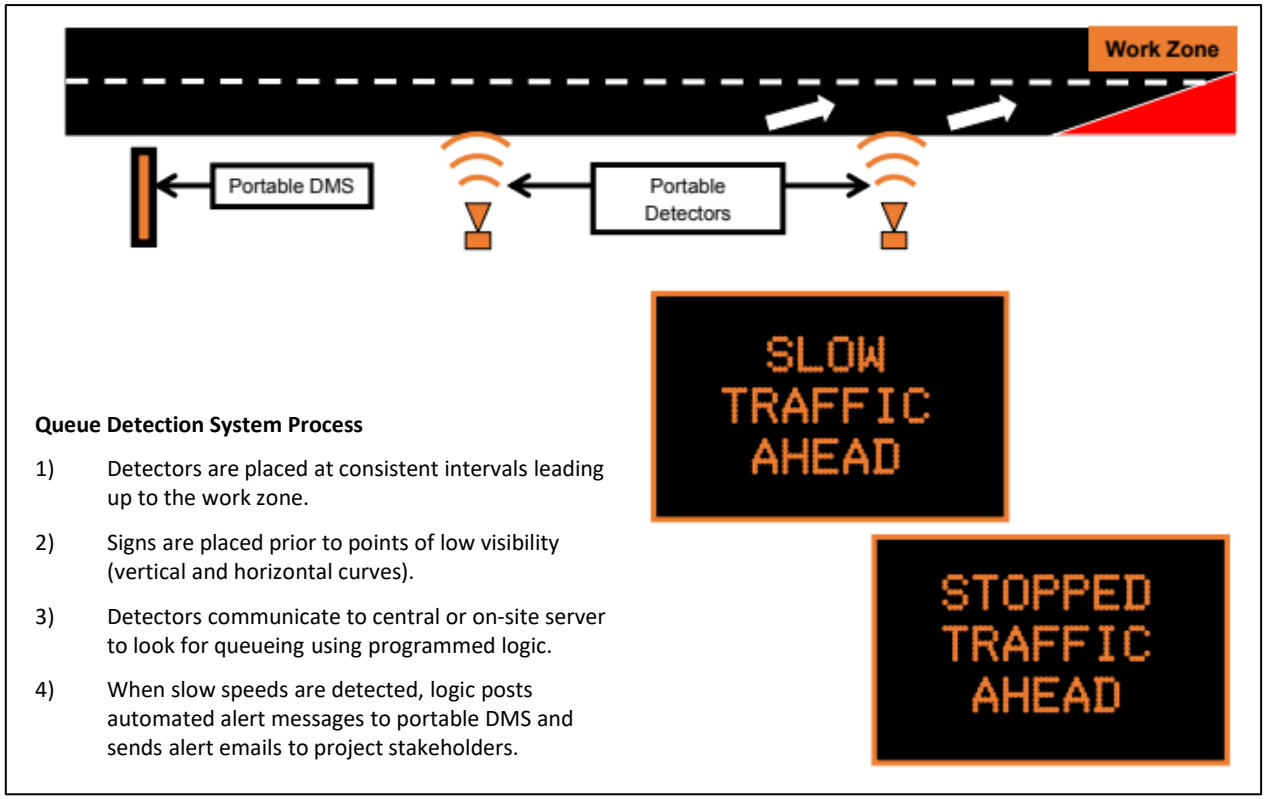
- General criteria to select work zones for the display of queue warning messages is as follows:
  - Work zone has limited access route or “higher average daily traffic route equivalent.”
  - Project duration is 6 mo or greater (with some exceptions).
  - Work zone has access to permanent or portable 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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