

# ITS technology adoption and observed market trends from ITS deployment tracking

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Research and Innovative Technology Administration  
U.S. Department of Transportation

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Cover photo taken from Minnesota DOT, "Evaluation of 2004 Dynamic Late Merge System" December 28, 2004 Accessed online <http://www.dot.state.mn.us/trafficeng/workzone/doc/2004DLMS-Evaluation.pdf> 10/7/2010

# 1. Executive Summary

## Introduction

This report examines the market dynamics and benefits associated with the deployment and diffusion of Intelligent Transportation Systems (ITS) technologies across the United States. A primary focus is on the qualitative analysis of the current ITS market structure, and the identification of key events that have influenced the trends in deployment and factors that may play an important role in shaping the market's future direction. Market information for this analysis was obtained mainly through discussions with suppliers and purchasers of ITS technologies. It is important to note that this study focuses solely on public purchasers of ITS (e.g., state transportation departments) and not on private sector purchasers.

A secondary focus is on examining the monetary benefits derived from the current level of ITS deployment. This analysis combines the results of published studies on ITS benefits with data on current nationwide deployment levels.

For both areas of analysis in this report, the level of ITS technology deployment and diffusion and information on purchasers of ITS technologies (transportation agencies) was obtained from the ITS Joint Program Office deployment statistics database.<sup>1</sup>

Leveraging the data contained within the ITS deployment tracking database, this report combines institutional knowledge, technical knowledge and interviews to better understand the market dynamics and benefits of historical and current generation ITS deployment. Knowledge and insight gained as a result of this analysis can be used to inform strategic planning efforts and guide research and related activities to support next generation ITS.

This report is presented in four main sections, all of which are self contained with an appendix. Three of these cover the qualitative market analysis for a particular technology or technologies and contain a summary (including considerations for future research) and a discussion on market background, trends, influences on deployment and conclusions. The benefits section contains a summary of results as well as details on the benefits calculation methodology, benefit categorization and monetization, results and a conclusion.

## ITS Markets Examined

The ITS technologies analyzed in this study were selected to provide insight into a range of markets. This allowed for examining how the different objectives and characteristics associated with ITS technologies in different markets affect deployment patterns (e.g., data collection technologies vs. data use technologies or technologies used on arterials or highways). For the benefits section, a requirement for inclusion of a technology in the study was the availability of published information and data on the level of benefits associated with their use. For each of the technologies selected, this study examines the market dynamics and reasons behind the different adoption rates and provides estimates of the benefits stemming from market diffusion levels. ITS benefits for this analysis were broken into three main categories: mobility, safety, and environmental.

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<sup>1</sup> <http://www.itsdeployment.its.dot.gov/Default.asp>

The market analysis covers the following technologies:

- Electronic Toll Collection (ETC)
- Highway Data Collection (HDC)
- Arterial technologies:
  - Vehicle Data Collection (VDC)
  - Transit Signal Priority (TSP)
  - Emergency Vehicle Preemption (EVP)
  - Traffic Management Software (TMS)

The estimation of the benefits from ITS deployments covers the following technologies:

- Electronic Toll Collection (ETC)
- Ramp Metering (RM)
- Red Light Cameras (RLC)
- Traffic Signal Coordination (TSC)
- Transit Signal Priority (TSP)
- Traveler Information Systems (TIS)

## Methodology

### *Qualitative Market Analysis*

The qualitative analysis of deployment trends is based heavily on interviews with both purchasers (transportation agencies) and suppliers of ITS technologies. Along with interviews, information was also gathered from attending a trade conference, published research or articles and an examination of data from the ITS deployment tracking survey. In an attempt to get a full view of the markets being studied, effort was made to reach out to a random selection of both large and small suppliers of ITS technologies and to speak with a variety of ITS purchasers. Both large and small agencies from various parts of the country were contacted and interviewed about their adoptions of ITS technologies.

### *ITS Benefits Section*

The methodology for estimating the monetary benefits of current ITS deployment is based on identifying and reviewing published papers that focus on quantifying these benefits. The literature review focused on papers published in scholarly or research-orientated journals that both provide estimates on benefits per unit of ITS deployment for the technologies under consideration, and describe the length of time over which the benefits were calculated. Papers were also examined and selected based on whether their methodology and results were compatible and credible enough to be utilized for calculating ITS benefits within the context of this study.

The model used to calculate benefits assumes a linear relationship (or constant returns to scale) between benefits and ITS deployment, (e.g., the 100<sup>th</sup> loop detector has just as much benefit to a city as the first

loop detector). It may be the case that ITS deployment exhibits increasing or decreasing returns to scale; however, with no specific information or research available on this subject, the simplifying assumption of constant returns to scale was used for the purposes of this study.

The benefit (\$/year) from the current level of ITS deployment were estimated using the following equation:

$$B_N = B_S \cdot \frac{U_N}{U_S} \cdot \frac{1 \text{ year}}{T_S}$$

where:

- $B_N$  = Monetary magnitude of annual nationwide benefit of technology, \$
- $B_S$  = Monetary magnitude of benefit of technology as estimated in the study, \$
- $U_N$  = Number of units deployed nationwide
- $U_S$  = Number of deployed units responsible for the benefit reported in the study
- $T_S$  = Length of time over which benefits reported in the study accrue

## Analysis Results: Qualitative Market Analysis Section

### *Electronic Toll Collection*

#### **Background**

Purchasing agencies have chosen to adopt Electronic Toll Collection (ETC) technology for a variety of reasons, including safety, congestion, environmental and cost considerations. In terms of safety, ETC allows fewer toll agency staff members to be in an environment with traffic, leading to fewer accidents. Congestion can be improved because fewer cars are required to stop at toll plazas, keeping traffic moving more smoothly and continuously. Less congestion means less pollution. Finally, potential cost savings are a large reason that purchasers may elect to adopt ETC, as an ETC transaction can cost roughly ten times less than a cash transaction. Nonetheless, price constraints do play a role and the availability of agency funds to offset ETC investment must exist for a switch to ETC to be considered.

Following the decision to adopt ETC, the selection of which ETC technology to use is very important. ETC technologies are supplied primarily by three major companies, some of which maintain their own technical standards and may not be interoperable<sup>2</sup>. Purchasers are highly sensitive to quality and desire well-proven technologies. The emphasis on proven technologies makes entry into the ETC market difficult and may explain the existence of so few suppliers, although the relatively small size of the market relative to other uses for such technologies is another important reason.

The large cost, durability of the equipment and interoperability contribute to what is referred to as the “lock-in” effect. That is to say, because the technologies do not operate together and the cost of replacing an entire system is high, purchasers become locked-in to a specific technology.

One final consideration is location. Agencies are likely to use technologies their neighbors use because they want to be interoperable, or their neighbor has shown that the technology is reliable. A prime example is the E-Z Pass Interagency Group, which oversees the E-Z Pass program and is comprised of 24 constituent agencies in 14 adjacent states.<sup>3</sup> In the situation where there is a regional coalition of ETC users, consensus is required for coalition wide adoption, which can hinder changes in the ETC technologies used.

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<sup>2</sup> Interoperability is affected by technology standards and back-office operations.

<sup>3</sup> About Us. (2010). E-ZPass Interagency Group. <http://www.e-zpassiag.com/aboutus.html>



## Future

The ETC market is currently poised for change as initial adopters are using readers that are near the end of their lifespan and new technologies offer extra benefits. IntelliDrive<sup>SM</sup>, smaller tags, cell phone payment technologies and cameras all have potential. Constraints to change may appear in the form of limited budgets, the need for proven technologies, high-profile negative experiences, and the “lock-in” effect. Suppliers will also be more motivated to produce new technologies that offer them larger potential profits.

The uncertain future of the introduction of the 5.9 GHz standard has led to lower rates of innovation in the ETC realm, as suppliers are unsure of the future and in what they should invest. In addition, the widespread implementation of 5.9 GHz would cause purchasers to incur significant costs to upgrade receiving and transponder equipment; many purchasers commented that they are waiting to see what the federal government will decide.

## Considerations for Future Research

Future research may concentrate on the following areas:

- **Environmental lifecycle of ETC equipment:** The expansion of ETC, which could result in the circulation of millions of transponders, may have some environmental implications. For example, active tags need disposable batteries to power them and any possible effects this may have on the environment will have to be considered. Furthermore, the environmental effect of policy recommending a national ETC standard utilizing active tags (with batteries) would need to be considered.
- **Market power of suppliers:** Network characteristics, proprietary technologies/systems, and the lock-in effect may create an environment prone to market power. Research investigating the issue of regional ETC networks would provide valuable insight into the associated cost incurred by consumers. This analysis would also be useful in guiding the decision-making process for a national standard.
- **Vehicle miles traveled (VMT) taxes:** A VMT tax is seen by some as a possible solution to offset the volatility and political intransigence of the gasoline tax; examining the impact of transitioning to a VMT tax on the ETC market would be a valuable addition to this discussion.
- **Bidding strategies for ETC technologies:** Bidding strategies may present a way to decrease lock-in. For example, in Europe a two-stage bidding process is used for ETC technologies, and research could be done to see if the European method tilts the benefits towards the purchasers more so than the suppliers.

## *Highway Data Collection*

### Background

Highway Data Collection (HDC) technologies are used to provide the necessary input data into other ITS applications, such as variable message signs (VMS) or traffic management systems (TMS). HDC can be classified into two main categories: sensor-based technologies (such as loop detectors) and probe-based technologies. The former are technologies that are well established (loops have been used since the 1960s) and form the large majority of all HDC deployments. Probe-based technologies are much newer and have a more limited market history, with the first technologies entering the market in the mid-1990s. These technologies are rapidly evolving, and utilize new technology that has become available, in some cases, only within the last few years (such as the use of smart-phones).

Loop-based deployments are highly accurate, which is part of the reason why they have been used so extensively. Additionally, because the market for loops is very mature, costs are very competitive and

there is little supplier market power. Nevertheless, loops are very invasive and need to be placed directly in roads, which may cause delays due to closed lanes. Other types of sensor-based data collection are being used, such as cameras, but these have not been shown to be as accurate as loops. The use of probe data is being explored; however, it too suffers from data inaccuracies and is not yet as accurate as loop-based data regarding both vehicle count and speed.

Despite the long history of HDC, data collected in the ITS deployment tracking survey show that of those freeway management agencies which responded to the survey in 2007, fewer than 50% reported having some kind of HDC technology. Still, this is a notable increase since 1997, when deployment was reported by fewer than 20% of respondents. The recent growth in deployment may reflect the increase in use of downstream ITS technologies, such as VMS and 511 services, which require HDC as an input.

Overall the market is too diverse to classify it as either competitive or uncompetitive. Examining individual segments of the market is necessary to determine the level of competition. For instance, the market for loops is fairly competitive, while there are relatively few probe data providers.

Prices have come down, but stabilized in recent years. No price trend has emerged in the probe data market, primarily because it is so new.

## Future

The 1201 Rulemaking could provide the impetus for further HDC adoption, as it sets minimum requirements for real-time traffic data collection. Additional ITS needs such as data dissemination through VMS and 511 programs may also drive agencies to adopt more HDC technologies.

While loop-based systems have matured, additional deployment growth may be seen in other sensor-based technologies areas, such as that of cameras. Growth in the probe-data arena is likely, as probes become more widely available and GPS technology continues to become more common. The introduction of IntelliDrive<sup>SM</sup> is intended to advance technology to allow vehicles to communicate with each other; in-vehicle devices used for IntelliDrive<sup>SM</sup> functions are expected to generate data similar to current probe data.

## Considerations for Future Research

- **Procurement / bid package / RFP guidelines:** There appears to be a gap in the market that would benefit from the development of guidelines for procuring data from a third party. Agencies tend to have to develop the process from scratch and the requirements for a data service are different enough from those of hardware that they likely require different sets of criteria and rules. In addition, there can be contention over who owns the data, how can it be disseminated, and can it be shared with other private companies (or agencies). Providing guidance on how to develop and manage a procurement process and how to address important issues (such as data ownership) would be a valuable market resource for ITS purchasers.
- **Accuracy of probe data:** A major concern in the HDC market is with the accuracy of probe data when compared to sensor data. Since claims of accuracy can be hard to verify, this would be a useful area for research. Such research should have several objectives, including some sort of certification method (to provide agencies with a better gauge of the quality of data they are purchasing), an examination of the current generation of technology, and exploration of ways to improve accuracy.
- **Supplier market power:** The probe-based data market seems to be structured in a way that could give rise to a natural monopoly. The utility of data collection depends on the strength of the network of probes; if not enough probes are available the collected data cannot be used to create an accurate portrayal of the on-ground situation. As a result, a one-supplier market

could be a natural outcome, with all probes feeding data to a single receptor, thereby increasing coverage. In this situation, a company with the entire set of probes is likely to have significant market power. A valuable area of analysis would be examination of the growth and structure in this market to determine whether it has the characteristics of a natural monopoly (either nation-wide or each region of deployment), which could affect the cost of purchasing probe-based data.

- **Google's entry into the HDC and VDC markets:** In late 2009, Google moved into the navigation business, utilizing their Android mobile operating system. The additional functionality of the new application, as well as the increased use of the Android operating system in new smart-phones has the potential to provide Google with millions of probes nation-wide. This raises the question of how Google will capitalize on the collection of data on a national scale, in such an important sector of the economy, and how this may affect federal policy making in the realm of HDC. As such, this is a development that is worth researching to determine how it may affect future decision-making in the HDC market.
- **IntelliDrive<sup>SM</sup>:** While the HDC market does not appear to be operating under the assumption that it will be implemented in the immediate future, the IntelliDrive<sup>SM</sup> program presents an interesting possibility, since it proposes to equip every car with an in-vehicle probe. The presence of a probe in every vehicle on the roadway would likely dramatically increase accuracy of probe-based data applications. Research into the development of HDC standards or the diffusion of probes would be worthwhile areas of focus connected with the IntelliDrive<sup>SM</sup> effort.

## Arterial Technologies

Arterial technology markets discussed within the scope of this study are:

- Vehicle Data Collection (VDC) for arterials
- Traffic Management Software (TMS)
- Transit Signal Priority (TSP)
- Emergency Vehicle Preemption (EVP)

### *Vehicle Data Collection*

#### **Background**

VDC is similar to HDC in that the two markets use many of the same technologies. Sensor-based technologies, however, are much more common in VDC applications. Among these deployments, loops continue to be the standard; however, newer technologies such as video detection are increasingly being used. As with HDC, loops are currently preferred due to their accuracy. When interviewed, purchasers explained that cameras often had trouble accurately identifying traffic due to environmental factors such as rain, fog, and glare caused by sunlight. They also mentioned that moveable VDC technologies may be preferable, especially due to the need to monitor traffic in construction zones. That, combined with the invasiveness of loop detectors, may make other methods of VDC more attractive should their accuracy increase. Nonetheless, other sensor-based technologies and probe data applications will need to improve in accuracy before arterial management agencies choose to adopt them as a suitable complement or substitute to loops.

As with HDC, VDC technology is an input to other types of ITS applications; it can be used for TSP, EVP, TMS and traffic signal coordination (TSC) applications. Of the 106 major metropolitan areas responding

to the 2004 deployment tracking survey, 87% had loop detectors at one or more intersections and among those surveyed, 40% of all signalized intersections had VDC.

The market structure, like that of HDC, is difficult to categorize as competitive or non-competitive. While some technologies such as loops can be considered to exist in a perfectly competitive marketplace, newer technologies do not. In addition, the market operates primarily through a supplier-vendor-purchaser structure in which a vendor partners heavily with one or a limited number of suppliers. Additionally, the benefits of a perfectly competitive marketplace, if it exists, may disappear as soon as an agency adopts a particular technology. After that point, there may be barriers to adopting a new type of technology from a different company, since it may be difficult to integrate into the existing system. The initial supplier is thus able to achieve strong continuing market power.

## Future

VDC deployment has increased in the last decade and the market appears to be expanding. Demand for related ITS deployments (e.g., TSP, EVP, TMS) will play a role in driving future growth, although it is not obvious which VDC technologies will be favored going forward; this depends heavily on agency preference as well as technological advancements in the industry.

## Considerations for Future Research

- **VDC benefits:** Explore existing and further research into benefits of adaptive/real-time TMS for effective capacity improvements, congestion/delay reduction, and emissions reductions. This would provide purchasers with valuable information on the benefits of utilizing VDC information in a more efficient manner.
- **VDC economies of scale:** Research economies of scale related to “region-wide integration” of ITS: multiple agencies, multiple arterials networks, multiple functionalities (e.g., EVP, TSP, parking, traveler information, etc.), and Integrated Corridor Management. This would provide potential purchasers with information on benefits and strategies for combining ITS arterials technologies and integrating their efforts effectively with other modes.

## Traffic Management Software

### Background

Traffic Management Software is a valuable tool to manage very complex or congested traffic networks. In order to effectively leverage the advantages of the system, good infrastructure needs to be in place, notably investments in VDC technology. As a consequence of the extensive infrastructure requirements, as well as the high cost associated with implementing and operating a TMS system, most TMS adopters are large agencies in densely populated and highly congested areas.

While TMS manufacturers may offer “off-the-shelf” or “one-size-fits-all” solutions, many purchasers interviewed viewed such pre-packaged systems with skepticism. Often, they stated that such systems had proved inadequate for their needs. As a result, the TMS market is characterized by a high degree of customization and the purchasing process most often involves an RFP. Importantly, price is not typically the highest consideration of agencies when reviewing an RFP. Purchasers often indicated that quality and capability were the most important aspects in a TMS deployment. In fact, one purchaser mentioned that their RFP process was designed to be price-blind until as late in the process as possible. Because of this, it is difficult to gather information on price trends in the TMS market; to some extent, TMS suppliers likely price their products according to the ability of the purchaser to pay. Based on a 2009 study, the price per intersection to implement an advanced TMS system was \$55,000, although prices varied widely

around this figure.<sup>4</sup> Due to the highly customized nature of this software, some agencies will elect to create an in-house TMS system or work with a supplier to create a custom-built solution.

## Future

“Adaptive” TMS is regarded as the future of TMS by both suppliers and purchasers. These systems currently only control 1% of signals in the U.S.<sup>5</sup> The majority of adaptive TMS users in the 102 major metropolitan areas had fewer than 2% of signals equipped with this technology. Currently, closed loop systems (a less advanced version of TMS) account for 90% of signal control systems in the U.S.<sup>6</sup>

As advanced TMS becomes more common it enables multiple municipalities and jurisdictions to communicate regarding congestion, EVP, and TSP.

## Considerations for Future Research

- **Estimate the performance time horizon of TMS:** TMS technology represents a significant investment and agencies have the expectation of operating it over a long period of time. Examining the life-span of this technology would provide guidance for the market on how long an investment in TMS would be productive and insight into the likely timing of when the market will be more open for new technology.
- **Consider environmental legislation and policy:** Examine and consider the implications of Federal legislation and local initiatives limiting emissions of carbon and other pollutants on the demand for TMS.
- **Advance research into adaptive/real-time TMS:** Explore existing and further research into benefits of adaptive/real-time TMS for effective capacity improvements, congestion/delay reduction, and emissions reductions. Areas of research on adaptive/real-time TMS that would benefit the market include:
  - Characterize existing base of advanced detection equipment (e.g., non-stop-bar detection) which can be leveraged for adaptive/real-time management use.
  - Examine and target funding opportunities for adaptive TMS in high-traffic-volume and high-congestion areas.
  - Characterize successful purchaser-supplier partnerships to provide guidance to potential adopters: for example, on how to efficiently and expediently conduct the procurement process, on what levels of pre-existing infrastructure (especially VDC) are necessary or helpful, and on what continuing relationship to expect or require from the supplier.

## *Emergency Vehicle Preemption (EVP) and Transit Signal Priority (TSP)*

### Background

EVP technology was originally created in the 1970s and used a strobe light system to communicate with signal controllers. This advanced into a separation of EVP and TSP systems and now includes strobe-, infrared-, and, most recently, GPS-based systems. Results from ITS deployment tracking surveys indicate an increase in EVP deployment over the last decade, with 91% of the 102 metropolitan areas reporting some kind of EVP capability in 2007. Nonetheless, few of these agencies have over 50% of signals under EVP, and one-third had fewer than 10% of signals covered. Of particular interest with regard to technology diffusion in this market is the fact that there may be substitutes for EVP technology in terms of

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<sup>4</sup> Selinger & Schmidt, 2009

<sup>5</sup> Federal Highway Administration, 2008

<sup>6</sup> Federal Highway Administration, 2008

functionality, such as in-vehicle navigation and computer-aided dispatch. These substitutes are not exclusively used for arterials operations, but serve a similar purpose. Whether an agency views these technologies as complements or substitutes, and which (if any) it chooses to deploy, may be dependent upon the agency's priorities (e.g., safety of emergency responders, efficient movement of traffic, etc.). In particular, the rate of adoption may be affected by the perception of EVP vis-à-vis congestion management; agencies may determine that EVP runs counter to their primary objective of congestion relief. The availability and implementation of these potential substitutes or complements may affect the rate of EVP adoption, along with the sophistication of field devices in place (i.e., controllers and detection equipment).

TSP, by contrast, currently has a much lower scope of deployment, although it has seen large growth (from practically 0% deployment in 1997 to 11% deployment on fixed-route buses among survey respondents in 2007.)

The market for EVP/TSP technology is controlled by relatively few suppliers, one of which controls the majority of the market. Prices, however, have decreased as GPS has been introduced to compete with older acoustic or strobe/infrared-based technologies. From the purchaser side, there is low adoption of both technologies for several reasons:

- The successful development of these technologies requires coordination between emergency management agencies, transit agencies, and arterial agencies.
- Lack of awareness of the technology.
- Need for signal controllers that are compatible with EVP/TSP technologies.
- The perception that EVP/TSP technologies may increase congestion, as traffic overall flows are disturbed in deference to an individual vehicle.

## Future

While there is a much higher installed base of TSP technology in Europe, deployment momentum within the US is increasing. Future adoption, however, is likely to be closely correlated with the adoption of real-time traffic management capabilities. Rather than disrupting coordination in a network of signals, which is a concern among agencies whose primary goal is to minimize congestion, the alterations to signal phase and timing are internalized using a real-time system, and the network is re-optimized based on current conditions (e.g., whether a bus is empty or full, or if an ambulance trip is time-critical).

## Considerations for Future Research

- **Understand impact of EVP and TSP in a TMS environment:** Since the technologies are related, it would be valuable to include the EVP and TSP markets when exploring existing and further research into benefits of adaptive/real-time TMS for effective capacity improvements, congestion/delay reduction, and emissions reductions.

## Estimation of Benefits across a Subset of ITS Technologies

The benefits chapter of this report attempts to measure the nationwide benefit of six technologies, (noted above), through secondary research and data obtained from the ITS deployment tracking survey. Benefits are based on the range of high and low values found in the published literature on ITS benefits and on the level (number of units) of ITS deployment in 2007. ITS benefits are captured in four main categories:

- Mobility benefits from travel-time reduction
- Environmental benefits from lower emissions
- Safety benefits
- Fuel consumption benefits

Improved mobility was the largest benefit in general—particularly for ETC, which had a high estimate of about \$1 billion per year. Environmental benefits were recorded as positive for ETC while ramp metering (RM) produced a negative benefit due to emissions associated with delays on ramps. Safety benefits were inconclusive and varied by technology. Fuel cost benefits were highest in the ETC market and negative in the RM category, once again owing to waiting time on ramps.

The summary table below presents the range of annual nationwide benefits for each benefit category within each technology. The “Total” columns show the range of *total* nationwide benefit estimates for each technology, summing across all benefit categories estimated in a given paper. The table yields the following observations:

- In the Mobility category, ETC appears to produce the greatest annual benefits nationwide, with a high estimate of over \$1 billion. ETC is followed by TIS, TSC, RM and TSP in descending order.
- In the Environmental category, ETC produces positive benefits, while RM produces negative benefits due to the delay it causes on the ramps.
- Results in the Safety category are less conclusive due to the large range observed in estimates of RLC benefits. The Safety benefits of RM are in the lower part of that range.
- In the Fuel Cost category, ETC produces greater benefits than RM. RM produces negative net benefits due to the delay it causes on the ramps.

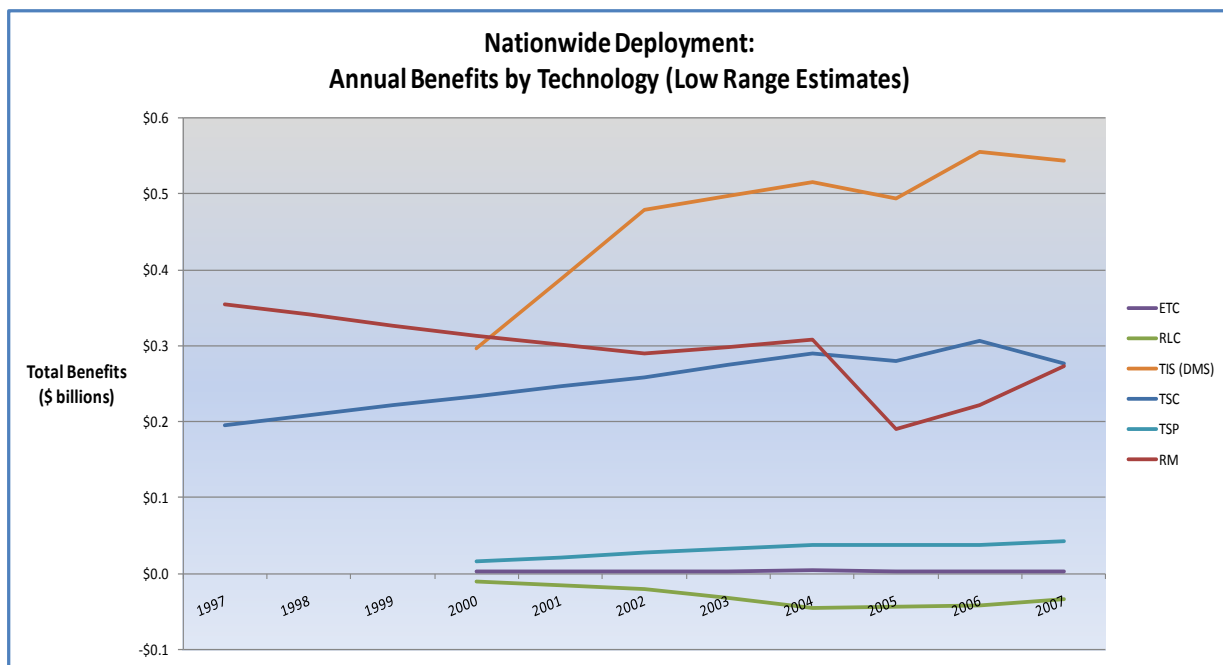
**Summary – Annual Nationwide Benefits at 2007 Deployment Levels (\$2009)**

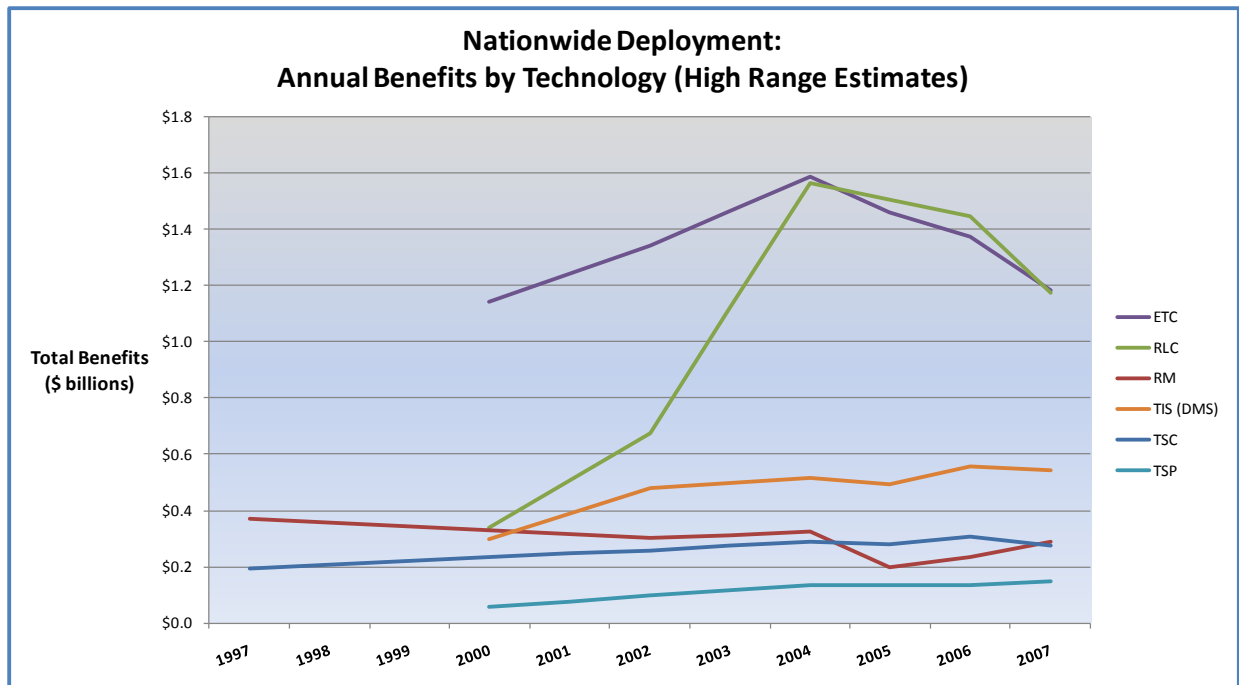
	Mobility		Environmental		Fuel Cost		Safety		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High
<b>ETC</b>	\$602,714,686	\$1,026,544,897	\$2,904,283	\$50,407,594	\$83,504,391	\$155,091,362	--	--	\$2,904,283	\$1,182,166,854
<b>RM</b>	\$175,051,077	\$273,619,082	-\$26,693,605	-\$26,693,605	-\$78,962,219	-\$78,962,219	\$217,736,931	\$217,736,931	\$273,619,082	\$287,132,183
<b>RLC</b>	--	--	--	--	--	--	-\$34,032,674	\$1,175,852,233	-\$34,032,674	\$1,175,852,233
<b>TSC</b>	\$276,544,507	\$276,544,507	--	--	--	--	--	--	\$276,544,507	\$276,544,507
<b>TSP</b>	\$42,260,073	\$149,986,037	--	--	--	--	--	--	\$42,260,073	\$149,986,037
<b>TIS</b>	\$543,102,791	\$543,102,791	--	--	--	--	--	--	\$543,102,791	\$543,102,791



An estimate of the annual nationwide benefit for each technology from 1997 to 2007 was calculated by multiplying the benefits per unit-year by the nationwide deployment counts obtained from RITA's ITS Deployment Statistics Database. As shown in the graphs below, the high range estimates and low range estimates differ dramatically both in terms of magnitude and relative benefit levels among technologies. TIS exhibits the highest benefits – nearly double the benefits produced by the next highest technology within the low range estimates, while RLC net benefits were negative. Within the high range, ETC and RLC produced the highest benefits and TSP the lowest.

There are no clear cross-technology trends evident in the annual benefits results. Some technologies show a decline in benefits and others a static level of benefits. It is important to note that the level of deployment is central to the pattern of these benefits; any changes in methodology or technology definitions in the survey will have a direct effect on the calculated benefits. Nevertheless, if these downward trends are not entirely due to survey issues then this would yield some interesting questions that might be worth answering in future research.





## Key Conclusions

Several key market observations and conclusions arise from this study. In the case of ETC technology, deployment is very high among toll roads in the US. Coalitions and location-based issues as well as safety and cost concerns are believed to have played a role in the high adoption rate of ETC. The size of an ETC coalition, however, may be an obstacle to enabling its members to get lower prices from purchasers; more members mean that it is necessary for multiple and complex technical requirements to be met. Indeed, a key insight from this study is that, in the ETC market, lock-in is a very strong force; decisions made now have a long legacy for future generations. The market expressed uncertainty over whether the Federal Government will mandate a national standard, such as 5.9 GHz. Recently launched research on IntelliDrive<sup>sm</sup> related applications, however, is engaging the community on this issue.

HDC has seen growth in deployment over recent years and loops remain the standard technology for this practice. Newer technologies are entering the market, notably probe-based solutions, but these are not as accurate as loops and have not achieved widespread use. Among the arterial technologies, VDC is very common, but most technology deployment, as for HDC applications, is concentrated in loops. For the same reasons mentioned with regards to HDC, newer VDC technologies are not yet widely used.

TMS technologies are not as prevalent in the U.S. as they are in Europe, but they are becoming more popular. Although expensive and requiring substantial investment in physical infrastructure, adoption is increasing and these advanced systems are clearly beneficial to aid in traffic management in dense and highly congested areas. Going forward, Federal legislation and local initiatives limiting emissions of carbon and other pollutants are expected to stimulate and broaden the demand for TMS. In contrast, EVP and TSP are not as widely adopted technologies, although because TSP has gained a following in Europe, it is possible that increasing adoption may happen in the U.S. as awareness of its benefits grows.

In examining the benefits of ITS deployment, different technologies exhibited both positive and negative benefits. While cumulatively, most of the ITS technologies examined had positive high and low estimates

for total benefits, red light cameras did have a negative low benefit; this was due to the findings of one study in the literature review, which reported an increase in rear-end collisions where drivers rapidly braked to avoid being fined (Washington and Shin 2005). In addition, even though the overall benefit was positive, ramp metering did have negative benefits in the areas of fuel consumption and environmental effects due to increased congestion near arterial ramps to freeways.

The construction of the benefits estimates presented in this study required several simplifying assumptions. In order to provide a more accurate and comprehensive picture of these benefits in the future, should the U.S. DOT ITS Program choose to contract out research on the benefits of a particular ITS technology, the resulting report should be required to include all data items necessary for extrapolation to a nation-wide scale. This would be an effective and efficient use of funding. In addition, some of the caveats discussed in the benefits section suggest areas of value for possible future research. These include:

- Determinants of regional variation in annual per-unit benefits of ITS technologies.
- The relationship between deployment levels and the marginal benefit of additional units of ITS deployment, both at the local and national levels.
- Examining any patterns or changes in the level of benefit during the normal life-span of a particular technology, at national, metropolitan, and per-unit scales of analysis.

