Benefits of Dynamic Mobility Applications

Preliminary Estimates from the Literature

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16. Abstract

This white paper examines the available quantitative information on the potential mobility benefits of the connected vehicle Dynamic Mobility Applications (DMA). This work will be refined as more and better estimates of benefits from mobility applications emerge.

The set of mobility applications provide more than just mobility benefits. They also have the potential to generate energy benefits (e.g., decrease in fuel consumption), environmental benefits (e.g., decrease in greenhouse gases (GHGs), and air pollutant emissions) and safety benefits (e.g., decrease in number and severity of primary and secondary crashes, reduced incident response time). This white paper, however, focusses on mobility benefits.

The results of the analysis show that the high priority Dynamic Mobility Applications will reduce congestion while simultaneously increasing safety and benefiting the environment. Based on the limited data currently available from modeling and field trials of similar applications, full deployment of the set of mobility applications may be capable of eliminating more than 1/3[rd] of the travel delay that is caused by congestion.

The Freight Advanced Traveler Information Systems (FRATIS) bundle of applications can provide significant improvements in freight travel times (approximately 20% in the one available study), as well as significantly reducing the total number of truck movements (which also reduces overall congestion) as well as other benefits.

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Executive Summary

Introduction:
This white paper examines the available quantitative information on the potential mobility benefits of the connected vehicle Dynamic Mobility Applications (DMA). This is intended to lead to an impact goal that is analogous to USDOT's safety impact goal of addressing 81% of vehicle crashes involving unimpaired drivers. [1] This work will be refined as more and better estimates of benefits from mobility applications emerge.

The set of mobility applications provide more than just mobility benefits. They also have the potential to generate energy benefits (e.g., decrease in fuel consumption), environmental benefits (e.g., decrease in greenhouse gases (GHGs), and air pollutant emissions) and safety benefits (e.g., decrease in number and severity of primary and secondary crashes, reduced incident response time). Several of the applications are, in fact, primarily focused on improving safety. This white paper, however, focusses on mobility benefits, including transit and freight-related metrics.

The DMA program has identified a wide range of useful metrics, tailored to each bundle or application (see Appendix A for the complete list). However, for the purposes of this work, the intent was to focus on a small number of metrics that are easily explained and for which at least some quantitative data are available. For the general roadway management metrics, we wanted to focus on traveler based measures such as delay travel time, and travel time reliability. In addition, several of the mobility applications have the potential to increase the effective capacity or throughput of the system, which is related to, but distinct, from travel time and delay. Therefore we looked for data on this type of benefit as well. In the end, based on the limited data available, the analysis focused on travel time, capacity, and delay, with a projected estimate of the potential national reduction in delay due to congestion.

The measures of interest for freight and transit related applications are different from those for roadway management and light vehicles. For freight-related applications, the metrics we looked for included freight travel time and freight travel time reliability. Unfortunately, we were unable to find and data on the freight travel time reliability benefits of connected vehicle applications.

For transit applications, we looked for data on transit passenger delay and the percentage of successful connections. Unfortunately, we could not find any quantitative modeling or field trial results for these two metrics.

Results
The high priority Dynamic Mobility Applications will reduce congestion while simultaneously increasing safety and benefiting the environment. Based on the limited data currently available from modeling and field trials of similar applications, full deployment of the set of mobility applications may be capable of eliminating more than 1/3rd of the travel time delay caused by congestion.[1]

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[1] In this paper, "travel time delay" or simply "delay" refers to delays on individual roadway facilities, rather than the total trip delay from origin to destination. The latter involves examination of correlations and other complicating factors and there was little or no quantitative information in the literature on the effects of these applications on total trip delay.

The Freight Advanced Traveler Information Systems (FRATIS) bundle of applications can provide significant improvements in freight travel times (approximately 20% in the one available study), as well as significantly reducing the total number of truck movements (which also reduces overall congestion) as well as other benefits.

Although there is qualitative data on the benefits of the Integrated Dynamic Transit Operations (IDTO) bundle of applications, there is at present no quantitative information available on the extent of connection protection that will be achieved nor on the improvements the applications may make to transit passenger travel times.

While outside the scope of this study, the Dynamic Mobility Applications will also reduce crashes, improve safety, provide emissions reductions, and reduce fuel consumption.

1 Introduction

1.1 Purpose

This purpose of this white paper is to begin consolidating the available quantitative information on the potential mobility benefits of the connected vehicle Dynamic Mobility Applications (DMA). This is intended to lead to an impact goal that is analogous to USDOT's safety impact goal of addressing 81% of vehicle crashes involving unimpaired drivers. [1] The mobility impact goal will corroborated with currently available sources and research on applications aimed at improving traveler mobility and transportation system productivity. This work will be refined as more and better estimates of benefits from mobility applications emerge.

1.2 Scope

The set of mobility applications provide more than just mobility benefits. They also have the potential to generate energy benefits (e.g., decrease in fuel consumption), environmental benefits (e.g., decrease in greenhouse gases (GHGs), and criteria air pollutant emissions) and safety benefits (e.g., decrease in number and severity of primary and secondary crashes, reduced incident response time.). Several of the applications are, in fact, primarily focused on improving safety. This initial white paper, however, focusses on mobility benefits, including transit and freight-related metrics.

1.3 Background

1.3.1 The Impact of Congestion

Congestion is a significant problem in the Nation's urban areas, and only seems to grow with time. The *Travel Time Index*, which measures the amount of additional time required to make a trip during the congested peak travel period, averaged 1.20 over all 439 urban communities studied in 2010 [2]. This implies that in 2010 a trip during the peak period would require 20 percent longer than the same trip during free flow conditions. This congestion created a $101 billion annual drain on the US economy in the form of 4.8 billion lost hours and 1.9 billion gallons of wasted fuel [2]. Yearly peak period delay for the average commuter has more than doubled from a 1982 value of 14 hours per year to 34 hours in 2010 [2].

Approximately 40 percent of total delay occurred during off peak periods (i.e., outside of the peak hours of 6 to 10 AM and 3 to 7 PM) when both travelers and commercial shippers expect free flow travel [2]. The delay experienced by large trucks was 710,000 hours, resulting in $23 billion of the total delay cost [2]. .

Congestion patterns and intensity may vary from one day to the next, making travel highly unreliable. This unreliability has severe adverse impacts. For travelers who need to catch a flight or arrive at work on time, the impact might be seen in wasted time and diminished quality of life, as each traveler must schedule extra time for travel in case delays are unusually long. The variability in travel time also reduces the efficiencies in transit operations and just in time freight delivery. One measure of the unreliability is the *Buffer Index* (BI). The buffer index is a measure of the extra time (the "buffer" time) that needs to be allowed for the trip in order to be on time 95% of the time (i.e., to be late no more than 1 trip out of every 20). It is expressed as the percentage of the average travel time that must be planned in to ensure an on-time arrival. For example, a BI of 60 percent on a 60 minute trip means that you must plan for the trip to take 1 hour and 36 minutes (60% of 60 minutes is 36 minutes). There are no national figures for the Buffer Index, however TTI's 2011 Congested Corridors Report [5] provides the 2010 Buffer Index values for 328 corridors across the country. The highest reported Buffer Index is 256%, for the 4.1 mile corridor on Atlanta GA-400 Southbound between Toll Plaza and I-85. Over 100 corridors have a buffer index of 100% or more, meaning that travelers must plan for the trip to take at least twice as long as average in order to have a 95% on-time arrival rate.

1.3.2 The Causes of Congestion

Congestion occurs when there is an imbalance between supply and demand. Depending on the source, either six or seven causes are identified [6]. The Federal Highway Administration (FHWA) Office of Operations identifies seven causes for congestion: (1) traffic incidents, (2) work zones, (3) weather, (4) daily or seasonal fluctuations in normal traffic, (5) special events, (6) traffic control devices, and (7) physical capacity (bottlenecks). Figure 1 illustrates how these seven sources interact to cause congestion.

