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Report to Congressional Committees

September 2023

INTELLIGENT TRANSPORTATION SYSTEMS

Benefits Related to Traffic Congestion and Safety Can Be Limited by Various Factors

Accessible Version

GAO-23-105740

GAO Highlights

Highlights of GAO-23-105740, a report to congressional committees

Why GAO Did This Study

Traffic congestion wastes time and money, and can also jeopardize drivers' safety. Moreover, congestion-related challenges are projected to increase. ITS is designed to improve the performance and/or safety of traffic systems through detecting and communicating information about road users or road conditions, among other things.

The Infrastructure Investment and Jobs Act includes a provision for GAO to review the potential societal benefits of improving the efficiency of traffic systems. This report describes (1) ITS technologies selected state and local government agencies have deployed and (2) the benefits identified from using ITS to manage traffic, and the associated factors and challenges of ITS use.

GAO reviewed information from the most recent (2019 and 2020) DOT surveys (conducted periodically since 1997) of state and local transportation agencies on ITS deployment. Additionally, GAO reviewed relevant studies and publications, and interviewed knowledgeable officials. In particular, GAO interviewed officials from 17 state and local transportation agencies selected to get perspectives from urban and rural locations in geographically dispersed areas where ITS has been deployed to varying degrees. The views GAO obtained from the states and localities are not generalizable. GAO also interviewed officials from DOT, the Department of Energy, and professional organizations and academic institutions with relevant knowledge about ITS.

View GAO-23-105740. For more information, contact Elizabeth Repko at (202) 512-2834 or repkoe@gao.gov.

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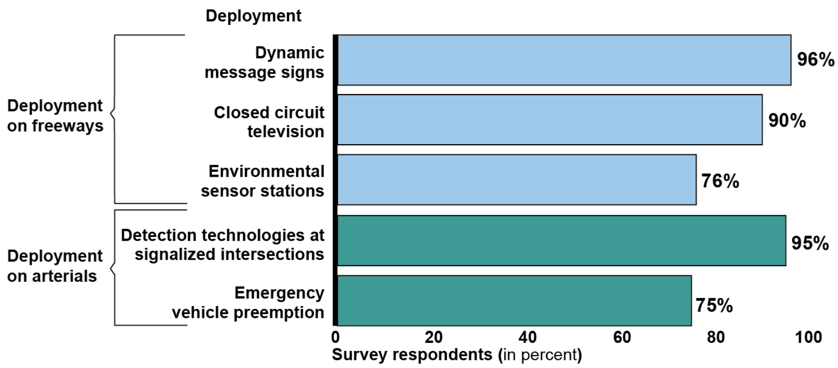
Benefits Related to Traffic Congestion and Safety Can Be Limited by Various Factors

What GAO Found

Deploying intelligent transportation systems (ITS) is one way that state and local transportation agencies have attempted to address issues related to traffic safety and congestion. ITS consists of sensors, computer hardware and software, and communications systems that, for example, automatically change the timing of traffic signals ("adaptive signal control technology"). According to Department of Transportation (DOT) 2020 surveys of state and local agencies, some technologies are widely deployed on arterials (roads with traffic signals) or freeways, while others are less widely deployed. Examples of widely deployed technologies include dynamic message signs, which provide information to travelers; technologies that detect vehicles and other roadway users to provide information on traffic flow; and emergency vehicle preemption, which provides green lights to emergency vehicles (see figure). Examples of technologies deployed by less than 30 percent of survey respondents include adaptive signal control technology and ramp meters that control vehicle access to freeways.

Examples of Intelligent Transportation System Technologies Deployed by 75 Percent or More of DOT Survey Respondents in 2020



Source: GAO Summary of Department of Transportation (DOT) survey information. | GAO-23-105740

Note: DOT surveyed transportation agencies responsible for freeways (response rate 73 percent) and arterials (response rate 68 percent) from 108 medium and large metropolitan areas. Closed circuit television cameras transmit video on traffic conditions in real time, such as to a transportation management center. Environmental sensor stations collect information on roadway conditions.

Survey respondents (in percent)	Deployment on freeways	Deployment on arterials
Dynamic message signs	96	
Closed circuit television	90	
Environmental sensor stations	76	
Detection technologies at signalized intersections		95
Emergency vehicle preemption		75

According to selected state and local transportation officials GAO interviewed and studies GAO reviewed, ITS can provide benefits related to traffic congestion and safety, but various factors and challenges can limit the extent of these benefits. For example, officials said that after a crash, ITS enables them to get emergency services to people and to clear lanes more quickly. Because blocked lanes can lead to secondary crashes, these activities reduce post-crash congestion and improve safety. One study of crash data from 2011 to 2018 on five corridors found that adaptive signal control technology, which is designed to keep traffic flowing smoothly, led to a reduction in crashes of about 5 percent. Many state and local officials told GAO that their ability to realize such benefits depends on sustained funding and leadership. In addition, these officials described challenges to operating their ITS, such as procurement and obsolescence issues, interoperability problems with ITS-related equipment, and staffing-related challenges.

Contents

Abbreviations

ASCE	American Society of Civil Engineers
COVID-19	Coronavirus disease 2019 caused by the virus SARS-CoV-2
DOE	Department of Energy
DOT	Department of Transportation
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
IT	Information technology
ITS	Intelligent transportation systems

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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Congressional Committees

Traffic congestion burdens Americans' quality of life through wasted energy, time, and money; increased pollution; and threats to safety, as we have reported previously.[1] In 2019, traffic congestion cost America an estimated $190 billion in wasted time and excess fuel consumption, and resulted in 36 million tons of excess greenhouse gas emissions, according to a report by the Texas A&M Transportation Institute.[2] Furthermore, the Federal Highway Administration (FHWA) has projected that vehicle miles traveled will increase 22 percent through 2049, which may increase congestion and related challenges on the nation's roads.[3]

One way state and local transportation agencies seek to address congestion is through the deployment of intelligent transportation systems (ITS). ITS is designed to improve the performance or safety of traffic systems through communications, electronics, sensors, and computer hardware and software technologies, among other things, for all road users.[4] Examples of ITS include systems that automatically time traffic lights to maximize the flow of traffic on arterials (roads with signalized intersections) or ramp meters that time the entry of vehicles onto freeways. Technologies such as closed circuit television cameras and dynamic message signs placed above or along roadways are also considered ITS.

[1]GAO. *Intelligent Transportation Systems: Improved DOT Collaboration and Communication Could Enhance the Use of Technology to Manage Congestion,* GAO-12-308 (Washington, D.C.: March 19, 2012).

[2]David Shrank, et. al, *2021 Urban Mobility Report*, Texas A&M Transportation Institute with cooperation from INRIX (Texas: June 2021). The amount of time, fuel, and greenhouse gas emissions beyond what would have been expected at free-flow speeds is considered "wasted."

[3]The Federal Highway Administration's Spring 2022 long-term forecasts of nationwide vehicle miles traveled were based on long-term economic and demographic outlooks produced by the economic forecasting firm IHS Markit.

[4]The term "all road users" includes not just vehicles, but also bicyclists, pedestrians, and other users.

The Infrastructure Investment and Jobs Act includes a provision for GAO to review the potential societal benefits of improving the efficiency of traffic systems.[5] This report describes (1) ITS technologies selected state and local government agencies have deployed, and (2) benefits identified from using ITS to manage traffic in the U.S., and the associated factors and challenges of ITS use.

To describe the ITS technologies that selected state and local government agencies have deployed, we reviewed summary reports about the Department of Transportation's (DOT) 2020 ITS Deployment Tracking Surveys. DOT administered one survey to arterial agencies and one to freeway agencies.[6] We also reviewed DOT's 2019 special topic survey report on connected vehicles and automated vehicles.[7] To determine the reliability of these survey data, we reviewed survey documentation, interviewed DOT officials responsible for the surveys, and examined the underlying survey data. Based on these steps, we found the information in the surveys sufficiently reliable for the purposes of describing survey respondents' ITS deployments.

In addition, we interviewed officials at 17 selected state or local departments of transportation or related traffic management agencies about their deployment of ITS.[8] (See appendix I.) This included a site visit in the Washington, D.C., area to tour transportation management centers

[5]Pub. L. No. 117-58, § 25027, 135 Stat. 429, 881 (2021).