## 2. Introduction

The objective of this study is to provide qualitative insights into historical deployment trends of Intelligent Transportation Systems (ITS). For selected ITS technologies, these insights will include an examination of the current market structure, key events that have influenced deployment, and factors that may shape the market's future direction. In addition, drawing upon published research, this study provides estimates of the benefits derived from the current nationwide level of ITS deployment. Overall, the trend analysis will allow the ITS Joint Program Office (JPO) to learn from the experience of historical and current generation ITS deployment and use this knowledge to guide research and related activities to support next generation ITS and inform strategic planning efforts.

The ITS trend analysis draws upon various sources for market and technology information. A central source was the ITS Deployment survey data summarized by Oak Ridge National Laboratory (ORNL), which was accessed through the ITS Deployment statistics website.<sup>7</sup> These data provided information on historical deployment patterns for various types of ITS technology and public purchasers. The ITS Deployment survey data was supplemented through interviews with market participants, both suppliers and purchasers, and secondary research.

Three ITS technology markets are covered in this trend analysis: Electronic Toll Collection, Highway Data Collection and Arterial Data Collection and Dissemination. These areas were selected to provide insight into a range of ITS technologies and markets covering both data collection and data use. It is important to note that this study focuses solely on public purchasers of ITS (e.g. State Transportation Departments) and not on private sector purchasers.

The benefits derived from ITS deployment were estimated for three main goals: safety, mobility and environmental. The estimation of benefits in these goal areas was done across a series of ITS technologies.

### Methodology

The study is broken into two components: a market analysis and an estimation of benefits from the deployment of ITS.

Information for the market analysis was gathered through interviews with ITS suppliers and purchasers, attendance at a trade conference, published research or articles, and an examination of data from the ITS deployment tracking survey.

For interviews, ITS purchasers were randomly selected from those surveyed for the ITS Deployment tracking survey. To ensure the broadest coverage of deployment trends, the sample was stratified by metro area size and level of ITS deployment. In cases where there were only a few suppliers an effort was made to speak with them all. Confidentiality was important to allow for an open dialogue; as a result, specific information and purchaser/supplier names have been excluded from this report. Where used, secondary information obtained from published sources has been footnoted and referenced in the appendix.

Monetary estimates of ITS deployment are drawn from existing studies in this area. Published work estimating the benefits from particular ITS technologies were obtained and then examined to determine if their methodology and conclusions were compatible and credible enough to be utilized for this study.

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<sup>7</sup> <http://www.itsdeployment.its.dot.gov>

These benefits were categorized under the broad categories of safety, mobility and environmental.

The market analyses are presented separately in Chapters 1-3, and the ITS Benefits section can be found in Chapter 4. Each of these chapters is a self contained analysis that can be read as a separate report or within context of the entire Deployment Tracking study. For convenience, each section contains its own appendix and bibliography.

*Note: In this report, technology or company names have been used as part of the discussion describing the influences on, and illustrating the trends of, ITS Deployment. The use of a particular technology or company name in this report, however, does not represent an endorsement or promotion for any technology or company.*

# 3. Electronic Toll Collection

Electronic Toll Collection (ETC) allows for the efficient and cost effective collection and processing of highway tolls. The primary technology used in this marketplace is a vehicle transponder using radio frequency identification (RFID) units to identify the vehicle to be charged as it passes through a tolled facility. Other technologies, such as number plate identification via camera and dedicated short range communication (DSRC), have not gained traction in the U.S. Electronic toll collection technologies are in use for both commercial and non-commercial vehicles.

This section of the study provides a qualitative analysis of the pattern of ETC deployment since the mid-1990s. A summary of key insights into the ETC market and an overview of the pattern of deployment are presented at the beginning of this chapter. This is followed by a more thorough examination of the ETC market, ETC market trends, key market attributes and the main influences on ETC deployment. The chapter ends with a series of conclusions and recommendations for future research.

## Summary

### Market Insights

- Regional zones of proprietary technology dominate the market and may reflect monopolistic influences.
- There appear to be no discernable price trends. The diversity of purchasers means they tend not to face a market price, but rather a price dependent upon the level and complexity of their requirements as well as their size. Price discrepancies may also be due to supplier market power.
- The majority of the market (suppliers and purchasers) is resistant to change.
- Once a purchaser adopts an ETC system, it is then essentially locked-in to its choice and faces large obstacles to switching.
- The domestic market is close to saturation in terms of ETC adoption. Most surveyed toll roads are using ETC, although usage is not yet 100%.
- Going forward, the events that could significantly change the market include:
  - federal government announcing a new national standard
  - movement to interoperability
  - implementation of a vehicle miles traveled (VMT) tax or similar user charge
  - a shift toward more tolling either as a congestion management measure or due to fiscal pressures
- The main factors driving the deployment of ETC technologies are:
  - cost savings of ETC versus cash transactions
  - congestion

- safety
- maturity of technology
- the price of the technologies
- toll revenues relative to expenses
- the number of agencies involved in the purchase
- location of purchaser
- trucking interests
- toll fare differentials
- federal government involvement

## Considerations for Future Research

### ITS JPO Policy Making:

- cost benefit analysis of ETC interoperability
- environmental life-cycle analysis of transponders
- estimating the impact of supplier market power
- market implications of mandating a national ETC standard

### Broader Market Issues of Interest:

- market implications of introducing a national VMT fee
- impact of the introduction of vehicle-to-vehicle and/or vehicle-to-infrastructure technology as a result of the IntelliDrive<sup>SM</sup> initiative
- market analysis of current bidding strategies and how these strategies are influencing ETC prices and deployment expansion
- The analysis of market power and bidding strategies would assist in understanding the larger question of why, in particular, there are such wide disparities in prices charged for transponders.

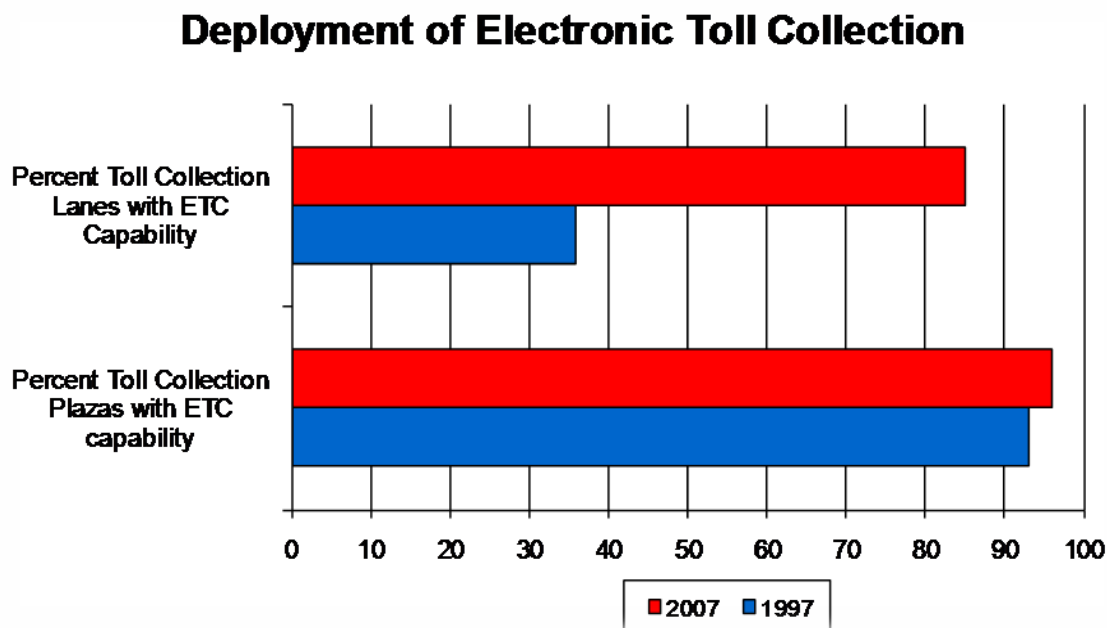
## Pattern of Deployment

The Electronic Toll Collection (ETC) market has experienced considerable change and growth since the mid 1990s. These changes have taken place both in terms of the amount of infrastructure investment and the use of ETC by commercial and non-commercial vehicle operators. Illustrating this rapid growth, the percentage of toll lanes using ETC more than doubled between 1997 and 2007 (See Figure 1). By 2007, 85% of all toll lanes (as identified in the ITS Deployment Tracking Survey) were using ETC, indicating the breadth of ETC deployment. ETC account holders show continued growth and the number of states using truck pre-clearance technologies that piggy-back on ETC technology and EZPass transponders has also grown.

The pattern of adoption since the start of 2000 has been one of relatively steady growth. Figure 2 below shows the yearly adoption of toll collection lanes with ETC capability. Between 2000 and 2007 there was a steady increase in the number of lanes equipped with ETC capability. During this period deployment

rose by 12 percentage points from 73% to 85%. By 2007, out of 4,113 toll collection lanes, 3,501 had ETC capabilities.

**Figure 1. Trends for Deployment of Electronic Toll Collection, 1997-2007**



*Source: Analysis performed by Oak Ridge National Laboratory and provided to the authors of this study. Data: ITS Deployment Tracking Survey*

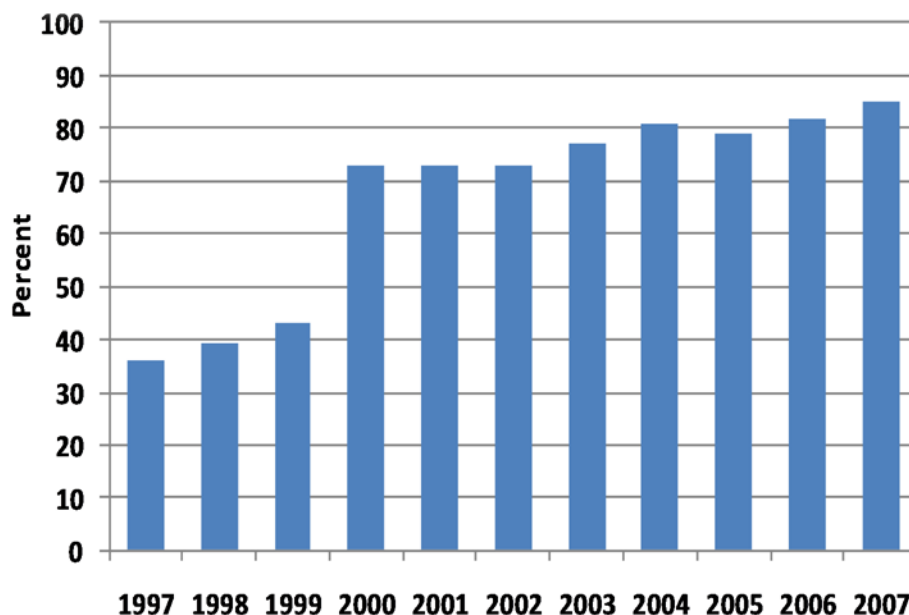
There is a noticeable break in the level of deployment between 1999 and 2000. A review of the ITS Deployment survey data reveals that the number of toll collection plazas with ETC capability did not change significantly during this time period; in fact it declined slightly in 2000 (Figure 3). This suggests that the spike in ETC equipped lanes is connected to the expansion of states with ETC in the latter half of the 1990s along with the addition of extra electronic tolling lanes being added to existing ETC equipped plazas. The increase in ETC lanes with the number of plazas remaining relatively constant may also be due to the open road tolling<sup>8</sup> used in many of the states.

There have been several key influences on the rapid growth in ETC. After the initial development of the communication technology and its application to tolling, the immense cost savings of an ETC system versus cash tolling spurred adoption. The cost of collecting a toll manually is roughly ten times larger than the ETC cost. ETC can also play a role in decreasing congestion, which is another factor causing rapid growth in ETC. As ETC gained a reputation for reliability and acceptance, more places began using ETC. The map in Figure 5 below shows the spread of ETC throughout the country from 1985 to present.

<sup>8</sup> The open road tolling in the U.S. is not always true open road tolling in the sense that they have an off-shooting cash lane to supplement the traditional open road tolling setup.



**Figure 2. Percent of Toll Lanes Using ETC**



*Source: ITS Deployment Database, Interpolated 1998, 2001, 2003*

The large adoption rate and prospect of federal government intervention will play an important role in this market's future as it deals with its largest issues: interoperability and new standards, environmental effects, tolling, vehicle miles traveled (VMT) tax, privatization, and market power. These issues are all interconnected. There is not much room for growth in terms of adoption of existing technologies on current toll roads. Figure 4 gives a sense of where there is room for growth in ETC adoption. The majority of states that have tolls are using ETC, but Indiana and Ohio have room to increase their deployment of ETC. Switching to a new standard, the introduction of new toll roads, or a VMT tax would all be events that could stimulate the market in the future.

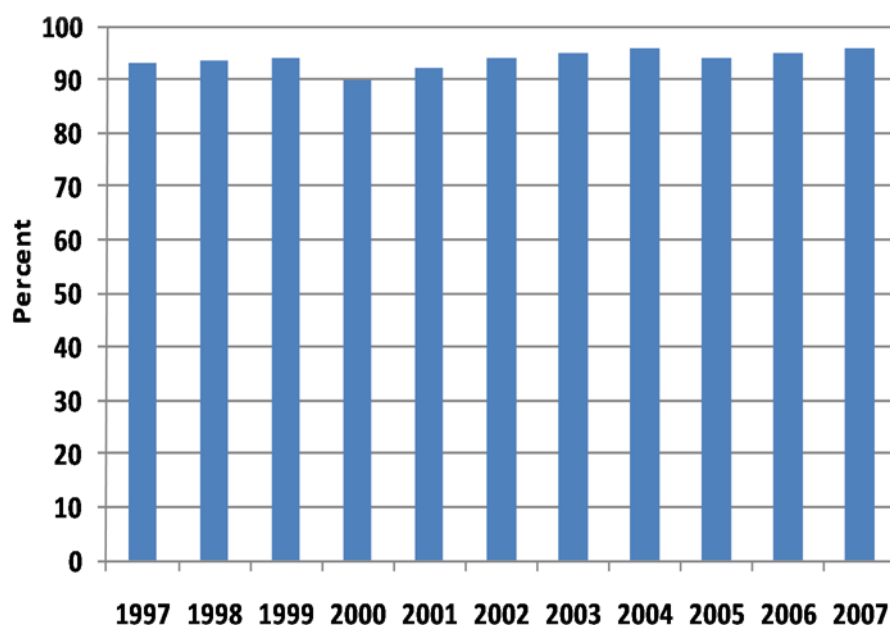
## Market Background

### Origins of ETC

Electronic toll collection (ETC) technology first appeared in the early 1980s as an outshoot of an agricultural research project.<sup>9</sup> This project utilized transponders and receivers to track the movement of livestock and it was realized that this technology could be applied to vehicle tracking and payment processing. Using this connection, the first ETC systems in the U.S were implemented in Dallas and Louisiana, utilizing Amtech's 128 bit read-only technology in 1989. After this, the American Trucking Association (ATA) adopted the same technology for their intermodal container standard.

<sup>9</sup> By 'ETC technologies' we are referring to either transponder and reader combinations or camera based tolling. In the U.S. the former technologies dominate and cameras are used for enforcement by documenting drivers that do not pay tolls. The value card technologies where money is stored on a smart card are not included as ETC for the purpose of this report. Value cards were not included because they require drivers to come to a complete stop at tolling booths and therefore do not have many of the benefits of ETC as defined for this report.

**Figure 3. Toll Plazas Using ETC**



*Source: ITS Deployment Database, Interpolated 1998, 2001, 2003*

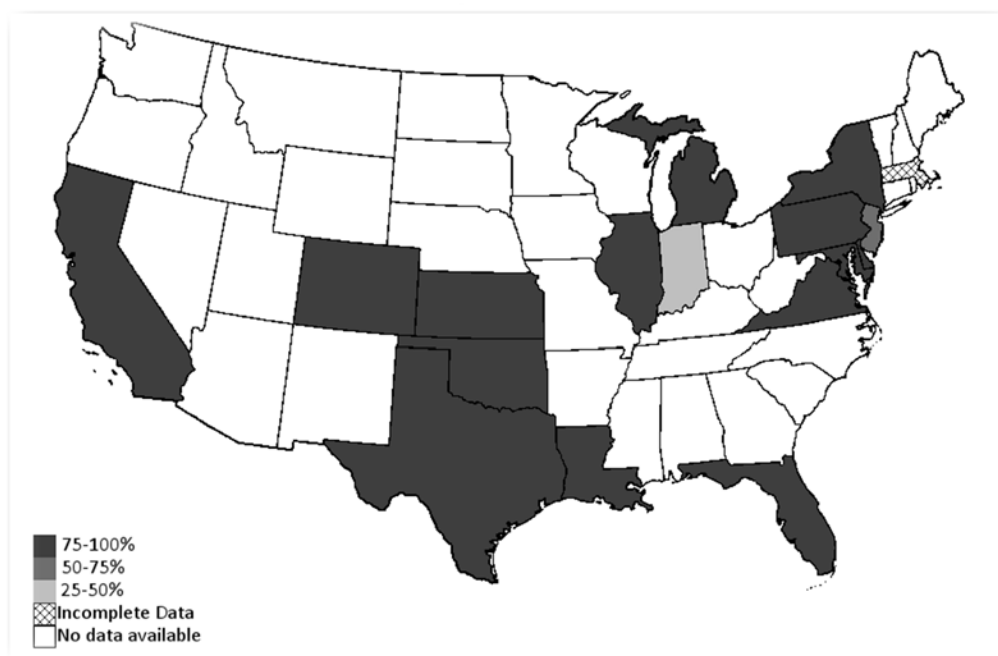
After the first two ETC systems were established, three states formed the E-Z Pass Interagency Group (IAG) in 1990.<sup>10</sup> This collection of states adopted ETC on a large scale beginning in 1993, forming the largest contiguous area of interoperable ETC systems. Eventually, eleven adjacent states would join IAG and use the same ETC system.<sup>11</sup> The system adopted by IAG, however, was not interoperable with the systems in Louisiana or Texas and presented no new innovations in the technology other than deployment scope.

The next major step forward occurred soon after IAG implemented ETC when California issued the Title 21 tolling standard in 1993. This created an open standard using 915MHz for use at all tolling facilities in the state, with the goal of ensuring interoperability throughout California. To date, the only other adopter of this standard is Colorado. Title 21 is currently the only open standard technology in the U.S. and is considered a nonproprietary technology. All other ETC systems are proprietary because the producers have patents on the technology and/or systems. Due to travel across regions, interoperability of technology is important in this market place and has led to the creation of regional monopolies.

<sup>10</sup> New York, New Jersey, and Pennsylvania

<sup>11</sup> IAG currently includes: Delaware, Illinois, Indiana, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Virginia and West Virginia.

**Figure 4. Percent of Toll Lanes Using ETC, by State, 2007**



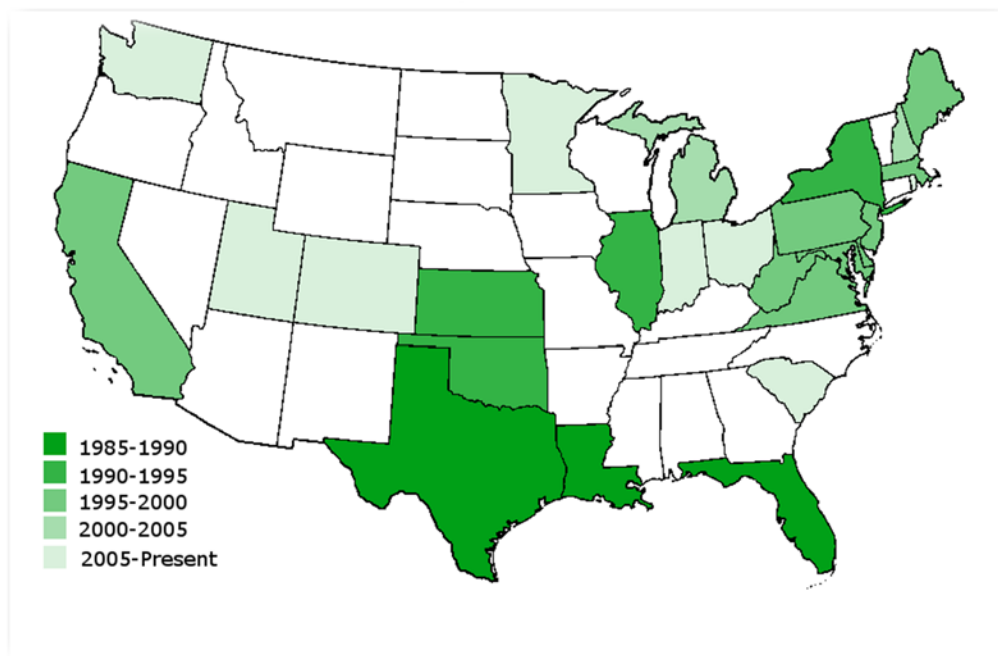
Source: ITS Deployment Database

Figure 5 illustrates the spread of ETC over time across the U.S., showing the year when ETC was first implemented on a toll road (Finkelstein, 2007).<sup>12</sup> The pattern of dispersion appears to have some discernable trends. The first wave of adopters is in dark green and includes Texas, Louisiana, and Florida. The next wave begins with the three original IAG states. Many of the states in the next wave are states that are adjacent to early adopters. Hence, part of the spread can be attributed to location factors and suggest that state agencies learn from their neighbors and/or are more comfortable adopting a technology that their neighbors use. A more detailed discussion of factors that affect adoption will appear later in this report.

Figure 6 shows that ETC technologies went through the traditional life cycle phases. In the early years it was innovative and had a few adopters. As the technology matured it was more widely adopted. In the later years, the rate of adoption has slowed as the market has exhausted the potential applications. The graph displays how the market began with some sparse deployment and then accelerated after ETC had proved itself and become a mature technology. In addition, there was a surge in deployment in the mid-to-late 90s through the early part of this decade, coinciding with the forming and subsequent expansion of IAG. With 85% of all toll roads monitored under the ITS Deployment tracking survey currently using ETC, the domestic market has little room for growth in new deployment unless a new standard is created, more roads become toll roads, a VMT fee is put in place, or states currently not using ETC elect to do so.

<sup>12</sup> It was not clear how exhaustive this survey was and it was supplemented to include the earliest adopters of Louisiana and Texas and the adopters during 2005 to present.

**Figure 5. Adoption of ETC over Time by State**



Source: Finkelstein (2007) and Volpe Center interviews

## Commercial Vehicle Operator (CVO) Systems

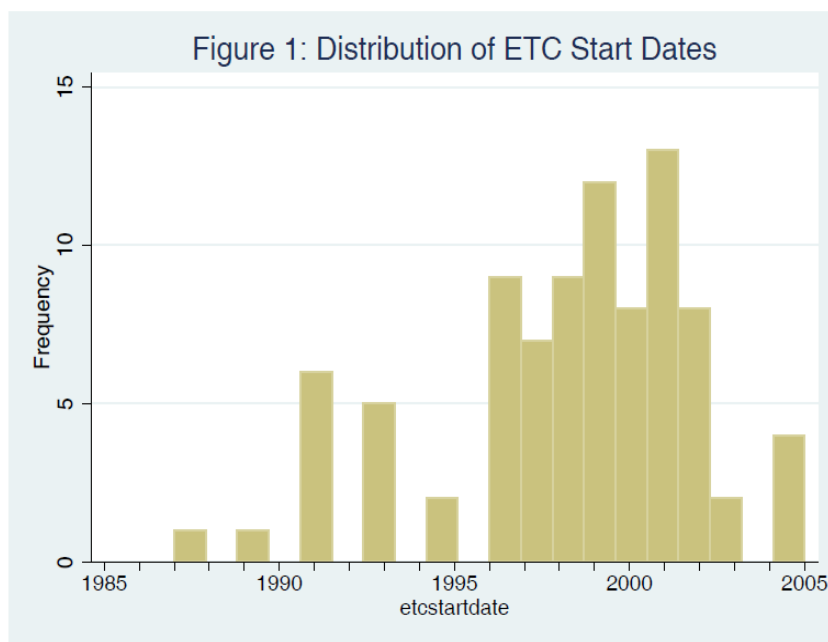
Commercial vehicles make more interstate trips than passenger vehicles and face extra delays due to weigh stations and credential checks. To address these costly delays, technology has evolved to provide more efficient weighing and paper checking alternatives: Automated Vehicle Identification (AVI), Automated Vehicle Classification (AVC), and Weigh-In-Motion (WIM) services. These systems read license plates and determine the chassis class of the vehicle and weigh the vehicles as part of truck inspection requirements.

The major types of electronic passes currently available in the market are:

- NorPass: North American Preclearance and Safety System
- PrePass: Offered by Heavy Vehicle Electronic License Plate Inc. (HELP Inc)
- Green Light in Oregon
- NCPass in North Carolina

These systems all use transponders that provide information for remote pre-clearance commercial vehicles at weighing or tolling stations. In particular, PrePass Plus merges the preclearance ability with the ability to pay tolls electronically. NorPass is a public-private partnership between state agencies, local agencies, and the trucking industry. Best Pass offers a single transponder to be used in the NorPass and PrePass systems (American Trucking Association Carrier Savings Program, 2009).

**Figure 6. Number of ETC Adoptions in Each Year, 1985-2005**



*SOURCE:* (Finkelstein, 2007)

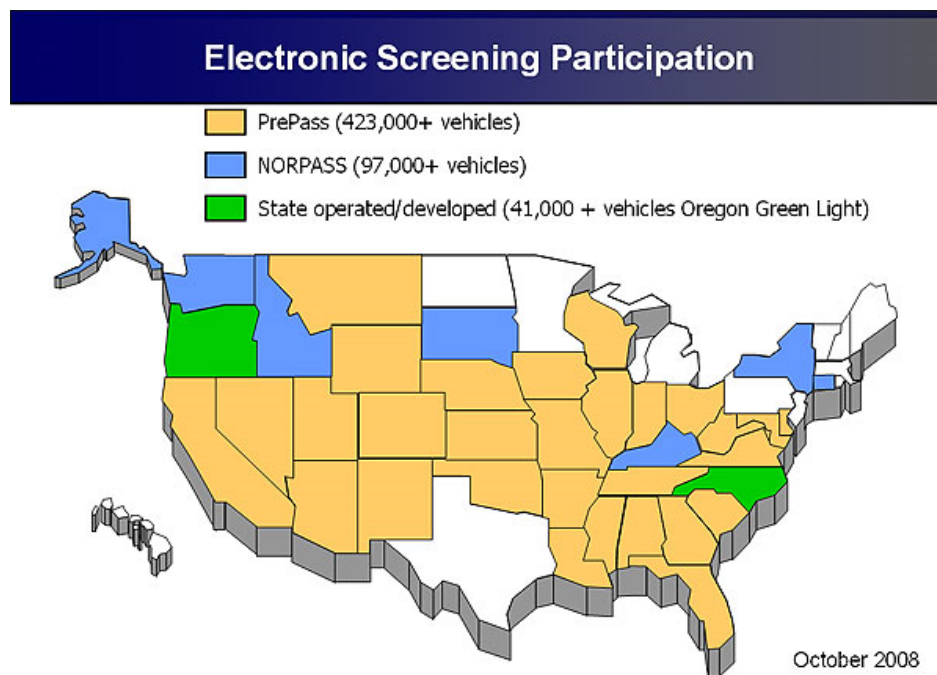
PrePass was launched in the 1980s, formally founded in 1995, and requires that members pass a safety screening (Galinas, 2009). Although NorPass and PrePass use the same transponders, they became more interoperable in 2000 (Fleet Owner, 2000). See Figure 7 for the NorPass and PrePass areas of interoperability and coverage. The transition towards greater interoperability was not smooth as Oregon, the largest holder of NorPass transponders, withdrew from the pre-clearance systems when the two competitors made the agreement. Oregon believed that the interoperability agreement between NorPass and Prepass unfairly required NorPass transponders to meet PrePass criteria (Patton, 2000).

The Federal government played a role in PrePass by subsidizing the Crescent Project which deployed PrePass in six states, attempting to create a path from the northwest to Texas (PrePass).

The estimated benefits accrued by firms using the PrePass system are large. It is estimated that from 1995 to 2007 the savings in fuel, operator time, and operating costs amounted to \$1 billion (Fleet Owner, 2007). The estimation of benefits did not include emissions reductions or impact on overall congestion.

The NorPass system has made progress in allowing their preclearance system to also do tolling. In Figure 8 below, the region marked in red indicates where the two abilities are available.

**Figure 7. Map of Commercial Vehicle Pre-Clearance Systems**



Source: (Federal Motor Carrier Safety Administration, 2008)

## Market Trends

### Market structure

There are currently three major suppliers in the ETC market:

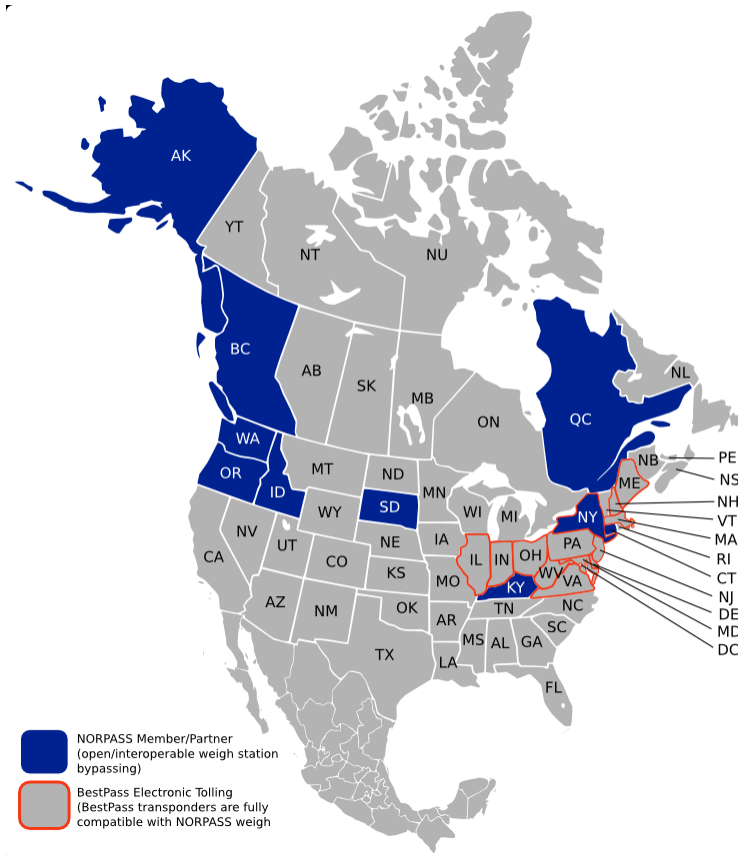
- Sirit: produces Title 21 transponders for California and abroad
- Transcore: produces a variety of transponders that are proprietary and not interoperable as well as some open standard transponders
- Mark IV: produces the proprietary IAG and PrePass transponders.

A new entrant in the market place is Kapsch, which is planning to specialize in 5.9 GHz transponders.

The ETC market began with a number of suppliers competing for market share in the late 1980's and early 1990's. Due to the similarity of the technology there were several lawsuits trying to establish patents during the initial years. Nevertheless, according to many respondents, the selection process that IAG used in selecting a supplier and technology for use in the mid-90s was very open and fair. After IAG selected a supplier, many firms exited the market, leaving the current suppliers identified above. Since then there has been a long period of no new entrants due to the perception of the market as being small, particularly as a result of technology lock-in.

On the purchaser side, IAG is the largest single purchaser of transponders and they collect 80% of U.S. toll revenue (EZ Pass Interagency Group).

**Figure 8. NorPass and BestPass Regions**



Source: (NorPass)

## Innovation

The ETC technologies, including readers and transponders, have evolved in terms of accuracy, speed, size, transaction ability, and production costs due to the falling costs of computer chips and the increase in processing power.

Cameras have also significantly improved in accuracy and speed. One respondent commented that the drastic improvements in cameras may make cameras the more dominant ETC technology in the future.

A key innovation is in the development of multi-readers enabling the reader to read a variety of transponders. The innovation offers part of a solution to the challenge of interoperability. It does not appear, however, that innovations in readers and transponders have had any effect on the deployment of ETC.

**Table 1. Number of RFID Tags Used in Different Industries, 2008**

Tag Location	Number of tags supplied in 2008 (millions)
Air baggage	60
Animals	90
Archiving (documents/samples)	9
Apparel	130
Books	85
Car clickers	48
Cold retail supply chain	0.01
Consumer goods	8
Conveyances/Rollcages/ULD/Totes	28
Drugs	10
Manufacturing parts, tools	70
Military	55
Other Healthcare	15
Passport page/secure documents	65
People (excluding other sectors)	1.3
Postal	2
Retail apparel	130
Retail CPG Pallet/case	200
Shelf Edge Labels	0.2
Smart cards/payment key fobs	559
Smart tickets	325
<b>Vehicles</b>	<b>7</b>
Other Applications	130
Total	1,968

## Input costs

Input costs for ETC suppliers have been falling, while at the same time the quality of inputs has improved due to technological factors independent of the ETC market. The suppliers have little ability to change their input costs due to the size of their market. Although a multi-million dollar industry, the suppliers do not have influence on the cost or production of the radio frequency identification (RFID), due to how small they are in this marketplace. As evidence of their small size, Table 1 shows the number of RFID tags used in different industries and that ETC tags are at most 7 million of the total 1.9 billion tags produced in 2008 (IDTechEx, 2009).



## Prices

Trends in the prices of ETC technologies are difficult to discern because of system differences and the diverse prices charged to different purchasers in any given year. Purchasers of this technology face a variety of prices charged due to unique needs and different systems comprising multiple components. In our survey sample we had a range of prices for transponders with similar technology and functionality from \$9 per transponder to \$23 per transponder in 1999 and also in 2009. Whatever price the agency had ten years ago appears to be their current price, but a larger sample would be necessary to confirm this result. The constant prices, despite lowering input costs, may be due to improvements in technology or an inability to renegotiate prices. Any upward pressure on prices due to higher commodity or labor costs may well be off-set by falling technology costs.