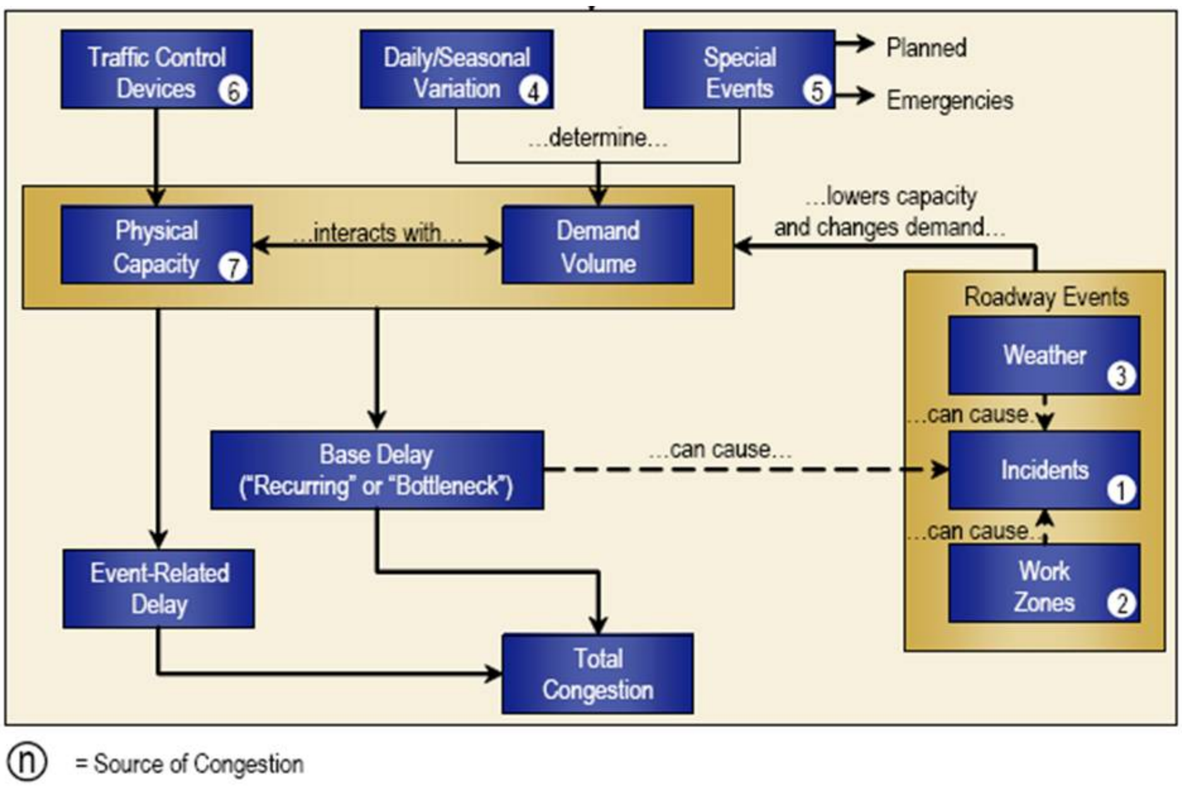

Figure 1. Anatomy of Congestion (*Source: Federal Highway Administration*)

Other references leave out fluctuations in normal traffic as a cause. This type of congestion means that the capacity is less than the "typical" demand on certain days, due to one of the other six causes. Using this six-cause approach, the FHWA has estimated the percentage of congestion that can be attributed to each cause, as shown in Figure 1-2.[9]

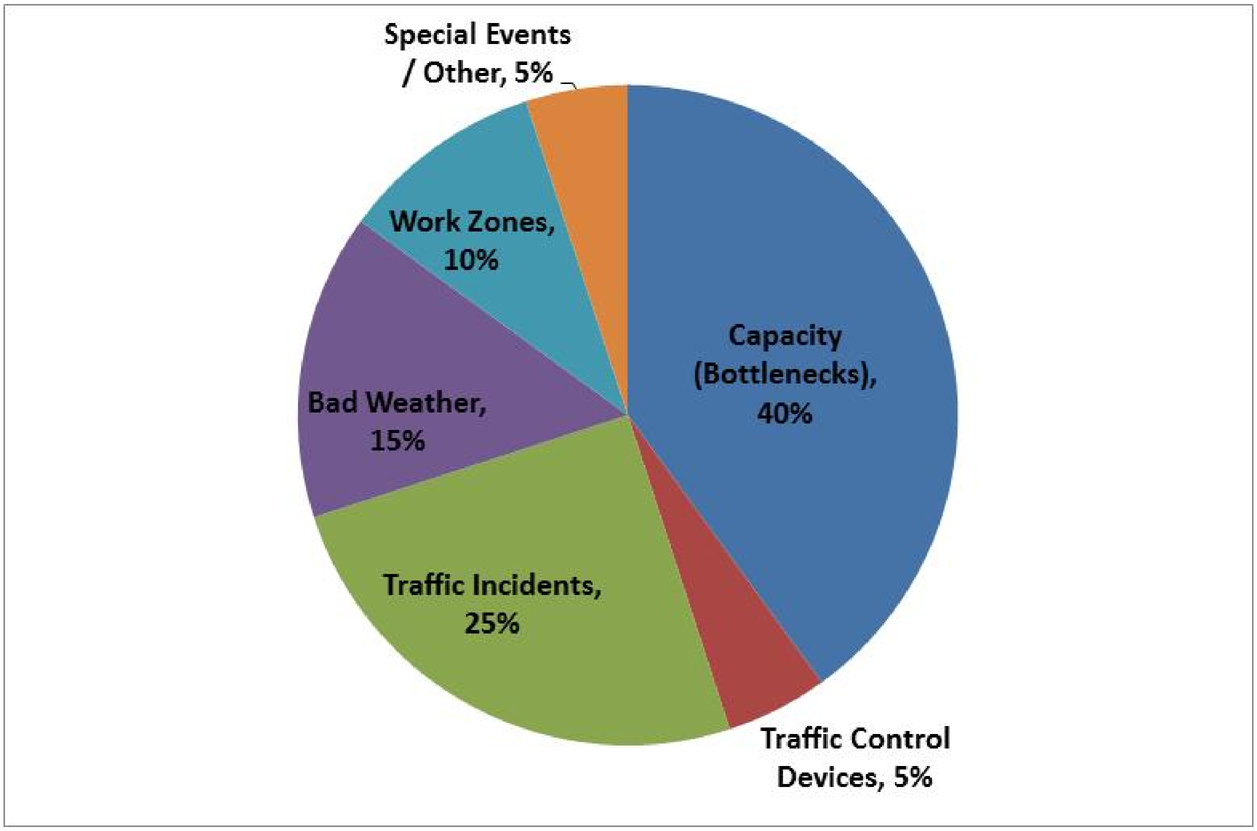

Figure 2. Sources of Congestion (*Source: Federal Highway Administration*)

Congestion due to inadequate capacity and signal timing occurs virtually every day, and is referred to as *recurring congestion*. About 45% of congestion is recurring. The other 55% is caused by disruptions that either temporarily reduce capacity (bad weather, traffic incidents, and work zones) or cause short term spikes in demand (special events).

1.3.3 Connected Vehicle Dynamic Mobility Applications

The connected vehicle research program is being sponsored by the U.S. Department of Transportation (USDOT) to enable safe, interoperable, networked wireless communications among vehicles (light vehicles, transit, and freight), the infrastructure, and travelers' personal communications devices to make surface transportation safer, smarter, and greener. As part of the connected vehicle research effort, the USDOT Intelligent Transportation Systems (ITS) Joint Program Office (JPO) initiated the Dynamic Mobility Applications (DMA) Program in 2009 to expedite the development, testing, commercialization, and deployment of transformative mobility applications by fully leveraging new technologies, including wireless communications, and federal investment to maximize the productivity of the surface transportation system and enhance the mobility of individuals within the system.

The DMA Program, utilizing input from stakeholders, identified 30 high-priority applications that can improve the nature, accuracy, precision and/or speed of dynamic decision making by both system managers and system users. These 30 applications are grouped into 7 categories commonly referred to as "bundles." Each bundle, which comprises two or more mobility applications, has the potential to accrue significant mobility benefits with connected vehicle technology. These bundles are defined in Table 1.