[6]DOT periodically sends the ITS Deployment Tracking Surveys to agencies and has done so since 1997. DOT has sent the surveys to arterial management agencies (agencies that manage roadways with signalized intersections) and freeway management agencies (agencies that manage controlled access roads with no intersections). This survey was sent to 108 large and medium metropolitan areas nationwide with a focus on agencies that serve populations of 50,000 or more. In 2020, the freeway survey had a response rate of 73 percent with 101 completed surveys. The arterial survey had a response rate of 68 percent with 341 completed surveys. Not all respondents answered all the questions.

[7]Similar to its previous ITS Deployment Tracking Surveys, these surveys were administered online to freeway, arterial, and transit agencies from 78 large metropolitan areas and 30 medium size cities (the same survey population as previous ITS Deployment Tracking Surveys). The connected vehicle survey was the most recent special topic survey. The final response rate was 60 percent, including 66 freeway, 301 arterial, and 108 transit agencies. Transit agencies' results are not relevant to our engagement.

[8]Officials from the Virginia Department of Transportation's Staunton and Culpeper Districts participated in the same interview and their remarks were considered together.

and observe ITS infrastructure at several locations.[9] We selected state and local transportation agencies to get a mix of geographic locations, population sizes, ITS deployment levels, and congestion levels. The views we obtained from state and local officials are not generalizable. We also interviewed officials at DOT and the Department of Energy (DOE), as well as stakeholders with relevant knowledge at three professional organizations and two academic institutions based on recommendations from other interviewees and background research. (See appendix I.) Although the perspectives of those we spoke with are not representative of all state and local departments of transportation, they provide relevant information about localities' experiences with ITS.

To describe benefits related to using ITS to manage traffic, we conducted a literature search to identify peer-reviewed studies of ITS benefits published from 2013 to 2022. Based on this literature search, we reviewed 26 relevant publications. We also reviewed 22 additional studies from DOT's ITS benefits database or that DOE officials or other stakeholders recommended.[10] The benefits we report from these studies are examples of the types of benefits found from ITS deployments and are not exhaustive. Findings from these studies are not necessarily generalizable to other deployments of technologies or other locations.

In addition, we analyzed responses from our interviews with selected state and local departments of transportation to determine common themes on (1) benefits from using ITS, (2) factors that influenced state and local agencies' ability to realize those benefits, and (3) challenges

[9]A transportation management center is a place where traffic management staff utilize software systems to control devices along roadways and to monitor data and video collected throughout the monitored area.

[10]We initially limited our review of systems' performance and safety benefits to studies that took place in the U.S., studied an infrastructure-related ITS technology, and incorporated real-world data rather than purely simulations, modeling, or test beds. For the literature search, a librarian conducted keyword searches using Scopus, EBSCO, ProQuest, and Dialog, and identified 40 potentially relevant publications. The search used terms such as *intelligent transportation systems* and *variable speed limit*. Based on a review of titles and abstracts of these studies, we selected 26 relevant studies that we then obtained and reviewed fully for relevant findings. We also identified and reviewed 22 additional studies from various sources. We performed these database searches and identified articles from March 2022 through May 2023. After learning that consideration of environmental benefits is primarily examined through studies that focus on modeling and simulations, we revised these criteria to consider studies focused on modeling or simulations related to environmental benefits only. These studies were identified by DOT's ITS benefits database and through recommendations from DOE officials and stakeholders at ITS America, an industry group.

using ITS for traffic management. We characterized the views of officials from 16 state or local departments of transportation in the following manner: “a couple” means responses from two departments, “several” means responses from three to five departments; “some” from six to 10 departments; and “most” from 11 or more departments of transportation. Due to the varying experiences of officials in the places we selected, not all officials had opinions on all questions or issues during our interviews. Finally, we reviewed studies on the benefits of ITS deployments that state or local officials provided to us, typically from contractors analyzing the results of state or local ITS deployments.

We conducted this performance audit from February 2022 to September 2023 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

ITS Technologies

“ITS” includes many different technologies and devices. These technologies, and the strategies that state and local transportation agencies use for deploying and using them, vary in complexity. At a basic level, technologies such as sensors or cameras on roadways used to detect the number and speed of vehicles traveling along them or monitor local conditions are considered ITS. Other ITS technologies include software systems that use the information provided by such devices to, for example, automatically change the timing of traffic signals or provide information to travelers. See table 1 for some examples of currently deployed ITS technologies.

Table 1: Examples of Intelligent Transportation Systems (ITS) Technologies Currently Deployed in the U.S.

ITS technology	Description	How it works
Adaptive Signal Control Technology	A software system that uses detection technologies to automatically adjust the timing of traffic signals to work with changing traffic conditions.	A central processor in the traffic signal controller evaluates data on traffic volume and speed, and determines whether to adjust the traffic signal timing to improve traffic flow. Adaptive signal control technology in the controller transmits resulting signal timing adjustments to the traffic signals. The process repeats periodically—such as every few minutes—to keep traffic flowing smoothly.
Closed Circuit Television	Video monitoring systems placed along roadways or intersections that transmit video for real-time viewing for uses such as identifying signal outages or incidents.	Closed circuit television cameras are tied into a transportation management center's network so that staff can view the video feed. Some cameras show the same view at all times, while others can be panned, tilted, or zoomed to get multiple views of the same roadway.
Connected Vehicles	Connected vehicle technologies enable the exchange of safety messages among vehicles and the roadway infrastructure.	Connected vehicle technologies use short-range radio signals. Vehicles equipped with transceivers send and receive messages with other vehicles, infrastructure, or mobile devices. Transportation infrastructure equipped with roadside transceivers can receive messages from and send messages to local vehicles to, for example, provide information to drivers about road surface conditions or the time remaining for a green traffic signal.
Detection Technologies	Various devices detect vehicles and other users of the road on a roadway, potentially including pedestrians and bicyclists. Detection technologies include inductive loops and video detection systems (i.e., cameras).	Inductive loops are coils of wire embedded in the pavement; an electric current changes when vehicles pass over them. Video detection systems mounted above intersections identify the presence of vehicles, count or classify them, and/or measure their speed. These devices transmit traffic information to traffic signal controllers that may be programmed to adjust the timing of traffic lights.
Dynamic Message Signs	Electronic road signs used to inform travelers of incidents, travel times, detours, or special events.	Dynamic message signs may connect to a transportation management center, from where the signs can be operated remotely, or they may update messages automatically based on traffic data. For example, software may process information on travel speeds from detection technologies and then automatically post travel times for a particular corridor.
Emergency Vehicle Preemption	Devices that alter planned traffic signal timing to give green lights to emergency vehicles going through intersections.	Equipment aboard an emergency vehicle emits a signal detected by devices at intersections. Software interprets the information and directs the traffic signal controller device to, for example, keep the light green until the emergency vehicle has gone through. (This type of system can use connected vehicle technology.)
Ramp Meters	Traffic signals on freeway onramps that regulate the frequency of vehicles entering freeway traffic.	Detectors placed on the freeway onramp and on the freeway itself feed data on traffic conditions into a ramp meter controller that uses this information to determine how to time the signals allowing waiting vehicles to enter the freeway.

ITS technology	Description	How it works
Road Weather Information System 	A system that processes information from environmental sensor stations along a roadway to alert traffic managers or the public about hazardous conditions.	Multiple environmental sensors along a roadway measure conditions such as visibility or humidity. Software processes and communicates this information to transportation management centers to help with decision-making. In an advanced road weather information system, software may automatically take certain actions, such as displaying a reduced speed limit on a dynamic message sign during hazardous conditions.
Transit Signal Priority 	Adjusts normal traffic signal timing to give priority to transit vehicles (e.g., buses).	A device aboard the bus sends a signal picked up by a detection device along the roadway. These data feed into a software system that determines whether to extend a green light for the bus to cross the intersection. (This type of system can use connected vehicle technology.)