## Key Market Attributes

### Lock-in

After adopting a specific ETC system, the purchasers become locked-in due to durability, cost, and state government processes. The long life of the technologies means that agencies do not need to replace their systems for many years and therefore do not need to consider switching to a new system in the short term.

The equipment predominantly used in ETC, readers and transponders with cameras for enforcement, have a relatively long lifespan. Readers last for approximately 20 years with some maintenance, battery transponders last for 7-10 years (with agencies replacing transponders at around 8 years) and sticker transponders last for 2-3 years. Cameras also last from 7-10 years.

The cost of switching systems also contributes to lock-in. Estimates of monetary costs of switching varied, but were always high. In addition to monetary costs, switching also exposes the purchaser to more immediate risks. For example, if a transition causes an increase in congestion then the purchaser risks losing his/her job or harming his/her reputation.

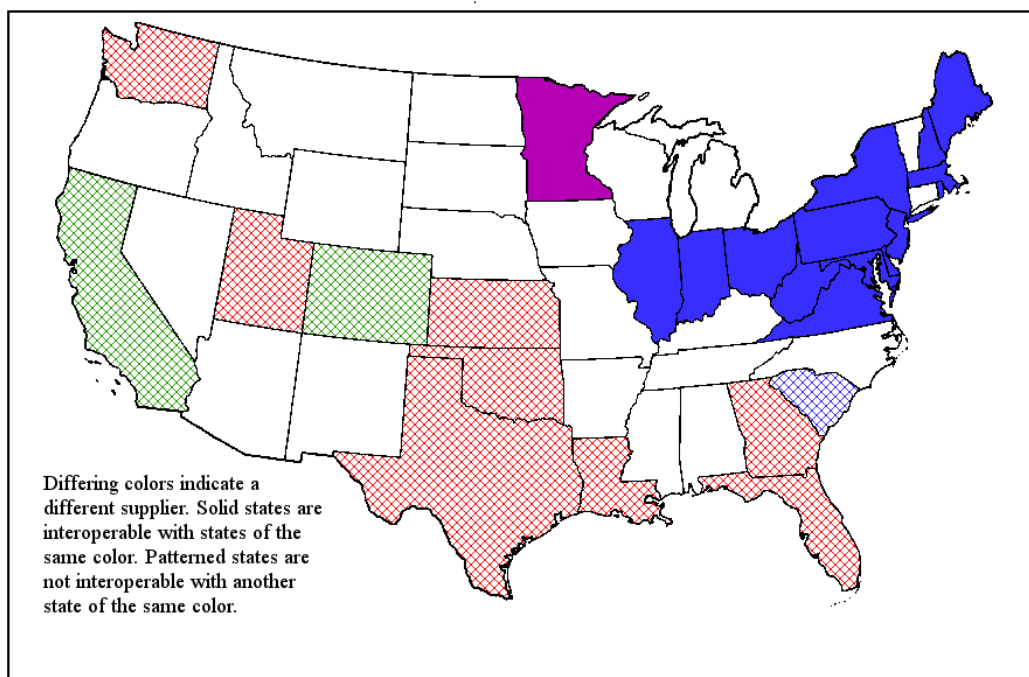
The lock-in caused by product durability is reinforced by the institutional factors involved in making changes to an expensive and important system. Purchasers mentioned the legal issues involved in contracts and the potentially long bidding process. These factors varied across purchasers in terms of how much of a delay or barrier they caused, but all cited them as forces which made switching systems difficult.

### Market power

The structure and nature of the ETC market makes it susceptible to purchaser market power. Key factors allowing for the creation of market power in the ETC market are: network characteristics, proprietary technology, and the lock-in caused by durability as discussed above. These factors are discussed in more detail below.

Figure 9 serves as reference for the discussion that will follow on factors creating market power in the ETC market place and depicts both the regional supplier concentration and the zones of interoperability. The only interoperable zone is the IAG which uses the proprietary technology of Mark IV and is indicated by solid blue. The red hatched areas are all non-interoperable and use the proprietary technologies of Transcore. The green hatched areas use the open standard which is, in the majority of years, supplied by Sirit. The California and Colorado ETC systems use the same transponder and reader technology, but are not interoperable due to the incompatibilities in their back-office operations. Minnesota uses technology provided by a fourth company, which is incompatible with other states.

**Figure 9. Regional Zones of Interoperable and Non-interoperable ETC Systems, 2009**



## Network characteristics

ETC is a network system and a network system necessarily entails special characteristics that may lead to market power.

An illustrative example of the forces involved in a network system is a credit card system. When a new credit card is created, the creators have to simultaneously attract and enroll a significant number of retailers that will accept the card for payment and consumers that will use the card for a transaction. The credit card processing devices that retailers need to process transactions are a fixed cost. The more consumers that use the credit card readers, the lower the per-transaction cost. Such a system naturally has economies of scale, meaning that the larger the network, the more efficient the system is and the lower the costs of each transaction. In turn, these market dynamics lend themselves to the creation of supplier market power; it is more efficient for there to be one provider of a network.

Having only one provider, however, creates opportunities for exploitation by charging prices that are higher than the cost of production. The research performed for this report suggests that due to the nature of ETC networks, a handful of suppliers have gained regional market power by using proprietary technology. More research would be necessary to formally test the hypothesis of whether this market power is leading to higher prices in the ETC market.

## Nonproprietary technologies

One way to potentially diminish market or monopoly power is through the creation of open technologies. The door was opened for nonproprietary providers when California passed Title 21 in 1992. This provided an open standard that made the technology for ETC transponders common knowledge and gave the exact specification for ETC technology that would be used in all of California. This open standard addressed the proprietary aspect that contributes to market power, but did not diminish the durability or network aspects.

The open standard approach, however, has not moved outside of California. One downside of the open standard was the inflexibility; the open standard has a hard time adjusting to technological innovations due to necessary procedures and consensus. It appears that the reason why later ETC adopters did not follow California's path was because they were more concerned with being able to be interoperable with existing proprietary networks than with the cost savings of calling for an open standard.

It is worth noting that some of the patents for proprietary suppliers may expire in the next few years. The uncertainty surrounding the extension of their patents is a motivator for suppliers to learn how to profitably switch to new standards. Alternatively, they may put more effort into extending their patents.

## **Durability and lock-in**

In addition to the network characteristics that create market power, the durable nature of ETC technologies and the large cost of switching increase the potential power of suppliers. When purchasers cannot credibly say that they will switch to another system if the prices are not competitive, then suppliers are able to charge a higher price.

## **International**

International considerations affect the U.S. ETC market by diminishing competition and by providing a source of business to domestic suppliers. The negative effect on competition comes from the international difference in spectrum regulations making it impossible for suppliers to produce the same products for both the EU and the U.S. Nonproprietary suppliers mentioned, however, that the South American market was an area of great growth for them.

## **Market uncertainty caused by the federal government**

The sentiment of not wanting to invest too heavily in any innovations because of uncertainty about what the federal government will do (e.g., in terms of mandating standards) was consistent and pervasive across all supplier conversations.

## **Opposition to IntelliDrive<sup>sm</sup> and 5.9 GHz standard**

All of the current proprietary suppliers to the U.S. ETC market are opposed to vehicle-to-vehicle (V-to-V) IntelliDrive<sup>sm</sup>. They believe it would negatively affect their business and, in particular, they do not see a role for their companies in a V-to-V scenario where ETC infrastructure is unimportant. Infrastructure is an important part of their business and, in the proprietary case, infrastructure is a large component of their market power. Infrastructure lasts for 20 years, which extends their market power, and the long-term maintenance of this infrastructure is a source of revenue. In addition, even in a vehicle-to-infrastructure scenario, the current proprietary suppliers fear losing market share to a new competitor.

The potential introduction of the 5.9 GHz standard is also likely to meet market resistance; it is much more expensive, especially in light of the expected further decline of current technology transponder prices. One estimate mentioned in an interview has each lane costing \$100,000 to replace with a new ETC technology. The cost of replacing all transponders in circulation would also be high. Transponder prices are more important to toll authorities that give out transponders for free in order to encourage ETC. Nevertheless, even if 5.9 GHz or IntelliDrive<sup>sm</sup> transponders are put in cars by auto manufacturers, purchasers that provide transponders to drivers would most likely be supportive.

To the extent that IntelliDrive<sup>sm</sup> presents an interoperable capability, purchasers may resist moving to this type of system due to the potential loss of back office operations. For some toll authorities the interest income from customer transponder account balances is significant. Toll authorities with larger expenses and less ETC penetration, making the interest income small by comparison to their costs, would welcome someone taking over their back office operations.

## Main Influences on Deployment

The main factors identified in this study as driving the deployment of ETC technologies are safety, congestion, cost savings, maturity, location, the price of the technologies, toll revenues relative to expenses, the number of agencies involved in the purchase, commercial vehicle demand, toll fare differentials, and federal government involvement.

### Safety

ETC was cited as a way to overcome the potential crashes that toll plazas can create. For example, drivers merge or try to get in the shortest lane as they approach a toll booth, have to slow down and, in the case of cash toll collections, have to come to a complete stop. All of these interactions create opportunities for crashes. Furthermore, with cash toll collections, the presence of people in the toll booths and walking between toll booths creates potential for accidents between pedestrians and cars. In 2006 the National Transportation Safety Board advocated a move to cashless tolling. Florida recently switched to cashless, all ETC, tolling due in part to safety concerns (Turnbell, 2009).

### Congestion

In general, ETC makes it so that drivers do not have to stop at the toll plaza, which keeps traffic moving at a higher speed than if they have to stop to pay a toll<sup>13</sup>. Many purchasers commented on the improvement to congestion, as well as congestion being cited as a motivator for adopting ETC in secondary literature (Turnbell, 2009). In the secondary literature there are also references to the benefits from ETC decreasing congestion (Currie & Walker, Traffic Congestion and Infant Health: Evidence from E-ZPass, 2009) which reinforce ETC adoptions.

### Cost savings

As mentioned earlier, ETC transactions cost approximately ten times less than cash transactions.

### Maturity and perceptions of quality

Purchasers look for proven technologies. During interviews both suppliers and purchasers emphasized the testing of technologies and requirements of successful previous implementation. This tendency tends to make the marketplace wary of new technologies. Recall Figure 6 (shown on page 24), which illustrated how the number of toll authorities adopting ETC changed over time. The uptick in deployment after a few adoptions occurred suggests that an initial trial period is necessary before more agencies will adopt the technology.

### Location

Location was a major factor in determining deployment. Those located on a travel route shared with someone using a given ETC technology tended to adopt the same technology. This was either due to a desire to be interoperable or due to knowledge spillovers. This dynamic lends itself to the creation of regional monopolies as seen in the expansion of EZPass in the Northeast (see Figure 5).

This creates an interesting situation, whereby states on the edge of two regional monopolies will have a choice between two technologies. Choosing one technology over the other would mean interoperability only on one border, unless a multi-level system is created.

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<sup>13</sup> There are some instances where there is very heavy traffic at toll plazas that force cars to stop due to traffic and ETC makes no difference to the levels of congestion.

## Prices of technologies

All purchasers interviewed mentioned prices as being a key variable affecting their decisions. Relative costs also appeared to play a role as they expressed difficulty justifying the selection of a more expensive option when a less expensive option was available. The variability of system requirements for different purchasers, and the ability of suppliers to customize prices to fit these requirements, makes identifying price trends in this market difficult. Indeed, given there is currently such a wide variety of ETC prices, using prices solely as a key predictor of growth in deployment would be difficult.

## Toll revenues relative to expenses

The ability and institutional will to adopt ETC depends to a large extent on the availability of revenues. Purchasers interviewed varied in terms of the gap they faced between toll revenues and expenses. Those that had excess funds were more actively pursuing adoption of new technologies, while agencies without an excess of revenues over costs were less likely to engage in the pursuit of new technologies. Agencies that are able to charge high enough tolls to adequately cover costs would be more likely to be first adopters of new ETC technology. Nonetheless, the presence of coalitions can inhibit the adoption of new technology.

## Number of agencies involved

When the purchaser is made up of a coalition of agencies, then the size of the coalition appears to slow down adoption. IAG took three years from when they formed the group to actually implementing a technology. IAG has not placed a bid on a new technology until now. The reason for the impediment is that each agency involved brings with it unique characteristics such as goals, solvency, attitudes towards tolling, accounting systems, and legal teams. The uniqueness of these characteristics makes consensus difficult. In turn, as coalitions grow in size, their ability to branch out and adopt new technology becomes increasingly limited.

An interesting consideration here is that as a coalition grows in size, it gains the potential to become a monopsony through acting as a single purchaser in the market place.<sup>14</sup> Nonetheless, coalition size seems to be an obstacle instead of enabling the coalition to get lower prices in the ETC market.

## Trucking interests

The needs of commercial vehicles have been a large factor in the adoption of ETC technologies for tolling directly and for the related pre-clearance and weigh-in-motion technologies. The expansion of IAG from three to eighteen states has been partly driven by the truck routes. The Crescent Project was motivated by truck traffic and the recent addition of Ohio to IAG is commonly known to be due to the truck traffic along its toll road that is between two zones of EZPass. The commercial preclearance systems of PrePass and NorPass are adding on the ability of ETC via PrePass Plus and BestPass, respectively.

## Federal government

The federal government has had both positive and negative effects on deployment levels and innovation in the ETC market. The funding of the PrePass Crescent Project in the early 90s helped the growth of commercial use of ETC. The Crescent Project gave PrePass, with transponders produced by Mark IV, the push needed to obtain the critical size to have a successful network.

On the non-commercial side, the uncertainty over whether the Federal Government is going to mandate a national standard, such 5.9 GHz, is creating some inertia in the market place. The ongoing research into new standards has created uncertainty about when and if there will be a dramatically different ETC

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<sup>14</sup> Monopsony describes a market where there are many sellers, but only one buyer. It is the opposite of a monopoly, where many buyers are in a market with only one seller.

technology that will need to be used. According to interview comments, the uncertainty has slowed innovation on the supplier side and increased the risk exposure of some suppliers. On the purchaser side, the concerns about new standards are more focused on the costs and not whether or when the Federal Government will select a new standard. Recent USDOT activity on IntelliDrive<sup>sm</sup> related research, however, appears to be reenergizing the community's participation in this area.

## **Toll differentials**

Toll differentials influence the willingness of drivers to use ETC instead of cash. In the beginning, toll authorities charged ETC users more for using ETC than drivers that used cash. They charged ETC users more by a combination of ETC account charge, making drivers purchase transponders, or charging higher tolls to ETC users. As awareness of the cost savings of ETC transactions and favorable impact on congestion of ETC grew, the trend is switching to ETC users paying less than cash users. The switch has increased the number of ETC accounts dramatically. In some cases the benefits of an increase in accounts has been diminished by the fact that the new accounts come from people that do not use the toll roads much.

## Conclusions: ETC

The ETC market has experienced tremendous growth and is nearly used universally due to the tremendous benefits of ETC, but will continue to be stagnant unless significant changes occur. The market appears to suffer from a use of market power that has two negative effects: costing agencies more for their transponders, and resisting change and innovation. Greater efficiency could come from integrating back-office operations, but such an effort would face the same challenges that beset IAG; large groups composed of agencies with unique characteristics have difficulty becoming interoperable and in making changes.

One key lesson for policy makers is that, in the ETC market, lock-in is a very strong force; decisions made now have a long legacy for future generations.

## Suggestions for Future Research

Suggestions for future research include a cost benefit analysis of interoperability, environmental life-cycle analysis of transponders, estimating the impact of regional supplier market power on the market, a cost benefit analysis of increased tolling, an estimation of the impact of VMT fees on existing tolling facilities, and an analysis of current bidding strategies and how the strategies are influencing prices. The analysis of market power and bidding strategies would assist in understanding the larger question of why there are such wide disparities in prices charged for transponders.

### *Interoperability*

Estimating the costs and benefits of interoperability would inform government policy on moving towards interoperability. The level of interoperability provided by PrePass would need to be assessed as well. Given the large cost of switching to an interoperable system, and the market power involved, such a study would be beneficial.

### *Environmental life-cycle analysis*

The expansion of ETC, which may result in millions of transponders being in circulation, may have some environmental implications. For example, active tags need disposable batteries to power them and any possible effects this may have on the environment will have to be considered. Consequently, a strategic decision made by the JPO to recommend a national standard for ETC that utilizes active tags (with batteries) would need to consider the effect this may have on the environment.

### *Market power of suppliers*

From the discussion above it is clear that market power of suppliers is due to network characteristics, proprietary technologies/systems, and the lock-in effect. What is not clear is how much this market power has affected the ETC market and what should be done if it indeed has a significant cost. By way of example, IAG currently has 18 million transponders in circulation, for which they pay approximately \$20 per transponder and another purchaser pays \$9. There is an \$11 difference between what the two parties pay. Simple multiplication of the difference times the number of transponders gives a rough estimate that the market power could be costing toll authorities and their users \$198 million. The presence of this market power would be addressed to some degree if the JPO recommends an open national standard for ETC technology. Still, even with a national standard, regional monopolies may be hard to break due to the nature and inertia of regional coalitions and their previous ability to get patents by patenting systems instead of just the technology. If a national standard is not pursued, then research investigating the issue of regional market power in the ETC market would provide valuable insight into the cost it imposes on the consumer.

### ***Tolling, VMT taxes, and road privatization***

With VMT taxes being a possible solution to offset the volatility and political intransigence of the gasoline tax, a study of what the impact would be on the ETC market and vice versa would be a helpful addition to the discussion about whether to switch to a VMT tax.

At the International Bridge, Tunnel and Turnpike Association's (IBTTA) 77<sup>th</sup> Annual Meeting and Exhibition, the subject of a VMT Tax was discussed as a "holy grail" to the tolling industry. A panel discussed the benefits and detriments of the VMT tax, public opinion, the role of government, keeping both the gas and the VMT tax, and tax incidence issues.

The benefits of the VMT tax listed and agreed to by all the panelists include:

- cessation of double taxation inherent in a gas tax and toll
- a source of revenue independent of gasoline consumption
- direct connection between the fee and geographic use of roads
- not avoidable by switching to a more fuel efficient vehicle (wear and tear on the infrastructure remains the same)
- potentially a less regressive tax than the gas tax

The negative sides of VMT tax discussed were:

- high cost of collecting the tax relative to the gas tax
- the potential lack of political will, due to public resistance
- perceived complexity
- difficulty of agreement on a national standard
- potential privacy issues
- accountability for performance and spending key to public opinion
- interoperability
- level of tax that would be acceptable and generate significant revenues
- regressiveness - low income groups end up paying more of the tax and are more affected

### ***Bidding strategies***

Bidding strategies may be a way to diminish market power if it is being used and could also decrease lock-in. Researching the most successful methods of bidding may aid the market. It is well established in the economics literature that some structures are more beneficial to purchasers than others.<sup>15</sup> For

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<sup>15</sup> See surveys - Milgrom, Paul. (1989). "Auctions and Bidding: A Primer." *Journal of Economic Perspectives* 3, no. 3: 3-22 and Klemperer, Paul. (2002). "What Really Matters in Auction Design." *Journal of Economic Perspectives* 16, no. 1: 169-189.



example, in Europe they use a two stage bidding process for ETC technologies. Research could be done to see if the European method tilts the benefits towards the purchasers more so than the suppliers.

# Appendix: ETC

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# 4. Highway Data Collection

Highway data collection (HDC) technology plays a central role in the facilitation of other forms of ITS technology. These technologies are used to gather information on the flow and density of traffic, which is then used as a critical input to other types of ITS data driven applications, including variable message sign systems and traffic management software. The importance of HDC deployment is expected to increase as the demand and requirement for real-time highway information increases.

HDC technologies can be separated into two main categories. The first of these are sensor based technologies, whereby the traffic information is typically collected through inductive loops placed underneath the road surface.<sup>16</sup> The second category covers probe based data collectors. This technology uses various forms of cell phone tracking or GPS based tracking to locate the vehicle on the roadway. A helpful distinction might be that sensor technology measures vehicles as they pass a fixed point; probe technology measures the location of the vehicle as the vehicle moves on the roadway.

This section of the deployment tracking study examines the highway data collection market and qualitatively analyzes the forces that have shaped deployment of these technologies. A summary of key findings is presented at the start of this chapter, followed by a discussion of the pattern of deployment of HDC technology. The HDC market structure is then examined along with a discussion of factors that impact deployment and finally conclusions and recommendations for future research are presented.

## Summary

### Market Insights

- The highway data collection market is composed of two distinct supply side segments:
  - Hardware oriented suppliers
  - Data oriented suppliers
- The data oriented side of the market is too new to observe any trend in prices.
- The hardware side of the market has been stable for many years.
- Data services supplied by third party vendors are not a complete substitute for sensor based systems.
- Accuracy of data services has increased over time.
- Deployment of data collection technology is surprisingly low.
- The data supply side of the market contains relatively few suppliers when compared to the hardware side.
- An increase in the demand for variable message signs will generally filter through to an increase in the demand for data collection technologies

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<sup>16</sup> Microwave sensors and cameras would also fall into this category.

- Factors affecting deployment:
  - National-level
    - Section 1201 Rulemaking
    - Data's complement with other ITS technologies
    - Traffic.com Contract
  - Purchaser level
    - Desire for additional data
    - Accuracy of data collection technology
    - Site specific installation requirements
    - Permanency of implementation

## Considerations for Future Research

### Policy Goals:

- Procurement/Bid/RFP guidelines for data purchases
- Accuracy of probe data
- Examination of accuracy of technology
- Certification or rating for suppliers of data services

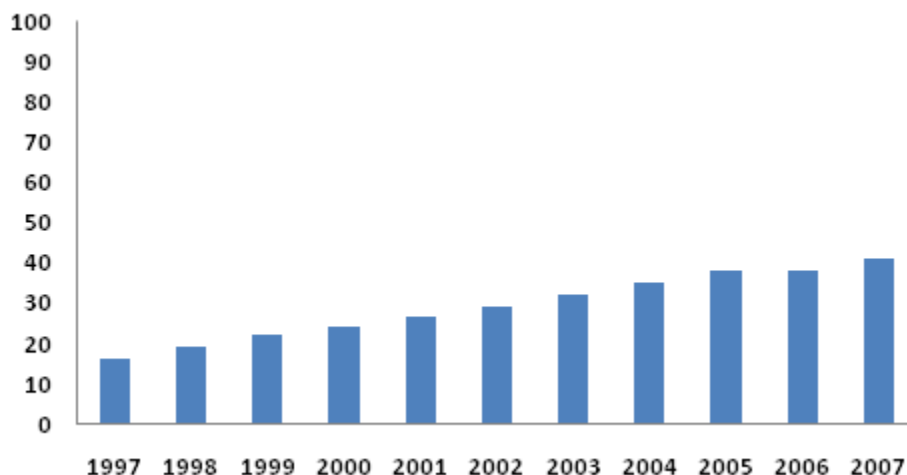
### Market Concerns:

- Rise of a natural monopoly
- Google's entrance into the marketplace
- The potential impact of IntelliDrive<sup>SM</sup>

## Pattern of Deployment

The deployment of real-time traffic data collection technologies has gone through a slow but steady increase since 1997 (Figure 10). Starting out at slightly more than 10%, the deployment of these technologies reached a level of 40% by 2007. The penetration of highway data collection is surprisingly low given its importance as a complement for other types of ITS and the fact that loops have been a common feature of highway infrastructure for many years.

**Figure 10. Metropolitan Freeway Miles with Real-Time Data Collection Technologies**



*Source: ITS Deployment Database; Interpolated 1998, 2001, 2003<sup>17</sup>*

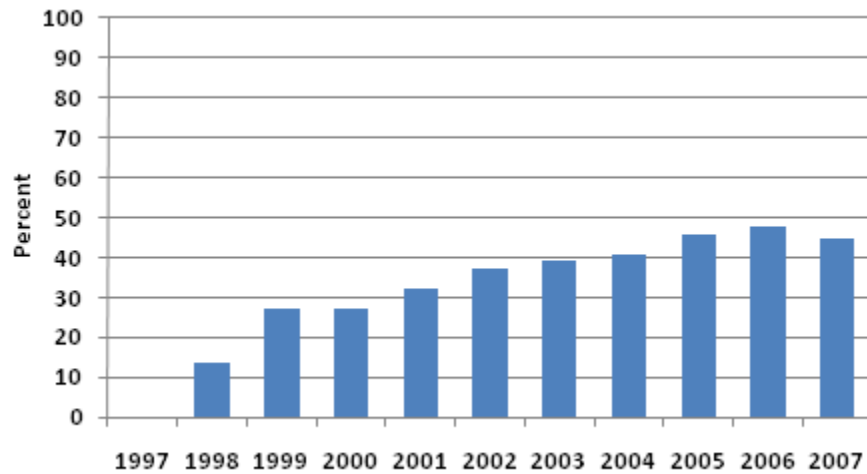
There have been several factors affecting the historical deployment level. Firstly, states are mandated to report some form of traffic data to the FHWA for use in the HPMS database. This requirement has resulted in, and maintained, an underlying level of deployment. Secondly, highway data collection is a key input into systems that relay travel time information to travelers (such as 511 systems or variable message signs). This means that the demand for data collection is derived from the demand for more downstream ITS technologies. The increased use of these technologies over time has likely contributed to the increase in highway data collection deployment. To illustrate, Figure 11 below outlines variable message sign deployment since 1998. The level of variable message sign deployment, as measured by miles covered, closely mimics that of highway data collection, starting out at just over 10% and climbing to over 40% by 2007. This suggests that the demand for these two technologies, which are complements, has been of a similar magnitude. Variable message signs require data as a primary input. As a result, in general an increase in the demand for variable message signs will filter through to an increase in the demand for data collection technologies.

There does appear to be a decrease in adoption of variable message signs between 2006 and 2007. Interestingly, this decrease in deployment corresponds to an increase in the use of 511 advisory systems. To illustrate, Figure 12 below outlines the deployment trend of 511 advisory systems. Again, 511 advisory systems require data as an input and the increasing deployment of 511 systems likely contributes to the increasing deployment of highway data collection. While variable message signs and 511 could be

<sup>17</sup> These data represent deployment information for 78 metropolitan areas. It is important to note that the number of metropolitan areas surveyed is greater than 78 in some years and that the metropolitan areas represented in the information may not be consistent from year to year. The same applies for the data in Figures 2 and 3.

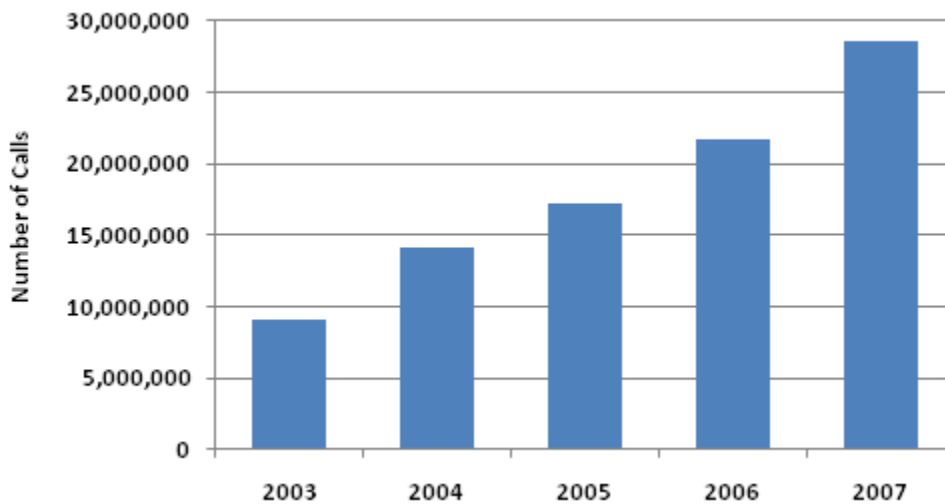
considered substitutes, it is difficult to determine whether the decline in variable message signs is directly related to the increase in the use of 511; further research would be needed to establish causality.

**Figure 11. Metropolitan Area Miles covered by Variable Message Signs**



Source: ITS Deployment Database; Interpolated 1998, 2001, 2003

**Figure 12. 511 Advisory System Use**



Source: ITS Deployment Database; Interpolated 2003

## Market Background

The technologies used for highway data collection can effectively be split into two different categories: sensor based or probe based collection. Sensor based technologies would be considered the more traditional methods of highway data collection. These data collection devices work from a static or fixed location, examples of which include cameras, inductive loops, and other direct measurement technologies. In contrast, probe based data collection devices rely on in-vehicle devices that, by definition, are not static (although the cell towers or devices that collect the probe data will be in fixed locations). Probe data detection devices can be vehicle-mounted or personal/handheld devices brought into the car.

The sensor based industry is now in a mature state with little innovation. Inductive loops were one of the first incarnations of this technology, are a proven technology, and remain relatively unchanged. Some other sensor technologies (such as microwaves) have been introduced into the marketplace as competitors to loops, but in essence they work in the same way: they all require in road (or near-road) fixed location infrastructure. These sensor based technologies represent a relatively mature part of the overall HDC market. As such, the deployment of these devices will help inform a historical examination of HDC deployment, but will not be as helpful in providing insight into the current dynamics of the marketplace.

Probe based technology is a relative newcomer onto the highway data collection scene. The first devices of this nature began to appear around the mid-1990s and are only recently being utilized actively for highway data collection. Probe HDC devices require little in the way of infrastructure investment and in the case of data from mobile phones utilize existing cell towers. This sector of the HDC market is less mature than the sensor side and as such will provide more insight into the current dynamics, and future direction, of the highway data collection market. Indeed, the dynamic between mature sensor technologies and newer probe data technologies may provide some interesting insights into the market conditions and influences surrounding the transition from an existing to next generation ITS technology.

An important point to note in the broader discussion about HDC technologies is that the act of collecting data has no value in its own right. In other words, collecting data for data's sake does not improve the efficiency of transportation management or the experience of individuals using a highway system (which is the purpose of ITS technology in general). Rather, what is important is using the data collected in such a manner (i.e. in other ITS applications) to help manage congestion or provide real-time traveler information. To this extent, the HDC market is intermediate in nature and used to provide information for other ITS applications, rather than as a means to itself.

## Historical Perspective

Inductive loops have become the primary highway data collection device since their inception in the 1960s (Department of Transportation, Federal Highway Administration, 2006). These loops rely on relatively simple construction: a typical inductive loop is a piece of wire embedded in the pavement. They are a well tested and capable technology for basic vehicle detection and speed detection, and newer models allow for vehicle classification (Cheung & Varaiya, 2007). Loops are often recognized as the “[industry] standard because of their high detection accuracy (e.g. >97%)” (Cheung & Varaiya, 2007). They are, however, highly invasive to the roadway (as they need to be embedded in the pavement) and the cost of installation is high relative to the cost of the loop itself. As such, they can be disruptive to traffic flow during installation and maintenance. In addition, the loops are subjected to the “stresses of traffic and temperatures, making its failure rate relatively high”; this combined with the disruptive maintenance

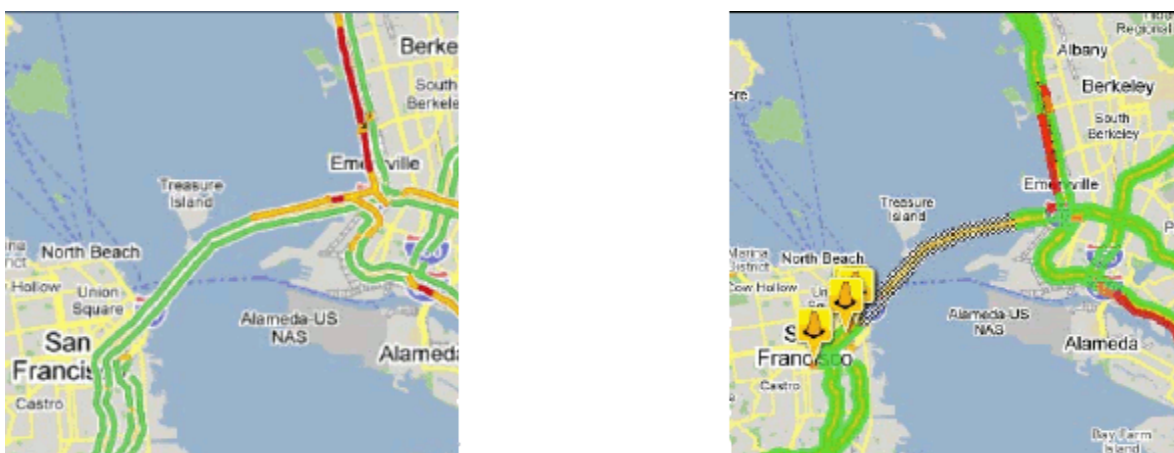


requirements mean that bad loops are often not replaced (Cheung & Varaiya, 2007). These concerns are what led to the desire for alternative traffic collection methods.

Other sensor types were developed to compensate for the weaknesses found in loops. A comprehensive examination of the major types of sensor technologies was performed by Cheung & Varaiya. Based on data collection, they outlined the level of error associated with each type of sensor, detailed environmental factors that affect performance and estimated lifecycle costs. Their analysis presents the overall advantages and disadvantages of each type of sensor; the accuracy of the sensors is quite high overall, with loops being extremely accurate (See the appendix for details of their results).

Probe-based data collection technologies have now entered the market place as a direct competitor to sensors. This has particularly become the case as the accuracy, efficiency, and availability of probe devices, such as mobile phones or GPS devices, has increased. It is unclear if this increased choice of data sources has increased deployment or not. The relatively slow growth in deployment in recent years suggests that this new technology is being used as a replacement for older deployments or as a supplement to current deployments.