Table 1. High Priority Mobility Application Bundles and Objectives

Bundle Acronym	Objective
EnableATIS	*Enable Advanced Traveler Information System* seeks to provide a framework for multi-source, multimodal data to enable the development of new advanced traveler information applications and strategies.
FRATIS	*Freight Advanced Traveler Information System* seeks to provide freight-specific route guidance and optimizes drayage operations so that load movements are coordinated between freight facilities to reduce empty-load trips.
ICM	*Next Generation Integrated Corridor Management* seeks to provide mobility and efficiency improvements along corridors through a variety of applications, including better integration between transportation operators along corridors, electronic toll collection, mileage-based user fees, and improved winter road maintenance operations. NOTE: The DMA program is not currently funding research in this area, although work on ICM is being carried out in other programs.
IDTO	*Integrated Dynamic Transit Operations* seeks to facilitate passenger connection protection, provide dynamic scheduling, dispatching, and routing of transit vehicles, and facilitate dynamic ridesharing.
INFLO	*Intelligent Network Flow Optimization* seeks to optimize network flow on freeway and arterials by informing motorists of existing and impending queues and bottlenecks; providing target speeds by location and lane; and allowing capability to form ad hoc platoons of uniform speed.
M-ISIG	*Multi-Modal Intelligent Traffic Signal System* is a comprehensive traffic signal system for complex arterial networks including passenger vehicles, transit, pedestrians, freight, and emergency vehicles.
R.E.S.C.U.M.E.	*Response, Emergency Staging and Communications, Uniform Management, and Evacuation* is an advanced vehicle-to-vehicle safety messaging over DSRC to improve safety of emergency responders and travelers.

The high priority applications in each bundle are listed in Table 2. In addition, the connected vehicle road weather program has identified a partially overlapping set of applications. These high priority and road weather applications are also listed in Table 1-2. Although there are other mobility related applications associated with connected vehicles, the term “mobility applications” in this paper refers to these high priority and weather-related applications.

The mobility applications mitigate each of the sources of congestion discussed in Section 1.3.2. For example, M-ISIG will specifically address congestion caused due to poor signal timing, R.E.S.C.U.M.E. will address congestion caused due to incidents, and INFLO will address inadequate physical capacity, bad weather, and fluctuations in normal traffic. IDTO and FRATIS will address transit and freight operations, respectively. EnableATIS will minimize unpredictability of travel and the weather applications will mitigate the impact of bad weather. The mobility applications accomplish this by increasing operational capacity through effective system management and operations and improved demand management to match better align capacity and demand. This is described in more detail in section 3.

Table 2. Dynamic Mobility and Road Weather Applications

Bundle Acronym	Bundle Name	Component Applications
EnableATIS	Enable Advanced Traveler Information System[2]	1. Multi-Modal Real-Time Traveler Information (ATIS) 2. Smart Park and Ride (S-PARK) 3. Universal Map Application (T-MAP) 4. Real-Time Route Specific Weather Information for Motorized and Non-Motorized Vehicles (WX-INFO)
FRATIS	Freight Advanced Traveler Information System	1. Freight-Specific Dynamic Travel Planning and Performance 2. Drayage Optimization (DR-OPT)
ICM	Next Generation Integrated Corridor Management	1. ETC: Electronic Toll Collection System 2. ICM: Next generation Integrated Corridor Management 3. WX-MDSS: Enhanced MDSS Communication 4. VMT: Mileage Based User Fee
IDTO	Integrated Dynamic Transit Operations	1. Connection Protection (T-CONNECT) 2. Dynamic Transit Operations (T-DISP) 3. Dynamic Ridesharing (D-RIDE)
INFLO	Intelligent Network Flow Optimization	1. Dynamic Speed Harmonization (SPD-HARM) 2. Queue Warning (Q-WARN) 3. Cooperative adaptive cruise control (CACC)
M-ISIG	Multi-Modal Intelligent Traffic Signal System	1. Intelligent Traffic Signal System (I-SIG) 2. Transit Signal Priority (TSP) 3. Mobile Accessible Pedestrian Signal System (PED-SIG) 4. Freight Signal Priority (FSP) 5. Emergency Vehicle Preemption (PREEMPT)
R.E.S.C.U.M.E.	Response, Emergency Staging and Communications, Uniform Management, and Evacuation	1. Advanced Automatic Crash Notification Relay (AACN-RELAY) 2. Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG) 3. Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE) 4. Emergency Communications and Evacuation (EVAC)
N/A	Road Weather Specific Applications	There is an overlap between the road weather and mobility applications, and much of the road weather requirements are addressed under mobility (e.g., WX-MDSS, Freight Dynamic

[2] The federal program for EnableATIS is focused on identifying high-value federal roles and activities rather than applications, however for purposes of quantifying benefits, the four originally defined applications are used in this report.

		Route Guidance, and SPD-HARM). Two road weather applications are outside the scope of the mobility bundles as currently defined: 1. Information for Maintenance and Fleet Management Systems 2. Variable Speed Limits for Weather-Responsive Traffic Management

1.4 Organization of this Report

Section 2 provides a brief summary of the approach taken to produce this report, including the sources used. Section 3 presents the quantitative mobility benefits data that was found, while section 4 compares the quantitative data currently available with the aspirational goals set for the program.

2 Approach

2.1 Selection of “A Few Good Metrics”

The first step was to identify candidate benefits metrics. The DMA program has identified a wide range of useful metrics, tailored to each bundle or application (see Appendix A for the complete list). However, for the purposes of this work, the intent was to focus on a small number of metrics that are easily explained and for which at least some quantitative data are available. For the general roadway management metrics, we wanted to focus on traveler based measures such as delay, travel time, and travel time reliability. In addition, several of the mobility applications have the potential to increase the effective capacity or throughput of the system, which is related to, but distinct, from travel time and delay. Therefore we looked for data on this type of benefit as well. In the end, based on the limited data available, the analysis focused on travel time, capacity, and delay, with a projected estimate of the potential national reduction in delay due to congestion.

The measures of interest for freight and transit related applications are different from those for roadway management and light vehicles. For freight-related applications, we looked for data for three metrics: the number of bobtail trips (trips where a tractor runs without a trailer), freight travel time, and freight travel time reliability. Unfortunately, we were unable to find and data on the freight travel time reliability benefits of connected vehicle applications.

For transit applications, we looked for data on transit passenger delay and the percentage of successful connections. Unfortunately, we could not find any quantitative modeling or field trial results for these two metrics.

All of these measures had been identified as important measures by internal USDOT staff and then vetted at a stakeholder workshop entitled *Mobility Workshop*, held on May 24, 2012. [7]

As discussed in Section 1.2, the mobility applications also provide safety and environmental benefits, however these types of benefits were outside of the scope of this study.

2.2 Sources of Information

The next step was to survey the available literature. Information on the potential benefits of the mobility applications came from the following sources:

- Mobility Application Bundles Concepts of Operation [36, 37, 39, 42, 43, 45]
- Mobility Application Bundles literature surveys [34, 35, 38, 40, 41, 44]
- The ITS Knowledge Resources Portal [8]
    - Multiple papers and reports [10-27]
- ICM Reports [28, 29, 30]

- The *Mobility Workshop* presentations [7] for information on the aspirational performance goals for the applications

2.3 Analysis Methodology

The Dynamic Mobility Applications are still being defined. They have neither been field-tested nor simulated. However there have been some simulation, field-testing, and deployment of closely related applications. This data on closely-related applications, gathered from the literature search, was collected and analyzed. These observed or simulated benefits were taken to be illustrative of the benefits that may be obtained from similar connected vehicle mobility applications. The metrics used varied from study to study, based upon the goal of the application being studied or of the project. Delay reduction was the most frequently found measure for mobility impacts, however others such as increased speed, capacity increase, and reduced stop time were among the others observed. Crash reduction was the most frequently cited safety metric.

Depending upon the study and the application, the benefits observed and cited in the reports may apply only to specific congestion causes, as defined in Section 1.3.2, or only to specific types of roadways (e.g., ramp metering does not apply to arterials, and similarly, intelligent signal control does not apply to freeways). In these cases the total mobility benefit must be multiplied by the percentage that scenario contributes to congestion. Using Intelligent Signal Control as an example, multiple studies show delay reduction benefits when congestion is caused by traffic control devices (14-41% delay reduction [14, 26]), as well as benefits when congestion is due to incidents (60-70% delay reduction on arterials [13]). Traffic control devices account for 5% of all congestion, whereas incidents account for 25%. [9] Unfortunately, this study did not find any estimation of the percentage of congestion that occurs on arterials versus freeways. For purposes of this report, we have chosen to hypothesize that half of all congestion occurs on arterials, and half on freeways, with negligible delay on unsignalized minor roads. With these estimates, one can estimate the possible range of delay reduction for the country, assuming full deployment in all congested areas:

$$14\ to\ 41\%\ DR\ x\ 5\%\ of\ congestion + 60\ to\ 70\%\ DR\ x\ 25\%\ of\ congestion\ x\ 50\%\ on\ arterials = 8\ to\ 11\%$$

$$where\ DR = total\ delay\ reduction$$

Therefore, based on studies of similar applications, Intelligent Signal Control applications are estimated to have the potential to reduce total delay by 8-11%.