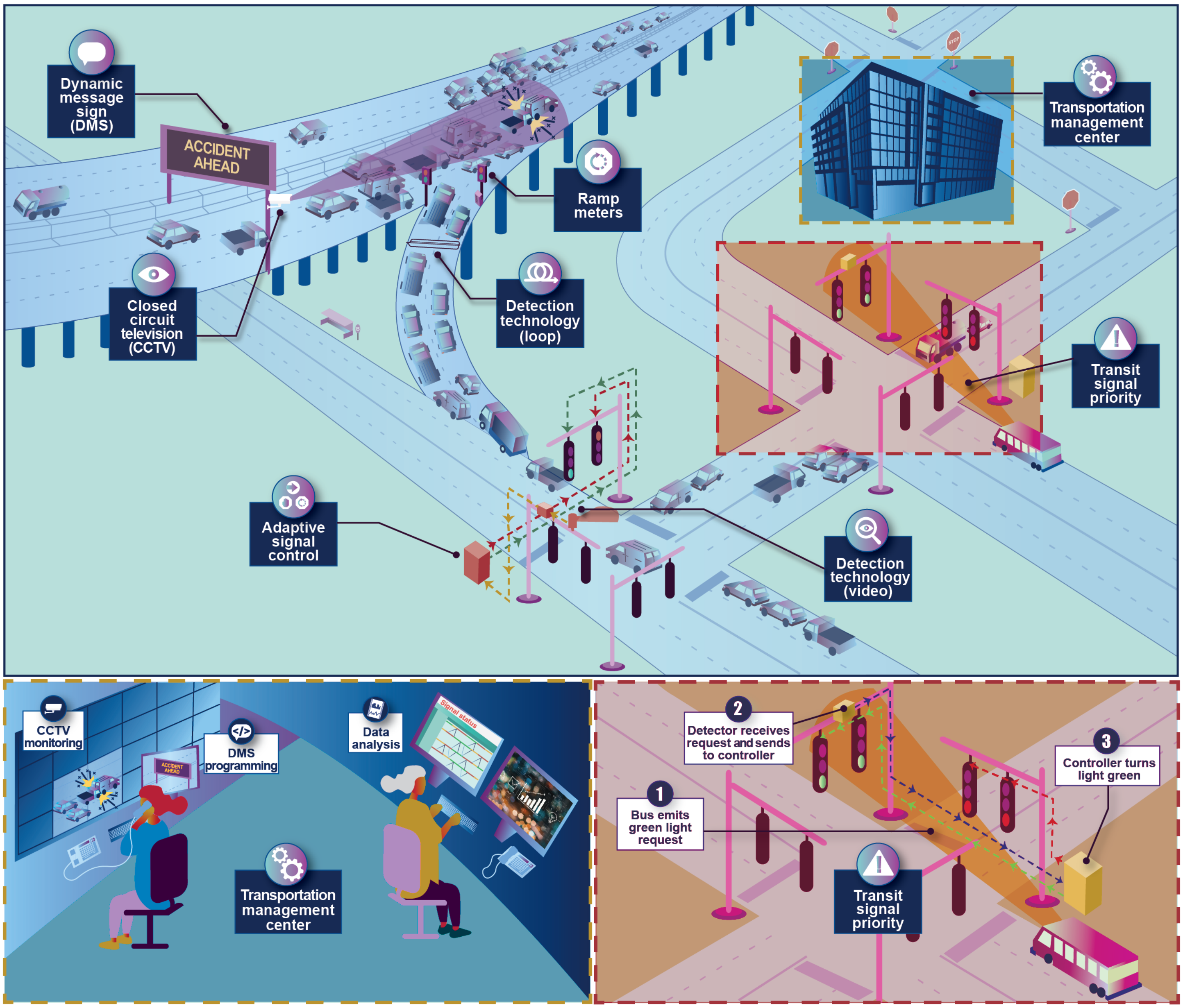
Source: GAO. GAO Visual Communications Analyst icons. | GAO-23-105740

Data from ITS technologies generally feed into a transportation management center. The center's equipment and computer systems enable traffic managers to receive and analyze information from deployed ITS technologies, and in some cases to remotely control the devices. Typically, these centers have large screens showing video feeds from closed circuit television cameras that traffic managers use to monitor traffic, crashes, and other roadway conditions. Data received from other ITS-enabled devices, such as traffic signal controller boxes using ITS computer software, can provide traffic managers with information on the area's traffic signals, such as which lights are green or if a signal has stopped working. Traffic managers analyze this information to help guide their incident management and traveler information strategies. For example, when operators see a crash on closed circuit television video, they may alert the proper authorities and program dynamic message signs in the area to lower the speed limit or suggest an alternate route to approaching drivers.

Examples of ITS Deployments

Often, particularly in highly congested metropolitan areas, various ITS technologies are deployed together, with each addressing different aspects of traffic congestion and roadway safety. Figure 1 illustrates how some ITS technologies can be deployed together within a jurisdiction to improve transportation management.

Figure 1: Examples of Intelligent Transportation Systems (ITS) Technologies That Can Be Deployed in Metropolitan Areas, and Associated Transportation Management Center Activities and Communications Infrastructure



Source: GAO; Intelligent Transportation System technologies. GAO Visual Communications Analyst illustrations. Monitor screen image (right); Tierney/stock.adobe.com. | GAO-23-105740

Note: Adaptive signal control is a software system that uses detection technologies to automatically adjust the timing of traffic lights for changing traffic conditions. Closed circuit television monitoring systems transmit video for real-time viewing. Detection technologies detect vehicles and other road users on a roadway. Dynamic message signs are electronic road signs that can communicate timely information to travelers. Ramp meters regulate the frequency of vehicles entering traffic on the freeway. A transportation management center (see left-hand box) is a place where traffic managers view video and data collected throughout the monitored area and use software systems to control devices along the roadway. Transit signal priority technology adjusts normal traffic signal timing to give priority to transit vehicles. Transit signal priority function (see right-hand box): (1) The bus emits a green light request that (2) is detected and sent to the traffic signal controller. (3) The traffic signal controller sends the command to turn the signal green.

ITS technologies can work alongside one another to address congestion. Ramp meters and adaptive signal control can be such an example. Ramp meters on freeway onramps control vehicle entry onto the freeway to lessen congestion. If freeway traffic becomes, or is predicted to become, congested, the timing of ramp meter signals preceding that part of the roadway may be altered to slow the rate of vehicles entering the freeway. Slowing vehicles' entry to the freeway could cause a vehicle backup on arterial roadways. In that situation, adaptive signal control technology could detect the congestion on the arterial roadway and trigger signal controllers to change the signal green-light timing along the arterial road to reduce congestion near the freeway onramp.

Different transportation agencies with distinct traffic management responsibilities may operate ITS technologies. For example, a state transportation department may be responsible for deploying ITS technologies on freeways, while the local transportation department may be responsible for ITS on arterials that connect with those freeways. The local transportation department may also work with other local entities to install the roadside infrastructure that some ITS technologies require to function. For example, to enable transit signal priority, a transportation department may work with a transit agency to install and maintain the equipment needed to receive and interpret signals from buses.[11] Furthermore, transportation management staff from different jurisdictions may work alongside each other in a transportation management center for a particular region.

[11]The National ITS Architecture was developed to provide a unifying framework for ITS infrastructure deployment to ensure that technologies, such as those that enable transit signal priority, can work together smoothly and effectively.

DOT and DOE ITS-related Roles

DOT is the primary federal agency with a role in assisting states with ITS deployment. DOT's ITS program includes efforts at FHWA and other administrations within DOT, as well as the ITS Joint Program Office. The Joint Program Office's mission is to lead collaborative and innovative research, development, and implementation of ITS to improve the safety and mobility of people and goods.[12] The ITS program was established by law in 1991.[13] The program conducts research and provides technical assistance to help state and local governments deploy ITS, among other things. The program's stated goals are to develop innovations that advance transportation safety, mobility, and environmental sustainability. DOT officials also told us that equitable access for road users other than vehicles is a policy focus of DOT's ITS program. As part of its work related to ITS and as previously mentioned, DOT periodically conducts and publishes surveys on ITS deployment, and maintains a database on ITS benefits, costs, and lessons learned.

DOE, through its laboratories, funds and oversees some research focusing specifically on ITS benefits related to reducing greenhouse gas emissions. For example, DOE has sponsored research on how reducing congestion has the potential to reduce greenhouse gas emissions. DOE and DOT have both focused recent research efforts on ITS technologies currently in use, as well as emerging technologies such as automated vehicles and connected vehicles.

[12]The ITS program is under the Joint Program Office in the office of the Assistant Secretary for Research and Technology.