**Figure 13. Comparing Probe and Sensor Data**



Source: INRIX Webinar, “Crowdsourcing Traffic Data: How Crowdsourcing GPS Data is Radically Altering the Traffic Information Landscape”

## Current State of the Market

The highway data collection market remains predominantly sensor based. In particular the primary technology used is loops. This is largely due to the inertia inherent in moving away from a technology that is proven and essentially hardwired into an agency’s traffic system. Indeed, some purchasers continue to use loops primarily because there is no impetus to change what works well. In addition, many agencies have the in-house capability to install new sensors, making maintenance and replacement more straightforward. Nevertheless, probe data technologies are filtering into the marketplace. A prime example is the move by the I-95 Corridor Coalition to purchase probe based data.<sup>18</sup>

While probe data is being implemented in some areas, it is not a complete substitute for sensor based data. One major pitfall of the current level of probe technology is that probes alone are not enough to detect on-road conditions. For example, Figure 13 shows how probe-only data (on the left) compares to

<sup>18</sup> I-95 Corridor Coalition Vehicle Probe Project:  
<http://www.i95coalition.org/i95/Projects/ProjectDatabase/tabid/120/agentType/View/PropertyID/107/Default.aspx>

probe and on-the-ground sensor data (INRIX, 2009). On the left, the bridge is indicated as being open while on the right, sensor verification indicates that the bridge is closed for construction.

In addition to verification needs, accuracy is another concern. This issue was highlighted in a recent paper (Fontaine, Smith, Hendricks, & Scherer, 2007) that examined seven separate implementations of probe based data, from 1994 up until 2005. While the quality of the technology examined in this study is likely lower than might be expected today, the results are worth reviewing. Indeed, in one instance, only 20% of the probes in the study produced speed data. In another, speed measurements were off by more than 20 mph 68% of the time. Compare this with inductive loops which produce speed and count data that is >97% accurate (see Appendix); although concerns have been raised regarding the failure rate of loops.

While the technology has improved over time, these facts concerning accuracy likely play an important role in influencing the current level of deployment of probe technologies. Improved accuracy of probe data will influence deployment levels in the future.

## The Future

The demand for other types of ITS technologies will be important in the future deployment pattern of HDC. Since HDC is a complement for other ITS applications, rising demand for these types of technologies will drive demand for accurate and useable real-time data. Technologies that complement the HDC market could include variable message signs, emergency vehicle preemption, or general traffic management software.

It is likely that probe based technologies will play an increasing role in data collection of all sorts. Probes, in the form of GPS devices or cell phones, are becoming more ubiquitous and the ability of these devices to process large amounts of real-time data will only improve. Suppliers of probe data collection technologies believe that as their data becomes more complete and accurate, they can begin to move into the arterial market, providing data collection for those technologies that are arterial focused. It is also thought that the overall increase in accuracy and processing power will also lead to a decrease in the importance of standard sensor technology.

An exogenous factor that could have a large bearing on this marketplace is the Federal Government's IntelliDrive<sup>SM</sup> program. At its core, the IntelliDrive<sup>SM</sup> initiative is advancing the idea of developing an in-vehicle probe, which would essentially give complete traffic coverage of every vehicle on the road. Many in the data collection industry expressed interest in IntelliDrive<sup>SM</sup>, but are approaching the technology development cautiously.

## Market Structure

As noted above, the Highway Data Collection market can effectively be split into two halves: sensor-based and probe-based. This investigation indicates that the sensor side of the market is relatively mature and competitive. The probe side, on the other hand, is relatively new and is less competitive. The relevant features of the market, and in particular the probe-based side, are outlined below, including number of participants, relative level of competition, and prices.

The discussion of the HDC market is broken into several sections. After an initial look at the market structure, the general business models in use in the marketplace will be examined (rather than focusing on specific companies); second, the I-95 Corridor Coalition's current experience with their probe data will be discussed; lastly, the experiences with the field trials of probe data will be presented.

## Market Participants

While the sensor-based market is mature and largely competitive, the probe-based segment of the market is relatively new. Since probe-based technology represents an important element of the future direction of HDC, the following discussion focuses primarily on this portion of the market. Currently there are only a few firms selling probe-based data, with two companies having a dominant position. The largest companies operating in this space are Traffic.com (a subsidiary of Navteq) and Inrix. There are other smaller competitors, such as Airsage, who also provide probe-based data.

On the purchaser side, any municipality or highway agency could conceivably purchase probe data. The I-95 Corridor Coalition is the largest such purchaser at the time this report was written. Probe-data remains relatively new in the marketplace, thus actual implementations are not as common. Nevertheless, the growing market awareness of this technology has resulted in purchasers engaging in several field trials, which are discussed below.

### **Business Models**

There are three main probe-based business models that seem to have gained the most traction in the HDC marketplace. Briefly, they can be described as the “cellular model,” the “owned and operated model,” and the “contract carrier model.”

The cellular model centers around the use of anonymous location data derived from cell phones. As such this business model requires contracts with cellular carriers, notwithstanding how the geo-location component of the technology works. The quality of the data gathered depends on the state of the cellular network in the area and the size of the cellular carrier’s subscriber base in the area (market share). For example, consider a company with a cellular geo-location contract with carrier A. However, there exist two distinct carriers in the cellular market: carrier A and carrier B. If carrier B is the predominant supplier of cellular data and has the broadest coverage, then this hypothetical company may not have enough cellular based information to provide accurate traffic data. As highlighted by this example, this business model depends heavily on the nature and breadth of the contracts that are able to be made.

The owned and operated model exists at the other extreme from the cellular model. Whereas the cellular model relies heavily on contracts, the owned and operated model relies heavily on privately owned sensors. While the company might contract with agencies to receive some data from government owned sensors, a fair amount of their data comes from sensors the company has financed (and thus retains the rights to the data from those sensors). This model relies heavily on the ability to get those sensors installed and maintain them at a high enough level such that the data is of good quality.

The last model, the contract carrier model, is somewhat of a mix between the two previous models. The contract carrier model centers on contracts with specific entities, commercial vehicle carriers for example, to provide location data. While some probe information comes from these contracts, the company can also deploy its own probes either through Smartphone software or obtain supplemental traffic data through licensing the traffic information collected to other parties (i.e. navigation device firms) in exchange for additional traffic information. Again, the contract side of this model relies heavily on having enough coverage through contracts. Nonetheless, some of the downsides of the contract-centric approach are mitigated through the ability to put probes out in the field.

It remains unclear at this point which business model(s) may become dominant over the long term. The HDC market is currently evolving and too embryonic to draw any significant conclusions about which business model or models might succeed. Each of the three models has advantages and disadvantages; nor is the list above exhaustive. It is entirely possible that additional business models will evolve over time as the technology evolves.

## ***The I-95 Corridor Experience***

The I-95 Corridor Coalition is an organization of transportation agencies that spans the entire length of the I-95 Roadway.<sup>19</sup> These agencies collaborate on transportation issues of common interest (such as traffic data collection) with the goal of improving performance along the entire corridor. While the I-95 Corridor coalition also addresses issues outside of ITS, the focus here will be on three key areas of their experience with highway data collection technologies and in particular probe based data collection. These areas include the initial RFP and procurement for purchasing highway data, the current contract, and overall impressions about their data.

The I-95 Corridor initial RFP contains several provisions of note. Perhaps most important, the RFP contains requirements for the accuracy of the data. The RFP specifies that the probe data must match on the ground sensor-based verification within specific bounds, for example. The overall approach to the procurement was focused on acquiring high quality data. The goal was not to replace their sensor networks, however, but to supplement them with additional data. As an indication of how young this market is, the I-95 Corridor contract was awarded in 2007.

The current contract itself also focuses on data quality. The probe data that the I-95 Corridor procured is subjected to monthly validation tests. The data is randomly checked in one state each month to validate the probe data against what they call “ground truth.” This ongoing process is actually tied to the payment structure for the contractor, and thus provides incentives to maintain an acceptable accuracy level. In addition to monthly validation checks, the current contract also has loose data use regulations. The I-95 Corridor Coalition members feel that these flexible data use guidelines are one of the key features of their contract for probe data.

The key to the I-95 experience has been to view the probe data as a supplement to the existing sensor networks. The validation is a critical part of this process. At this stage, probe data is not accurate enough to entirely replace sensor data for the Coalition, but provides a valuable source of supplemental data.

Table 2 below details a summary of probe data field tests since the mid-1990s. The first thing to note is that not one of the installations had performance requirements on the data. While the low accuracy seems to stem from the technological side, it is possible that performance requirements would result in increased accuracy. Secondly, the results are varied. While none of the tests boasts high accuracy, the accuracy problems range from miscalculated location to generating no data at all. Thirdly, the time period covered is rather large: spanning more than a decade.

Lastly, keep in mind that these field trials detailed above focused exclusively on cell phone based technology; thus the location of vehicles was largely interpolated rather than directly measured (as with a GPS system). These results may not be representative of the accuracy of a current generation system which uses more advanced locational technology.

Liu, Danczyk, Brewer & Starr also examined a field test deployed in Minneapolis, Minnesota. They examined the accuracy of a cell phone based system on several roads deployed in 2005. Again, the accuracy of the measurements varied when compared with ground truth measurements. The researchers conclude that in major congestion or no congestion situations, the probe data is relatively close; in moderate congestion, the probe accuracy is not as accurate. They also highlight the caveat that “[whether] or not this system would produce acceptable margins of error for speeds and travel times depends on the guidelines established by the responsible transportation agencies (Liu, Danczyk, & Starr, 2009). Figure 14 outlines the different estimated travel times produced by on the ground observers and the probe data. As shown, the cell phone data is considerably more variable than the loop based data. In conclusion, the authors note that the “full capacity of the cell phone tracking system” had not been activated in 2005. Liu et al. urge further research into whether or not accuracy has improved.

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<sup>19</sup> Coalition members include DOT agencies ranging from Maine down the East Coast to Florida.  
<http://www.i95coalition.org/i95/Home/Members/tabid/108/Default.aspx>

**Table 2. Evolution of Probe Data Collection**

Summary of Deployment Results					
Location	Year	Vendor	Performance Requirements?	Type of Technology	Results
Washington, D.C.	1994-1997	Raytheon, Farradyne, Bell Atlantic	No	WLT signal analysis using triangulation	Only 20% of probes generated speeds Could not consistently monitor traffic
San Francisco and Oakland	2000	US Wireless	No	WLT signal analysis using pattern matching	60-m mean location accuracy 60% of locations could not be matched to road No usable traffic data generated
Washington, D.C.	2000-2001	US Wireless	No	WLT signal analysis using pattern matching	5% of 10-min intervals had no data 6 to 8 mph mean speed estimation error Some intervals had errors >20 mph
Lyon	2001	Abis/A	No	Unclear	Good agreement at one site, speed overestimated by 24% to 32% at another
Munich	2003	Vodafone	No	Handoff-based analysis	Errors between 20 and 30 km/h
Hampton Roads	2003-2005	Airsage	No	Handoff-based analysis	68% of speed estimates had errors > 20 mph No reliability measures could be generated
Tel Aviv	2005	It is	No	Handoff-based analysis	Limited Data during off-peak hours WLT estimates different from floating car and loop data by 10% to 30% during congested conditions

Source: Fontaine, Smith, Hendricks, & Scherer, 2007

**Figure 14. Travel Time Data Collection Variability**

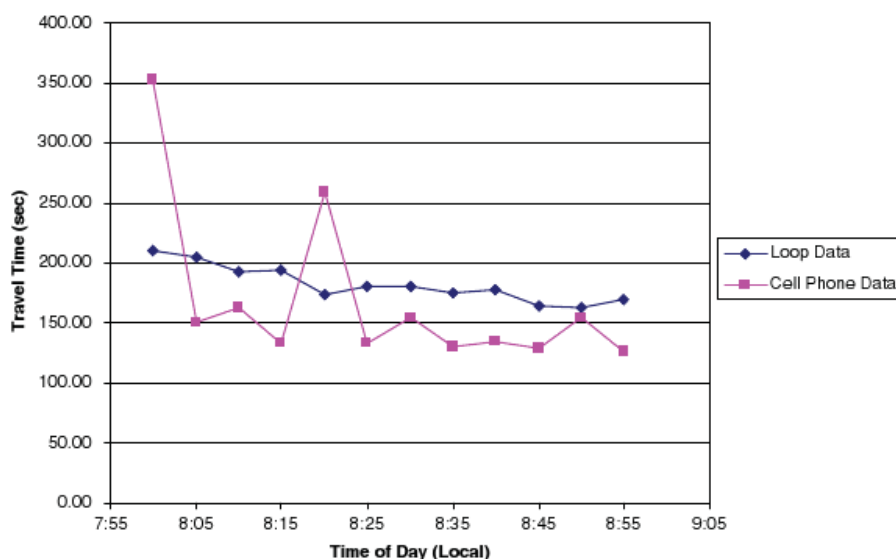


FIGURE 1 Representative illustration of travel times reported by the cell phone tracking system compared with observed travel time on I-394; morning peak period travel time.

Source: (Liu, Danczyk, & Starr, 2009)

Further discussions of deployment experiences, can be found in the Transportation Research Board of the National Academies (2007) and University of Virginia Center for Transportation Studies; Virginia Transportation Research Council (2005). These two papers, while covering some of the deployments mentioned above, do outline additional deployments of both sensor and probe based data. In general, the experiences mimic those of the deployments discussed above, in that probe data is more volatile and not as consistently accurate as sensor data.

## Competition

Competition in the highway data collection market is analogous to the types of technologies: there are really only two sides to consider. Firstly, there are those companies selling the hardware required to collect data, such as inductive loops and other kinds of sensors. Secondly, there are those companies who sell data they have collected and processed. These latter companies are usually probe-based, but not entirely.

As noted earlier, the sensor market is relatively mature. The design and manufacturing process for the various kinds of sensors is comparatively simple when considering the processing required for probe based data. It appears that, in some instances, there are only a few suppliers of a given sensor type. However, it is unclear to the extent to which sensors are substitutes for one another.

The substitutability of different sensors seems to be based on established practices. For example, if a state only wants to use loop detectors, than a radar system is not a substitute and vice versa. On the other hand, a purchaser may view the different sensors as substitutes. There was no clear cut evidence as to whether one of these paradigms dominated the market. Lastly, it is possible for there to be a mix of both, where the different sensors are applied in different situations or where a purchaser believes only a

certain sensor will suffice. Thus, the concentration of the sensor side of the market depends on the definition of the market.

The data service sector of the market, on the other hand, is quite concentrated. Research indicates that there are two main companies that handle most of the business. Additional medium-sized to smaller firms compete as well, but none have quite gained a foothold. One interviewee speculated that the market is at most \$10 million annually. So any share of the market, while possibly large in percentage terms, does not represent a large amount of revenue.

Overall, the highway data collection market is too diverse to classify it as either competitive or uncompetitive. That classification likely depends on the definition of the market (one type of sensors or many) and the sector (hardware or data services). Some definitions of the market lead one to believe that the market is relatively competitive – for example, on the hardware side when considering all sensor types – or that the market is relatively uncompetitive – on the data service side.

## Prices

Again, before entering a discussion of prices, the distinction between hardware and data services needs to be noted. Initially, attention is focused on the hardware side and some impressions of the price trends that we have examined are presented. Subsequently, the discussion will focus on the data services side, and give impressions of the price trends observed there.

For hardware, prices seem to have dropped over time but look to have stabilized in recent years. One purchaser indicated that prices are highly installation specific. That is, certain environmental factors of the installation site can affect price. However, for a given installation site, prices seem to have shown little sign of changing in recent years. The lifecycle cost chart presented in the appendix shows more specific information on prices for hardware.

For data services, the price story is much less clear. Due to the relatively new nature of this side of the market, no clear price trend has emerged. However, our interviews led to several insights into what kind of factors can affect price.

One such factor is the quality of the data provided. Lower quality levels obviously result in a lower price. Quality can be measured in several ways; for example: coverage, accuracy of measurements, what kind of data is provided. Another factor affecting price are the rights acquired to use the data. If a state deploys their own sensors, they then own the rights to the data they collect via those sensors. If they are purchasing data from a third party, however, the data rights may potentially become the property of a third party, even if that data is collected via sensors the state originally installed. Examples of these rights include the ability to share this information with private consumers, to distribute it via 511, and even possibly make it available to other companies. More liberal usage rights result in a higher price.

Anecdotally, prices have remained constant for probe data. For example, one purchaser told us that they acquired additional (previously uncovered) lane-miles for the same price as the initial contract. It is unclear if this is a result of the short time frame for this part of the market or indicative of a market trend.

## Impacts on Deployment

The central focus of this research is to gain insight into those factors that affect the decision to deploy highway data collection technology. To help organize the presentation of these factors, they have been divided into two groups: macro effects, which have affected the nationwide deployment level, and micro effects, which affect an individual state's decision to deploy certain technology. This is not to imply that the micro effects are in any way less important than the macro effects; it is merely a way to distinguish between the different decisions that take place.

## Macro Effects

One macro effect that might affect deployment in the future is the federal “1201 Notice of Proposed Rulemaking (NPRM).” The NPRM focuses on setting minimum requirements for real-time traffic information. These requirements center on how quickly data is reported, how accurate that data is, and how much data should be available in terms of roadway covered (Department of Transportation, Federal Highway Administration, 2009). It also proposes that every state should have a real-time system up and running within four years (Department of Transportation, Federal Highway Administration, 2009).

The proposed regulation essentially increases the demand for primary traffic data. There are no prescribed methods for acquiring this data, so states can go several routes in acquiring this data. They can purchase a data service from a private company and ensure that the data use clauses of the contract conform to any guidelines for reporting set out in 1201. Another route would be to deploy sensors owned by the state. A further possibility is some sort of public-private partnership. Finally, 1201 will be established to be technology independent, encouraging states to “consider any salient technology, technology-dependent application, and business approach options that yield information products consistent with the requirements set forth in this proposed rule” (Department of Transportation, Federal Highway Administration, 2009).

Another macro level effect is data’s complementary nature with other technologies. What is meant by this is that an increasing number of technologies require traffic data as an input. 511 systems, variable message signs, and emergency vehicle preemption are but a few examples. As the deployment of these systems increases, we can expect the demand for data collection (both on and off the highway) to increase. As mentioned above, there are several solutions to this increased demand. This factor, however, might drive deployment slightly differently than that required by the 1201 rulemaking. For example, some states, due to privacy or other issues, may wish to own their data collection methods and infrastructure. In this case, a third party provider might seem relatively less attractive when compared with a state-owned system.

A third macro effect that affects deployment is the government award of a \$50 million contract to Traffic.com. In brief, Traffic.com was selected as the sole source provider for traffic sensors to be deployed with federal funds. These deployments occurred throughout the early part of the last decade. This contract clearly increased deployment of data collection. The federal funds went directly to deploying sensors in metropolitan areas. The funds were allocated as part of the Transportation Technology Innovation and Demonstration (TTID) program. TTID was specifically geared towards increasing the deployment of data collection technology. According to FHWA’s website, “The purpose of this program is to address national, local, and commercial data needs through enhanced surveillance and data management in major metropolitan areas.”<sup>20</sup>

The nature of the contracts and the procurement process in which they were distributed raised some concerns. As a result, the USDOT Inspector General office performed an audit of FHWA’s “management and oversight” of the funding.<sup>21</sup> The final report concludes that

*TTID has benefited the public by expanding the deployment and use of traffic data systems in metropolitan areas, generating revenues for reinvestment, and producing software to generate traffic reports for Federal, state, and metropolitan agencies. However, FHWA allowed the service provider to control significant aspects of the program, consequently diminishing TTID’s value to the public partners. (p. 13)*

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<sup>20</sup> USDOT Federal Highway Administration, 2009.

<sup>21</sup> USDOT Office of Inspector General, “Final Report on the Transportation Technology Innovation and Demonstration Program,” Report Number MH-2010-030, Dec. 8, 2009.



## Micro Effects

The micro effects on deployment can vary from purchaser to purchaser. While there are some reasonably common factors that influence deployment, not all factors affect deployment decisions in the same way. For example, some factors influence the choice to deploy data collection in general, and some factors affect the choice to deploy a specific technology.

In general, the desire for additional data plays an important role in the choice to deploy data collection. This may seem similar to the macro level effect of “complementary nature” mentioned above. This macro level effect focuses on the need for data as an input into other technologies. What is meant by the “desire for additional data” is a desire to enrich already existing data. To elaborate further, a state may already have sensors installed, but turn to probe data as a way to enrich their data in the area covered by sensors and simultaneously expand their data coverage to areas without sensors. This data may feed into an existing deployment of a traffic management technology, not necessarily a new one.

Another interesting micro effect centers on the decision to deploy specific technologies. One producer mentioned that there are two schools of thought regarding sensor placement. On one side, some purchasers feel that one sensor type is absolutely superior to other kinds, and will use that sensor type in all situations. On the other hand, some purchasers feel that certain sensor types have advantages in some situations, but not others. Thus, the specific installation site can make a large difference in the type of sensor deployed, or it may not; overall the effect is ambiguous.

The accuracy of the technology also plays a significant role in the decision to deploy data collection (both in general and in terms of a specific technology). All producers indicated that accuracy was a major concern. It might seem obvious, but as accuracy improves one might expect deployment to be positively affected. This is likely especially true for probe data, as the major downside to this technology is the lack of accuracy when compared with traditional sensors.

Another factor that was mentioned was the “permanency” of the deployment. The installation of inductive loops can be quite disruptive to the roadway and are permanent features. If the data is only desired for a short time span (traffic management for a sporting event, for instance), such an invasive product is not the best choice. This might push the purchaser towards something like a portable radar unit or probe data.

This is by no means a comprehensive list of all those factors that affect deployment. However, these are some of the common factors that we found influenced decisions to deploy technology. Those macro factors mentioned above affect deployment nationwide. On the other hand, those micro factors mentioned above are more localized, but when aggregated help spell out of the story of national deployment. Table 3 below presents an overview of the key factors affecting HDC deployment.

**Table 3. Key Factors Affecting Deployment**

Macro Factors	Micro Factors
1201 Rulemaking	Desire for data
Complementary nature with other technologies (e.g. Variable Message Signs)	Purchaser preference for technology type
Traffic.com award	Accuracy
	Permanency of the deployment

## Conclusions: HDC

The highway data collection market is multifaceted. Captured within it are two distinct sub-markets: hardware and data services. These two sectors are in some sense substitutes, but are also somewhat complements, as illustrated by the discussion of verification above. The hardware side of this market appears to be relatively competitive when considering the entire marketplace. That might change, however, depending on the definition of the market (ranging from a specific technology to all sensor types). The data service side of the market is relatively consolidated into several major players. However, at this point, the market is too young to make any classification of its structure.

One major issue in this marketplace centers on the accuracy of probe data. Unless this accuracy improves, sensors will continue to dominate the marketplace, with probes remaining in a position as a complement to loops rather than a clear substitute.

## Suggestions for Further Research

The area of highway data collection presents several interesting options for further research. These areas will provide additional insight into different aspects of the market place as well as helping the market to mature.

### ***Procurement/ Bid Package / RFP Guidelines***

One of the main marketplace concerns revealed during this research was the clear lack of a method (or guidelines) for procuring data. In the cases where a state actually procured data, they were clearly able to develop a process for procurement competition. However, the concern was still mentioned that they had no guidelines. They had to develop the process from scratch. A data service is different enough from a hardware competition that they likely require different sets of criteria and rules. Issues of importance include: who owns the data, how can it be disseminated and can it be shared with other private companies (or agencies). There appears to be a gap in the market that would benefit from the development of guidelines for procuring data from a third party.

This reference should not be a mandate, however; each procurement process will have different needs and any reference should remain flexible with this in mind. However, there are likely some aspects that are common to each. For example, requirements on data quality may be a common characteristic that different agencies would cite in their procurements.

### ***Accuracy of Probe Data***

As mentioned above, one of the major concerns about probe data is its accuracy when compared to sensor data. Claims of accuracy are also hard to support. We suggest research into this area. This research should have several facets: some sort of certification method, an examination of current generation technology, and research into ways to improve accuracy.

Certification plays into the discussion above about guidelines for procuring data. Some sort of federal level (or private/non-profit body) certification standards would help agencies better gauge the quality of the data they are procuring. The certification should include some sort of rating that helps purchasers easily compare two sources of probe data. This paper does not propose a form for the rating; however, some criteria of the rating are discussed below.

First and foremost, the rating should be easy to interpret. That is to say, given two (or more) companies, it is simple to determine which one received the better rating. Second, the rating should examine the

accuracy of the data in a multitude of circumstances (such as free flow, light congestion, heavy congestion, etc.).<sup>22</sup> Third, the rating should punish over and under counting of vehicles at the same rate.

### **Supplier Market Power**

The probe-based data market seems structured in a way that could give rise to a natural monopoly. The entire basis of the data collection is a network of probes. As mentioned above, if you do not have enough probes, the data collected is not an accurate portrayal of the on the ground situation.

This feature of the marketplace means that, in some sense, a one supplier market could be a natural outcome. In this way, all the probes are feeding data to the same place, increasing coverage. Nonetheless, a company with the entire set of probes is likely to charge monopoly prices. This is similar to the natural monopoly that power utility companies present – it doesn't make sense to have three sets of power lines. It may be worth examining the growth and structure in this market to determine if a situation begins to present a natural monopoly (either nation-wide or in a region).

If there is a concern that a monopoly situation is developing, there is a multitude of ways that can be used to examine whether this is the case. One relatively straight forward method involves the Herfindal-Hirschman Index (HHI). The HHI is defined as the sum of the square of the market share of each firm. Expressed as an equation:

$$HHI = \sum_{i=1}^N s_i^2$$

Where  $s_i$  is the market share of firm  $i$  and  $N$  is the number of firms in the market. The Department of Justice considers an HHI of .18 or greater to indicate a "concentrated market."<sup>23</sup>

In the case of a market place with many firms,  $N$  is capped at 50 and the firms considered in the analysis are those with the largest market shares. While the HHI itself is simply defined, there are a number of important questions to be answered before employing it. In particular, the definition of the market is highly important. This means aspects such as geographical area and substitutability of the goods or service need to be considered carefully before using a methodology such as this to exam the structure of a market.

It is also important to keep in mind that the HHI is only a rough identification tool, and is subject to interpretation. Before using this, or any other, method to look for the presence of a monopoly it would be important to perform a thorough preliminary market analysis.

### **Google**

On October 28<sup>th</sup>, 2009 Google announced its new foray into the navigation business (Google, 2009). Their new product centers around turn-by-turn navigation through the Google maps application on their Android mobile operating system. Currently, the Google maps application for Android sends GPS location data to Google as long as the application is open. The additional functionality of the new application, as well as the increased use of the Android operating system in new smart-phones, poses an interesting question into how the HDC market may evolve.

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<sup>22</sup> It should be possible to develop a rating for each type of traffic situation. This, however, will complicate comparison between firms. Ideally, these conditions would be fixed so that the measurement captures variation in the technology, not the variability of traffic patterns.

<sup>23</sup> For more information regarding the Department of Justice's legal interpretation of the HHI, please refer to <http://www.justice.gov/atr/public/testimony/hhi.htm>

This has the potential to provide Google with millions of probes nation-wide. The obvious issue arising from this initiative is one of how Google will capitalize on the collection of data on a national scale and in such an important sector of the economy? This may not be a “game changer” development, but the entry of Google into this marketplace (and the reactions of current participants) is surely one to consider carefully.

### ***IntelliDrive<sup>SM</sup>***

As mentioned in the beginning of this chapter, IntelliDrive<sup>SM</sup> came up in some of the research interviews. While no current market participant is banking on that technology becoming available soon, IntelliDrive<sup>SM</sup> presents an interesting possibility to equip each and every car with an in-vehicle probe. The presence of a probe in every vehicle on the roadway would likely dramatically increase accuracy of probe-based data. Research into the development of HDC standards or the diffusion of probes would be worthwhile areas of focus connected with the IntelliDrive<sup>SM</sup> effort.

# Appendix: HDC

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**Table 4. Data Collection Technology Specifications**

(Cheung & Varaiya, 2007)

**1. Data type available in different surveillance technologies**

<u>Data Type</u>						
Technology		Data Type				
		Count	Speed	Classification	Occupancy	Presence
Intrusive						
	Inductive Loop	Y	Y	Y	Y	Y
	pneumatic road tube	Y	Y	Y	N	N
	piezoelectric cable	Y	Y	Y	N	N
Non-Intrusive						
	WIM system	Y	Y	Y	N	N
	Microwave Radar					
	CW Doppler	Y	Y	Y	Y	N
	FMCW	Y	Y	Y	Y	Y
	Infrared					
	Active	Y	Y	Y	N	N
	Passive	Y	Y	Y	Y	Y
	Video Image Processing	Y	Y	Y	Y	Y
	Ultrasonic	Y	N	N	N	Y
	Passive Acoustic	Y	Y	Y	Y	Y
Wireless Sensor Network						
	Magnetometer	Y	Y	Y	Y	Y
Y: available, N: not available						

## 2. Error rate of different surveillance technologies in field tests

<b>System Performance</b>					
System		Mounting	Error [%]		Sources
			Count	Speed	
Inductive Loop					
	Saw-cut	Pavement	0.1-3	1.2-3.3	MNDOT[2.26]
Pneumatic Road tube					
		Pavement	0.92-30		SDDOT[2.27]
Microwave Radar					
	TDN 30	Overhead	2.5-13.8	1	MNDOT[2.28]
	RTMS	Overhead	2	7.9	MNDOT[2.28]
Active Infrared					
	Autosense II	Overhead	0.7	5.8	MNDOT[2.26]
Passive Infrared					
	ASIM IR 254	Overhead	10	10.8	MNDOT[2.26]
Video Image Processing					
	Autoscope solo	Side-fire	5	8	MNDOT[2.26]
	Autoscope solo	Overhead	5	2.5-7	MNDOT[2.26]
Ultrasonic					
	Lane King	Overhead	1.2		MNDOT[2.28]
Passive Acoustic					
	SAS-I	Side-fire	8-16	4.8-6.3	MNDOT[2.26]
Wireless Sensor Networks					
	VSN240	Pavement	1-3		[section 4.4]

### 3. Environmental factors that affect the performance of different surveillance technologies

<u>Environmental Factors</u>							
Technology			Environmental Factor				
			Penetration	Wind	Temperature	Lighting	High traffic flow
Intrusive							
	Inductive Loop				Y		
	Pneumatic Road Tube				Y		Y
	Piezoelectric Cable				Y		
Non-Intrusive							
	Microwave Radar						
		CW Doppler					Y
		FMCW					
	Infrared						
		Active	Y				
		Passive					
	Video Image Processing		Y	Y	Y	Y	
	Ultrasonic						
	Passive Acoustic		Y		Y		Y
Wireless Sensor Network							
	Magnetometer				Y		
							Y: Affected



#### 4. Estimated life-cycle costs of a typical freeway application<sup>24</sup>

<b>Lifecycle Costs</b>					
Technology	Device	Installation	Maintenance	Lifetime	Life-Cycle Cost [\$]
	Cost [\$]	Cost [\$]	Cost [\$/ yr]	[yr]	
Inductive Loop					
Saw-cut	12x750=9000	Included	700	10	14,904.73
Microwave Radar					
TDN 30	6x995=5970	3200	600	7	12,915.28
RTMS	2x3300=6600	400	200	7	8,248.42
Active Infrared					
Autosense II	6x6000=36000	3200	600	7	366,945.30
Passive Infrared					
ASIM IR 254	6x700=4200	1200	600	7	9,145.28
Video Image Processing					
Autoscope solo	2x4900=9800	1000	400	10	14,174.13
Ultrasonic					
TC 30	2x735=1470	400	200	7	3,118.42
Passive Acoustic					
SAS-I	2x3500=7000	800	400	7	10,296.85
Wireless Sensor Networks					
VSN240	450x12=5400	200	200	10	7,287.06

24

$$\text{Life Cycle Cost} = (\text{Device Cost} * \text{Quantity} + \text{Installation Cost}) + \left( \frac{1 - \left( \frac{1}{1+i} \right)^{OY}}{1 - \left( \frac{1}{1+i} \right)} \right) * \text{Annual Maintenance Cost}$$

OY = System lifetime in year, i = interest rate (0.04 is used)

Joint Program Office  
U.S. Department of Transportation, Research and Innovative Technology Administration

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# 5. Arterial Technologies

This chapter examines the deployment trends of ITS technologies for data collection, traffic management, and signal preemption on arterials. For the purposes of this study, “arterials” are broadly defined to include all signalized roadways designed to move large volumes of traffic. They are distinguished from highways, which have controlled access and free-flowing traffic.

Four separate ITS applications for arterials—and the technologies that facilitate these applications—are the focus of this analysis: first, detection and collection of real-time data on vehicles (referred to as vehicle data collection (VDC)); secondly, processing and use of this data by overarching system software for management of the network (traffic management software (TMS)); and, finally, preemption and prioritization procedures in service of emergency response and transit vehicles (emergency vehicle preemption (EVP) and transit signal priority (TSP)) will be discussed.

These four focus areas were selected from within the broader market for arterial ITS technologies, because these markets, and the products related to them, have witnessed technological innovation and changes in adoption patterns in recent years. Other ITS technologies and products used in arterials management and not specifically addressed in this study are, for example, red-light enforcement cameras and dynamic message signs.

It is worth noting that in each of these four areas, purchasers (e.g., local transportation departments) may have the choice between multiple different technologies to achieve the same functionality. The functionalities of ITS technologies are not discrete: for example, the same technology may be used for EVP and TSP, and both may be integrated into a TMS algorithm which draws on real-time information from VDC devices throughout the network.

The Arterials chapter is separated into two sections: Section 1 provides a description of each of the four arterial ITS functionalities, as well as background on adoption patterns and the present extent of adoption. Section 2 discusses the structure of the market for each functional area, and highlights factors that will affect the rate of technology adoption and market penetration and trends in the future.