In other cases, the benefit estimates were combined benefits observed over multiple roadway types and regardless of the cause of congestion. For example, one study found that Integrated Corridor Management reduced delay in the corridor by 5.9%. This is the total net reduction for the corridor, across all types of delay and across both freeways and arterials that comprise the corridor.

Estimating the combined benefits from multiple applications is difficult in the absence of better data. Some benefits can simply be added. For example, one can add the weighted delay reduction achieved on arterials from the I-SIG application (the delay reduction x the % of delay that occurs on arterials) to the weighted delay reduction obtained on freeways from Cooperative Adaptive Cruise Control. However, if the benefits apply to the same root cause, one can't simply add them. For example, three applications that each eliminates 50% of delay caused by incidents can't together eliminate 150% of delay, as that is more delay than exists. In the absence of better data, a reasonable assumption is that each application reduces the remaining delay by the amount reported in the literature. For example, if one application reduces incident delay by 30% and another by 20%, the combined benefit is estimated to be:

$$30\% + 20\% \; x \; (1 - 30\%) = 30\% + 20\% - 6\% = 44\%$$

This is the approach taken in this paper.

3 Results: Preliminary Estimates of Mobility Impacts

3.1 Congestion Impacts

3.1.1 Qualitative Estimates

The set of high priority mobility applications addresses all six causes of congestion. In some cases this is accomplished by eliminating root causes, e.g., reducing the number of incidents through Speed Harmonization. In other cases it is accomplished by mitigating the effects, e.g., using improved corridor management techniques to more efficiently route traffic around incidents. Integrated Corridor Management and Advanced Traveler Information Systems both reduce the impact of capacity bottlenecks by allowing more efficient use of existing capacity, through approaches such as route, time, and mode shifts in demand. These applications provide the same benefits for weather, work zones and special events. Speed Harmonization will also reduce delays associated with incidents and work zones by smoothing traffic flows, increasing the throughput of the system under these conditions. Intelligent Signal Control (ISIG) provides improved signal adaption to real-time changes in demand, reducing the delays caused by traffic control devices. I-SIG can also better adapt signal systems to handle special events, reducing the delays that these events cause. Table 3-1 shows how each of the mobility applications will reduce delay due to congestion. The columns in the table are the causes of congestion, with the second row showing the percentage of congestion each cause is responsible for. Each of the rows below the second is for a specific application. The cells shaded in green and marked “YES” show that the application can have significant impact on reducing congestion from that specific cause, whereas the blue shaded cells marked “SOME” show areas where positive impact is expected, but to a lesser extent. This assessment is somewhat subjective.

It is important to note that many of the applications are aimed at providing other types of benefits. Mobile Accessible Pedestrian Signal System (PED-SIG), for example, improves pedestrian safety. It is not intended to provide mobility benefits.

3.1.2 Quantitative Estimates

The connected vehicle mobility applications are new concepts. Even when drawing upon similar applications, there is a sparsity of quantitative data available from deployments, field tests, and modeling studies. The DMA program is undertaking modeling analyses and field trials to provide additional data, but this data is not yet available. The available data on travel time reduction, delay reduction, travel time variability, and capacity increases are shown in Table 3-2. The mobility applications are listed as rows and the causes of congestion are the columns, with the percentage of congestion due to each cause shown in the second row. The rightmost column holds information on overall mobility impacts that includes all possible causes.

The absence of quantitative data for some applications makes it impossible to project the total mobility benefits that may be expected, however by using the data that is available, one can estimate a reasonable lower bound on the benefits. To do so, the combined benefits in the last column of Table 3-2 were used. Because the metrics varied from study to study, several conservative simplifying assumptions were made:

- If only travel time reduction was reported, the delay reduction was set equal to the travel time reduction, as the delay reduction percentage will always be greater than the travel time percentage reduction.
- If only capacity increase information is available, the delay reduction is taken to be the inverse of the capacity increase (e.g., a doubling of capacity is assumed to reduce delay by 50%. Again, this is a conservative estimate, as delay often increases more rapidly as capacity limits are reached.
- If no quantitative data is available for an application, it is not included in the calculations.

First, the combined benefits from Cooperative Adaptive Cruise Control (CACC) and Speed Harmonization are calculated. Both of these applications smooth traffic flow, preventing breakdown of smooth flow and thereby increasing throughput and reducing delay. CACC can also increase the capacity of each lane through closer spacing between vehicles and more uniform flows. Although both may provide arterial benefits as well, all available data is from freeways, so for this analysis, only freeway benefits are counted. In addition, it is likely that the benefits of CACC are highly dependent upon the roadway geometry and traffic conditions. For example, the benefits would be reduced in weaving areas or during traffic incidents. For this reason, we have counted the benefits as occurring only for recurring congestion (45% of congestion). As before, we also assume that half of the total congestion occurs on freeways:

$$(60\%\ FDR\ x\ 45\%\ R\left(\frac{RC}{TC}\right) + 10.1\%\ FDR - \left(60\%\ x\ 45\%\ R\left(\frac{RC}{TC}\right) x\ 10.1\%\right) FDR)\ x\ 50\%\ \left(\frac{DR}{FDR}\right) = 17\%\ DR\ \ (Equation\ 1)$$

$$FDR = Freeway\ Delay\ Reduction$$
$$DR = Total\ Delay\ Reduction$$
$$RC = Recurring\ Congestion$$
$$TC - Total\ Congestion$$

The Cooperative Adaptive Cruise Control benefit value is taken from [29], adjusted as discussed above, and the Speed Harmonization benefit is from [28].

Then we add the arterial delay reduction (ADR) due to Intelligent Traffic Signal Systems (ISIG) to the previously calculated subtotal from Equation 1. ISIG only provides benefits on signalized roadways, not freeways. ISIG provides these delay reductions through real-time optimization of signal systems:

$$30\%\ ADR\ x\ 50\%\ \left(\frac{DR}{ADR}\right) + 17\%\ DR = 32\%\ DR \quad \text{(Equation 2)}$$

The arterial delay reduction benefit value is taken from [25].

These two can be added because we are looking at delay on different types of roadways and we have weighted the results by the estimated amount of delay on each roadway type (50% on freeways, 50% on arterials).

In addition, ICM, which provides more efficient utilization of existing multi-modal transportation resources, has been shown to reduce delay by 5%. However, this is 5% must be taken from the remaining delay, after the benefits from the other applications have been calculated, in order to avoid double-counting. This yields:

$$32\%\ DR + 5\%\ DR - (32\% * 5\%)DR = 35\%\ DR \quad \text{(Equation 3)}$$

While ATIS has been shown to reduce delay as well, it is not clear how much additional benefit connected vehicle ATIS will provide over what is already available, so to be conservative, that is not included. Similarly, while Queue Warning and other mobility applications not included above may provide delay reduction, there is no quantitative data available, so they are not included. If one includes the potential benefits of road user fees, a potential future application for which data is available, the delay reduction increases further. Road user fees can substantially alter demand patterns to reduce or spread demand in order to utilize existing capacity more efficiently. Adding these benefits yields:

$$35\%\ DR + 30\%\ DR - (35\% * 30\%)DR = 54\%\ DR \quad \text{(Equation 4)}$$

The road user fee benefit value is taken from [18].

While there are a large number of assumptions that went into this estimate, it indicates that *full deployment of the high priority mobility applications may be able to reduce the delay due to congestion by over 33%, even without the VMT application*, with the largest single contribution provided by the capacity increase obtained through Cooperative Adaptive Cruise Control.