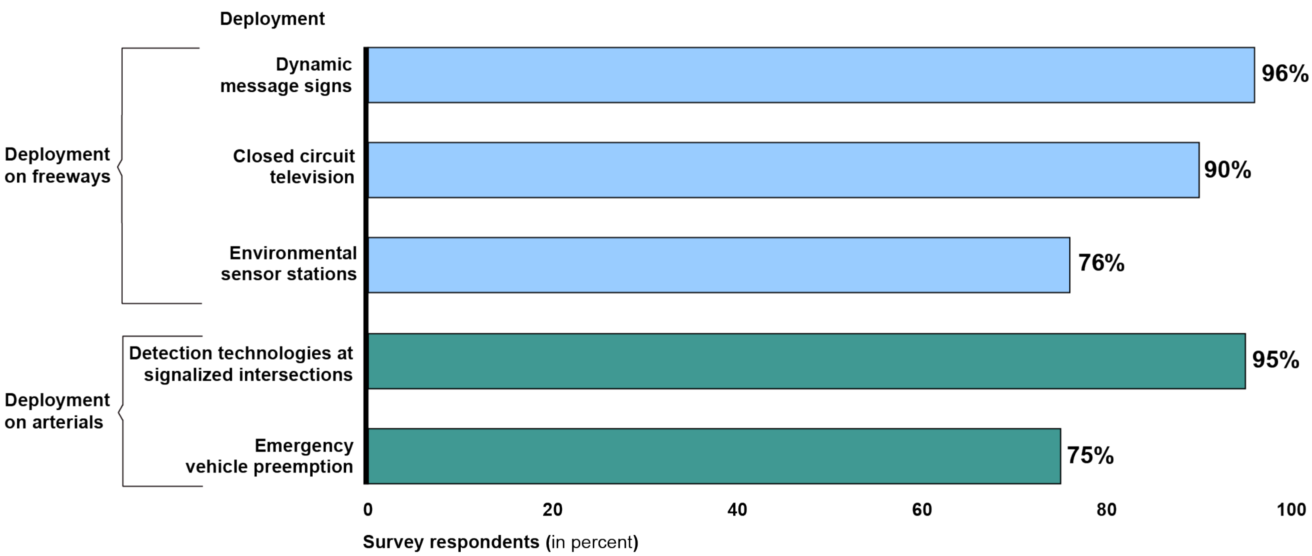
[13]The Intermodal Surface Transportation Efficiency Act of 1991 established an Intelligent Vehicle Highway System (IVHS) program with an initial timeframe of 6 years and authorized a budget of $660 million. Pub. L. No. 102-240, §§ 6051-6059, 105 Stat. 1914, 2189. In February 1994, the U.S. DOT established a Joint IVHS Program Office to coordinate intermodal policy in the implementation of the IVHS program. With policy direction from the Office of the Secretary and Modal Administrators, the Joint IVHS Program Office was located within FHWA. The Office provided overall management and oversight of the IVHS program, including those of FHWA, the Federal Transit Administration, the National Highway Traffic Safety Administration, and the Research and Special Programs Administration. In 1994, the national IVHS program was renamed the ITS Joint Program Office, to clarify the multimodal intent.

State and Local Governments Have Widely Deployed Some ITS Technologies but Others Less So, with Deployment Influenced by Local Priorities

Widely-Deployed ITS Technologies

Some ITS technologies are widely deployed by the state and local transportation departments that responded to DOT's 2020 ITS deployment tracking surveys. (See figure 2.)[14] Several of these technologies have existed and been in use for decades.

Figure 2. Examples of Widely-Deployed Intelligent Transportation Systems (ITS) Technologies among Respondents to DOT's 2020 ITS Deployment Tracking Surveys



Source: GAO summary of Department of Transportation (DOT) survey information. | GAO-23-105740

Note: We considered "widely deployed" to be technologies deployed by 75 percent or more of freeway or arterial agencies responding to the surveys. DOT sent surveys to arterial management agencies (that manage roads with signalized intersections) and freeway management agencies (that manage controlled access roads without intersections) within 108 large and medium metropolitan areas nationwide, focusing on serving populations of 50,000 or greater. The freeway survey had a response rate of 73 percent with 101 completed surveys. The arterial survey had a response rate of 68 percent with 341 completed surveys.

[14]We considered "widely deployed" technologies to be those used by 75 percent or more of survey respondents for either freeway or arterial agencies.

Survey respondents (in percent)	Deployment on freeways	Deployment on arterials
Dynamic message signs	96	
Closed circuit television	90	
Environmental sensor stations	76	
Detection technologies at signalized intersections		95
Emergency vehicle preemption		75

Officials we spoke with described using these widely-deployed technologies to monitor traffic or weather, or to provide information to the public about traffic conditions, among other things. For example, officials at several states and localities said they used closed circuit television to see conditions on roadways and to monitor traffic volumes and potential incidents such as crashes. An official in one county told us the agency was placing cameras on tall buildings to watch traffic flow, both within its jurisdiction and between it and neighboring jurisdictions. An official in one state described using dynamic message signs to notify motorists of (1) a crash or road work ahead, (2) travel time to a particular destination, and (3) impending weather events.

Some officials we spoke with also described supplementing or replacing information gleaned from roadside detection technologies with traffic information data purchased for their jurisdictions from third parties.[15] These data are collected mostly through cell phones and other transmitters in vehicles that communicate in real time with global positioning system mapping applications as they drive along the roadways. For example, the company Waze provides a navigation app for users via their cell phones that advises and guides users to their destinations. As vehicles travel, Waze collects and analyzes data, such as traffic speeds, from all its users in an area and provides aggregated traffic information to both the users of the app and its data customers, such as a freeway or arterial agency.[16]

According to DOT’s 2020 ITS deployment tracking surveys, 82 percent of freeway agency survey respondents purchased data from such third-party providers, while 34 percent of arterial agency respondents reported doing

[15]Traffic data generated by monitoring the position of individual vehicles (i.e., probes) over space and time is called “probe data.”

[16]State and local transportation agency officials told us they also use location data from the companies HERE, Google, INRIX, and other companies.

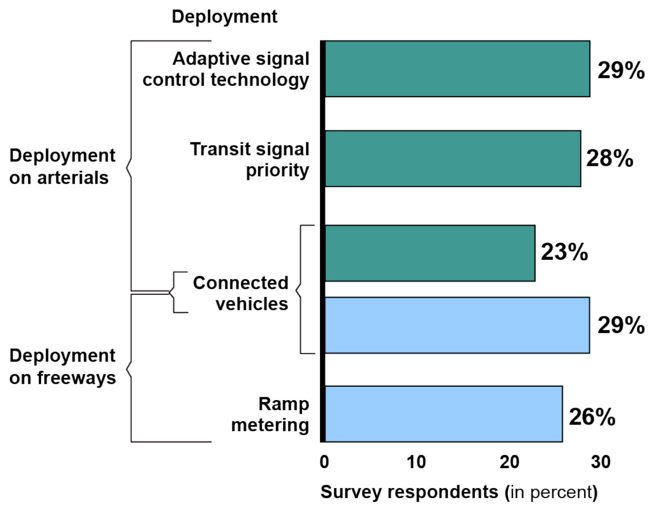
so. Agencies generally use these data to supplement their own traffic detection data collected by their ITS devices stationed along the roadways. While officials at half the freeway agencies we interviewed told us they purchase third-party probe data, one official said their agency relies solely on such data and has stopped using its own physical detection devices on roadways for monitoring and reporting travel times. This official said that the third-party probe data was of similar quality to the data the agency had previously obtained from sensing equipment positioned along roadways but without the maintenance or staffing costs. Another official told us that their agency may move in the future to rely solely on third-party traffic probe data and stop using its own physical detection devices on roadways.

Less Widely-Deployed ITS Technologies

Other ITS technologies, even some that have existed and been in use for over a decade, have not been adopted as widely by respondents to DOT's 2020 ITS deployment tracking surveys.[17] (See figure 3.) For instance, according to respondents, adaptive signal control technology was not widely deployed by arterial agencies, and was not widely deployed within the jurisdictions of those agencies deploying it, either. Specifically, of the 29 percent of arterial agency respondents using adaptive signal control technology, the majority (59 percent) reported deploying it at less than 10 percent of their signalized intersections.