## Summary

### Market Insights

- Vehicle Data Collection and Detection (VDC)
  - Unlike highway data collection, “traditional” sensor data collection methods dominate the markets for detection and data collection, and will continue to do so in the foreseeable future
  - Non-intrusive sensor types are preferred to in-road devices, but no clear-cut alternative has yet emerged as a perfect substitute for loops
  - Use of video for VDC purposes is rapidly spreading, but many purchasers are strongly opposed to using cameras, citing unreliability and weaknesses with respect to environmental conditions
  - The market for VDC hardware and equipment is characterized by nearly perfect competition, particularly in terms of life-cycle costs, stability, and multiple suppliers and technologies
  - Purchasers are increasing the quantity and diversity of their VDC investments

- Traffic Management Software (TMS)
  - Driving factors in the market for TMS are demand for mitigation of congestion and vehicle emissions
  - The supply side contains few suppliers which have the majority of market share: generally, they are large, well established, and highly vertically integrated
  - There is much foreign influence on the supply side, both in terms of foreign companies, and “learning” experiences for companies where ITS TMS are already deployed
  - Purchasers’ primary concerns in the bidding process are reputation, quality, and customer service. Price is often a secondary factor
  - Suppliers specializing in TMS are increasingly a “one-stop shop” for arterials management. These companies provide regional solutions which integrate such applications as TSP and EVP into region-wide traffic management solutions
  - Pricing for TMS is not transparent, and may vary widely on a case-by-case basis in a discriminatory fashion
  - Lead adopters of advanced real-time systems have often worked jointly with suppliers to develop software
  - The extent and quality of pre-existing VDC and field-device investment, (e.g., advanced traffic signal controllers, advanced detection methods, loops at stop-bars, etc.) influence the decision to purchase TMS through potential equipment and upgrade cost burdens
  - Adaptive real-time traffic management is acknowledged to be future of TMS
- Traffic Signal Preemption (TSP/EVP)
  - Purchasers are not in agreement as to whether EVP facilitates or disturbs overall traffic flows. Some transportation agencies consider EVP to be undesirable due to its effects on traffic flow.
  - TSP represents a major growth area in arterials ITS: Adoptions have rapidly increased in the past decade, from a very small initial installed base
  - GPS-based preemption and priority, which came to market in the early 2000s (and recently been recognized as reliable), has become the state of the art in terms of capability, cost advantage, and complementing with other ITS applications
  - Technologically, TSP and EVP are highly complementary to each other, as well as real-time traffic management software, and automatic vehicle location
  - Going forward, increasing environmental concerns are expected to positively stimulate agencies’ demand for TSP, as a mechanism for incentivizing mode shift to transit

## Considerations for Future Research

### Policy Goals:

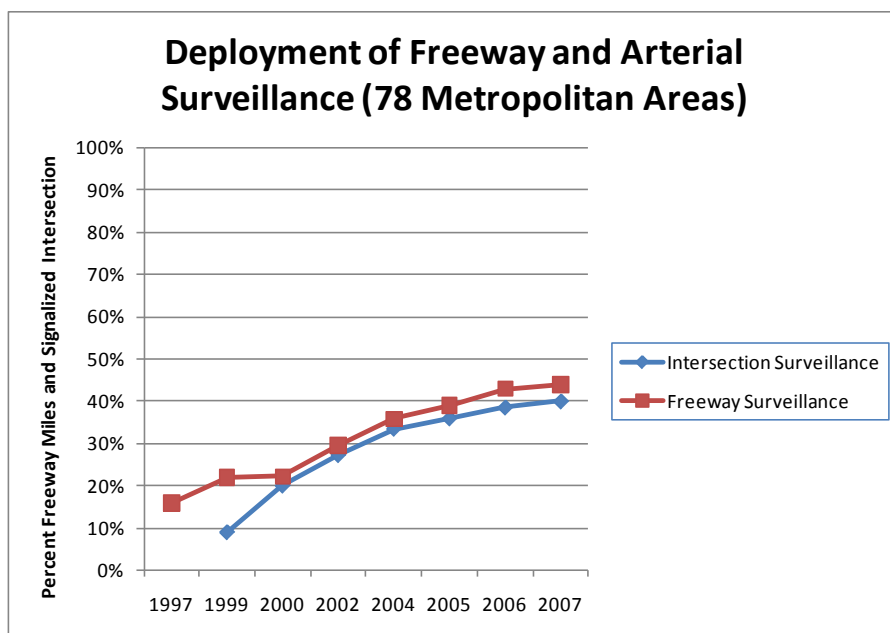
- Promote joint deployments of EVP and TSP
  - Further research into benefits of combining the two
  - Promoting adoption of common standards and protocols
  - Promote opportunities for joint funding
  - Research the use and benefits of GPS technologies for EVP and TSP purposes

- Examine how probe data is being used on arterials where it is collected
  - Examination of accuracy of probe data
  - Potential application for lane-level arterials management practices
  - Explore potential uses for IntelliDrive<sup>SM</sup> program goals
- Explore existing and further research into benefits of adaptive/real-time TMS for effective capacity improvements, congestion/delay reduction, and emissions reductions
  - Characterize existing base of advanced detection equipment (e.g., non-stop-bar detection) which can be leveraged for adaptive/real-time management use
  - Promote funding opportunities for adaptive TMS in high-traffic-volume and high-congestion areas
  - Identify characteristics and process of lead adopters and purchaser-supplier partnerships in developing TMS research process of lead adopters and joint developments of TMS
  - Research economies of scale in “regionwide integration” of ITS: multiple agencies, multiple arterials networks, multiple functionalities (e.g., EVP, TSP, parking, traveler information, etc.)
- Development and refinement of standards/protocols to allow for improved interoperability of systems.
  - Establish specifications to enable purchasers to obtain support and service from multiple sources and offer protection from inferior products
  - Carefully consider whether requirements would affect the adoption of new technologies
- Estimate the performance time horizon of TMS (TMS is a significant investment and agencies have the expectation of operating it over a long period of time)
- Consider the implications of Federal legislation and local initiatives limiting emissions of carbon and other pollutants on the demand for TMS

**Market Concerns:**

- “Fly-by-night” companies in the VDC market
- Budget constraints of purchasing agencies following the recent economic downturn
- Impact of 1201 rulemaking on technology investment
- Potential impact of IntelliDrive<sup>SM</sup>

**Figure 15. Deployment of Freeway and Arterial Surveillance in Large Metropolitan Areas**



Source: Analysis performed by Oak Ridge National Laboratory and provided to the authors of this study. Data: ITS Deployment Tracking Survey

## Historical Trends and Current State of Deployment

This section discusses the technologies and equipment used to achieve each of the four functionalities in arterials traffic management mentioned above, the historical deployment trends among these technologies, and the current state of deployment for these applications.

### Vehicle Data Collection

#### *Market Background*

Vehicle detection and data collection (VDC) on arterials is differentiated from the equivalent operation on highways by one obvious feature of arterials: intersections. The presence of intersections not only increases the complexity of collecting and interpreting data accurately; it also affects the purpose of data collection, as well as the ITS technologies which can be used in this area. Nevertheless, a comparison of methods for VDC on the two roadway classes provides insight into arterial VDC from both a technological and adoption standpoint. First of all, new technologies introduced for arterial VDC often closely track those designed for highways, but with a market lag time. This trend is exemplified in Figure 15 above for the case of electronic surveillance: the practice was originally used for highway data collection purposes (as measured by the percentage of freeway miles under surveillance), but deployment at signalized intersections on arterials followed quickly thereafter. Secondly, whether and how a transportation agency, or its neighbors', collects data on highways may significantly influence its existing and future VDC practice on arterials.

The past decade has seen major advancements in ITS technologies for data detection and dissemination on highways, and widespread adoption of these technologies by transportation agencies. Market patterns indicate that arterials VDC will undergo similar growth in the coming years. Arterial traffic accounts for

more than half of all vehicle miles of travel in the United States, and the majority of total person-hours of congestion in urban areas, yet very little real-time data are collected on arterials relative to highways.<sup>25</sup> However, as one ITS purchaser remarked, arterial ITS products “are becoming the alternative to road-widening and capacity expansion.” For this as well as other reasons, transportation agencies will improve and expand data collection practices on arterials in the coming years, increasing the rate of investment in arterial VDC equipment, as well as shifting the market shares of technologies within the installed base of equipment.

As noted above, data needs and use on arterials differ from those of highways. Activity at traffic management centers (TMCs) show that transportation agencies have an interest in incident and special-event management and network surveillance on both roadway classes. Arterial TMCs, however, use data primarily for signal coordination, whereas highway TMCs are increasingly focused on processing and disseminating data to provide en-route traveler information.

As on freeways, it is possible to detect and collect data on vehicles using either sensor or in-vehicle (probe) equipment. For the purposes of non-real-time analysis of traffic flows, both technological approaches may be equally feasible on highways and arterials. Nonetheless, differing strategies for congestion management dominate the two functional classes. By providing real-time information to travelers, operators expect that freeway demand will be reduced commensurate to available supply. Arterials management, however, has adopted the opposite approach: traffic managers seek to increase the effective roadway supply by adjusting and optimizing signal timing. Thus, while probe data collection is expected to play an increasing role in highway data collection in the near term, “traditional” data collection methods will continue to dominate transportation agencies’ investments with regards to arterials VDC.

Primary end-users of arterial data are traffic managers— whether human or computerized—whose main objective is real-time signal control. Traffic data accurately reported with respect to the position of the intersection (that is, at lane-level precision) are of greater importance than the location, speed, and flow of the individual vehicles themselves. Thus, in-road and roadside equipment that is fixed with respect to intersection location is—and will continue to be—the primary source of data on arterials.

### ***Equipment and Technologies***

As on highways, the main in-road and roadside data collection technologies are loop detectors, cameras, and other types of sensors, including microwave and infrared radar, ultrasonic, and magnetic loops.<sup>26</sup> Importantly, “traditional” VDC technologies can be separated into “intrusive” (in-road) and “non-intrusive” (above-ground) devices. As noted in Chapter 2, the industry for “traditional” sensor-based technologies is well established and long-standing. Nevertheless, there is continued motivation for improvement and innovation in this field for arterials applications, particularly in service of real-time congestion management. Vehicle detection at the stop-bar has long been an easy feat using existing technology. Obtaining information appropriate to use in real-time traffic management, however, is more difficult. The typical arterial network is comprised of roadway segments containing multiple intersections and lanes, varying speed limits, intersection departure points, and so on. Whereas slowly moving traffic on a freeway segment is likely indicative of congestion or a problematic incident, low speeds on an arterial segment may be a desirable reaction to a stoplight, or a normal deceleration pattern preceding a turn. Advanced systems for traffic management increasingly require advanced detection—that is, accurate data collection in non-stop-bar locations.

The different technologies currently available for vehicle detection and data collection on arterials are substitutes for one another to some extent—but not perfectly so. The minimum functionality is essentially equivalent among the various sensor options: nearly all are able to capture traffic volumes, vehicle

<sup>25</sup> FHWA *Highway Statistics 2007*, Table VM-1.

<sup>26</sup> Tables 6.1 and 6.2 of FHWA’s *Traffic Control Systems Handbook* (2006) also provide an overview of the relative strengths, weaknesses, and costs of widely available VDC technologies.

classification, speed, density, and occupancy. As would be expected, each type of equipment has advantages and disadvantages in terms of count accuracy, difficulty of installation, hardware and installation costs, required maintenance and repair, durability and resistance to weather conditions, expected lifetime and service and support requirements.

### ***Historical Pattern of Deployment***

As discussed in a previous chapter, inductive loop detectors were the first technology to dominate the VDC arena. In spite of several weaknesses and the emergence of many competing technologies, loop detectors have maintained a wide installed base, and most transportation agencies continue to use them to some extent. Of the 106 major metropolitan areas responding to the 2004 ITS survey, 87% had loop detectors at some signalized intersections within their jurisdiction. On average, 29% of signalized intersections in these metro areas were outfitted with loops.

A frequent refrain among ITS purchasers is that while loop detectors can be surpassed in nearly every capacity by alternative VDC technologies (with the possible exception of vehicle-count accuracy) no single substitute is available which encompasses as many advantages at a tolerable level of count accuracy. Loops are considered technologically “outdated,” but are nevertheless expected to remain a fixture of arterial VDC—though as a declining share of new VDC investments.

Loop detectors are not an evolving technology; other intrusive and non-intrusive sensor technologies for VDC, however, are undergoing significant changes and improvements. Technologies such as magnetometers and infrared sensors are marketed as a direct substitute for loops. Loops have a relatively short lifecycle: they are prone to failure, and are frequently damaged by road repaving and replacement. The wide installed base of loop detectors and high replacement rate presents a market opportunity for other sensors to replace failed loop detectors. This in turn incentivizes innovation in the market: A new technology, if it were considered a preferred substitute for loops, would face high market demand, and, because of the high replacement rate and short lifecycle of loops, could replace the entire installed base of loops in a region in a relatively short time period if installed during routine replacements.

Use of video technologies for traffic detection and data collection purposes has grown rapidly in recent years. Video is the most controversial of the detection technologies: camera performance is highly susceptible to environmental barriers (e.g., direct sunlight, intemperate weather conditions, etc.) and initial adoption is often hindered by privacy concerns. Nonetheless, VDC by video processing has been spurred by several factors. From the standpoint of hardware attributes, cameras are flexible (they can be re-aimed or re-located easily) and non-intrusive, and can be used for multiple purposes outside of basic VDC (for example, real-time observation). From an evolutionary standpoint, a decrease in the price of bandwidth, and an increase in quality and capabilities (for a relatively constant price) have driven adoption.

### ***Current State of Market Penetration***

There is no consensus among ITS purchasers on the comparative value of varying VDC technologies; purchasers have differing—but strong—opinions. Some purchasers stick purely and adamantly to one or several familiar VDC products in the same technological vein, reinvesting and replacing equipment regularly. Others employ a wide mix of VDC technologies, seeing different advantages in each different approach to VDC, or value in having a diversified mix of data collection equipment. Many agencies report that they expect to continue to use loops for simple detection (for example, detection at the stop-bar), while increasing investment in other technologies to gain advanced detection and data collection capabilities.

In all cases, the extent of data collection on arterials—especially for use in real-time traffic management applications—is rapidly increasing. As shown in Figure 15 above, the percentage of signalized intersections under electronic surveillance has increased from under 10% to 40% in less than a decade in



major metropolitan areas. In 2007, about 6% of arterial mileage in these areas was covered by CCTV cameras. In addition, the extent and complexity of historical traffic data collection and archiving is increasing. Non-real-time data analysis has always been a primary functionality of VDC, but this application may continue to grow as data transmission and storage become increasingly easier and less expensive.

## Traffic Management Software

Traffic management software compiles information received from VDC devices and equipment throughout the arterial network, and implements one of several methods for coordinating and managing signals and signs accordingly. It is widely accepted that advanced TMS packages (as described below) can produce significant benefits with regards to stop/delay, travel time savings, and emission reductions (Selinger & Schmidt, 2009).

### *Equipment and Technology*

The incremental cost of traffic management software itself is small, since it requires very little in the way of equipment. The primary input to traffic management software is development of the underlying coordination algorithm and the user interface. Only a computer is required to run the software itself. Access to software applications is generally Internet-based, and compatible with common operating systems such as Windows. Input data for TMS, however, is entirely dependent upon the sophistication of field devices for vehicle detection and data collection, and traffic signal controllers. Furthermore, network connectivity (whether through wireline or wireless) is required to transmit data from field devices. Many ITS purchasers have pre-existing investments that can be leveraged at the time of TMS purchase; otherwise, successful operation of TMS may require hardware purchases or upgrades.

Conventionally coordinated traffic control systems can be time-based signal control, interconnected control, or traffic-adjusted control. Time-based signal control allows only for fixed, pre-determined signal control plans. The architecture of the two latter types of conventionally coordinated traffic signal systems are of three varieties: three-distributed computational level (“closed loop”), two-distributed computational level, or central control.<sup>27</sup> Signal timing plans are stored at the level of the local controller, and controllers must be interconnected by wired or wireless techniques.

Simple signal coordination techniques for conventionally controlled systems analyze stored traffic data for the network, and output a pre-timed, (i.e., time-of-day/day-of-week, or TOD/DOW) plan for signal coordination. Minimal coordination plans for closed loop systems (which have the widest installed base) are frequently provided directly by the equipment supplier (rather than a supplier specializing in TMS). Traffic-responsive plans, which employ specific algorithms to coordinate and optimize networks of signals (examples include SCOOT [Split, Cycle, Offset Optimization Technique] and SCATS [Sydney Coordinated Area Traffic System]), can also be selected for traffic-adjusted control. These plans require specialty software to run the optimization algorithms—however, optimization is not performed dynamically.

Advanced traffic signal control techniques—“real-time” optimization of a traffic network (that is, dynamic response to current conditions)—can be one of two varieties: traffic responsive (rapid reaction to detected traffic conditions) or traffic adaptive (cycle-free, rapid response to detected traffic conditions).<sup>28</sup> According to Selinger and Schmidt (2009), the main difference between responsive and adaptive systems is that “adaptive systems typically do not select from a menu of signal timing plans; they make more complex

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<sup>27</sup> See Federal Highway Administration, *Traffic Control Systems Handbook*, Chapter 8, “System Control.”

<sup>28</sup> The ITS Deployment Survey (2000) qualifies traffic adaptive systems in the following way: “Traffic adaptive control systems gather data on traffic flows in real-time at each intersection and uses these data to make adjustments to traffic signal timings based on minute to minute (real-time) changes in traffic flow at each intersection.”

adjustments.” These control techniques have more stringent system requirements for field equipment.<sup>29</sup> Advanced traffic responsive systems implement the algorithms noted above in real-time; traffic adaptive systems dynamically optimize subject to specified criteria (e.g., maximum delay reduction). Examples include models such as RHODES and OPAC (Optimized Policies for Adaptive Control).

Transit signal priority (TSP) and emergency vehicle preemption (EVP) capabilities are often available as applications in an advanced TMS package. Among the conventional traffic management methods, signal preemption (such as for TSP or EVP) mainly acts as a disruption to optimization efforts, though central control architecture can, in principle, accommodate priority schemes. Advanced traffic responsive and traffic adaptive packages internalize signal preemption capabilities into the dynamic optimization plan.

### ***Historic Pattern of Deployment***

Advanced TMS packages using SCOOTs and SCATS first came into practice in the UK and Australia, respectively, in the 1970s. The Federal Highway Administration (FHWA) has consistently supported research and development to provide transportation agencies with access to minimal traffic management software packages for little or no cost. In 1986, FHWA developed McTrans Highway Capacity Software, public domain software for traffic systems management, the functionality of which included static optimization of signal timing on arterials networks.

In the 1990s, FHWA sponsored the development of RT-TRACS (Real-Time Traffic Adaptive Signal Control System). (The efforts of this research additionally spawned the adaptive TMS models RHODES and OPAC.) In 2005, FHWA introduced ACS-Lite, which is designed to provide adaptive control capabilities for closed-loop systems. The software was developed in partnership with Siemens. Four controller manufacturers (Eagle, Econolite, McCain, and Peek) have integrated the ACS-Lite to operate with their systems. Initial demonstrations of the system have recently been completed.

Advances toward interoperability, such as the development of the National Transportation Communications for ITS Protocol (NTCIP) (for equipment interoperability) in 1996 and the 2070 Advanced Transportation Controller (open architecture for controller hardware and software) in 2007, have played a crucial role in advanced TMS adoption to date, providing assurance to purchasers and guiding the development of technological specifications. Nevertheless, there is still a marked concern among purchasers that although proprietary software systems should be able to “talk” to any standardized controllers and devices, TMS suppliers’ products function significantly better with input from their own (or partners’) controllers (i.e., the devices that control the phase change and timing of individual traffic signals).

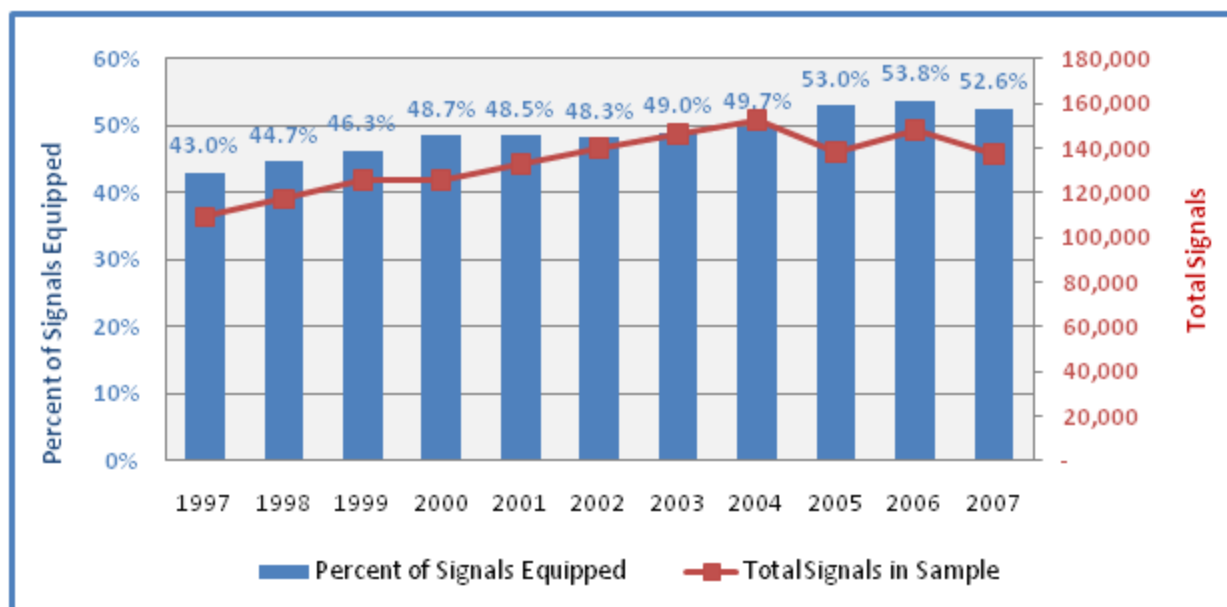
Significant effort and resources are required to calibrate TMS to a particular network and accommodate the needs of the purchasing agency; suppliers of advanced TMS were not initially able to achieve this successfully independent of the transportation agency, even with software marketed as “off-the-shelf” products. For this reason, lead adopters of TMS have undertaken the development process jointly with suppliers in several instances (for example, the city of Seattle). Some purchasers still prefer to contract explicitly for joint development of a “boutique” software system. As further discussed below, advanced and adaptive real-time TMS are still in early stages of market penetration, and purchasers should expect to invest significant resources in customization, adjustment, and maintenance of ITS products of this type.<sup>30</sup>

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<sup>29</sup> Real-time use of the SCOOTs algorithm requires advance detection (SCATS does not). As for adaptive systems, “...standard NEMA TS2 controllers generally require software modification to operate with adaptive systems. Type 2070 and ATC controllers with appropriate software are often used for adaptive systems. More intensive deployment of traffic detectors is generally required for adaptive systems as compared with conventional traffic responsive systems” (Federal Highway Administration, 2005).

<sup>30</sup> See Selinger and Schmidt (2009) for survey results on maintenance costs and reliability of various adaptive TMS deployments.

**Figure 16. Traffic Signals under Closed Loop or Centralized Control**



Source: ITS Deployment Data, Interpolated 1998, 2001, 2003

### Current State of Market Penetration

Proactive approaches to traffic management on arterials using signal coordination are now spread widely—although not exhaustively—throughout the United States. Most arterials traffic management systems, however, are not state-of-the-art. Currently, 90% of signal control systems are closed loop systems. In a closed loop system, control logic is distributed among three levels: 1) the local controller, 2) the on-street master, and 3) the central computer. Since control cannot be exercised over intersections under different masters in a unified fashion, control area boundaries in closed loop systems cannot easily be adjusted in response to changing traffic conditions.<sup>31</sup>

The 2007 ITS survey revealed that 73 of the nation’s 78 largest metropolitan areas had conventional control and software—that is, either centralized or closed-loop signal capabilities—in place for signal coordination on at least some traffic signals. Figure 16 illustrates the results of the ITS Deployment Survey for all of the transportation agencies surveyed in this effort over the past decade. Nearly 53% of the traffic signals controlled by these agencies were under the control of centralized or closed-loop systems as of 2007. During the late 1990s, growth in equipped signals outpaced that of overall signals in the panel of participants.<sup>32</sup> However, the graph reveals that signalized intersections have remained relatively unchanged for the past several years; in fact, although the ratio of equipped to non-equipped signals has risen by almost 10% over the course of the decade, the share of signalized intersections under this type of coordination actually shows a decline in several years.

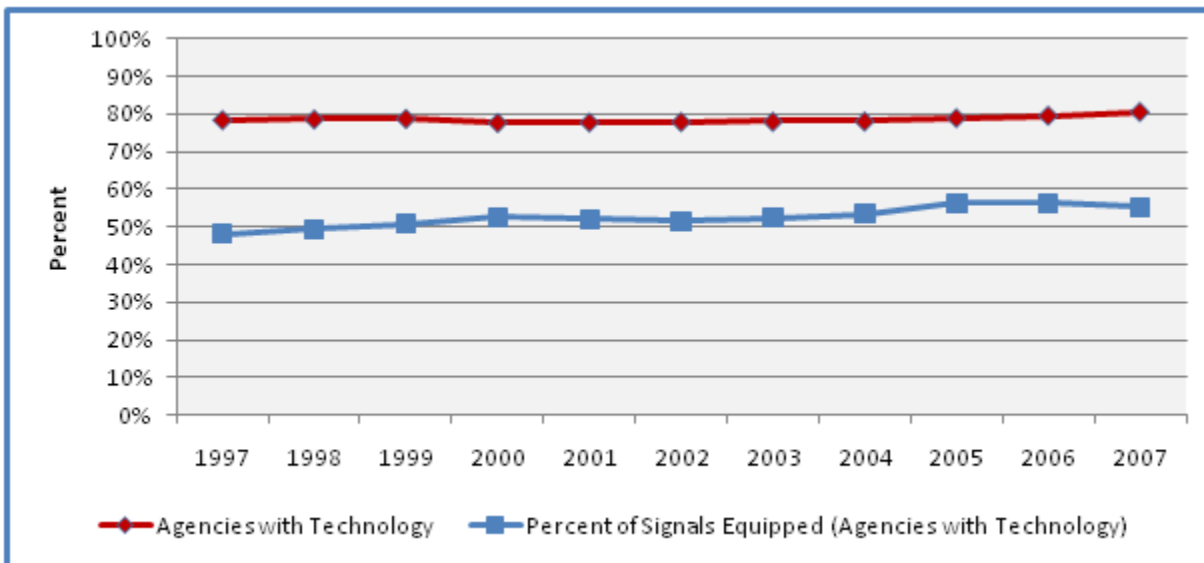
Indeed, evidence from the ITS survey may indicate that adoption of conventional TMS has reached a steady state. Figure 17 shows that the fraction of participating agencies with conventional traffic control

<sup>31</sup> (Advanced Traffic Control Systems, 1997)

<sup>32</sup> The ITS Deployment Survey represents an unbalanced panel of data across years; that is, individual respondents are not necessarily the same from year to year.

capabilities has consistently been about 79% for the past decade. Nor do these agencies appear to be rapidly equipping or retrofitting additional signals: in 1997, 48% of signals were equipped, compared to 55% in 2007.

**Figure 17. Transportation Agencies with Closed-Loop or Centralized Signal Control Capabilities**



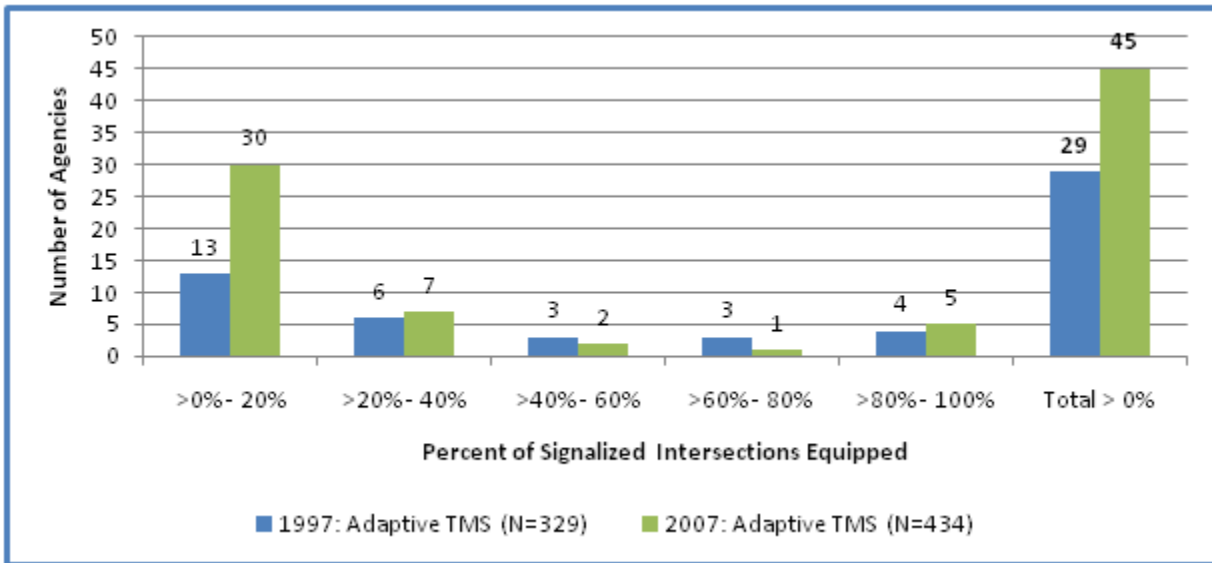
Source: ITS Deployment Data, Interpolated 1998, 2001, 2003

As discussed above, closed-loop systems can be statically coordinated using controller software. Multiple studies, however, have shown advanced TMS to have significant advantages over static TOD/DOW timing plans; advanced TMS (traffic-responsive and traffic-adaptive) is widely recognized by suppliers and purchasers to be the future of traffic control. Given the survey results presented above, it is possible that conventional methods of signal coordination have reached a steady state, and advanced or adaptive systems will replace closed-loop and centralized system deployments.

Throughout the United States as a whole, advanced and adaptive TMS currently controls less than 1% of all signals (Federal Highway Administration, 2008). Of the 102 major metropolitan areas that responded to the 2007 ITS survey, 28 contained at least one agency operating advanced or adaptive control at some signalized intersections within the jurisdiction. In none of these areas were more than 35% of signalized intersections equipped; the majority had fewer than 2% of total signalized intersections equipped.

Thus far, adoption of adaptive TMS overall in major US urban areas remains in its early stages. Figure 18 compares the results of the 1997 and 2007 ITS surveys, illustrating the number of adopters according to the share of their signalized networks under advanced or adaptive TMS. Though the respondent samples are different between the two years, the portion of agencies reporting TMS-equipped signals increased from approximately 8.8% to 10.4%. Advanced and adaptive traffic management software is not yet a fully mature technology. As Figure 18 indicates, only a handful of agencies in the survey sample have experimented with it.

**Figure 18. Agencies with Real-Time Advanced or Adaptive TMS, by % of Equipped Intersections**



Source: ITS Deployment Data

## Signal Preemption and Priority

### Background

Signal preemption and prioritization for the purposes of EVP and TSP generally use the same equipment and technologies. A simple in-vehicle priority or preemption system consists of an emitter in the vehicle, and a receiver on the traffic signal. When a request from the vehicle is received, the receiver communicates with the signal controller and/or a central traffic system. Phase change may then be granted based upon pre-determined prioritization schemes or preemption conditions.

Signal preemption treatments can be passive (continuous and non-changing), active (e.g., early or extended greens, phase insertion, or phase rotation), or real-time/adaptive. Preemption schemes have varying levels of complexity, and the options available to an agency that is considering an isolated investment in preemption capabilities will depend on the sophistication of controllers, signals, and detectors in place. Fixed-time signals and actuated signals can support only limited TSP and EVP applications (often due to controller limitations), and these may increase rather than decrease overall traveler delay in the area. Actuated and adaptive/real-time signal control systems, however, allow signal preemption algorithms to take more conducive and flexible forms, and to be more easily controlled by the traffic manager (ITS America, 2004).

### Equipment and Technologies

Initial approaches to signal preemption used a push-button to change signal phase at a single strategic intersection (such as the intersection immediately outside a fire or police station), or passive applications of TSP for fixed-time-controlled signals. Currently, most preemption involves communication between in-vehicle devices and equipment at the signalized intersection. In-vehicle signal preemption was first introduced in the 1970s by 3M Company, which developed strobe-light emitters for use on emergency

vehicles. The 3M Opticom brand was refined in 1979 to offer two levels of priority, effectively separating EVP and TSP applications (Bruner, 2008). Media currently used for communication between preemption devices—and with the traffic management center, if applicable—include loop-to-transponder detection, optical (typically infrared) signals, radio frequency transmission (typically at 900 MHz), acoustics, cellular, and—most recently—GPS.

GPS-based preemption was introduced in the early 2000s. Technologically, GPS avoids some of the pitfalls inherent in optical and acoustic communication: these media constrain preemption capabilities to line-of-sight or short-range detection. This constraint makes communications between vehicles and signals susceptible to obstruction and late recognition, with the result that preemption may not be frequently or optimally granted. Early and low-tech preemption attempts encountered difficulties in handling situations such as multiple priority vehicles in the same vicinity, closely spaced intersections, and turning movements. GPS-based preemption can be achieved at longer range and does not suffer from line-of-sight obstruction (though GPS may be prone to other disruptions, such as urban canyon effects).