Table 3. Qualitative Delay Reduction Benefits

	Notes	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events
		40% of congestion	5% of congestion	25% of congestion	10% of congestion	15% of congestion	5% of congestion
Enable ATIS							
ATIS		YES (more efficient use)		YES	YES	YES	YES
S-PARK							SOME (to extent parking is issue)
T-MAP	No direct impact on congestion						
WX-INFO						YES	
FRATIS							
DR-OPT		SOME (reduces freight demand)					
[EV] DRG	Focus is on emergency vehicles						
F-ATIS		SOME (for freight vehicles)		SOME (for freight vehicles)	SOME (for freight vehicles)	SOME (for freight vehicles)	SOME (for freight vehicles)
F-DRG				SOME (for freight vehicles)	SOME (for freight vehicles)	SOME (for freight vehicles)	SOME (for freight vehicles)
ICM							
ETC		SOME (eliminates toll plazas)					

	Notes	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events
		40% of congestion	5% of congestion	25% of congestion	10% of congestion	15% of congestion	5% of congestion
ICM		YES (more efficient use)	YES (optimize timing based on real time changes)	YES	YES		YES
WX-MDSS						YES	
VMT		YES					
IDTO							
D-RIDE		SOME (mode shift)		SOME (mode shift)		SOME (mode shift)	SOME (mode shift)
T-CONNECT		SOME (mode shift)					
T-DISP	Focus is on improved operations and service to individual riders						
INFLO							
CACC[1]		YES				YES	
Q-WARN		SOME (gives drivers time to take action in response to downstream queues)	SOME (gives drivers time to take action in response to downstream queues)	SOME (gives drivers time to take action in response to downstream queues)	SOME (gives drivers time to take action in response to downstream queues)	SOME (gives drivers time to take action in response to downstream queues)	SOME (gives drivers time to take action in response to downstream queues)
RAMP		YES	SOME (at ramp meters)				

	Notes	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events
		40% of congestion	5% of congestion	25% of congestion	10% of congestion	15% of congestion	5% of congestion
SPD-HARM[1]		YES (smoothing flow can improve throughput)	SOME (smoothing flow can improve throughput)	SOME (smoothing flow can improve throughput)	YES (smoothing flow can improve throughput)	SOME (smoothing flow can improve throughput)	SOME (smoothing flow can improve throughput)
M-ISIG							
ECO	Focus is on reducing emissions.						
FSP			SOME (freight vehicles only)				
I-SIG			YES	YES		SOME	YES
PED-SIG	Focus is on pedestrian safety.						
PREEMPT	Focus is on reducing delay for emergency responders.						
TSP		SOME (to extent it promotes mode shift)					
R.E.S.C.U.M.E.							
EVAC[1]	Not applicable. Addresses emergency response and communications						

	Notes	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events
		40% of congestion	**5% of congestion**	**25% of congestion**	**10% of congestion**	**15% of congestion**	**5% of congestion**
INC-ZONE[1]				SOME (to extent it clears incidents more quickly)			
AACN-RELAY[1]	Not applicable. Intent is to provide safety rather than mobility benefits						
RESP-STG[1]				SOME (to extent it clears incidents more quickly			

[1] These applications are primarily aimed at improving safety.

Table 4. Quantitative Mobility Benefits

	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events	Combined
	40% of congestion	5% of congestion	25% of congestion	10% of congestion	15% of congestion	5% of congestion	100% of congestion
Enable ATIS							
ATIS							3.4% reduction in vehicle delay [11], 5-16% improvement in on time reliability [12]
S-PARK							No quantitative data found on capacity increase, travel time reduction, or delay reduction
T-MAP							No quantitative data found on capacity increase, travel time reduction, or delay reduction
WX-INFO							No quantitative data found on capacity increase, travel time reduction, or delay reduction

	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events	Combined
	40% of congestion	**5% of congestion**	**25% of congestion**	**10% of congestion**	**15% of congestion**	**5% of congestion**	**100% of congestion**
FRATIS							
DR-OPT							Provides travel time and delay reduction for freight vehicles. See Section 3.2
[EV] DRG							Provides travel time and delay reduction for emergency vehicles
F-ATIS							Provides travel time and delay reduction for freight vehicles. See Section 3.2
F-DRG							Provides travel time and delay reduction for freight vehicles. See Section 3.2
ICM							

	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events	Combined
	40% of congestion	**5% of congestion**	**25% of congestion**	**10% of congestion**	**15% of congestion**	**5% of congestion**	**100% of congestion**
ETC	Significant reduction if transition to Open Road Tolling, but unable to roll up to national estimates (22-26% delay reduction [2])						
ICM			8% [22] to 20% travel time reduction [24]				5.9% delay reduction [20], 5 % reduction in non-recurring delay [21]
WX-MDSS							No quantitative data found on capacity increase, travel time reduction, or delay reduction
VMT							30% reduced delay, 30-89% speed increases, 20-50% travel time reduction [18]
IDTO							

	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events	Combined
	40% of congestion	**5% of congestion**	**25% of congestion**	**10% of congestion**	**15% of congestion**	**5% of congestion**	**100% of congestion**
D-RIDE							Not applicable. Application is aimed at encouraging ride-sharing, which may indirectly reduce congestion, but no quantitative data available.
T-CONNECT							Not applicable. Application is aimed at reducing transit rider delay. This may encourage mode shift and reduce congestion, but no quantitative data available.
T-DISP							Not applicable. Application is aimed at increasing efficiency of paratransit applications.
INFLO							

	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events	Combined
	40% of congestion	**5% of congestion**	**25% of congestion**	**10% of congestion**	**15% of congestion**	**5% of congestion**	**100% of congestion**
CACC[1]							Studies focused on increased capacity (and safety), not congestion reduction, however this should have a large impact on congestion caused by capacity constraints 0-100% increase in capacity (freeways) [28, 29]. Another study cited 60% [29].
Q-WARN							No quantitative data found on capacity increase, travel time reduction, or delay reduction

	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events	Combined
	40% of congestion	**5% of congestion**	**25% of congestion**	**10% of congestion**	**15% of congestion**	**5% of congestion**	**100% of congestion**
RAMP							While there is data on the benefits of ramp metering, there is no quantified data to infer the additional benefits from using connected vehicle technology.
SPD-HARM[1]							0-20% improvement in travel times, 0-10.1% TTI reduction, 0-7% increase in throughput [28, 29]
M-ISIG							
ECO							Focus is on reducing emissions. No quantitative data found on capacity increase, travel time reduction,

	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events	Combined
	40% of congestion	**5% of congestion**	**25% of congestion**	**10% of congestion**	**15% of congestion**	**5% of congestion**	**100% of congestion**
							or delay reduction
FSP							Focus is on reducing freight delay. No quantitative data found on overall network capacity increase, travel time reduction, or delay reduction
I-SIG		25-41% delay reduction [13], 36% travel time reduction [27] / 14-19% delay reduction, 7-17% speed improvement [26]	60-70% delay reduction [13]				30% reduction in travel times [25]
PED-SIG							Focus is on pedestrian safety. No quantitative data found on capacity increase, travel

	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events	Combined
	40% of congestion	**5% of congestion**	**25% of congestion**	**10% of congestion**	**15% of congestion**	**5% of congestion**	**100% of congestion**
							time reduction, or delay reduction
PREEMPT							Focus is on reducing delay for emergency responders. No quantitative data found on capacity increase, travel time reduction, or delay reduction
TSP							Focus is on reducing transit delay. No quantitative data found on overall network capacity increase, travel time reduction, or delay reduction
R.E.S.C.U.M.E.							
EVAC[1]							Not applicable. Addresses emergency response and communications

	Physical Capacity (Bottlenecks)	Traffic Control Devices	Traffic Incidents	Work Zones	Weather	Special Events	Combined
	40% of congestion	5% of congestion	25% of congestion	10% of congestion	15% of congestion	5% of congestion	100% of congestion
INC-ZONE[1]							Not applicable. Primary purpose is work zone safety.
AACN-RELAY[1]							Not applicable. Intent is to provide safety rather than mobility, benefits
RESP-STG[1]							Not applicable. Addresses incident responders. However benefits include clearing incidents more quickly, reducing delay

[1] These applications are primarily aimed at improving safety.

3.2 Freight Movement Benefits

The Cross-Town Improvement Project: Freight Travel Demand Management (TDM) project provides information on the potential reduction in bobtail trips. Based on the trip reduction table found in the case study report [14], that project reduced the number of bobtail trips by 61%, making the 10-year aspirational goal (see Appendix A) of 15% and 20% long-term reduction quite reasonable.