[17]We consider "less widely deployed" technologies to be those used by greater than zero but less than 30 percent of survey respondents for either freeway or arterial agencies.

Figure 3. Examples of Intelligent Transportation Systems (ITS) Technologies Deployed Less Widely by Respondents to DOT Surveys



Source: GAO summary of Department of Transportation (DOT) survey information. | GAO-23-105740

Note: We considered technologies to be "less widely deployed" if used by greater than zero to 30 percent of freeway or arterial agencies responding to the surveys. DOT sent surveys to arterial management agencies (that manage roads with signalized intersections) and freeway management agencies (that manage controlled access roads without intersections) within 108 large and medium metropolitan areas nationwide, focusing on serving populations of 50,000 or greater. The information on technologies other than connected vehicles comes from 2020 surveys. The 2020 freeway survey had a response rate of 73 percent with 101 completed surveys. The 2020 arterial survey had a response rate of 68 percent with 341 completed surveys. The information on connected vehicles comes from a 2019 DOT survey of the same populations on the deployment of connected vehicles and automated vehicles. The final response rate was 60 percent, including 66 freeway and 301 arterial agencies. It also included 108 transit agencies, but the information provided by transit agencies is outside of the scope of this review.

Survey respondents (in percent)	Deployment on freeways	Deployment on arterials
Adaptive signal control technology		29
Transit signal priority		28
Connected vehicles	29	23
Ramp metering	26	

Officials at several of the arterial agencies we interviewed said they deployed some of these less widely-deployed ITS strategies, like transit signal priority or adaptive signal control technology, in specific instances where they thought it suited the roadway conditions and would fulfill traffic management needs. For example, officials at a couple of agencies said they deploy transit signal priority on specific corridors throughout their jurisdictions to reduce transit travel time and improve reliability to encourage more use of public transportation. Similarly, officials at one agency said they use adaptive signal control technology to automatically re-time lights to manage the flow of traffic around a shopping mall, where the volume of traffic can vary significantly and irregularly. In contrast, officials at one agency said traffic managers do not see the need to deploy adaptive signal control technology because they use other strategies. For example, these managers are able to closely monitor traffic patterns using detection technologies and remotely adjust traffic signal timing in response to traffic changes. Additionally, many of their traffic signal systems can reset signal timing from a bank of predetermined patterns in response to changes in traffic data. These officials said these strategies adequately address their traffic congestion issues.

Officials in a couple of locations described limited use of connected vehicles.[18] These state or local transportation agencies had developed connected-vehicle corridors by deploying roadside transceivers along selected roads that pick up information from connected vehicles and send it to a roadside signal controller or other infrastructure. "Smart" infrastructure can then send back information to drivers on signal phasing and timing, such as if a traffic signal is red and how soon it will turn green. For example, officials in one city described deployment of transit signal priority by placing connected-vehicle equipment for that purpose at intersections along specific corridors. Buses transmit data about their location and speed to infrastructure that analyzes it and, if needed, transmits instructions to alter a traffic signal's green phase to accommodate the bus.

Officials in another locality created a 4-mile connected vehicle corridor by equipping 15 intersections with roadside transceivers that can communicate with vehicles that have connected-vehicle technology installed.[19] Although not widely deployed overall, DOT's 2019 survey on connected vehicles and automated vehicles found that emergency vehicle

[18]Connected vehicles are equipped with an onboard transceiver that can send and receive messages with other vehicles, infrastructure, or mobile devices.

[19]Some connected vehicle corridors rely on dedicated short range communications, which run on a particular band of spectrum. Equipment for dedicated short range communications includes on-board transceivers (i.e., units on-board the connected vehicles) and roadside transceivers. An on-board unit is a transceiver that is normally mounted in or on a vehicle. A roadside unit is a transceiver that is typically mounted along a road or pedestrian passageway. The roadside unit broadcasts at, or exchanges data with, on-board units in its communications zone. We discuss issues related to connected vehicles and dedicated short range communications service later in this report.

preemption, transit signal priority, and intelligent traffic signal systems were among the most deployed or planned applications for connected vehicles among survey respondents.[20]

Local Priorities Affect How Transportation Agencies Use ITS

Officials told us that local priorities or conditions largely drove their deployment of ITS technologies. For example, officials in three cities stated that, due to significant regional growth and an inability to add or widen roads, enabling increased numbers of vehicles to move on existing roads was a high priority. As a result, they use ITS, such as adaptive signal control technology, to increase roadway efficiency. This enables existing roads to accommodate more vehicles during peak hours by lessening congestion. In another example, state officials said that, in a rural area they manage, they are less concerned with recurring congestion (such as from regularly occurring peak travel hours) and, instead, primarily use ITS to help with incident management and safety, particularly related to weather. They stated that closed circuit television cameras are useful for monitoring roadways for incidents and mobilizing responses to them; additionally, they have a fog warning system, similar to that described below, to warn drivers of foggy conditions.

Officials in a few localities we spoke with said that one of their priorities was to create more opportunities for bicyclists and pedestrians to safely travel along roadways and be in public spaces. Officials in one small city described a historical focus on multimodal transportation, with dedicated bus lanes and other pedestrian and transit priority efforts. They said that efficiency gains from using ITS had enabled them to repurpose roadway space for bicyclists and pedestrians without negatively affecting vehicle traffic. Officials in another small city similarly described repurposing roadway efficiency gains from using ITS to create a more walkable and bicycle-friendly downtown area.

Officials in several localities also described prioritizing safety and mobility for pedestrians, bicyclists, and transit in their ITS deployment planning. For example, officials in one state said they are utilizing a pedestrian smartphone app that uses text-to-speech. This function allows pedestrians to hear the traffic signal status on their phone, access

[20]The 2019 survey also inquired about automated vehicle use. However, this was largely focused on automated vehicle testing, which is outside the scope of this report.

information like street names and directions, and activate crosswalk signals without having to locate or touch push-buttons. Officials at another location said that in recent years, safety for vulnerable road users like pedestrians and bicyclists has become a priority. To facilitate that, the county currently deploys detection technology that can detect bicycles, and they are considering having the detectors interact with the traffic lights to change the timing of the lights when there is a bicycle crossing. In addition, this locality's officials said that they have changed the emphasis on some signals from moving as many vehicles as possible through intersections to promoting the movement of pedestrians, bicyclists, or transit.

ITS Benefits Were Influenced by Various Factors and Challenges

ITS Benefits Include Improved Safety, Reduced Congestion, and Operational Efficiency

According to federal, state, and local officials we talked to and studies we reviewed, ITS has resulted in some safety- and congestion-related benefits, as well as some potential environmental benefits. ITS has also made transportation operations more efficient, enabling state and local officials to manage their roadways with limited staff.

At the same time, most state and local DOT officials we spoke with stated that the benefits they experienced were hard to quantify. For example, officials in one state explained that it has been challenging to demonstrate benefits from some of the ITS they use to manage traffic, such as dynamic message signs or cameras. Even with these limitations, state and local DOT officials were able to describe benefits they had observed from their ITS deployments.

Safety Benefits

According to most state and local transportation officials we spoke with and studies discussed below, ITS has provided safety benefits such as improved incident response, reduced crashes, and reduced speeds under hazardous conditions. For example, officials we talked to said that ITS improved their ability to respond to incidents and get emergency services to people more quickly. One state official explained that ITS—using a variety of technologies including detectors, dynamic message signs, closed circuit television cameras, and highway advisory radio—enabled them to monitor traffic conditions and clear lanes more quickly, which helps reduce secondary crashes.[21]

Officials in two localities mentioned that some of their ITS had resulted in safety benefits for pedestrians. For example, in one county, officials said they installed flashing beacons with communications infrastructure at crosswalks that improved pedestrian safety in two ways. First, they said that the flashing beacons had high compliance rates in terms of vehicle drivers stopping, which improved pedestrian safety. Second, they said that the communications infrastructure embedded in the flashing beacons provided the traffic department real-time and historical information on how often and at what times pedestrians pushed the button to activate each beacon. The department has analyzed this information to further improve pedestrian safety by, for example, potentially adding a traffic light or sign when the level of pedestrian traffic warrants it.