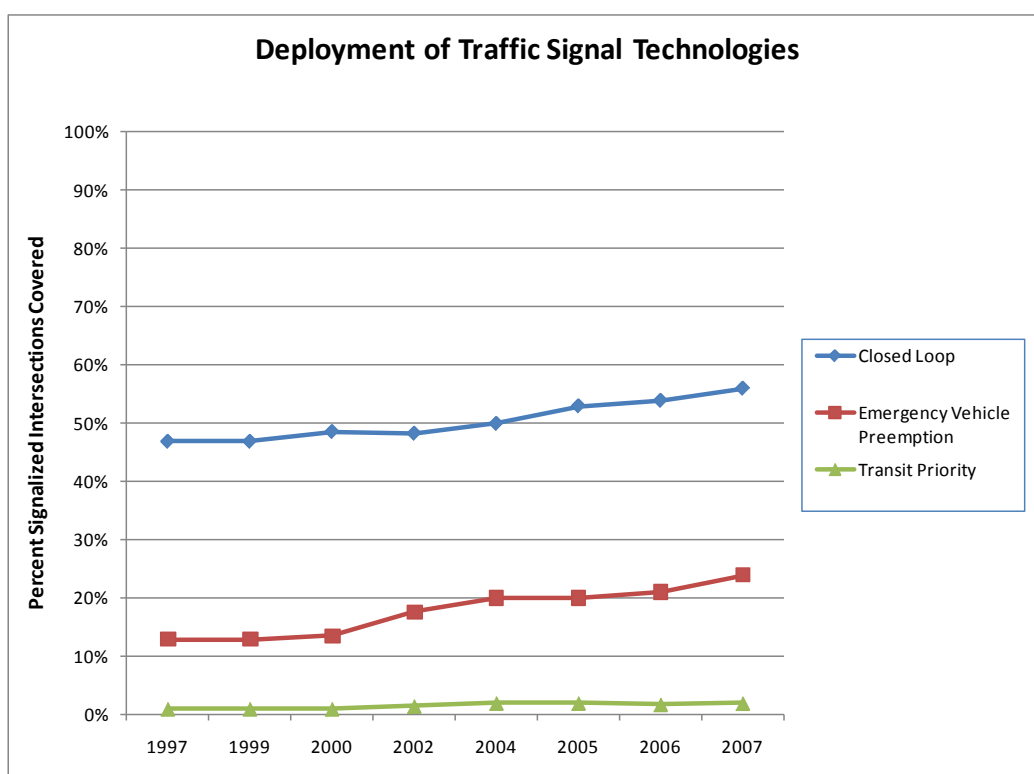
Hardware for preemption purposes—regardless of how preemption is achieved—is very reliable. Physical components of preemption systems are long-lived, and can typically be serviced rather than replaced as necessary. Constituent algorithms and software design are more highly valued than hardware (which is essentially equivalent among competitors for each type of preemption) in complex systems. While hardware has been dependable for quite some time, the last decade has seen overarching preemption algorithms and software systems mature to match hardware’s reliability. As noted above, signal preemption applications within fixed-time or actuated traffic control systems have limited use and effectiveness, and may cause significant traffic delays on arterials. Preemption algorithms for EVP and TSP, however, can now be integrated successfully into advanced intersection signal control models (e.g., SCOOT, SPLIT), and real-time adaptive traffic control systems (e.g., RHODES) (Liao & Davis, *Bus Signal Priority Based on GPS and Wireless Communications*, 2006).

### ***Historical and Current Market Penetration***

Whereas the functionalities performed by VDC equipment and TMS for arterials management purposes are considered by purchasers to be universally desirable (that is, agencies are eager to gain capabilities in both areas to the extent that budget constraints allow), the same consensus does not apply to signal preemption. Some agencies choose not to pursue preemption in the belief that it runs counter to mobility goals (i.e., congestion relief and delay reduction). One ITS purchaser in a high-traffic region noted that they had not invested in EVP equipment because it ran contrary to their primary objective of congestion relief: “[EVP] is opposed to signal synchronization.”

As of 2008, 98 metropolitan areas had signal preemption capabilities in place, whether to be used for emergency vehicle preemption or transit signal priority, at more than 30,000 intersections across the United States (one-fifth of total signalized intersections) (Bruner, 2008). Figure 19 compares the historical pattern of deployment of preemption equipment on signalized intersections over the past decade within the 78 largest metropolitan areas with that of conventional signal control. The rate of EVP adoption for individual intersections has followed roughly the same pattern as that of signal control systems. TSP, on the other hand, has not seen a similar scale of deployment in terms of the number of equipped intersections. Signalized intersections however, may not be a useful indicator of the market penetration of TSP as for other arterial ITS technologies: fully functional TSP systems necessitate equipping only those intersections or corridors where transit vehicles operate on a shared road.

**Figure 19. Signal Control and Preemption Deployments in Large Metro Areas**



Source: Analysis performed by Oak Ridge National Laboratory and provided to the authors of this study.  
Data: ITS Deployment Tracking Survey

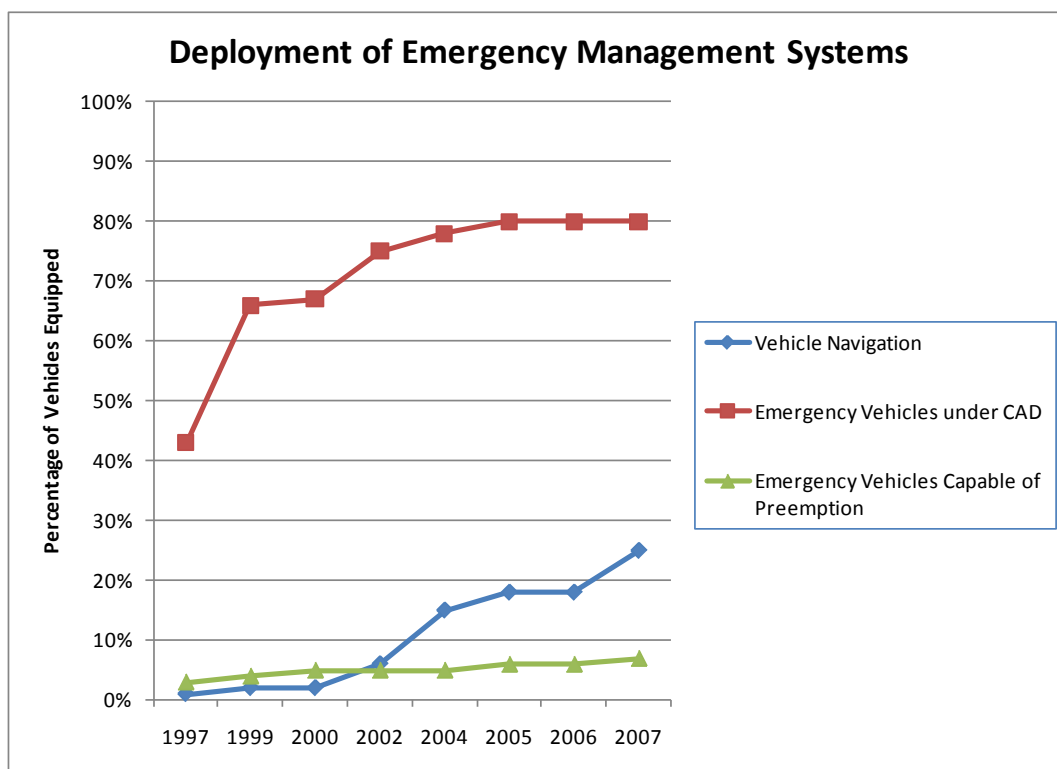
### **EVP Deployments**

Results from past years' ITS surveys indicate that both the number of areas adopting EVP technologies, as well as the number of signals in these areas equipped to provide EVP, has grown in recent years. In the 2007 ITS survey, 91% of the 102 responding metropolitan areas reported having emergency vehicle pre-emption capabilities.<sup>33</sup> As Figure 20 shows, about 24% of signalized intersections in these areas were EVP-equipped in 2007.

Among these metro areas, only 18% had more than half of their signalized intersections equipped for EVP; one-third had fewer than 10% of signals equipped. Low levels of installation in spite of initial technology adoption (and inherent economies of scale) may indicate one of three things: 1) agencies are using older technologies that control only a single intersection (rather than linking to an overall traffic management system), 2) agencies outfit signalized intersections periodically or on a case-by-case basis (rather than network-wide), or 3) signal preemption for emergency vehicles is not considered necessary or desirable everywhere throughout a network, even by agencies that use this technology at selected signalized intersections.

<sup>33</sup> The response rate for the 2007 ITS survey was lower than in previous years (102 responding metro areas, as compared to 106 in both 2004 and 2006 surveys). While the respondents were not the same in all years, indications are that the number of areas with EVP capabilities has remained relatively constant over this time. Nonetheless, among agencies with EVP deployments, the number of outfitted signals is increasing slightly.

**Figure 20. Emergency Management Systems in Metropolitan Areas**



Source: Analysis performed by Oak Ridge National Laboratory and provided to the authors of this study. Data: ITS Deployment Tracking Survey

Unlike the functionalities associated with VDC or TMS, signal preemption for EVP applications has several close substitutes in terms of functionality. These include, for example, computer aided dispatch, which was present in 80% of emergency vehicles in the 78 largest metro areas in 2007, and in-vehicle navigation, deployment of which increased from practically zero to one-quarter of emergency vehicles in the space of the decade prior to 2007. By contrast, only 7% of vehicles in the same areas were equipped for EVP—although this figure has made impressive strides over the past decade, as well, as shown in Figure 20. These substitutes are not exclusively concerned with arterials operations, but serve the same purpose (i.e., emergency management) and target the same safety goals.

Thus, while EVP adoption has been increasing in recent years, the pace of future EVP adoptions may not be determined by the same factors that influence other ITS adoptions (i.e., price, proven technologies, increasing competition among suppliers, and so on). Rather, adoption may have been determined by the availability of substitutes, the sophistication of field devices in place (i.e., controllers and detection equipment), and the perception of EVP vis-à-vis congestion management.

### **TSP Deployments**

Adoptions of transit signal priority are, of course, contingent upon the existence of a transit system, limiting market demand for TSP to agencies in regions that have transit. Further limiting demand is the fact that transit does not generally utilize all arterials in a region; thus, full coverage of all signalized intersections is not typically necessary.

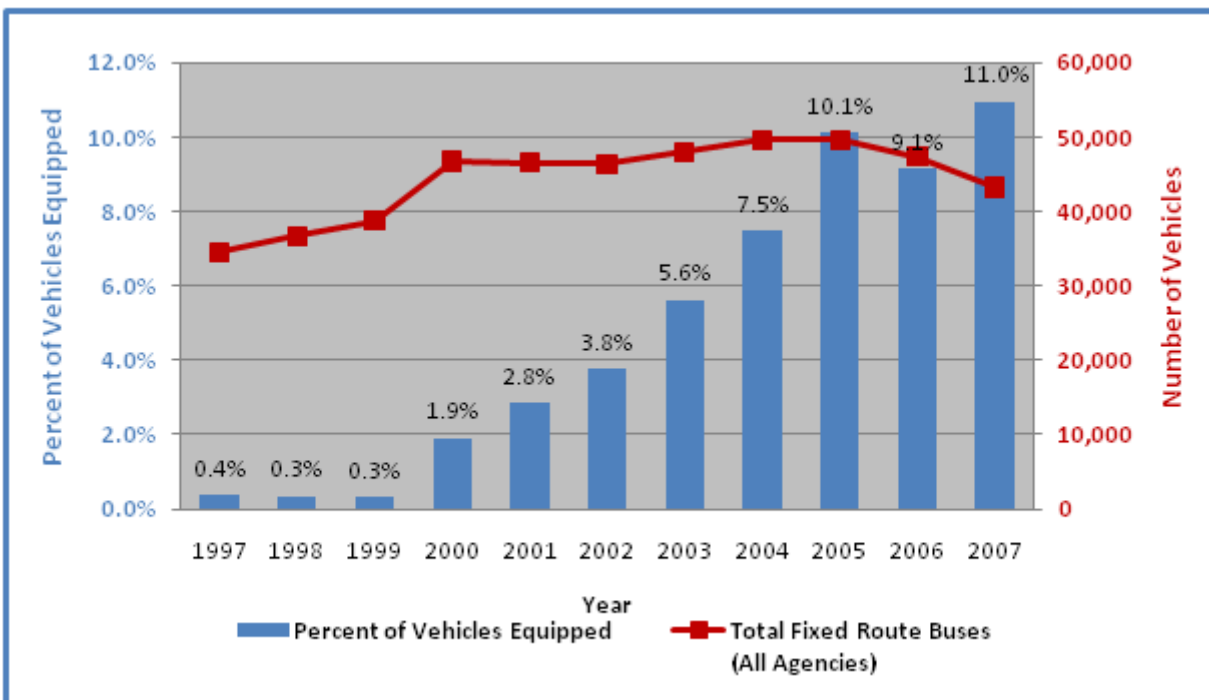


Transit signal priority is much more widely installed in Europe than in the United States<sup>34</sup>; however, momentum for TSP implementation is growing. A survey conducted in December of 1999 by the Canadian Urban Transit Association (CUTA), which had a 75% response rate among transit providers that operate over 100 vehicles, found that 70% of all such agencies were either implementing or planning TSP projects; 44% had TSP projects underway, and 55% had projects in the planning stages.<sup>35</sup>

Of the 78 largest US metropolitan areas, 33 had signalized intersections capable of providing priority for transit vehicles, according to the 2007 ITS survey; equipped intersections accounted for 2% of total signalized intersections in these areas. From 1997 to 2007, the number of TSP-equipped fixed-route vehicles in these metro areas saw rapid increase, from practically zero to 11%.

Figure 21 and Figure 22 display deployment characteristics for fixed-route buses and light rails, as found in ITS Survey data. In the case of fixed route buses, even when the sample size (as measured by the total number of vehicles belonging to all responding agencies) decreases, growth in TSP adoptions nearly always remains positive. Light-rail vehicles are owned and operated by much fewer agencies, and the data are highly sensitive to sample size. Nevertheless, it is evident that agencies have been quicker to adopt TSP for light-rail vehicle than for fixed-route buses. It is notable that deployments have grown rapidly, from 3.4% of agency light-rail vehicles in 1997, to a high of 50% in the year 2004. (Sample size in terms of total transit vehicle stock reached a maximum in the 2004 ITS survey. Following the 2004 survey, the total vehicle stock of all participating agencies declines; the percentage of vehicles equipped with TSP also declines in the sample.

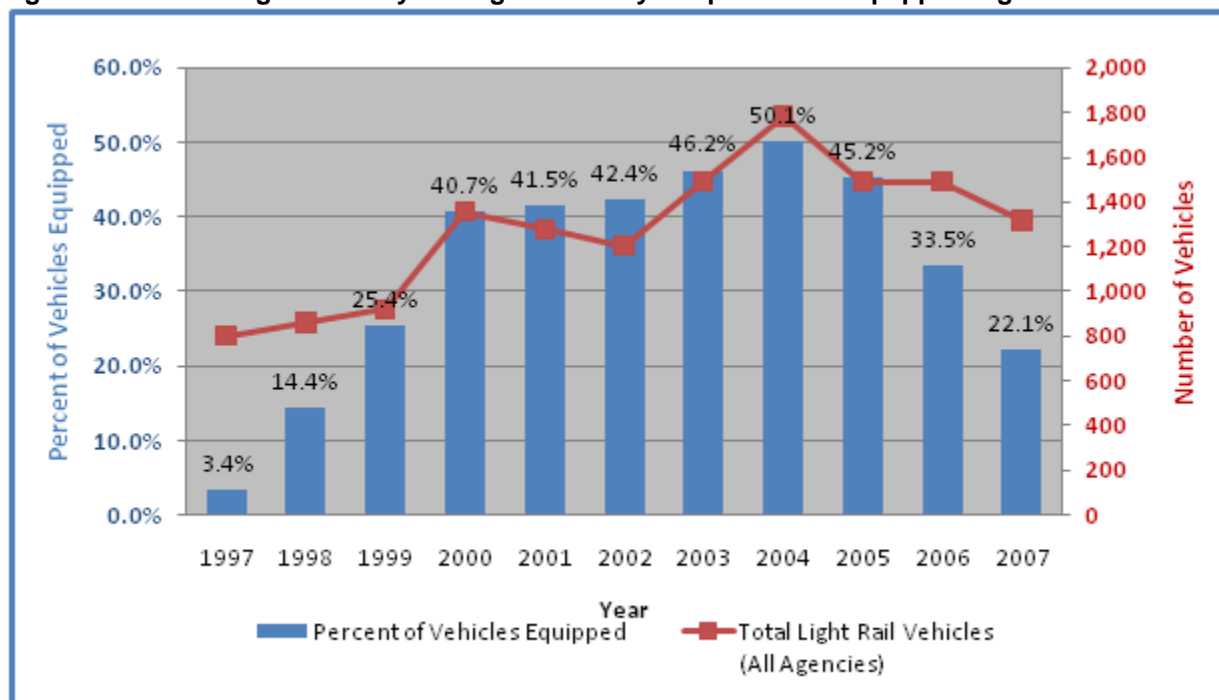
**Figure 21. Transit Signal Priority among ITS Survey Respondents: Equipped Fixed-Route Buses**



<sup>34</sup> (Daniel, Lieberman, & Srinivas, January 2005)

<sup>35</sup> (Intelligent Transportation Society of America)

**Figure 22. Transit Signal Priority among ITS Survey Respondents: Equipped Light-Rail Vehicles**



According to the results of the 2007 ITS survey, 24% percent of the responding metro areas had or were implementing priority for bus rapid transit systems; equipped vehicles accounted for 17% of all BRT vehicles in these areas, and four areas had TSP equipment in every vehicle. Nine percent of agencies had or were implementing TSP capabilities for light-rail systems; 22% of light-rail vehicles in these areas were equipped.

## Market Structure and Trends

### Arterial ITS: Factors Affecting Overall Adoption Rates

#### *Purchaser Characteristics*

Agencies controlling arterials and intersections are smaller in terms of funding and personnel, on average, than those controlling freeways. Furthermore, it is frequently the case that arterials and intersections in a network are not controlled by a sole manager. That is, the roadways in a single area may be owned and operated by several different agencies; furthermore, in the same area, intersection and traffic signal control may also be spread among several agencies. These agencies may exist at different levels of government, have different budget sizes, represent different constituencies of stakeholders or public interests, and have differing priorities or concerns in managing the network. The extent of cooperation, coordination, and communication among the various agencies responsible for arterials management in a network is a primary determinant of the extent and nature of arterials ITS investment in a region.

At smaller agencies, ITS deployment decision-making power often rests with a single individual, often a traffic engineer. Time constraints due to daily work commitments placed on these individuals can make it difficult for them to keep current with innovative options for investment or be able to focus on performing

the research and cost/benefit analysis necessary to differentiate among ITS technologies. Furthermore, many traffic engineers are trained as experts in civil rather than electrical engineering. These factors may deter the adoption of new, unproven, or unfamiliar ITS products.

ITS purchases are often made through distributors, systems integrators, or consultants—particularly in the case of smaller-scale investments or for small-budget agencies. Since such vendors have relationships with particular suppliers, this market structure may limit the supplier options individual agencies have available (depending upon the distributors servicing the region)—and, to the extent that different technologies are seen as substitutes for one another, may also limit the technology options available.

### ***Supplier Structure***

The market for traffic management systems in Western Europe is experiencing market consolidation; there has been an increase in recent years of end-to-end suppliers. For example, Siemens, a German company with a significant market share in both the domestic and international markets, has highly specialized traffic management software; yet, Siemens also makes VDC devices as well as transit signal priority equipment. If this pattern toward marketplace integration continues, it could mean that suppliers have fewer options, and that there will be resistance to standards in certain areas of the industry.

Where there is no vertical integration, close relationships and partnerships are often maintained between equipment manufacturers and transportation systems management companies—they are “tied at the hip,” in the words of one purchaser—creating local monopolies. This may have the largest effect on purchasing decisions when ITS products are purchased through a distributor (rather than directly).

### ***Infrastructure Connectivity***

In the past, infrastructure costs for harvesting data in real-time (i.e., wiring or cable to connect signals to one another or to a central hub, by twisted-pair copper wire or fiber-optic cable) scaled significantly with the size of the network. Such costs could be prohibitive to adopting overall systems management approaches, and discourage the adoption of data-intensive forms of VDC (in particular, video processing, since CCTV cameras require broadband capabilities).

Wireless technologies, for which costs do not scale sharply with network size, are becoming increasingly reliable and affordable, and installation of wireless networks for transportation management purposes is increasing. This coincides with a decline in the price of bandwidth. This makes VDC by video a more affordable option for agencies that find it attractive. Likewise, if communications infrastructure increasingly exhibits economies of scale, the purchase of adaptive traffic management software systems will become increasingly attractive: the marginal costs of linking additional intersections and equipment in the overall network would be low.

## **Vehicle Data Collection**

Market demand for arterial VDC products is strong and increasing: purchasers are expanding both the quantity and variety of ITS investments in this area. Nevertheless, ITS purchasers hold significant power in the market for several reasons:

- Equipment and technologies are relatively simple and well-established. Purchasers have many options, both in terms of technologies and suppliers
- Unit costs of equipment are low, and several- or even single-unit purchases are common practice, and decisions are often price-based

- Many purchases are needed to cover an entire system; incremental purchases need to be made frequently (incentivizing suppliers to provide quality products and be price competitive)
- Expectations are that VDC equipment will be highly interoperable, and costs of integrating new equipment into existing traffic management systems is generally low
- It is common and expected that agencies will rely on more than one type of VDC product
- Costs of switching between or mixing differing technologies are declining
- Minimal resource requirements for equipment operation and use: generally, little training or explanation is required, and data collection procedures are increasingly automated

Technological innovation in the market for VDC is concentrated in the area of non-intrusive technologies, which have significantly lower installation and replacement costs. There is particular emphasis on flexible and adjustable equipment, which can be adapted to accommodate changing urban dynamics and traffic patterns.

### ***Market Participants***

The market for VDC technologies is broad and deep; it includes suppliers of all sizes and levels of establishment. Some hardware/equipment suppliers are highly vertically integrated, or partner closely with other companies in a particular region. Often, vendors offer multiple products (i.e., with varying levels of complexity), but it is rare that a single supplier offers more than one type of VDC technology (e.g., cameras *and* magnetic sensors). The market for simpler technologies (i.e., loops) is nearly a perfectly competitive environment. This is not the case, however, for new and rapidly expanding technologies, such as video image processing and certain sensors.

Barriers to entry in the market for VDC are low, since equipment technologies and manufacturing procedures are relatively well-established and simple. A common refrain among purchasers and suppliers alike is a cautionary word on so-called “fly-by-night” companies: start-up market entrants that disappear or are driven out of the market, leaving their customers unable to maintain or upgrade purchased equipment. The development of standards or protocols for commonly used technologies where none exist (e.g., video processing for VDC) could ensure that purchasers were able to find continuing service for equipment from other sources.

Domestic companies dominate the VDC market. This is due in part to Buy American provisions, but also in consideration for continuing service to products, which is made easier if suppliers are located nearby. Some purchasers—particularly smaller agencies—reported that they actively seek to buy from domestic rather than foreign suppliers. Reasons given were preference of constituents or voters, and ease of acquiring post-purchase service and maintenance.

### ***Probe Data Development***

Probe data sources (such as cell phones or GPS devices) could feasibly be leveraged to gather information on arterial traffic—private sector and proprietary providers have already made some strides in this area—but probe data sources for arterials have not attained widespread use among transportation agencies. Some agencies may have an interest in purchasing probe data, either to process for non-real-time management, planning, and research purposes, or to disseminate real-time traffic information as a service to private travelers. Probe data, however, is unlikely to be viewed as a substitute or replacement to in-road or roadside data collection methods in the near future. Indeed, not only do the data lack sufficient precision to support real-time network management procedures, but the data would need to be

available with equal quality from every vehicle on the roadway—in low- and high-volume traffic, and slow- and fast-moving traffic alike.

Increases in the development and deployment of non-roadside data collection methods for arterial networks will depend upon the strength of demand for real-time travel information, disseminated by transportation agencies for consumption by private travelers—a motive that currently falls far behind that of real-time network management.<sup>36</sup> Increasingly, individual travelers can obtain customized real-time travel time reports for arterials from private providers (through smartphones, GPS devices, etc.); there may be little impetus for publicly provided travel time information from transportation agencies. This may afford transportation agencies the time to wait until methods for travel-time information collection and dissemination have been “proven,” and companies have learned from experience while being supported by their efforts in highway data collection or demand from private travelers.

### ***Pricing and Competition***

The markets for various vehicle detection and data collection devices are highly price-competitive within technology groups.<sup>37</sup> Perfect competition is particularly the story among manufacturers of simpler or older equipment: as one purchaser stated, “loops are loops; any construction manager can figure them out.” Still, initial hardware costs are widely understood to constitute only a portion of lifecycle costs in the case of most VDC technologies. Unit costs fluctuate highly with labor as well as commodity costs; installation procedures can be as much of an expense to purchasers as equipment itself. As such, non-intrusive technologies are preferred to intrusive (in-road) equipment, when there is little difference in functionality for the purposes of the purchaser. Maintenance and repair costs also constitute a large portion of comprehensive lifecycle costs for most VDC products.

Purchasing agencies sometimes experience an exception to perfect competition for hardware after solidifying a relationship with a particular supplier. Prices for marginal equipment purchases can be dependent upon pre-existing levels of investment (that is, suppliers may “hook” purchasers on their products, and increase prices once they have captured a significant portion of the local market).

A large existing market or base of deployed ITS technology can occasionally work against purchasers. For example, some small transportation agencies report that despite efforts to encourage competition, it is difficult to entice new firms into the market to compete against existing suppliers, either because the overall installed base of equipment is not of their own making, or the scale of purchase, at a smaller agency, would be too small to make additional competitors’ efforts worthwhile.

For more complicated technologies (e.g., cameras) there may be start-up costs and economies of scale (to using one particular provider) on the purchaser end in terms of the training and learning. Nevertheless, with most detection/data collection equipment, there are not major barriers to adopting one technology above another. Anecdotal evidence indicates that purchasers frequently make the decision to purchase either sensors or cameras prior to considering suppliers. Thereafter, if sensors are the desired product, suppliers of several different sensors typically compete with one another for large bids. After the group of potential suppliers is narrowed to those whose products have desired functionality and fulfill technological specifications, price is typically the main determinant in purchasers’ decision-making process.

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<sup>36</sup> This does not entail that such probe technologies which provide real-time traveler information on arterials will not continue to be developed. Future business models will likely focus on marketing this information either directly to the traveling public, or to transportation agencies for application in non-real-time analysis.

<sup>37</sup> For a range of typical costs associated with VDC technology, see (Federal Highway Administration, 2005), Table 6.2. Prices range from loops, ultrasonic, magnetometers, and microwave and passive infrared on the low end, to active infrared, acoustic, and finally video on the high end.

## **Influences on Deployment**

### ***Marketing by Demonstration***

Pilot tests and demonstrations are often conducted in potential purchasers' jurisdictions at the expense of suppliers. This opportunity is highly dependent upon the size and budget of the purchaser: demonstration is commonplace for larger agencies. While it frequently leads to adoption, purchasers report that they feel no obligation to invest. Smaller agencies may not be approached with such opportunities, unless they have been significant ITS purchasers in the past.

### ***Economies of Scale***

Significant economies of scale exist for particular technologies, in terms of training employees to operate and understand VDC devices, incorporating and integrating devices into an existing or overarching TMS or system. Traffic management systems may be designed—and software purchased—with the expectation of continued investment in a particular VDC technology. This can be beneficial or detrimental: transportation agencies may see significant cost savings on the margin from purchasing additional VDC devices for an existing system, leading to a greater scale of adoption and utilization of ITS. On the other hand, agencies may continue to invest in a single or obsolete technology (when newer or different equipment may better serve a purpose) for fear of having to abandon existing systems integration or traffic management software. If a particular VDC technology is offered only by a single supplier (or two) in the region (as is common for smaller agencies), suppliers may have the opportunity to charge high prices. This may possibly result in an oligopolistic market, or even in a single supplier gaining significant market power.

### ***Technological Specifications***

Specifications protect purchasers against inferior products—in particular, they can provide insurance against the “fly-by-night” companies discussed previously. Still, specification requirements may also limit or slow the adoption of new technologies if technologies are excluded from the initial bidding process. Purchasers report that they do not have the resources to rewrite specifications as frequently as new technologies are available. Since a second factor in adoption is reputation and demonstration, tight specifications may compound the start-up difficulties for producers of new and innovative technologies, making it difficult to achieve a foothold in the market. This may particularly be the case for sensors offered as a substitute to loops. Standards and protocols can counteract the problem of out-dated specifications.

### ***1201 Rulemaking***

The proposed 1201 rule requires agencies with major metro areas under jurisdiction to report travel times and conditions every 20 minutes. Many agencies do not currently have the capabilities to do so, and building these capabilities will require significant additional investment in VDC equipment. Agencies raise concern about the costs of this rulemaking; if a significant portion of agencies struggle to achieve compliance with this regulation, the impetus may exist to find funding and subsidies for investment, further stimulating the market for VDC.

### ***Network Integration and Sharing***

Within the past decade, wireless, Ethernet, and fiber optics networks have seen increasing deployments for transportation purposes. Broadband communications using these networks are significantly more cost-effective relative to copper wired systems. A decline in the price of bandwidth, as well as an increase in their reliability and capacity, has made these networks an increasingly attractive option for network connectivity. Since video detection and data collection requires high data transmission capacity, the increasing affordability of bandwidth effectively decreases the costs associated with video detection

relative to other VDC techniques. Furthermore, sharing video footage and data over long distances in real-time between agencies or TMCs can now be done in a high-quality and inexpensive fashion. These trends signal further market demand for VDC by video processing, and augur favorably for inter- and intra-regional cooperation between agencies.

## Traffic Management Software

Traffic management software is a large and lasting investment. Only a single system need be purchased, and agencies purchase software with the expectation of operating it over a long period of time.

The major impetus for investment in TMS is the need to manage complicated systems. Areas with high traffic volumes, many signals, congestion problems, and the need for incident and event management stand to benefit the most from advanced traffic management software.

## Market Participants

### *Large and Well-Established Suppliers*

The market for traffic management software has relatively few suppliers. Market participants tend to be well-established, large companies with proven records. Suppliers must do several things to successfully enter the market, all of which involve significant start-up costs prior to recording revenue growth: complete initial product development and demonstration, establish a reputation and “track record,” and be capable of providing continuing support for existing deployments (firms often operate their systems as part of the purchase contract). This entails a high cost-related uncertainty for suppliers (and thus a large risk), which may be most easily absorbed by firms with a large market-capitalization. Consistent with the notion of a limited-player market, suppliers report that while their competition varies somewhat on a regional basis—particularly for small and less complex product deployments—competition for all domestic projects is generally dominated by the same several firms.

Firms producing traffic management software have a high tendency toward vertical integration: many TMS suppliers offer individual hardware components and controllers at the intersection level to transit signal priority applications. This introduces convenience and ease by ensuring a compatible solution; however, it may also box out competition while at the same time tying purchasers to a proprietary system. It is unclear whether the high degree of vertical integration is a cause or effect of the predominance of large companies in the TMC industry.

Development of the market for traffic management software in the United States may be following the precedent established in European and Australian markets. Densely populated and highly congested urban areas in Europe created an initial demand for advanced management techniques; the relative absence of privacy concerns in traffic surveillance meant that there was little resistance to potentially controversial components such as video detection. If TMS adoption in the US continues to follow international patterns, most metropolitan areas with high traffic volumes can be expected to adopt adaptive traffic management systems, and the number of active experienced suppliers within the US market can be expected to increase marginally.

As a part of the 2004 ITS Deployment survey, agencies were asked which software, if any, was used to manage signals; 391 responded. Among the closed loop and non-real-time software mentioned by multiple respondents were packages by Synchron, Siemens (Marc NX), BiTrans (QuicNet 4), Econolite (ARIES), Naztec, and Peek. Among those using advanced or adaptive software, Siemens’ ACTRA software was most frequently cited.

## ***Purchasers***

Small agencies represent a small share of the purchaser market for adaptive traffic management software, due to several factors: agencies with small budgets cannot afford the high up-front and continuous stream of costs and resources associated with TMS. Smaller agencies located outside of densely populated metropolitan areas typically have less traffic and congestion and these agencies hold less leverage with, and are less intensely targeted by, TMS suppliers. Smaller agencies—and those less experienced with ITS—are more likely to opt for “off-the-shelf” TMS products sold by a distributor, systems integrator, or consultant. “Sophisticated” customers approach TMS companies directly.

In response to the cost hurdle posed by TMS investment, large agencies (such as state DOTs) in a particular region may make an investment in TMS and allow smaller partner agencies (such as county or local transportation agencies, transit agencies, or emergency response departments) to use or buy the software at little or no marginal cost.

## **Competition**

### ***Reputation and Quality are Key***

Because of the high cost of the TMS deployments—particularly when accompanied by up- or down-stream supporting equipment or applications—TMS purchases nearly always require an RFP process. Price is not generally the primary criterion in the decision-making process: purchasers rank high quality, and often other considerations, such as supplier reputation, past relations and customer service, over low price in the evaluation process. Proven instances of successful deployments and firm reputation are considered the key indicators of quality. In evaluating competing suppliers, it is common for traffic engineers to consult and visit with representatives of peer agencies, for word-of-mouth review and demonstration of existing systems.

Most major market players offer “off-the-shelf” solutions for a relatively low price; these products tend to be viewed very skeptically by purchasers seeking more than a simple time-of-day/day-of-week approach to traffic management. Generally, high levels of customization are necessary; this entails extensive coordination between the purchasing agency and the supplier. Thus, continuing customer service and accessibility are highly valued. This high level of continuing operations may mean that agencies with smaller budgets are unable to obtain premium software systems, since affordable contracts would not include significant ongoing service and operating payments.

Price is a secondary or even tertiary factor, especially in the case of complex software systems to be implemented in large networks. One purchaser reported that their RFP and procurement process—up to the final stage of TMS purchase—was designed to be entirely price-blind.

### ***International Firms***

Given that the European market is more developed, international firms have a major advantage in the traffic management software market. Foreign firms have “learned” from past experience in international markets, possess the size to absorb risk inherent in new deployments, and already have low marginal costs (the bulk of costs are in development, which need only be accomplished an initial time; thereafter, new deployments are a matter of customizing the existing software, if required). Since most components of a traffic management software package are not subject to “Buy America” and similar restrictions, foreign companies do not face significant obstacles in the US market.