This same project showed that freight traveler information systems (combining real-time traffic monitoring and dynamic route guidance) could reduce provide a 19-21% improvement in freight vehicle travel times. [34]

3.3 Transit Benefits

SAIC's study of prior and ongoing research found very little information on transit connection protection and no information on the percentage of connections protected. [35] The 10-year aspirational goal, as shown in Appendix A, is to ensure that 90-95% of connections are made, but there is, as yet, no modeling or field trial results to compare against this goal. One study did find that 86% of riders surveyed in a transit connection protection study were satisfied with their connection experience.

Similarly, while there is a wealth of data on transit delay reduction due to transit signal priority applications (an M-ISIG application), there is no quantitative data available on the transit passenger travel time improvement that may result from deploying the three Integrated Dynamic Transit Operations applications:

- Connection Protection (T-CONNECT)
- Dynamic Transit Operations (T-DISP)
- Dynamic Ridesharing (D-RIDE)

4 Summary

The high priority Dynamic Mobility Applications will reduce the impact of all six causes of congestion while simultaneously increasing safety and benefiting the environment. Based on the limited data currently available from modeling and field trials of similar applications, full deployment of the set of mobility applications may be capable of eliminating over 1/3rd of the travel time delay caused by congestion.

The Freight Advanced Traveler Information Systems (FRATIS) bundle of applications can provide significant improvements in freight travel times (approximately 20% in the one available study), as well as significantly reducing the total number of truck movements (which reduces overall congestion as well).

Although there is qualitative data on the benefits of the Integrated Dynamic Transit Operations (IDTO) bundle of applications, there is at present no quantitative information available on the extend of connection protection that will be achieved nor on the improvements the applications may make to transit passenger travel times.

While outside the scope of this study, the Dynamic Mobility Applications will also reduce crashes, improve safety, and provide emissions reductions.

5 Next Steps

This initial report represents a first step in estimating the national impacts from deployment of the suite of Dynamic Mobility Applications. The work will be refined as additional data becomes available, expanded in scope to encompass safety impacts and weather-related application, and expanded to project the evolution of impacts over time, based on likely deployment scenarios.

Three DMA program activities will provide additional information on impacts:

- Evaluations of Bundles/Applications in Isolation: Mobility impacts of each bundle will be estimated exclusive of interaction with other bundles. This effort will be conducted in conjunction with the prototyping of the bundle.
- Evaluation of Regional Deployment of Multiple Bundles/Applications in a Simulation Testbed: Mobility impacts of a regional deployment of two or more bundles will be estimated in a simulation environment
- Evaluation of Large-Scale Demonstration of Multiple Bundles: DMA-sponsored demonstrations of one or more bundles in non-laboratory or test facilities will be evaluated.

The results of the three types of activities will be integrated into an evolving National Mobility Impact Estimation which will provide initial estimates in 2013 and be refined over the next three years.

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Appendix A. Aspirational Goals

The preliminary work conducted on the high priority applications identified multiple performance metrics and target goals for each application. These "aspirational goals" were vetted with ITS stakeholders at the Mobility Workshop held in April of 2012. [7]

Table A-1 Aspirational Performance Goals for Each Application

Bundle	Performance Measure	10-Year Target
EnableATIS	Multi-modal end-to-end trip planning information (time of departure, cost, mode, route, parking) integrated with search results	Common for major metropolitan areas
	Corridor or regional transportation management systems utilizing systematically obtained traveler trip data	Emerging state-of-practice (one or more)
	Predictability and reliability of travel	Total unanticipated late arrivals reduced by 50%
FRATIS	Travel time	Reduce by 17%
	Fuel consumption	Reduce by 10%
	Level of criteria pollutants and greenhouse gas equivalents	Reduce by 10%
	Number of bobtail trips	Reduce by 15%
	Terminal queue time	Reduce by 35%
	Number of freight-involved incidents (e.g., bridge strikes)	Reduce by 35%
	Number of weight-compliance infractions (Percentage of vehicles over legal gross weight limit)	Reduce by 20%
IDTO (T-CONNECT)	Percentage of successful connections involving more than one agency	Increase to 95%
	Percentage of successful connections involving more than one mode	Increase to 95%
	Percentage of successful connections involving fixed and flexible modes	Increase to 90%
IDTO (T-DISP)	Duration of time from making a request to receiving a trip confirmation	Approximately 45 seconds
IDTO (D-RIDE)	Passenger waiting time	Reduce to 10 minutes or less
INFLO (SPD-HARM)	Number of shockwaves formed	Reduce by 25%
	Length of formed shockwaves	Reduce by 25%
	Propagation speed of formed shockwaves (backwards)	Reduce by 25%
	Compliance rate of posted or recommended speed limit	75% compliance
	Variability (spread) of speeds within traffic stream (in-lane, between-lane, and over time)	1 standard deviation of traffic speeds are within 2 mph of average stream speed
	Average travel time (delay)	Reduce by 10%
	Travel time reliability (buffer or planning time index)	Reduce by 25%
	Ratings on public opinion surveys	75% positive ratings of system

Bundle	Performance Measure	10-Year Target
	Number of primary crashes	Reduce by 25%
	Severity of crashes	Reduce by 25%
	Number of secondary crashes	Reduce by 50%
	Level of CO_2 (equivalent) emissions	Reduce by 25%
	Amount of energy consumed (MPG/fuel efficiency)	Reduce by 25%
	Cost of SPD-HARM infrastructure and related systems construction	Reduce by 25%
	Cost of SPD-HARM infrastructure and related systems operations and maintenance	Reduce by 25%
INFLO (Q-WARN)	Number of secondary crashes at fixed queue point locations	Reduce by 50%
	Number of secondary crashes at non-fixed queue point locations	Reduce by 50%
	Severity of crashes	Reduce by 25%
	Length (distance) of formed queues at variable locations	Reduce by 50%
	Duration of formed queues at variable locations	Reduce by 50%
	Number of shockwaves formed	Reduce by 25%
	Length of formed shockwaves	Reduce by 25%
	Propagation speed of formed shockwaves (backwards)	Reduce by 25%
	Ratings on public opinion surveys	75% positive ratings of system
	Number of false positive queue detection alerts	5% rate of false positive queue detection alerts
	Number of non-detected queue events	10% rate of non-detected queue events
	Cost of Q-WARN infrastructure and related systems construction	Reduce by 25%
	Cost of Q-WARN infrastructure and related systems operations and maintenance	Reduce by 25%
INFLO (CACC)	Vehicles per hour	50% increase
	Average vehicle headways	25% decrease
	Number of shockwaves formed	Reduce by 25%
	Length of formed shockwaves	Reduce by 25%
	Propagation speed of formed shockwaves (backwards)	Reduce by 25%
	Variability (spread) of speeds within traffic stream (in-lane, between-lane, and over time)	1 standard deviation of traffic speeds are within 2 mph of average stream speed
	Average travel time (delay)	Reduce by 10%
	Travel time reliability (buffer or planning time index)	Reduce by 25%
	Ratings on public opinion surveys	75% positive ratings of system
	Number of primary crashes	Reduce by 25%
	Severity of crashes	Reduce by 25%
	Number of secondary crashes	Reduce by 50%
	Level of CO_2 (equivalent) emissions	Reduce by 25%
	Amount of energy consumed (MPG/fuel efficiency)	Reduce by 25%
	Cost of ATM infrastructure and related systems construction	Reduce by 25%
	Cost of ATM infrastructure and related systems operations and maintenance	Reduce by 25%
M-ISIG	Overall Vehicle Delay	Reduce by 25%