In another example, a study that analyzed crash data from 2011 to 2018 on five corridors with adaptive signal control technology indicated a total reduction in crashes of approximately 5 percent after this technology was deployed.[22] Another study showed reductions in mean speeds after the activation of a variable speed limit system in a foggy area of a rural freeway, from 2016 to 2017. Drivers drove closer to the safe speed in low-visibility conditions after activation of the system. (See text box.)[23]

[21]Highway Advisory Radio has been in use since the 1970s as a tool for government organizations to report public information via radio. It is most often used by departments of transportation to report about road conditions, construction, and other traffic conditions.

[22]John H. Kodi, Angela E. Kitali, Thobias Sando, Priyanka Alluri, and Raj Ponnaluri. “Safety Evaluation of an Adaptive Signal Control Technology Using an Empirical Bayes Approach,” *Journal of Transportation Engineering Part A: Systems* 148, no. 4 (2022). doi: 10.1061/JTEPBS.0000652.

[23]Daniela E. Gonzales, M. D. Fontaine, and N. Dutta. “Impact of Variable Speed-Limit System on Driver Speeds during Low-Visibility Conditions,” *Journal of Transportation Engineering Part A: Systems* 145, no. 12 (2019). doi:10.1061/JTEPBS.0000282.

Variable Speed Limit System for Fog in Fancy Gap, Virginia

In Fancy Gap, Virginia, a variable speed limit system was installed in a foggy area of I-77 and activated in October 2016. According to the study, the road traveled through mountainous terrain with steep grades in an area prone to severe, recurring fog events. It had been the scene of numerous fog-related incidents in recent years, including a 95-car chain-reaction crash in 2013. Prior to the deployment of the new system, the Virginia Department of Transportation had installed fixed dynamic message signs to provide advance warning of foggy conditions. However, given the severity of the fog crash events, state officials wanted to install a system that provided more continuous, direct feedback to the drivers along the corridor about the safe travel speed for conditions.

The new project deployed a combination of dynamic message signs, full matrix variable speed limit displays, speed limit signs with dynamic variable speed limit cutouts, closed circuit television cameras, traffic sensors, and road weather information systems. Power and fiber optic communications had to be added to support the project. Dynamic message signs were installed at the start of the corridor and throughout the site to warn users of fog conditions and reduced downstream speeds. The base regulatory speed in the corridor is 65 miles per hour but the variable speed limits can post speeds as low as 30 miles per hour when conditions dictate. The various devices continuously collect traffic, weather, and pavement condition information as well as visibility data. These data are fed into a system that uses an algorithm to determine the posted speed limit, which is sent out to the variable speed limit signs.

Source: GAO summary of information from *Journal of Transportation Engineering, Part A: Systems*, with permission from ASCE | GAO-23-105740

Note: Article entitled "Impact of Variable Speed-Limit System on Driver Speeds during Low-Visibility Conditions," https://doi.org/10.1061/JTEPBS.0000282.

Congestion-related Benefits

According to most state and local transportation officials and a study, discussed below, ITS technologies have also provided congestion-related benefits, such as less time stopped at red lights, less time spent traveling, and improved mobility through a region. Officials in different places cited different ITS technologies as helping with congestion. An official in one state explained that better coordination of traffic lights helped keep traffic moving; an official in another state cited adaptive signal control as a technology that can improve congestion. An official in a third state described using closed circuit television cameras to monitor traffic flow, including early detection of and response to incidents, which improved congestion resulting from such incidents according to the official.

Additionally, a study of two different coordinated ramp metering systems on two freeway corridors in Northern California using data from 2016 through 2019 found reductions in morning and evening peak period travel times. Specifically, the study reported reduced vehicle hours of travel of 2 to 9 percent depending on corridor and time of day. The authors of the study also reported a 2 to 15 percent improvement in travel-time reliability during peak periods, using the travel time index, depending on the road section and direction of travel.[24] This study also highlighted the difficulty of measuring benefits from ITS. Specifically, it concluded that both ramp

[24]The travel time index represents the average additional time required during peak times as compared to times of light traffic.

metering systems improved corridor traffic performance. However, differences in the characteristics of each corridor and ITS implementation made it difficult to compare the performance of the two systems and their overall effectiveness.[25]

One local agency moved some of its ITS technologies to different intersections to increase the level of benefits from the deployment. This agency described using an evaluation to alter how it operationalized transit signal priority in order to increase its congestion-related benefits. (See text box.)

Transit Signal Priority in Washington, D.C.

Officials at the District Department of Transportation (DDOT) in Washington, D.C., described their willingness to evaluate and alter their deployed intelligent transportation systems as an important component of realizing benefits. Specifically, they told us that after they installed transit signal priority throughout much of the downtown area, several evaluations by DDOT and the Washington Metropolitan Area Transit Authority found that transit signal priority was not equally effective in every route where it was installed. Specifically, although their transit signal priority system had improved the ability of many buses to stay on schedule, some of the intersections in downtown had so much traffic and needed such substantial time for pedestrian crossings that transit signal priority did not significantly improve the ability of buses in those areas to stay on schedule.

As a result, DDOT relocated traffic signals with transit signal priority equipment from 40 intersections where it was found not to be as effective as they had expected, to intersections where it was expected to be more effective. When they relocated the signals, they moved them to more disadvantaged parts of the city, which allowed them to further equity goals as well as congestion-related goals. According to officials, the primary objective of this move was to maximize system effectiveness by focusing on areas exhibiting the greatest potential for traffic efficiency and time-saving benefits, which also promoted equity.

Source: GAO | GAO-23-105740.

Some state and local transportation officials emphasized that safety benefits and congestion-related benefits are often interrelated. For example, one state official emphasized that clearing lanes more quickly helps reduce secondary crashes (a safety benefit of crash avoidance) and allows traffic to flow again more quickly (a congestion-related benefit of clearing lanes).

Potential Environmental Benefits

ITS technologies also have the potential to provide environmental benefits, according to DOT and DOE officials and several state or local officials we interviewed. According to some studies we reviewed, ITS-related environmental benefits could occur through ITS technologies that reduce congestion or increase safety. With regard to mobility, a DOT-sponsored white paper noted that ITS technologies that reduce

[25]Michael Mauch and Alexander Skabardonis, *Evaluation of Coordinated Ramp Metering (CRM) Systems in California,* California PATH Final Report (UCB-ITS-RR-2020-02). March 30, 2021.

congestion, engine idle time, and unproductive fuel consumption can also reduce transportation-related environmental impacts, including greenhouse gas and other pollutant emissions that lead to poor air quality.[26] As we have recently reported, greenhouse gas emissions contribute to climate change through the greenhouse effect, a process in which atmospheric gases trap reflected sunlight, warming the planet. Transportation activities, mostly light-duty vehicles, are the largest source of emissions, accounting for 29 percent of total U.S. greenhouse gas emissions in 2021, according to the Environmental Protection Agency.[27]

While DOE officials also stated that ITS can have emissions-related benefits, they cautioned that the relationship between reducing congestion and emissions is complex. For example, according to DOE officials, one concern when considering the effects of ITS on emissions is whether any congestion-related benefits cause an increase in drivers on the road. Specifically, officials told us that ITS technologies that reduce congestion have the potential to reduce vehicle emissions, especially when vehicles are idling in traffic jams. However, these efforts to ease congestion could result in encouraging people to drive more, which could result in an overall increase in emissions.

We found several examples of research on environmental benefits based on optimizing signal timing through ITS. For example, one pilot study analyzed data from October 2020 to February 2021 on a highly congested segment of a road in Henderson, Nevada, that used adaptive signal control technology. The authors of the study calculated that signalization timing led to lower emissions.[28] Another study, conducted in February 2020 in Chattanooga, Tennessee, found that when engineers implemented optimized traffic signal timing at four signal controllers along

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[26]Matthew Barth, Guoyuan Wu, and Kanok Boriboonsomsin, *Intelligent Transportation Systems for Improving Traffic Energy Efficiency and Reducing GHG Emissions from Roadways: A White Paper from the National Center for Sustainable Transportation*, November 2015.

[27]GAO. *Climate Change: State and Local Efforts to Reduce Greenhouse Gas Emissions from Vehicles*, GAO-23-106022 (Washington, D.C.: August 3, 2023), and Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021*, EPA 430-R-23-002 (2023).