## **Other Sources of Market Competition**

While the playing field for competitive TMS bids is generally restricted to several established firms, informal competition may be introduced into the market from “home-grown” systems. Some traffic engineering departments and management centers report having developed their own traffic management software in-house. Sometimes development is done in partnership with a TMS supplier; sometimes it is done by entering into a relationship with an ITS supplier that has no prior experience in the TMS market; sometimes it is achieved purely through the efforts of traffic engineers. In-house development creates a highly customized traffic management approach, tailored to the specific region, and may be a more effective means of managing traffic than “off-the-shelf” software systems. These in-house software systems, however, may present a barrier to achieving adaptive or real-time control across US arterials networks: adaptive control management software is extremely complex, and would be difficult to develop in-house; and agencies habituated to a “home-grown” solution may be reluctant to invest in external technologies, even if external ITS products offer greater capabilities.

## **Prices**

Pricing mechanisms across the market for TMS are neither standardized nor transparent. The average magnitude of the price for a TMS system was estimated in a 2009 survey of 28 advanced TMS users: the average price per intersection to implement the chosen TMS was \$55,000 (inclusive of signal upgrade prices). According to one study, prices varied widely around this average.<sup>38</sup>

Due to the nature of the product, a large portion of the price for any TMS system represents a premium charged for intellectual development costs, most of which have been undertaken by the time the company is ready to compete in a bidding process. Standard prices are rare for other reasons, as well:

- Prices are tailored to the level of customization, budget, size of system (number of signals), additional features, and user friendliness
- TMS costs are not front-end heavy (e.g., there are few installation costs, but continued service, operation, upgrades, and adaptations are needed to accommodate new technologies)
- Since many companies that offer TMS have a high degree of vertical integration in arterials products, TMS purchases are often accompanied by purchase of hardware/equipment from the same supplier, as well
- Often a deal is negotiated for joint development of a customized system with the supplier

These factors make it difficult to isolate the price of the traffic management software itself. Because of this difficulty in assessing a “fair price” based upon past deployments, suppliers may practice a high degree of price discrimination. Anecdotal evidence suggests that pricing may be based upon:

- Knowledge of the purchaser’s budgetary constraints
- Importance of the purchaser as a hallmark client for further marketing or reputation-building
- Level of ITS-related sophistication of the purchaser
- Strength of purchaser’s ties to particular suppliers (themselves or others) via pre-existing investments

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<sup>38</sup> (Selinger & Schmidt, 2009)

If a purchaser already has a heavy investment in the supplier's upstream or downstream products or those of its exclusive affiliates (for example, hardware or equipment), the TMS supplier may be able to fulfill the bid at a significantly lower cost than its competitors. Nonetheless, because these pre-existing investments make it a priori more likely that the particular supplier will be selected, the bid price may be higher to provide additional profits.

As discussed above, reputation is the main factor in purchaser decisions. It was noted during the research that in a bid to enhance or grow a reputation, some bids for projects with important potential clients may be made below cost, in order to place products where they could serve as evidence of a successful deployment in negotiations with future customers.

## **Influences on Deployment**

Unlike in the case of detection and data collection equipment that can be deployed incrementally and at low cost, traffic management software is a large, one-time, and long-term investment. This investment entails major risk for purchasers, since traffic management software cannot be tested or tried out on a small scale in the same way that VDC equipment can.

For an agency to have demand for advanced (real-time) traffic management capabilities, it must 1) have or foresee the need to manage heavy or complicated traffic patterns, congestion, incidents, or events (i.e., where traffic would significantly vary from a pre-timed plan); and 2) have the resources available to utilize and manage the software. The former entails that not all agencies will see the need to make such an investment. The well-established, simple time of day or day of week algorithms—and the software that runs them—may be sufficient for many areas. For the purposes of these agencies, the “off-the-shelf” varieties of traffic management software may suffice.

In general, however, adaptive traffic management software is quickly becoming the standard for new deployments. The available body of literature documents significant benefits in terms of delay, stop, and emissions reductions, and there is no need to periodically update signal timing plans—a process that can be highly resource-intensive for transportation agencies.<sup>39</sup>

### ***Transportation Agency Resources***

Even if grant funding can be found for TMS, funding the initial purchase may not be sufficient to successfully implement TMS. Ongoing operations, maintenance, and training represent a significant portion of lifecycle costs to agencies operating advanced TMS. In a 2009 survey, 55% of responding advanced TMS users replied that staff time was insufficient to work with existing systems, and 64% had found that implementation had required more effort or training than expected.

### ***Government Initiatives***

The Federal Highway Administration has supported the development of two software systems that set a minimum standard for software against which any proprietary software must compete: Highway Capacity Software, provided by McTrans, provides signal optimization for pre-timed and actuated signals, and ACS-Lite, licensed by Siemens, provides adaptive control capabilities. The availability of these systems at low cost will ensure that transportation agencies can utilize software at low cost, and encourage innovation among private-sector suppliers to provide highly attractive alternatives.

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<sup>39</sup> (Federal Highway Administration, 2005)

## **Existing ITS Investments**

An agency must have well-functioning (and generally, standards-compliant) controllers and detectors already in place in order to make adoption of traffic management software successful; and, furthermore, it must have accurate, reliable, and generally standards-compliant equipment to utilize real-time management features, unless investment in a full system is planned. “All adaptive systems are critically linked to good detection systems. While some adaptive systems will have better tolerance of detector faults than others, the reliability and accuracy of the decisions made by the adaptive algorithms cannot be achieved without well-maintained detection” (Federal Highway Administration, 2008).

A full outfit (hardware and software) may cost about four times as much as the stand-alone software, according to one supplier. While costs scale non-linearly with the size and complexity of the network, a survey of 28 advanced TMS adopters found that, on average, initial deployment cost was \$55,000 per intersection—of which an average of \$20,000 went to signal improvements to make the system operational (Selinger & Schmidt, 2009). Thus, adoption of advanced TMS requires that an agency have an extensive and reliable detection system already in place—and, furthermore, that it can afford the upkeep and maintenance of such a system—or that it be able to invest in VDC equipment and intersection upgrades simultaneously with TMS.

While most traffic management software on the market is capable of collecting information from the majority of controllers and detectors, regardless of manufacture (owing to NEMA, NTCIP, and other families of standards and protocols), anecdotal evidence suggests purchasers find it significantly more convenient to function with proprietary upstream equipment (e.g., same-source hardware, in the case of vertically integrated suppliers; or products manufactured by partner and subsidiary firms). Thus, whether the supplier of an agency’s existing hardware and ITS investments also offers traffic management software may influence adoption, since the transition to utilizing the software would be easy and less costly. Additionally, the agency may be influenced by marketing for the TMS from supplier, or representative distributor or systems integrator.

Some suppliers advertise a “growth path” for existing customers, from existing non-real-time systems to newer advanced or adaptive systems. This may speed the adoption of adaptive TMS.

## **Neighboring Purchasers**

As discussed above, traffic signals and roadways on arterials in a single region may be under the operation and control of several different agencies (e.g., transit, police, fire, traffic control). Optimization and incident management necessitates that these agencies work together by using the same traffic management software. TMS presents the opportunity for significant advantages and scale economies when shared across multiple nearby agencies. Decreases in the cost and difficulty of sharing information over distances (e.g., a decline in the price of bandwidth) may encourage this trend in deployments influenced by or performed jointly with nearby purchasers. Alternatively, the need to coordinate may present a *barrier* to initial adoption of traffic management if cooperation among closely related agencies is difficult.

By the same token, sharing across neighboring jurisdictions introduces significant economies of scale. The impetus to coordinate with neighboring agencies may be a primary determinant of the choice of supplier for agencies: in order to communicate, operate, and share information with neighboring areas, an agency may primarily consider the proprietary technologies already in use by its neighbors. This can create regional monopolies among suppliers—particularly in cases where the supplier is vertically integrated, and provides hardware as well as software components.

This deployment pattern is being seized upon by suppliers in a trend toward “regional integration”: traffic management software that orchestrates not only signals and passenger traffic, but integrates all desirable multiple modes (e.g., by incorporating transit signal priority) and applications (e.g., parking information).

## The Future

### ***Expanding Market***

In comparison to Europe, the US market for advanced traffic management software is underdeveloped; the installed base of advanced systems is relatively small. As demand increases, a larger number of established international providers are expected to increase activity in the US, leading to a more competitive environment, and a possible decline in prices.

### ***Adaptive Systems and Regional Integration***

Bigger and better will be the theme for the future of the TMS market. As noted above, adaptive traffic management software is becoming standard for large new deployments of traffic management. Processing of complex real-time information on large arterial networks will become increasingly feasible with the innovations and implementations of wireless technologies and decreases in the price of bandwidth.

Adoption of advanced adaptive systems will be accompanied by an increasingly integrated approach taken by TMS developers: not just controlling and optimizing an agency's signals, but doing so across multiple jurisdictions—and incorporating transit, parking, rail, and other features of the regional transportation system. As products become capable of managing multiple jurisdictions, adoption can be initiated by larger umbrella agencies (i.e., state DOTs), and shared down among smaller constituent or subsidiary agencies.

### ***Political Initiatives***

As social and political impetus for environmental initiatives increases, the elimination of traffic congestion has become a primary policy lever and talking point for near-term emissions reductions. Multiple studies have been published quantifying the environmental benefits of advanced traffic management systems and software.<sup>40</sup> This follows a trend in Europe, where traffic management systems seem to have become accepted as an environmental solution in their own right. Federal legislation and local initiatives limiting emissions of carbon and other pollutants are expected to stimulate and broaden the demand for TMS.

In the same vein, traffic management software may come to be widely seen as a means of supplying additional road capacity. By smoothing traffic patterns and decreasing congestion, successful TMS deployments provide travel time savings and increase the efficiency of the existing road supply. In this capacity, TMS may effectively develop as a substitute to road-building in the future. This could be leveraged from a policy perspective, as an argument for the implementation or subsidization of such systems—particularly in regions where space and funding are in short supply.

### ***Standards Development for Open Platform/Open Source Models***

Development of protocols and standards for open-platform architecture and devices (e.g., the NCTIP family of protocols, and Model 2070 controllers) is expected to continue to positively influence advanced TMS adoption. Transportation agencies show a high degree of risk aversion with regards to advanced TMS adoptions; insurance provided by the development of standards for flexible systems could be highly effective in increasing adoptions.

The next step in this direction may be toward open-source software (Darter, Yen, Ravani, & Lasky, 2006). Future shifts toward open architecture would reinforce the trend described above—that of regional integration of multiple aspects of transportation networks (e.g., transit, parking, etc.) within a single managing software: applications could be added to the initial TMS investment on an as-needed, as-

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<sup>40</sup> For examples, see Chapter 8 of FHWA, *Traffic Control Systems Handbook* (2005).

available, or as-affordable basis with little difficulty. This provides flexibility to evolving regions, and spreads costs out for financially constrained agencies. Software built to open-source standards would also eliminate the current difficulty encountered by small agencies: budgetary restrictions limit small agencies to inferior “off-the-shelf” systems and low levels of support service.

## Preemption and Priority

### Market Participants

#### *Purchaser Demand*

Given the resources required for purchase and operation, nearly all transportation agencies consider the functionalities performed by VDC equipment and TMS to be important contributors to arterials traffic management practice. By contrast, arterials ITS purchasers are not in universal agreement regarding the value of signal preemption. As such, the equilibrium or saturation level of deployment for EVP and TSP may be far below 100 percent.

Development of signal preemption capabilities—whether for EVP or TSP—almost invariably requires the coordination of multiple agencies. Emergency response and transit agencies hold the primary incentive to invest in preemption equipment; however, these are not the organizational bodies that control traffic signals. As discussed above, many traffic management agencies view preemption as running counter to the goals of smoothing traffic flows and reducing delay on arterials. Areas that could stand to gain the most from preemption capabilities (due to high traffic volumes and congestion) are often those that stand to lose the most in the way of these goals, because signals are closely spaced and preemption is complicated. This disjoint between stakeholders may be further complicated in the case of TSP if the transit agency is privately held, since the benefits associated with TSP may increase ridership and revenue flow for the transit agency.

#### *Competition and Pricing*

The “lion’s share” of the signal preemption market remains with a variant of its original inventor, Opticom. The Opticom unit was sold by 3M in 2007, and is now privately held Global Traffic Technologies (Bruner, 2008). ITS purchasers report very few supplier responses to requests for proposals from providers of signal preemption devices, particularly for TSP applications—chief among these are Opticom and Tomar in the EVP market, and McCain in the TSP market. The market for EVP technologies includes multiple small companies with regional market presence, but in the case of both EVP and TSP, other suppliers with significant market share tend to be highly vertically integrated companies offering complete regional traffic management systems. While the demand for TSP is growing rapidly (see “TSP Deployments” above), it may continue to be the case that the market is dominated by only a few suppliers: the size of the market is inherently limited by the fact that not every area has transit, nor do existing transit systems require priority at every signalized intersection.

The costs of GPS-based preemption systems are less than for radio or acoustic technologies, and purchasers and suppliers indicate that prices have declined significantly since the introduction of such systems in 2003. The price of the Opticom GPS system, for example, is reported at approximately \$5,300 per intersection and \$3,000 per vehicle (Bruner, 2008).

### Influences on Deployment

The desirable market penetration of signal preemption capabilities may not be 100 percent. If, for example, traffic volumes are low, optimal function of emergency vehicles and transit vehicles (if applicable) can be achieved in existing traffic conditions without resorting to preemption. Furthermore, as

discussed above, some agencies view even well-functioning signal prioritization schemes as a disruption to network management.

Several important factors will affect both the share of agencies that could benefit from preemption capabilities, and the share of agencies that choose to adopt such capabilities. These include, for example, changes in congestion, urban density, transit utilization and advanced TMS adoption.

A 2004 study by ITS America enumerated key factors thought to be holding back widespread deployment of TSP at that time (ITS America, 2004). This list included:

- Institutional, planning and partnering issues between the transit properties and the local transportation departments (who often operate the traffic control signals)
- Lack of broad awareness of the technical feasibility and cost-benefit
- Lack of proven, accurate, reliable and cost-effective detection products
- Limited installations of vehicle location systems by transit properties
- Absence of standards
- Traffic signal controllers did not have the capability to support TSP
- Traffic signal controller software did not have the ability to support TSP
- Costs associated with deploying and maintaining traffic signal controllers, transit vehicle, and TSP was cost prohibitive.

Of these issues, several have been directly addressed in the six-year span since completion of the report—most notably, the adoption of standards for open architecture controllers (ATCs).

### ***Traffic Conditions***

The causal influence of traffic conditions on adoption of EVP is unclear. The level of vehicular traffic congestion plays an ambiguous role: transportation agencies with very little congestion see little need to introduce EVP, whereas agencies in highly congested areas may believe EVP would compound the congestion problem. By contrast, high volumes of traffic, or concern for pedestrian traffic, seem to provide a clear deterrent to adoption of emergency vehicle preemption. Where travel time *predictability* is the primary goal, the adoption of EVP tends to be discouraged, and adoption of TSP may depend upon the usage of transit relative to personal vehicles on arterials among the traveling public.

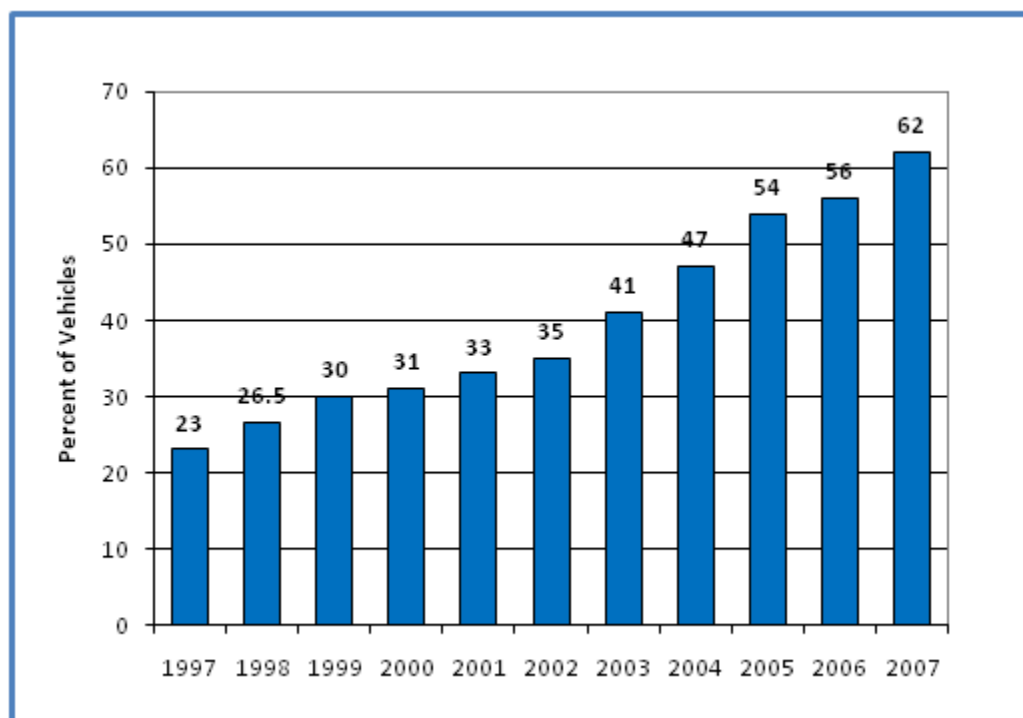
### ***Adaptive Real-Time Signal Control***

With the implementation of real-time management capabilities, reliable and effective TSP capabilities are more easily achieved. Rather than disrupting coordination in a network of signals, the alterations to signal phase and timing are internalized, and the network is re-optimized. Adaptive and real-time adaptive applications dynamically monitor the provision and level of preemption; priority can be overridden or denied based on a set of remotely determined criteria. This allows transportation agencies to react to the specific conditions of an individual vehicle trip. For example, transit system operators can provide selective priority based upon whether a bus is full or empty; emergency vehicle controllers can base preemption upon whether an ambulance's trip back to a hospital is time-critical. In addition to increasing the effectiveness of TSP and EVP (i.e., schedule adherence, expedited arrival, etc.), adaptive and real-time control may ensure rather than endanger pedestrian safety, and mitigate rather than compound

congestion problems. This flexibility and level of control will make both TSP and EVP increasingly attractive as agencies gain real-time arterials management capabilities.

Adaptive applications of EVP and TSP require the existence of a real-time adaptive control system (as well as advanced transportation controllers capable of supporting such systems, such as Type 2070). Increasingly, EVP and TSP capabilities are offered as an application in comprehensive traffic management packages. For these reasons, TSP and EVP deployments can be expected to depend upon and positively correlate with adoption of adaptive traffic management systems and software.

**Figure 23. Fixed-Route Transit Vehicles Equipped with Automatic Vehicle Location**



Source: ITS Deployment Survey Data

## GPS

GPS-based signal preemption represents significant technology-, reliability-, and cost-related advantages over other preemption methods. Furthermore, its unique usefulness within adaptive real-time traffic management systems makes GPS-based preemption a potential solution to the concern over pedestrian safety, which is frequently cited as a barrier to adoption (particularly in the case of EVP). Because preemption requests can be reliably relayed at long range, pedestrians can be allowed time to clear the roadway before the signal priority or preemption is granted.

GPS-based preemption also has potential synergies with automatic vehicle location (AVL) capabilities, which are increasingly achieved through GPS-based systems, as well (Liao & Davis, Simulation Study of Bus Signal Priority Strategy, 2007). Retrofitting a fleet with EVP or TSP capabilities can be done at a significantly lower cost if vehicles are already AVL-capable. As shown in Figure 23, AVL adoptions have vastly increased in the past decade: in the largest US metro areas, the portion of the fleet equipped with AVL has risen from 23% to 62% from 1997 to 2007. The presence of AVL capabilities—particularly in the case of GPS-based systems—is expected to have a strong influence on and correlation with adoption of signal preemption (especially TSP) going forward. As suppliers continue to increase their share of GPS-

based preemption relative to other methods, some offer upgrades to GPS for existing customers at little or no cost.

### ***Funding Opportunities***

#### **Stimulus Funding for Transit Projects**

Obviously, the need for TSP is contingent upon the existence of a transit system. In addition to retrofitting existing transit systems with TSP capabilities, the rate of deployment will depend, to some extent, on new construction for, or extension of, existing transit systems. As economic stimulus funds are used to expand existing systems, transit signal priority may become a standard feature included in projects. This will particularly be the case if automatic vehicle location (AVL) becomes a standard feature: As noted above, AVL and TSP increasingly use the same technologies.

#### **Joint Funding for TSP and EVP**

Since EVP and TSP utilize the same technologies, the two functionalities can be combined into the same system. The opportunities this could present could encourage the adoption of both signal preemption functionalities, with the combined interest and funds of both emergency services and transit agencies. This would particularly benefit TSP: safety concerns generate powerful political interest in TSP, and funding opportunities are widely available (for example, the Federal Transportation Equity Act of 2005 provided funding opportunities for agencies interested in implementing EVP).

### ***Environmental Concerns***

There are increasing efforts to promote mass transit in light of concerns over vehicle emissions. The literature on TSP indicates that this technology can significantly reduce travel times for transit riders in many cases; thus, implementing TSP can be used as one way to incentivize the use of transit, as well as to reduce emissions on existing routine transit trips.



# Appendix: Arterial Technologies

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# 6. Estimating the Benefits from ITS Deployment

This chapter attempts to quantify the monetary benefits gained from the 2007 level of nationwide ITS deployment. It examines the level of benefit derived from deploying one unit of ITS technology and then extends this analysis to national deployment levels. Using information from the ITS Deployment tracking survey, the change in benefits is then estimated during the eleven year period from 1997 through 2007. To align with the U.S. DOT ITS Program policy objectives, ITS benefits are broken down into three main areas: mobility, safety and environmental.

Six ITS technologies are examined as part of this effort:

- ELECTRONIC TOLL COLLECTION (ETC)
- RAMP METERS (RM)
- RED LIGHT CAMERAS (RLC)
- TRAFFIC SIGNAL COORDINATION (TSC)
- TRANSIT SIGNAL PRIORITY (TSP)
- TRAVELER INFORMATION SYSTEMS (TIS)

The first step in preparing estimates of nationwide ITS deployment benefits was an extensive literature review of the published work on ITS benefits. This was a central component of this work and more than 80 papers and research reports on this subject were examined. The papers used in calculating actual benefits are discussed in the Literature and Results section, while the methodology for selecting these papers is presented in the Paper Selection Criteria section. A bibliography of all papers reviewed is at the end of this chapter.

The second step required developing a methodology and approach to capture the benefits gained from deploying a particular ITS technology and then expanding this across the current level of ITS deployment in the U.S. As previously noted, while there have been many studies focusing on the benefits of deploying ITS technology in a small area, or region, there is little in the literature dedicated to examining total nationwide benefits of ITS deployment. This study attempts to bridge this gap and provide estimates of the monetary benefits of ITS based on the deployment levels captured in the ITS Deployment tracking database.

Developing a nationwide benefit requires being able to determine the benefit from the deployment of a single unit of technology. This requirement meant that only papers that captured a unit benefit in their analysis of ITS deployment were used as part of this study. Another filter was the necessity of being able to isolate benefits in absolute terms, as opposed to percentage terms. This is important to be able to determine an absolute level of benefit (e.g., fewer crashes) that could then be monetized.

The methodology employed here extrapolates a unit benefit for a given ITS technology through to the total nationwide deployment as measured in the ITS Deployment Tracking database. It is important to be

aware that this extrapolation makes an assumption of a linear increase in benefits with respect to an increase in deployment. It is highly likely this assumption does not accurately represent the change in benefits as deployment increases. Indeed, there are multiple factors that would have to be considered in how benefits would grow including regional variation in congestion, existing levels of ITS deployment and network benefits from higher levels of deployment. In addition, there is evidence from some research on localized ITS deployment indicating that it exhibits decreasing returns to scale.

The scope and focus of this study did not allow for examining these questions. As such, a linear extrapolation of ITS benefits from a unit to nationwide deployment was used. The issues surrounding this assumption are detailed later in this chapter, and the results of this report need to be seen in the light of the caveat that benefits may not display a linear trend, but may show diminishing returns to scale. In this case, the results presented here could be seen to represent an upper bound. There were no specific papers on this topic found in the literature review and, as such, it presents a promising area for possible future research.

Following a summary of results, this chapter is presented in three sections. The first section provides an overview of each of the six technologies examined, along with logic models to illustrate the processes, relationships, and mechanisms involved in the production of benefits from these technologies. The second section describes the methodology of the study and comments on some of the crucial assumptions and caveats involved. The third section presents and then discusses the final results, including the nationwide benefit estimates.

## Summary of Results

The final results of the ITS benefits analysis are presented in Table 5 below. This table details nationwide benefit estimates by ITS technology based on 2007 deployment levels obtained from the ITS deployment tracking survey. As noted previously, the six ITS technologies for which benefits are calculated are:

- ELECTRONIC TOLL COLLECTION (ETC)
- RAMP METERS (RM)
- RED LIGHT CAMERAS (RLC)
- TRAFFIC SIGNAL COORDINATION (TSC)
- TRANSIT SIGNAL PRIORITY (TSP)
- TRAVELER INFORMATION SYSTEMS (TIS)

Where possible for a given technology, the benefits of ITS deployment were estimated in four distinct categories:

- **Mobility** benefits take the form of travel time reduction. This is based on the idea that reducing the time spent in travel increases the time that can be devoted to more productive or enjoyable activities.
- **Environmental** benefits take the form of reductions in emissions of criteria pollutants, as well as carbon dioxide.
- **Safety** benefits take the form of reductions in costs associated with crash-related property damage, injury, and death.
- **Fuel consumption** benefits take the form of savings on gasoline expenses.

**Table 5. Summary – Annual Nationwide Benefits at 2007 Deployment Levels (\$2009)**

	Mobility		Environmental		Fuel Cost		Safety		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High
<b>ETC</b>	\$602,714,686	\$1,026,544,897	\$2,904,283	\$50,407,594	\$83,504,391	\$155,091,362	--	--	\$2,904,283	\$1,182,166,854
<b>RM</b>	\$175,051,077	\$273,619,082	-\$26,693,605	-\$26,693,605	-\$78,962,219	-\$78,962,219	\$217,736,931	\$217,736,931	\$273,619,082	\$287,132,183
<b>RLC</b>	--	--	--	--	--	--	-\$34,032,674	\$1,175,852,233	-\$34,032,674	\$1,175,852,233
<b>TSC</b>	\$276,544,507	\$276,544,507	--	--	--	--	--	--	\$276,544,507	\$276,544,507
<b>TSP</b>	\$42,260,073	\$149,986,037	--	--	--	--	--	--	\$42,260,073	\$149,986,037
<b>TIS</b>	\$543,102,791	\$543,102,791	--	--	--	--	--	--	\$543,102,791	\$543,102,791

**ETC = ELECTRONIC TOLL COLLECTION**

**RM = RAMP METERS**

**RLC = RED LIGHT CAMERAS**

**TSC = TRAFFIC SIGNAL COORDINATION**

**TSP = TRANSIT SIGNAL PRIORITY**

**TIS = TRAVELER INFORMATION SYSTEMS**

The benefits calculations were limited to these four categories as the methodology used in this study, and the limitations of the available data, meant that a formal benefits analysis could not be credibly or meaningfully applied to all possible benefit categories described in the Benefit Categorization and Monetization section of this report. For example, vehicle throughput, which is a benefit from the deployment of ETC, was not formally analyzed due to the fact that vehicles per hour is difficult to plausibly monetize, an extrapolated value in these units would not be particularly meaningful and results in terms of vehicle throughput are scarce in the literature. It is worth noting, however, that this metric will be reflected somewhat in the mobility category through travel time reduction.

ITS benefits were calculated through determining the annual benefits per unit of deployment estimated in the published literature, and multiplying these benefits by the 2007 deployment levels (that is, the total number of units deployed nationwide as of 2007). Graphs showing the change in deployment benefits between 1997 and 2007 can be found in the section titled Nationwide Benefits over Time. The final two columns of Table 5 show the range of *total* nationwide benefit estimates for each technology – these are the sums of the estimates reported for each benefit category.

It is important to note that the ITS benefits presented in Table 5 and elsewhere in this study are based upon results from prior evaluations reported in the current literature on ITS benefits. As such, future research and evaluations of ITS technologies, and their benefits, may lead to noticeably different results than those presented here.

## Results

Several key observations can be made from the results presented in Table 5. Within the context of this analysis, ITS deployment appears to have the most broad-based benefit in the area of improved mobility. This benefit is captured in the literature for all technologies except RLC, which is geared primarily towards safety. ETC appears to produce the largest annual mobility benefit nationwide, with a high estimate of over \$1 billion per year. ETC is followed by RM, TSC, TSP, and TIS in descending order.

Environmental benefits are only captured for two technologies: ETC and RM. Positive benefits are recorded for ETC, while RM produces negative net benefits due to the delay it causes on the ramps.

Results in the Safety category are less conclusive due to the large range observed in estimates of RLC benefits. Indeed, even though RLC appears to have the potential to provide large safety benefits, in some instances deployment of this technology is estimated to result in negative safety benefits. The safety benefits as a result of RM deployment are in the lower-middle part of that range. Finally, in the fuel cost category, ETC produces the highest level of estimated benefits, while RM produces negative net benefits due to the delay the use of this technology can cause on the entry ramps.

## Caveats

There are several important caveats to these results. The extrapolation procedure relies critically on the assumption of a linear relationship between benefits and deployment levels, yet there is reason to suspect that this relationship does not hold in reality. Depending on the total level of deployment of a technology at the time of the study (on which the extrapolation is based), and on whether the benefit produced by each additional unit of deployment increases or decreases as the deployment level rises, the calculation may underestimate or overestimate benefits.

Additionally, the extrapolation procedure does not account for certain factors that may be sources of variation in benefit levels among individual units of deployment. These factors include:

- The magnitude of existing costs in the deployment area (annual delay, emissions, crashes, etc.)
- The scale of existing ITS deployment in the study area

- The level of technological refinement of the ITS deployment in question

There is reason to suspect that the deployments in the studies selected for analysis in this report are not representative of all deployments nationwide in terms of these factors, in which case the results of this report would exhibit some degree of bias. These factors are discussed in the Benefit Estimation Model section of this report.

## Technology Overviews

Six basic technologies were selected for the benefits analysis. These were selected on the basis of enough information being available in the literature to estimate benefits. This section provides a brief overview of each technology, including logic models to illustrate the processes, relationships, and mechanisms involved in the production of benefits from these technologies.

### Electronic Toll Collection (ETC):

USDOT Federal Highway Administration (1997) describes Electronic Toll Collection as follows:

*ETC is combination of techniques and technologies that allows vehicles to pass through a toll facility without requiring any action by the driver (i.e., stopping at toll plazas to pay cash). In fact, today's conventional toll plaza is not necessary in a fully dedicated ETC facility.*

*ETC components can be categorized as in-lane/roadway components and Facility Management and/or Customer Service Center components. Three major in-lane/roadway components are required for the successful implementation of an ETC. These components are:*

- *Automatic Vehicle Identification (AVI);*
- *Automatic Vehicle Classification (AVC); and*
- *Video Enforcement Systems (VES).*

*All in-lane/roadway components are in communication with and controlled by a computer called the "lane controller." The lane controller takes input from the AVI, AVC, and VES components. Its database, through which a list a valid tags is maintained, is used to validate the AVI and charge the customer's account. The information from each lane controller is passed on to a plaza host computer. Each plaza host computer is in constant communication with the central computer in the Facility Management and/or Customer Service Center, thereby consolidating the database, as well as equipment requirements. The Customer Service Center manages the accounts, enrolls customers and issues tags, processes the violations, handles all inquiries, and serves as the facility management center. (p. 5-3)*

Over the course of the 2000s, various improvements to this type of system have been developed that are designed to increase the efficiency and impact of ETC. These improvements include Automatic License Plate Recognition and Open-Road Tolling. However, the bulk of the benefits literature is based on systems that more closely resemble the above description, and these systems will be the focus of this report.

A logic model for ETC is located on page 102.

## Ramp Metering (RM):

Jacobson et al. (2006) describe ramp metering as

*the deployment of a traffic signal(s) on a ramp to control the rate vehicles entering a freeway facility. By controlling the rate vehicles are allowed to enter a freeway, traffic flow onto the freeway facility becomes more consistent, in essence smoothing the flow of traffic on the mainline and allowing efficient use of existing freeway capacity. (p. 5.2.1)*

Meters may be isolated (local) or coordinated (system-wide), and they may be pre-timed or traffic-responsive. Each approach requires a different form of algorithm. Traffic-responsive metering also requires freeway loop detectors or other surveillance systems to collect data used to determine optimal meter timing (Jacobson et al., 2006, p. 5.3.3).

A logic model for RM is located on page 103.

## Red Light Cameras (RLC):

USDOT Federal Highway Administration's *Priority, Market-Ready Technologies and Innovations* (2006) describes Red Light Cameras as follows:

*Red light cameras (RLC) detect a motor vehicle that passes over sensors in the pavement after a traffic signal has turned red. The sensors are connected to computers in high-speed cameras, which take two photographs of the violation. Typically, the first photo is taken of the front of the vehicle when it enters the intersection, and the second photo is taken of the rear of the vehicle when the vehicle is in the intersection. Law enforcement officials review the photograph, and a citation is mailed to the registered owner of the vehicle. The owner can challenge the citation if he or she was not the driver at the time of the violation. (USDOT Federal Highway Administration, Priority, Market-Ready Technologies and Innovations, 2006)*

A logic model for RLC is located on page 104.

## Traffic Signal Coordination (TSC):

Koonce et al. (2008) describe Traffic Signal Coordination as

*a tool to provide the ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system. Examples include arterial streets, downtown networks, and closely spaced intersections such as diamond interchanges. (p. 6.1)*

Outcomes are achieved through the adjustments of several key parameters related to the timing of signal changes, including yield points, splits, and offsets.

Some coordination systems are “adaptive,” meaning they incorporate traffic data collected from nearby detectors.

A logic model for TSC is located on page 105.