Bundle	Performance Measure	10-Year Target
	Throughput	Increase by 15%
	Queue Length	Reduce by 15%
	Average Pedestrian Wait Time	Reduce by 20%
	Average Transit Delay	Reduce by 35%
	Average Commercial Vehicle Delay	Reduce by 15%
	Average Emergency Vehicle Delay	Reduce by 40%
	Extent of System-Wide Congestion (i.e., failure to clear queue in a cycle)	Reduce by 25%
	Duration of System-Wide Congestion	Reduce by 40%
	Duration of Response to a Traffic Incident (overall incident clearance time)	Reduce Total Response Time by 30%
R.E.S.C.U.M.E.	Responders to vehicle incidents will be provided with comprehensive information regarding the incident prior to dispatch (incident dynamics, condition of the victims, materials involved, etc.)	Increase the amount of comprehensive information available by 25%
	Number of incidents where additional equipment and/or responders post-first responder arrival need to be dispatched due to on-scene triage (i.e., secondary dispatch)	Reduce Secondary dispatch events by 20%
	Equipment staging impact on travel conditions (e.g., throughput, delay)	Reduce congestion as measured by throughput and delay times by 20%
	En-route time for responders during congested conditions	Improve En-Route travel times by 10%
	Number of incidents involving on-scene emergency responders	Reduce secondary incidents by 15%
	Number of incidents involving construction and maintenance staff	Reduce primary incidents by 15%
	Number of secondary incidents due to congestion	Secondary incidents will be reduced by 15%
	System throughput (end-to-end throughput of the system, not just a specific facility)	End-to-End system throughput will be maintained during severe traffic incidents
	Ability to employ dynamic dispatching and routing of available resources (e.g., vehicles) across agencies during an evacuation	Use of mixed agency vehicles for evacuation of special needs population will be widespread
	Evacuation time needed for all persons, including special needs populations	Reduce total evacuation time for large-scale populations by 25%

Appendix B. Definition of the Dynamic Mobility and Road Weather Applications

Bundle/Application	Description
Next Generation Integrated Corridor Management (ICM)	*This bundle seeks to provide mobility and efficiency improvements along corridors through a variety of applications, including better integration between transportation operators along corridors, electronic toll collection, mileage-based user fees, and improved winter road maintenance operations. NOTE: The DMA program is not currently funding research in this area, although work on ICM is being carried out in other programs.*
Electronic Toll Collection System (ETC)	The purpose of the proposed application is to upgrade existing electronic toll collection (ETC) systems to the 5.9 GHz DSRC standard. This concept can be leveraged to potentially simplify the infrastructure necessary to handle toll payments, as well as provide flexibility with regard to tolling schemes, toll payment options and operating models. The proposed application will make use of connected vehicle technology (DSRC), along with the appropriate back office agreements and information exchange to afford the capability for a toll authority to accept electronic payments from vehicles equipped with electronic-payment services (EPS), regardless of who owns the EPS account.
Next Generation Integrated Corridor Management (ICM)	This application will augment corridor management through the use of multi-source, real-time connected vehicle data. Connected vehicle technology affords the capability to capture and use high-fidelity data in near real-time on freeways, arterials, rural roads, freight networks, and transit systems. The application will also allow traffic management and transit agencies to leverage their existing systems, including traffic signal systems, ramp metering systems, lane control systems, and transit systems to directly affect freeway, arterial, and transit performance. The application will improve system throughout, increase travel time reliability by improving travel predictability, and enhance incident management by providing an integrated and coordinated response during major incidents and emergencies.
Enhanced Maintenance Decision Support System (MDSS) Communication (WX-MDSS)	The application improves MDSS by providing the systems with expanded data acquisition from connected vehicles. Snow plows, other agency fleet vehicles, and other vehicles operated by the general public will provide road-weather connected vehicle data to the Enhanced-MDSS, which will use this data to generate improved plans and recommendations to maintenance personnel.
Mileage Based User Fee (VMT)	As electric and high efficiency vehicles become more common, there will continue to be less gas tax revenue for transportation for the same amount of vehicle miles traveled (VMT), while the cost of providing transportation infrastructure and services will increase due to rise in inflation. Mileage

Bundle/Application	Description
	Based User Fees (MBUF) may eventually replace the gas tax. The proposed application will accumulate miles driven in categories determined by policy and charge for the miles driven. Categories may or may not include vehicle type, time of day, roadway type, jurisdiction, direction of travel, geographic area of travel, etc. Revenue could augment or replace the gas tax as determined by policy. The system will be interoperable across the U.S. and allow for charges by federal, state, and local governments.
Integrated Dynamic Transit Operations (IDTO)	*This bundle will facilitate passenger connection protection, provide dynamic scheduling, dispatching, and routing of transit vehicles, and facilitate dynamic ridesharing.*
Connection Protection (T-CONNECT)	Connection Protection (T-CONNECT) enables public transportation providers and travelers to communicate to improve the probability of successful transit transfers, e.g., by delaying a bus departure to accommodate a late arriving subway train). This application would potentially include intermodal and interagency coordination.
Dynamic Ridesharing (D-RIDE)	This application makes use of in-vehicle (drivers) and hand-held devices (riders) to dynamically identify and accept potential ridesharing opportunities along the travel route. This application makes ridesharing easier by enabling the use of location information and in-vehicle and handheld devices to arrange ridesharing between drivers and riders.
Dynamic Transit Operations (T-DISP)	This application links available transportation service resources with travelers through flexible, dynamic transit vehicle scheduling, dispatching and routing capabilities. It would also enable travelers to make real-time trip requests through personal mobile devices.
Intelligent Network Flow Optimization (INFLO)	*Intelligent Network Flow Optimization seeks to optimize network flow on freeway and arterials by informing motorists of existing and impending queues and bottlenecks; providing target speeds by location and lane; and allowing capability to form ad hoc platoons of uniform speed.*
Dynamic Speed Harmonization (SPD-HARM)	This application will dynamically adjust and coordinate vehicle speeds in response to congestion, incidents, and road conditions to maximize throughput and reduce crashes.
Queue Warning (Q-WARN)	This application will provide drivers timely warnings and alerts of slow moving or stopped traffic ahead.
Cooperative Adaptive Cruise Control (CACC)	This application will dynamically adjust and coordinate cruise control speeds among platooning vehicles to improve traffic flow to improve traffic flow stability and increase throughput.

Bundle/Application	Description
Multi-Modal Intelligent Traffic Signal System (M-ISIG)	*Multi-Modal Intelligent Traffic Signal System is a comprehensive traffic signal system for complex arterial networks including passenger vehicles, transit, pedestrians, freight, and emergency vehicles.*
Intelligent Traffic Signal System (I-SIG)	This application integrates data collected through wireless communications and other sources to improve traffic signal operations. It integrates several more specific applications in order to provide overarching system optimization. I will maximize overall arterial network performance, taking into account transit and freight signal priority, emergency vehicle preemption and pedestrian movements.
Transit Signal Priority (TSP)	This application utilizes connected vehicle technology provide improved signal priority to transit at intersections. Equipment onboard the transit vehicle would communicate information such as passenger count data, service type, scheduled and actual arrival time so that algorithms could determine the optimum trade-off between expediting transit vehicles and delays to other vehicle types.
Mobile Accessible Pedestrian Signal System (PED-SIG)	This application will allow "Automated pedestrian call" from smart phones for visually impaired pedestrians; communicate wirelessly with the traffic signal controller to obtain real-time signal phase and timing (SPAT) information, and inform visually impaired pedestrian as to when to cross and how to remain aligned with the crosswalk.
Freight Signal Priority (FSP)	This application gives priority to freight vehicles at intersections near freight facilities (ports, rail terminals, warehouses, distribution centers), resulting in reduced delays, reduced negative environmental impacts, and increased travel time reliability for freight traffic.
Emergency Vehicle Preemption (PREEMPT)	This application uses connected vehicle technology to provide improved signal preemption for emergency vehicles. It could also inform drivers through in-vehicle alerts and roadside signs of the presence of emergency vehicles, thus reducing the risk of accidents for motorists and pedestrians due to lack of awareness of the location and likely path of responding emergency vehicles.