[28]Ludian, *Eastern Avenue Adaptive Signal Control Technology: Final Report*, March 2021.

a corridor, the resulting changes reduced energy usage along the corridor.[29]

Specifically, a simulation showed that optimizing the traffic signals reduced fuel consumption during afternoon peak hours from 542 gallons to 452 gallons, a 16.6 percent reduction. The study also collected real-world data over 2 days after optimization, which showed reduced energy usage along the corridor. However, the study was paused because of the COVID-19 pandemic, which meant that the researchers did not have enough data to make a statistically significant determination. In June 2021, another analysis of simulations focused on the same corridor found reduction in energy usage of 1 to 5 percent from optimizing signals.[30]

In another example, a case study of a signal-retiming project on a corridor in Indiana calculated that resulting reductions in travel time could cause a nearly 1,000-ton reduction in carbon dioxide emissions over a year. The case study used real-world data collected in 2012 for a week before and a week after the signal retiming.[31]

DOE-funded studies have also looked at the potential of connected vehicles to reduce the effect of vehicles on the environment, including by combining connected vehicles and signal optimization efforts.[32] According to these studies, connected vehicles offer the potential for reductions in travel time and energy usage if there is a sufficient penetration of

[29]Qichao Wang and Joseph Severino, et al. *Offline Arterial Signal Timing Optimization for Closely Spaced Intersections,* published in 2021 IEEE Green Technologies Conference, April 2021. In this study, researchers optimized the timing of traffic lights on a busy corridor using traffic simulation models and then convinced engineers to implement changes based on its results at four different signal controllers.

[30]Qichao Wang and Joseph Severino, et al. *Deploying a Model Predictive Traffic Signal Control Algorithm-A Field Deployment Experiment Case Study,* published in 2022 IEEE 25th International Conference on Intelligent Transportation Systems, October 2022.

[31]Christopher M. Day, Darcy M. Bullock, et al. *Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach,* Purdue University, West Lafayette, Indiana, 2014. doi: 10.5703/1288284315333.

[32]According to a report on connected vehicles by DOE, connected vehicles provide a full description of the vehicle and its path along a corridor to the signal controller through a communications link, such as dedicated short-range communication or possibly 5G. The controller can effectively see all connected vehicles as they approach the intersection. If the percentage of vehicles equipped with connected vehicle technology is sufficient, the controller can infer detailed traffic characteristics with which to further optimize signal timing.

connected vehicles operating along a corridor. For example, according to a DOE summary, researchers developed a traffic simulation model that showed a possible 8 percent reduction in average travel time and 8 percent reduction in energy use when vehicles on the road were fully connected.[33]

In addition, in a simulated environment using real-world data from two roads in North Hollywood, California, and Springfield, Illinois, a DOE-funded study found that these technologies used together may have environmental benefits. The study found that even when connected vehicles make up less than 100 percent of vehicles on the road, environmental benefits can still be realized. Specifically, with the assumption that 40 percent or more of the vehicles on the road were connected vehicles, researchers found it was possible to reduce travel time and energy consumption along these corridors using signal optimization.[34]

DOE also funded research that established a framework with which to assess the energy consumption associated with crashes as a way to consider potential benefits from using ITS technologies that reduce crashes.[35] The framework established in the study considered a variety of direct energy costs from crashes. These included fuel wasted during induced congestion, energy expended to repair property damage, the lost embedded energy of totaled vehicles, and energy impacts of emergency medical services.[36] The study concluded that the energy costs of crashes

[33]U.S. Department of Energy, SMART Mobility: Urban Science Capstone Report, July 2020.

[34]S. M. A. Bin al Islam, H. M. Abdul Aziz, Hong Wang, and Stanley Young, *Investigating the Impact of Connected Vehicle Market Share on the Performance of Reinforcement-Learning Based Traffic Signal Control,* (Oak Ridge, TN: Oak Ridge National Laboratory, June 2019).

[35]Lei Zhu, Stanley Young, and Christopher M. Day. 2019. *Exploring First-Order Approximation of Energy Equivalence of Safety at Intersections: Preprint.* Golden, CO: National Renewable Energy Laboratory. NREL/CP-5400-73405. https://www.nrel.gov/docs/fy19osti/73405.pdf.

[36]The framework was developed to calculate the Gross Domestic Product (GDP)-weighted energy equivalence of safety. The study's authors extracted an equivalency rate from national-level statistics on total energy consumption of the transportation sector and combined this with estimates of total direct and indirect costs for all crashes to create this estimate. Indirect energy equivalent costs considered included the energy equivalent costs of reduced human productivity during rehabilitation after being injured in a crash.

are substantial and, therefore, technologies that can reduce crashes have significant potential value.

Operational Efficiency Benefits

Some state and local officials we talked to also told us that ITS allowed them to monitor and operate equipment remotely, which enhanced their ability to work more efficiently, including better leveraging limited staff. For example, officials at one locality told us they can remotely verify whether equipment is functioning or not, including outside of normal business hours. Furthermore, they said that this ability allows them to respond to problems more quickly and function with the limited staff they have. An official in a state with ITS deployments in rural areas told us the state's road weather information system was helpful for field maintenance staff to learn about road conditions and inform travelers of them by dynamic message signs. They were able to accomplish this from their office, rather than having to travel to distant areas of the state. Additionally, multiple places noted that the ability to operate remotely was particularly beneficial during the COVID-19 pandemic.

Funding and State and Local Leadership Were Factors That Influenced Communities' Abilities to Realize Benefits from ITS

Most state and local transportation officials cited funding and state and local leadership as factors that influenced—either positively or negatively—the extent to which they were able to realize benefits from ITS deployments.[37] For example, officials in one state told us that steady state funding for ITS projects was instrumental in the state's ability to realize benefits from ITS. This funding was flexible and allowed program managers the autonomy to meet their needs, they said, and transportation project leaders generally supported expending resources for ITS. According to these state officials, the funding situation allowed them to comprehensively deploy and operate ITS across the state.

Conversely, in another city, officials told us that, for most of the fiscal year, the department uses its funding to repair and replace defective or end-of-life equipment to improve traffic safety within its jurisdiction. This can limit the funding available to invest in newer technologies, including

[37]Officials we spoke with were not always clear about the source of the funds they discussed.

ITS, according to officials. At the end of the fiscal year, the department may be able to consider installing “extra” equipment, which could include some ITS technologies, but only if they have leftover funds with which to do so. For example, an official explained that when the traffic engineering department wanted to purchase and deploy emergency vehicle preemption technology, it did not have all of the funds available to do so. The city traffic engineer thought that emergency vehicle preemption would enhance safety at a particular intersection, so he asked the fire department to provide the additional funding, $2,000, to allow them to install the system, which the fire department provided.

Having state and local leadership support ITS investments can also be instrumental to successful ITS deployments. For example, transportation officials in one state explained that having an “executive champion” to advocate for investment in ITS was important. In the case of this agency, officials stated that their commissioner understands the benefits of using ITS, including that deploying ITS can be far less expensive and quicker to complete than other transportation projects. With executive support, this state was able to build an integrated system of traffic signals across the state, optimizing traffic signals and traffic flow across the system, according to officials. Conversely, officials in another locality said that local leadership did not see traffic management as a priority. As a result, they explained, they only get 40 to 50 percent of the resources they need to keep up with broken items in need of repair. Officials in this locality described difficulty maintaining existing systems, such as closed circuit television cameras that were beyond their usable lifecycle.

State and Local Officials Described Challenges to Operating Their ITS

Officials we spoke with at the state and local level described challenges to operating their ITS, including procurement and obsolescence issues, interoperability problems, staffing-related challenges, and cybersecurity.

Procurement and obsolescence. Some state and local transportation officials we spoke with described procurement and obsolescence issues as hindering their ability to operate ITS effectively. For example, one city official said lead times in procuring equipment can be so long that by the time the equipment arrives, it is outdated. Furthermore, it can take the city over a year to procure basic items, which affected the city’s ability to implement projects in a timely fashion. Obsolescence was also a challenge. For example, according to a local official, one city will soon be unable to get needed parts for old equipment. Specifically, officials said the city will soon need to replace signals at 1,600 intersections when the company that made the signals stops making replacement parts in the next few years. Planned obsolescence by equipment manufacturers was also a challenge. For example, officials at one local transportation agency said manufacturers may stop supporting old devices when they release new devices. In such cases, when devices fail, the department cannot get the replacement parts for them. Officials in a couple of locations told us that the pace of upgrades for equipment can come as quickly as every few years.