Bundle/Application	Description
Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.)	*Response, Emergency Staging and Communications, Uniform Management, and Evacuation is an advanced vehicle-to-vehicle safety messaging over DSRC to improve safety of emergency responders and travelers.*
Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)	This application will provide situational awareness information to responders while en route to the scene of an incident. It will also provide input to responder vehicle routing, staging and secondary dispatch decisions, including: • Staging plans • Satellite imagery • GIS data • Current weather data • Real-time modeling outputs.
Advanced Automatic Crash Notification Relay (AACN-RELAY)	When a connected vehicle is involved in a crash, but outside of cellular communications coverage, This application will continually send a mayday message that includes vehicle location via DSRC. When a passing connected vehicle receives the message, it would forward it as soon as possible, either via cellular or a roadside DSRC receiver.
Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)	This application has two components: • It alerts drivers about lane closings and unsafe speeds for temporary work zones (and may also provide drivers with guidance on merging and speeds) • It warns on-scene workers of vehicles with trajectories or speeds that pose a high risk to their safety
Emergency Communications and Evacuation (EVAC)	This application provides information to address the needs of two different evacuee groups. • Provides those using their own transportation with o Dynamic route guidance information o Current traffic and road conditions o Location of available lodging o Location of fuel, food, water, cash machines and other necessitates • Provides those requiring assistance with: o Identify and locate people who are more likely to require guidance and assistance o Identify existing service providers and other available resources

Bundle/Application	Description
Enable Advanced Traveler Information System (EnableATIS)	*Enable Advanced Traveler Information System seeks to provide a framework for multi-source, multimodal data to enable the development of new advanced traveler information applications and strategies. The federal program is focused on identifying high-value federal roles and activities rather than applications, however for purposes of quantifying benefits, the four originally defined applications are used in this report.*
Multi-Modal Real-Time Traveler Information (ATIS)	This application will utilize connected vehicle-enabled real-time data and communications capabilities to empower travelers to make informed travel choices in real time, pre-trip and en-route. Based on real-time and historical travel conditions for the traveler's trip (pre-specified origin, destination, and time of departure) the application will suggest potential routes and modes (e.g., auto, transit, bicycle, walk) with approximate travel times, travel time reliability, and costs for each alternative. If transit is included in one of the alternatives, locations of transit stations, arrival time of next bus or train, parking availability and cost, will be also be provided. The application will "predict" travel times based on existing and predicted traffic congestion, weather and pavement conditions, incident locations, work zone locations and timings, transit availability and schedule, parking availability, possible use of HOT and HOV lanes (depending on time of travel). Information may be provided via: personal mobile devices, transit stations on vehicle interactive screens, in-vehicle devices, internet, and 511. The collected information, including traveler choices, can also be used by the transportation system operators and managers for performance monitoring as well as for selecting congestion pricing strategies.
Smart Park and Ride (S-PARK)	This application will combine monitoring sensors with connected vehicle communications to provide more real-time information on park and ride lot availability, and communicate that to potential travelers at effective decision points that would encourage more use of transit for commuting, and more efficient utilization of limited park and ride capacity.
Universal Map Application (T-MAP)	Most, if not all, current CAD/AVL systems use proprietary map applications. Consequently, transit agencies often need to load additional map applications for accommodate information from other sources, such as traffic alerts, weather and transit travel information. This requires additional time, leads to operational cost and adds complexity in integration and analysis of data to support decision making. This application will use the open map concept to establish a universal map application supported by private transit CAD/AVL systems. The application could then receive information feeds from supporting agencies and automatically incorporate critical traveler information, such as incidents, detours, street closures, alternative transit alternatives, and traffic flow on the transit agency's map application. Likewise, transit agencies could also provide vehicle locations, passenger amenities, and service level to municipalities who need to schedule street repairs, or other road closures or detours.
Real-Time Route Specific Weather Information for Motorized and Non-Motorized Vehicles	This application will continuously collect weather-related probe data generated by probe vehicles, analyze, and integrate those observations with weather data from traditional weather information sources, and develop highly localized weather and pavement conditions for specific roadways, pathways, and bikeways. The current and forecasted

(WX-INFO)	information will be available in-vehicle, and via the internet, variable message signs (VMS), highway advisory road (HAR), 511, and personal communication devices. Knowledge of real-time weather conditions along an anticipated route can help a traveler determine whether to reschedule or postpone the trip, or take an alternate route or mode. The localized weather information can also be used by transportation system operators to implement strategies that minimize the impact of inclement weather.
Freight Advanced Traveler Information System (FRATIS)	*Freight Advanced Traveler Information System seeks to provide freight-specific route guidance and optimizes drayage operations so that load movements are coordinated between freight facilities to reduce empty-load trips.*
Freight-Specific Dynamic Travel Planning and Performance	This application will enhance traveler information systems to address specific freight needs by providing route guidance to freight facilities, incident alerts, road closures, work zones, routing restrictions (hazmat, oversize/overweight), and performance monitoring. It will: • Build on the Cross-Town Improvement Project (C-TIP) Real Time Traffic Monitoring (RTTM) and Dynamic Route Guidance (DRG) applications for best route between freight facilities. • Provide intermodal connection information, container disposition and schedule • Leverage existing data in the public domain, as well as emerging private sector applications to provide benefits to both sectors.
Drayage Optimization (DR-OPT)	This application will reduce freight delays at key facilities that currently overbook their capacity to ensure uninterrupted operations within the terminal/warehouse. DR-OPT will optimize drayage operations so that load movements are coordinated between freight facilities. Individual trucks will be assigned time windows within which they will be expected to arrive at a pickup or drop-off location. Early or late arrivals to the facility are dynamically balanced and web-based forums for load matching will be provided to reduce empty moves.

Bundle/Application	Description
Road Weather Specific Applications	*There is an overlap between the road weather and mobility applications, and much of the road weather requirements are addressed under mobility (e.g., WX-MDSS, Freight Dynamic Route Guidance, and SPD-HARM). Two road weather applications are outside the scope of the mobility bundles as currently defined.*
Information for Maintenance and Fleet Management Systems	Maintenance and fleet management systems are primarily concerned with the control of a transportation agency's physical assets, including its maintenance vehicles and materials (in this context, these are the chemicals and related materials used to control roadway icing and snow removal). This application will collect vehicle data, such as powertrain diagnostic information from maintenance vehicles; the status of vehicle components such as plow blades and spreaders; the current location of maintenance vehicles; and the types and amounts of materials onboard maintenance vehicles. These types of information are key inputs to Maintenance and Fleet Management Systems.
Variable Speed Limits for Weather-Responsive Traffic Management	VSL systems provide real-time information on appropriate speeds for current conditions and warn drivers of coming road conditions. Connected vehicle systems provide opportunities to enhance the operation of VSL systems and dramatically improve work zone safety during severe weather events. Additional road-weather information can be gathered from connected vehicles and used in algorithms to refine the posted speed limits to reflect prevailing weather and road conditions.

Appendix C. List of Acronyms

AACN-RELAY	Advanced Automatic Crash Notification Relay
ADR	Arterial Delay Reduction
ATM	Active Traffic Management
BI	Buffer Index
CACC	Cooperative adaptive cruise control
CHART	Coordinated Highways Action Response Team
D-RIDE	Dynamic Ridesharing
DMA	Dynamic Mobility Applications
DR-OPT	Drayage Optimization
DRG	Dynamic Route Guidance
DSRC	Dedicated Short Range Communications
ECO	Connected eco-driving
EDL	Electronic Document Library
ETC	Electronic Toll Collection
EVAC	Emergency Communications and Evacuation
FHWA	Federal Highway Administration
FRATIS	Freight Advanced Traveler Information Systems
FSP	Freight Signal Priority
ICM	Integrated Corridor Management
IDTO	Integrated Dynamic Transit Operations
IFTWG	Intermodal Freight Technology Working Group
INC-ZONE	Incident Scene Work Zone Alerts for Drivers and Workers
INFLO	Intelligent Network Flow Optimization
ISIG	Intelligent Traffic Signal Systems
ITE	Institute of Transportation Engineers

ITS	Intelligent Transportation Systems
JPO	Joint Program Office
MDSS	Maintenance Decision Support System
M-ISIG	Multi-modal Intelligent Traffic Signal System
MPG	Miles Per Gallone
ND	North Dakota
PED-SIG	Mobile Accessible Pedestrian Signal System
PREEMPT	Emergency Vehicle Preemption
Q-WARN	Queue warning
RAMP	Next Generation Ramp Metering System
R.E.S.C.U.E.M.E.	Response, Emergency Staging and Communications, Uniform Management, and Evacuation
RESP-STG	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders
RITA	Research and Innovative Technology Administration
S-PARK	Smart Park and Ride
SPD-HARM	Dynamic Speed Harmonization
T-CONNECT	Connection Protection
T-DISP	Dynamic Transit Operations
T-MAP	Universal Map Application
TDM	Travel Demand Management
TSP	Transit Signal Priority
TTI	Texas Transportation Institute
USDOT	United States Department of Transportation
VMT	Vehicle Miles Traveled
VTRC	Virginia Transportation Research Center
WX	Weather
WX-INFO	Real-Time Route Specific Weather Information for Motorized and Non-Motorized Vehicles

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