Interoperability. Officials at most state and local agencies we talked with described interoperability challenges, that is, cumbersome or fragmented systems that made it harder for traffic managers to use their ITS technologies. For instance, officials in one department described traffic management staff using multiple computer systems to perform their tasks. These systems were not integrated, creating usability problems for them. Similarly, a few state and local agencies told us that often, different ITS devices have different software and do not work together. As one official noted, this is an increasing rather than decreasing challenge because of the proliferation of new technologies. In another locality, officials described having to band together with other regional agencies to get what their department needed in terms of data and system integration. They explained that they had to force a vendor to work with two of its competitors to bring data together into a useable format, which took considerable effort.

Staffing and expertise. Most officials we spoke with noted state and local workforce challenges. In particular, they described being short-staffed or lacking staff with the right expertise or experience. For example, one city—among the most populous in the state—had two electricians responsible for the maintenance of all traffic signal equipment in the city. Officials said that it would be beneficial to have more than two signal electricians because many of their tasks require two people to complete. Officials described the department as “very small and very busy.” Similarly, in another state, an official explained that the agency had only two engineering technicians for ITS across the entire state. If an issue occurs, one of the two technicians must drive from their office to address the issue.

Officials also identified challenges with finding staff with the appropriate expertise. Officials in one locality we visited explained it was very difficult to find staff with the appropriate technical skill sets and the ability to understand the types of systems they use and what the systems do. Moreover, in the opinion of officials we spoke with in several departments, civil engineers, who have historically worked as traffic managers, do not typically have information technology (IT) expertise, which is key to deploying and using ITS. As a result, in one county, an official explained that ITS deployments require the traffic department to rely on the IT department, which may not understand the traffic engineers' needs and priorities. According to the official, historically, a gap exists between IT and civil engineering perspectives.

Operations and maintenance. Most state and local officials we talked to explained that any benefits realized from ITS depend on successfully operating and maintaining the ITS, which can be difficult, particularly for more complex systems. In particular, some officials we talked to who had deployed adaptive signal control technology said that, while the technology helped them manage traffic, they experienced difficulties regarding operating and maintaining the technology. For example, one local transportation agency deployed an adaptive signal control technology pilot on a corridor. Officials stated that one type of detector they deployed—provided for free from the vendor—required frequent and time-consuming recalibration and was "not worth it," despite being free, because of the many staff hours required to set up and maintain the detectors. This agency continued using its adaptive system with other detection equipment and realized enough positive results that it planned to expand its use of the technology to more intersections.

Officials in a different locality also described operations and maintenance challenges that stemmed from adaptive signal control equipment provided by a vendor that did not fulfill the vendor's promises. These officials explained that an end-to-end adaptive signal control system they had previously installed functioned like a "black box." The vendor monitored the system's performance, controlled the way it managed traffic, and sent technicians out to maintain and make changes to the system.

Although department staff knew the system received inputs, they had no idea how it made its decisions. As a result, when roadway users called to notify them about signal timing or other traffic issues, staff were unable to address the complaints. Officials stated that often the vendor's technicians themselves did not understand the system well enough to troubleshoot problems. Officials explained that the department ultimately removed the adaptive system and transitioned to a system that was easier to operate and maintain. Officials in a couple of other locations also said that they know of vendors that have overpromised the capabilities of their ITS products. This can cause agencies to remove underperforming ITS systems, wasting agencies' time and money.

Cybersecurity. Officials in several states and localities described cybersecurity challenges. For example, one city official explained that cybersecurity has become a bigger challenge over time. Few professionals in the industry have a good understanding of the magnitude of the impact if a breach occurred, they continued. Officials at another agency described a cybersecurity incident in which a hacker got access to its network and sent malware applications through the network. Among DOT survey respondents, nearly one-fifth (18 percent) of freeway and 10 percent of arterial agencies reported experiencing a cybersecurity event that affected their IT systems and/or transportation operations. While we did not evaluate the networks of the state and local transportation agencies we interviewed, we have previously reported on cybersecurity risks to our nation's critical infrastructure, including transportation systems.[38]

Regulatory changes. Officials at some state and local agencies we talked to explained that regulatory changes had created a challenge for connected vehicle technology deployment, with one official stating that regulatory uncertainty in this area was an "enormous" challenge. As we have reported previously, in 2020 the Federal Communications Commission (FCC) repurposed 60 percent of the spectrum formerly reserved for uses including connected vehicle technologies, and changed the communication protocol from dedicated short range communications to another protocol.[39] An interoperable connected vehicle environment relies on, among other things, having a shared communication protocol. The shared protocol provides a "common language" for exchanging information, to ensure, for example, that messages can be reliably and quickly sent and received between vehicle on-board and roadside transceivers. Different protocols are not interoperable, so any connected vehicle environment would need to use one or the other. At the time that FCC repurposed this spectrum, which it had allocated to connected

[38]GAO. *Cybersecurity High-Risk Series: Challenges in Protecting Cyber Critical Infrastructure,* GAO-23-106441 (Washington, D.C.: February 7, 2023).

[39]The other protocol is *long-term evolution cellular-vehicle to everything* (also known as LTE C-V2X). *Use of the 5.850-5.925 GHz Band*, ET Docket No. 19-138, *First Report and Order, Further Notice of Proposed Rulemaking, and Order of Proposed Modification*, 35 FCC Rcd 13440 (2020). GAO. *Connected Vehicles: Additional DOT Information Could Help Stakeholders Manage Spectrum Availability Challenges and New Rules,* GAO-23-105069 (Washington, D.C.: November 22, 2022).

vehicle applications in 1999, much of the connected vehicle deployment in the U.S. had been based on the first protocol.

Officials in one city that had developed a connected-vehicle corridor said the corridor had been based on dedicated short-range communications, and that the allocation of spectrum away from that technology would make it more challenging to successfully use the corridor. Although they said they would be able to rely on cellular communications, they preferred dedicated short-range communications due to its lower cost and better results. An official in another state explained that connected vehicles were a key part of the state's strategy for achieving its safety goals. The official said that they saw connected-vehicle technologies as critical for improving safety, but that the changes FCC has made to the spectrum have caused some agencies and automakers to pause their connected-vehicle plans. Specifically, the official said uncertainty around the spectrum has pushed out widespread use of connected vehicle technology by a few years.

Agency Comments

We provided a draft of this report to the Departments of Transportation and Energy for review and comment. The Department of Transportation provided us with technical comments, which we incorporated as appropriate. The Department of Energy informed us that they had no comments.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Transportation, the Secretary of Energy, and other interested parties. In addition, the report is available at no charge on the GAO website at https://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-2834 or repkoe@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix I.

Elizabeth Repko
Director, Physical Infrastructure Issues

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The Honorable Rick Larsen
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Committee on Transportation and Infrastructure
House of Representatives

Appendix I: State or Local Transportation Agencies and Other Stakeholders Interviewed

State Transportation Agencies

Caltrans
Georgia Department of Transportation
New Jersey Department of Transportation
New Mexico Department of Transportation
Utah Department of Transportation
Virginia Department of Transportation, Culpeper District
Virginia Department of Transportation, Northern Virginia District
Virginia Department of Transportation, Staunton District

County and Municipal Transportation Agencies

Arlington County Department of Transportation
City of Alexandria Department of Transportation and Environmental Services
City of Bridgeport Engineering Department
City of Greensboro Department of Transportation
City of Madison, Department of Traffic Engineering
City of Newark Department of Engineering
District Department of Transportation
Montgomery County Department of Transportation
San Francisco Municipal Transportation Agency

Professional Transportation Organizations

American Association of State Highway and Transportation Officials
Intelligent Transportation Society of America
Transportation for America

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Appendix II: GAO Contact and Staff Acknowledgments

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Staff Acknowledgements

In addition to the contact above, Alwynne Wilbur (Assistant Director); Elke Kolodinski (Analyst-in-Charge); Lilia Chaidez, Saar Dagani, Melanie R. Diemel, Jennifer Franks, Nathan Hanks, Gina Hoover, Sara Usha Maillacheruvu, Marium S. Mukhtar, Jonathan Munetz, Todd Schartung, Melissa Swearingen, Amelia Michelle Weathers, and Jennifer Whitworth made key contributions to this report.

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