## Transit Signal Priority (TSP):

Smith et al. (2005) describe Transit Signal Priority as

*an operational strategy that facilitates the movement of transit vehicles (usually those in service), either buses or streetcars, through traffic-signal controlled intersections. Objectives of TSP include improved schedule adherence and improved transit travel time efficiency while minimizing impacts to normal traffic operations.*

*TSP is made up of four components. There is (1) a detection system that lets the TSP system know where the vehicle requesting signal priority is located. The detection system communicates with a (2) priority request generator that alerts the traffic control system that the vehicle would like to receive priority. There is software that processes the request and decides whether and how to grant priority based on the programmed (3) priority control strategies. And there is software that (4) manages the system, collects data, and generates reports. (p. viii)*

A logic model for TSP is located on page 106.

## Traveler Information Systems (TIS):

USDOT ITS Joint Program Office (1998) describes Traveler Information Systems as follows:

*Effective traveler information systems are multimodal and support many categories of drivers and travelers. They apply many technologies to allow customers to receive roadway, transit network, and other information important to their trip. This information assists the customers in selecting their mode of travel (car, train, bus, etc.), route and departure time. Transit schedule and status information may be obtained from Transit Management Systems. Most of the roadway-based information is collected by surveillance equipment (vehicle detectors, cameras, automated vehicle location systems) and is processed by computers in transportation management centers for further distribution to traveler information systems. Other information used in a traveler information system may be static in nature, such as: map databases, emergency services information, and information on motorist services and tourist attractions and services. The technologies for requesting, receiving, and interacting with all of this information can be based in the home, office, passenger vehicle, commercial vehicle, transit vehicle, public transit station, or in the case of personal communication devices, can travel with a person. (p. 1-3)*

This analysis focuses on one particular form of TIS, Dynamic Message Signs (DMS), which are described by Dudek (2004) as

*programmable traffic control devices that can usually display any combination of characters to present messages to motorists. These signs are either permanently installed above or on the side of the roadway, or portable devices attached to a trailer or mounted directly on a truck and driven to a desired location. Portable [DMS]s are much smaller than permanent [DMS]s and are oftentimes used in highway work zones, when major crashes or natural disasters occur, or for special events (e.g., sport events).*

*When installed, [DMS]s become a part of the total motorist information system. Thus the information presented on [DMS]s and the placement of the signs must be consistent and compatible with static signs used on the freeway.*

*[DMS]s perform a critical role on freeways. Such signs can furnish motorists with real-time information that advises them of a problem and in some cases, a suggested course of action.*

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*[DMS]s are also used to improve motorist safety and reduce traffic congestion and delay. [DMS]s can also be used to manage traffic by displaying early warning, advisory and alternative route messages. (p. 2-1)*

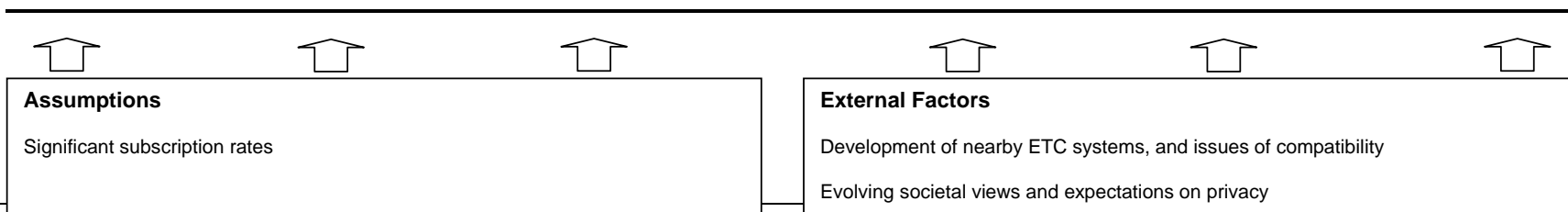
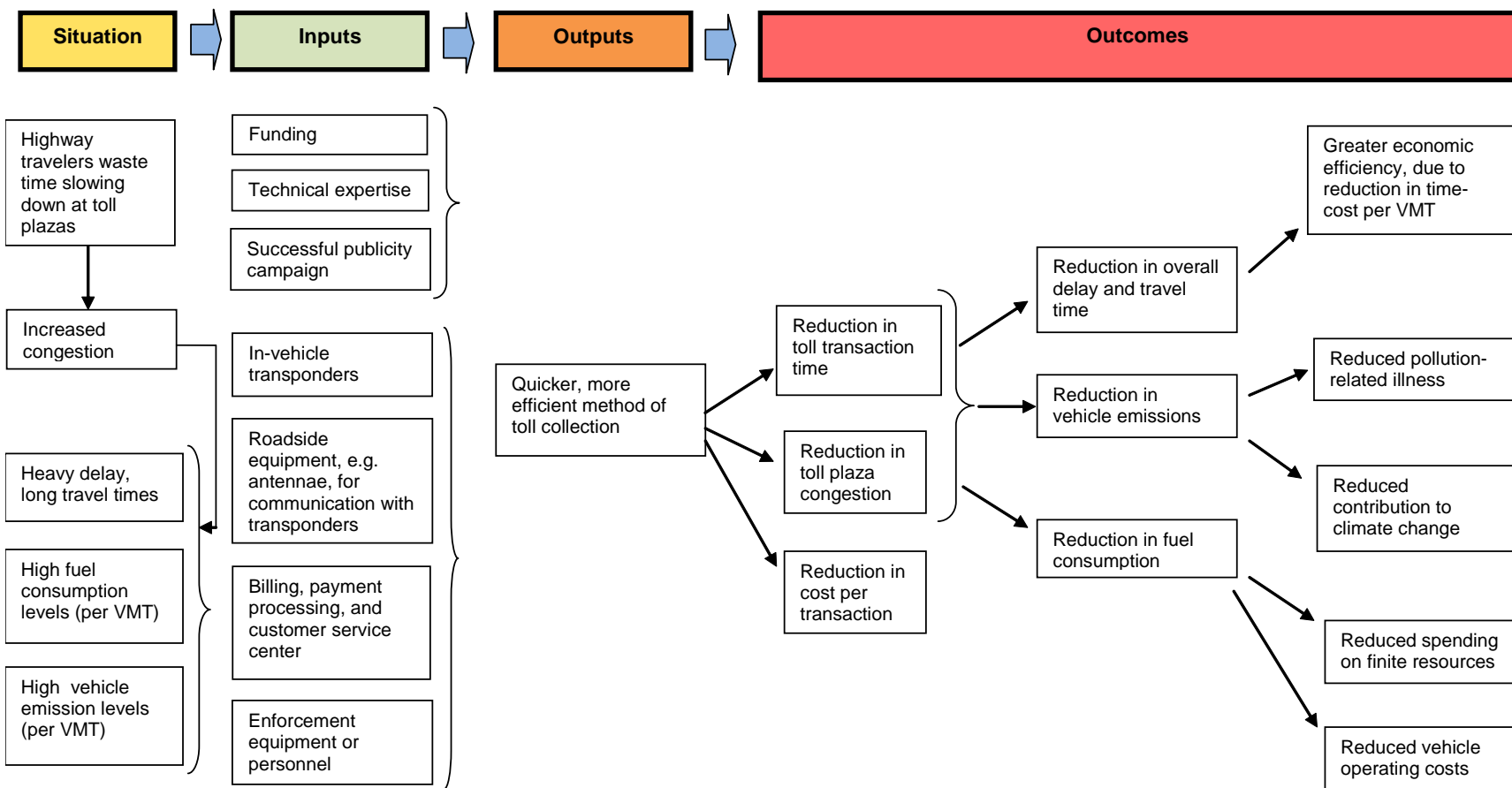
A logic model for TIS is located on page 107.

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*Note: The logic models on the following pages are based primarily on documents encountered during the course the literature review.*

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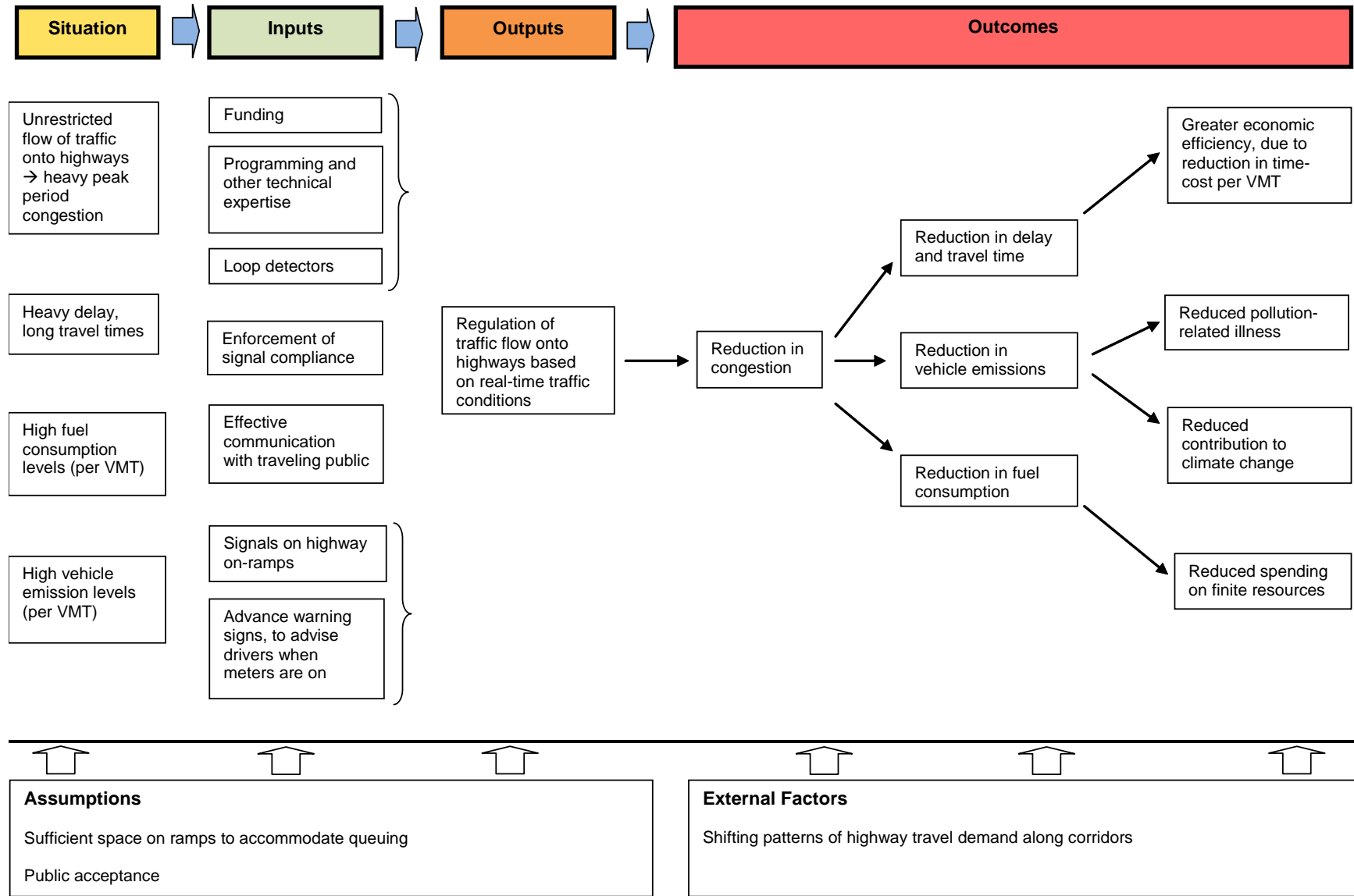
## Electronic Toll Collection



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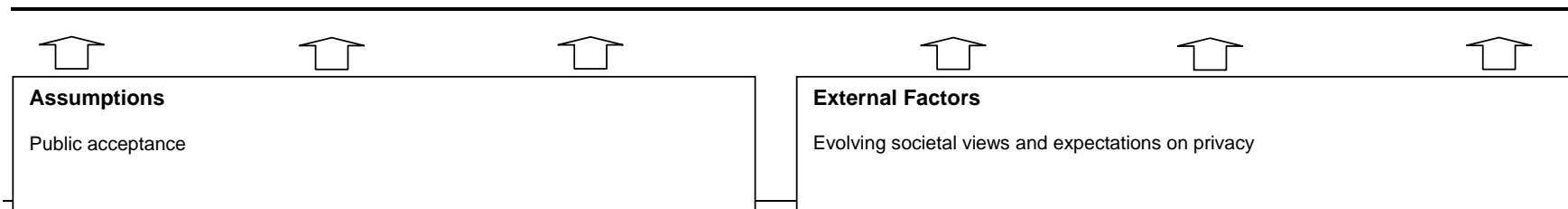
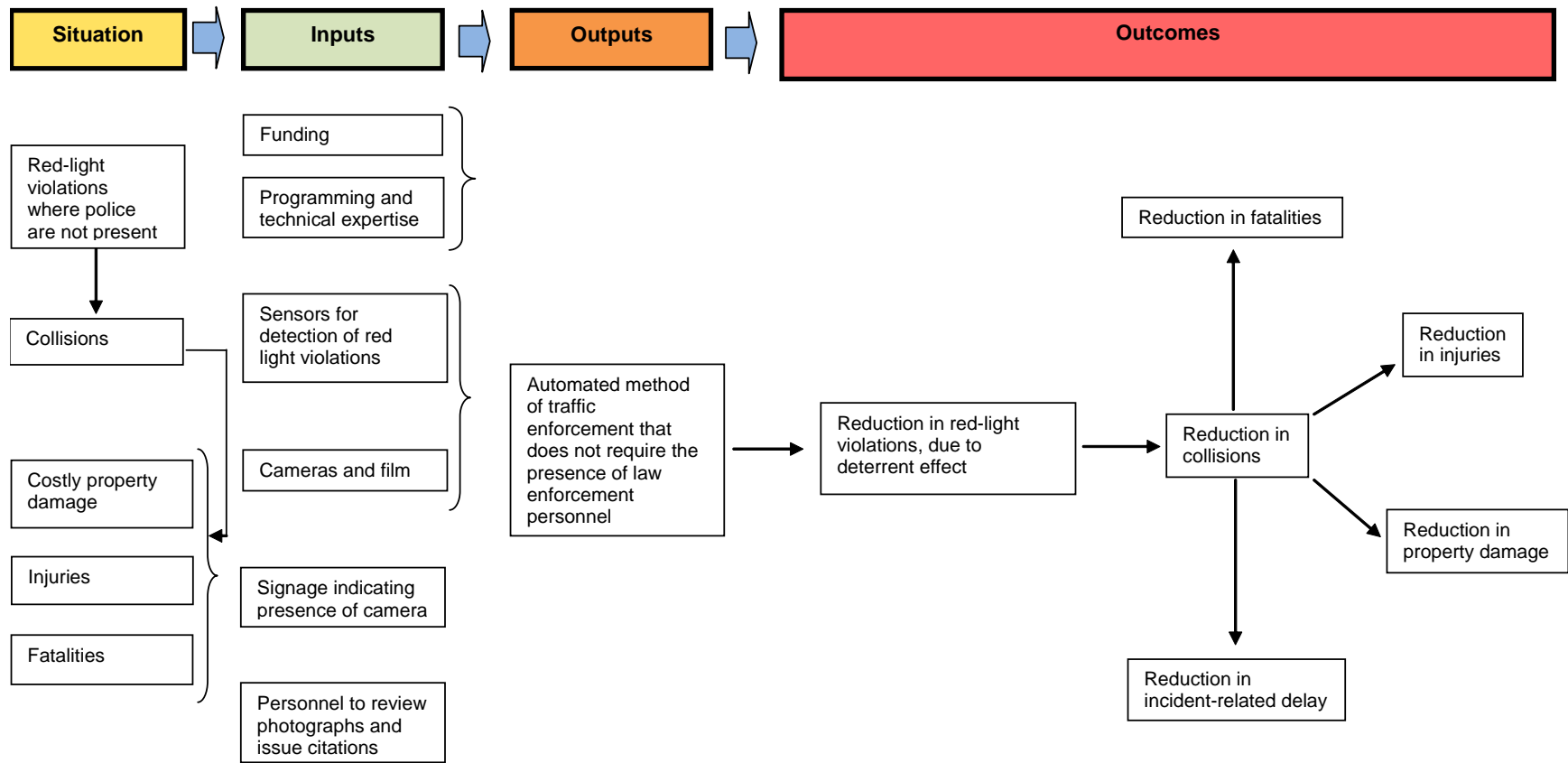
## Ramp Metering



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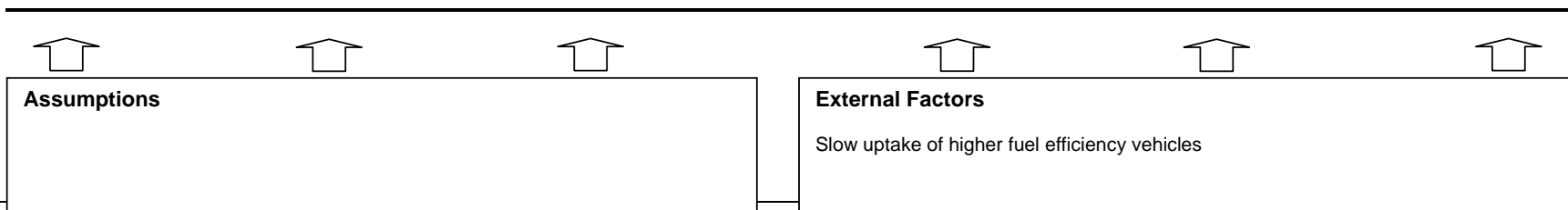
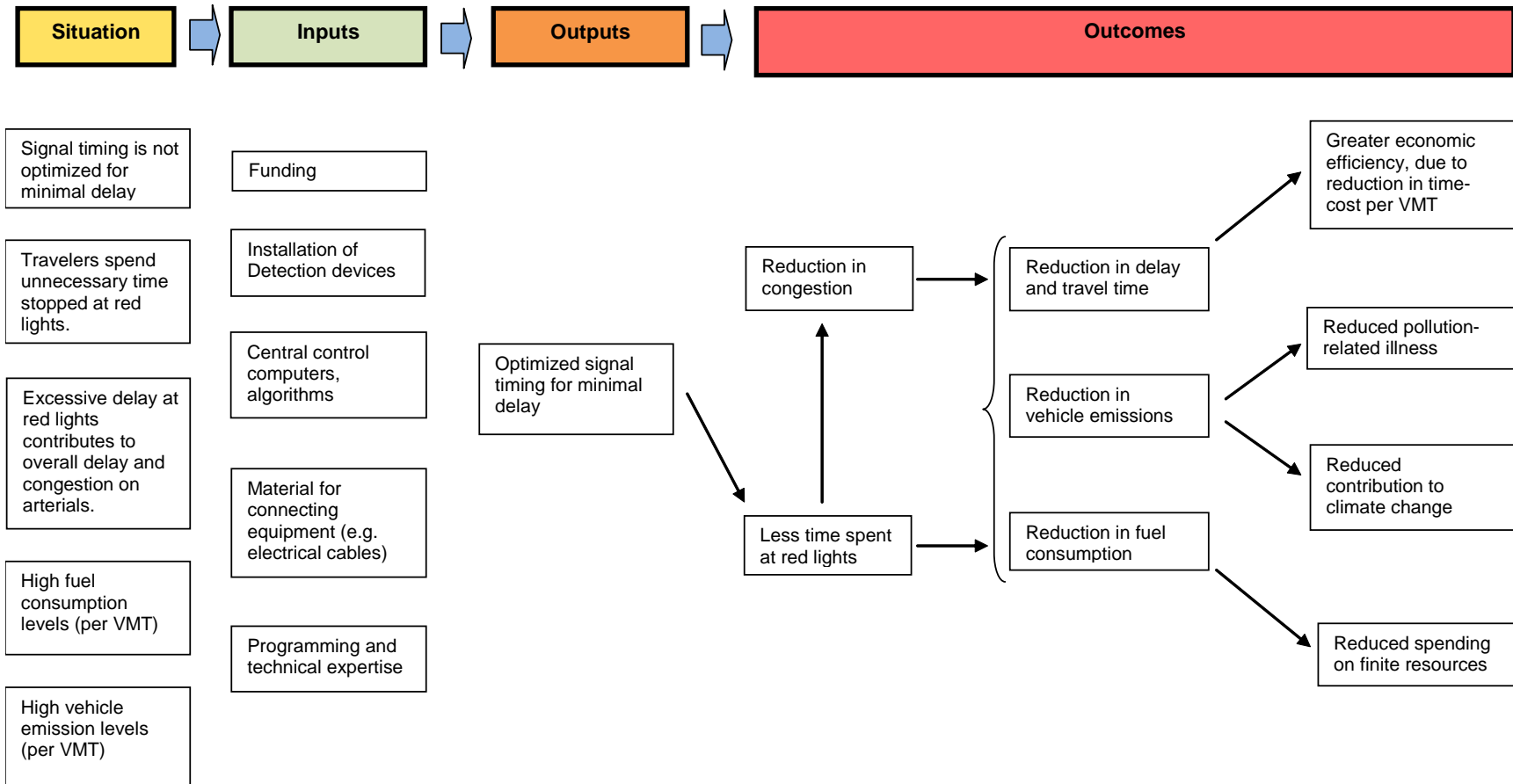
## Red-Light Cameras



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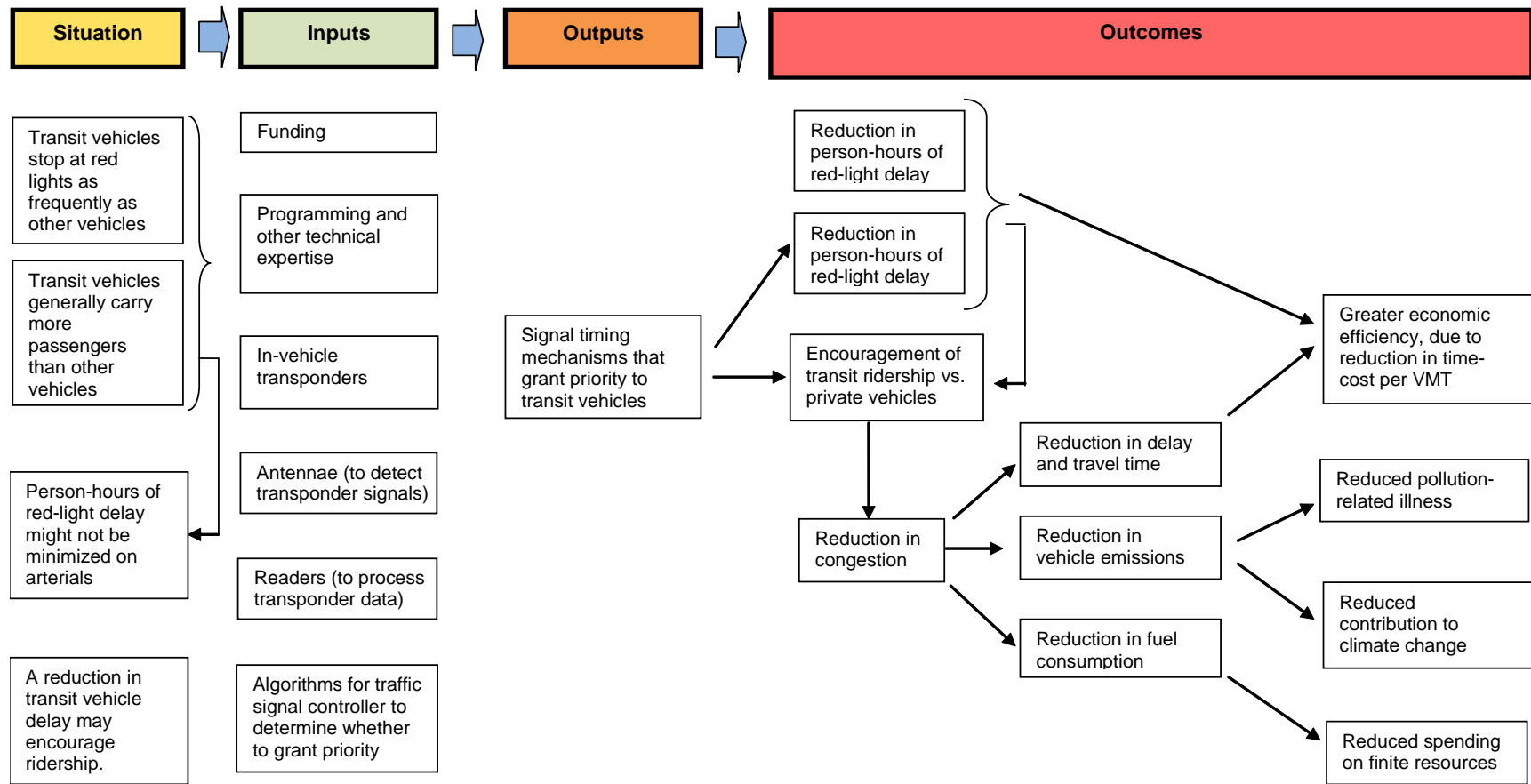
## Traffic Signal Coordination



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## Transit Signal Priority



↑

**Assumptions**

Any inconvenience to non-transit travelers will be kept to a level generally acceptable to the public.

↑

**External Factors**

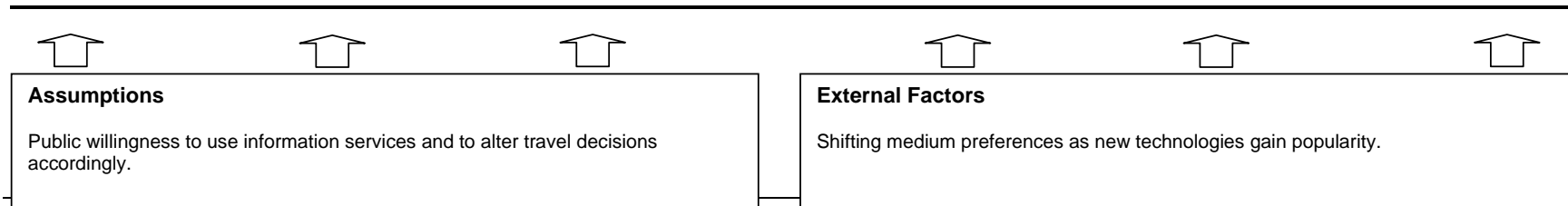
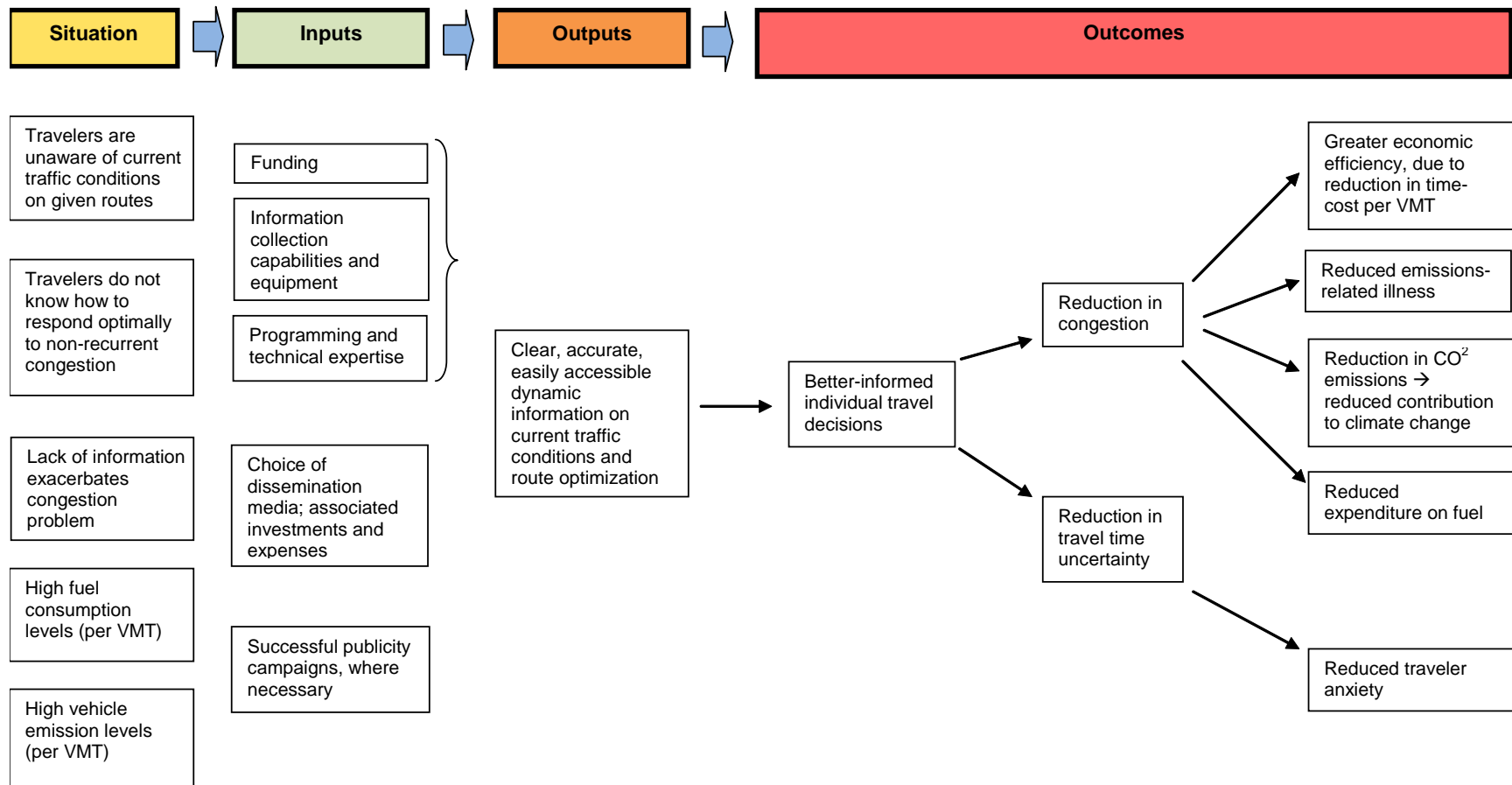
Changing levels of demand for transit

Changing levels of arterial congestion

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## Traveler Information Systems



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## Benefits Calculation Methodology

The annual nationwide benefits of each technology were calculated based on the results of previous studies calculating the benefits of ITS deployment. The process used to estimate nationwide benefits involved 4 basic steps:

1. Gathering literature
2. Selecting literature to be used for the calculations
3. Classifying benefits into categories and converting them to monetary values
4. Performing the final calculation to arrive at the monetized annual nationwide benefits of each technology

This section describes each of these steps and comments on some of the crucial assumptions and caveats encountered along the way.

### Summary of Literature Review

Over 80 papers were gathered for this study, using search engines and databases including RITA's ITS Benefits Database, the Transportation Research Board's Transportation Research Information Services database (TRIS Online), and EBSCOhost. These papers consisted primarily of articles from scholarly journals, reports prepared for or by government agencies, and papers prepared by research institutions.

The following general observations were made regarding the literature initially gathered:

- Literature on RLCs was the easiest to come by, perhaps because RLCs are newer than the other technologies, or because they have attracted a considerable degree of controversy. (Allen, 2009)
- Most of the papers estimate the benefits of individual projects at discrete locations (not nationally or even regionally).
- Most of the literature relies to some degree on simulations to arrive at final benefit estimates. Some reports, such as Bergmann Associates (2006), use simulations in conjunction with data they have collected. Others are entirely simulation-based, such as Mirchandani et al. (2001), which is based on a hypothetical project. As will be discussed, the frequency and degree of reliance on simulations depends greatly on the type of technology being evaluated. Reliance on simulations is also dictated in some cases by the type of benefit being estimated. Environmental and Fuel Cost benefits, for example, are quite difficult to estimate without the aid of a simulation. This approach is used instead of econometric models due to the fact that the effect of these limited deployments is so small in relative terms that its effect on higher-level measures (air quality, etc.) would not be expected to be significant.
- The vast majority of benefits estimated are in the Mobility category.

## Paper Selection Criteria

Of the papers gathered in the initial literature review, 14 were selected for the national ITS deployment benefits calculations. Papers were selected based on the criteria described in this sub-section.

### **Basic Criteria:**

**1)** Papers were required to **report benefits in terms of amounts or a percent in conjunction with a baseline figure**, as opposed to percentages alone. The Benefit Categorization and Monetization Section presents the types of metrics used in the papers to report benefit amounts.

This criterion was a very common basis for the elimination of papers as candidates for extrapolation: many papers were found to report benefits only in percentage terms. Using these percentage changes to calculate nationwide benefits would have required an assumption regarding the *hypothetical* magnitude of the problems (delay, pollution, etc.) in the locations where the technology is currently deployed *had the technology not been deployed at those locations*.

Absolute benefit amounts were presumably necessary for the calculation of percentage figures in these papers, and were thus available for inclusion in the papers along with the other results. The non-inclusion of absolute amounts suggests that the analysts made a positive decision to exclude these numbers, perhaps thinking they were not of interest to the intended audience. They likely reasoned that their audiences were interested in seeing results that could be generalized to other possible deployment scenarios, and that percentages served this purpose better than amounts.

Benefit amounts *per unit deployed* may be viewed as a generalized form of result, albeit with the various caveats noted in subsequent sections of this report. Amounts per unit deployed may even have some advantages over percentages, in terms of being generalized – for example, while percentages may have the advantage of being less dependent on the baseline congestion data in a given study area, amounts per unit deployed presumably have the advantage of being less dependent on the number of existing units deployed in a given study area.

Yet there are at least two possible reasons why many analysts still appear to prefer presenting benefits as percentages rather than amounts per unit deployed, despite the fact that both are in some sense generalized:

- i)** Analysts may foresee their audience struggling to interpret aggregate amounts. For example, an estimate such as 107,106 person-hours saved per plaza-year (derived from Wilbur Smith Associates, 2001) would probably not be meaningful to the typical reader without an explicitly stated point of reference. Presenting results as percentages, of course, effectively takes an aggregate amount and a point of reference (the baseline), and rolls them into one convenient and more interpretable number. (Note that non-aggregate amounts are a very popular way of presenting results among the papers reviewed for this report – see criterion #2 below.)
- ii)** Analysts may believe that percentages can function as instantly interpretable stand-alone results, whereas the usefulness of benefit amounts per unit deployed is bound up too closely with a separate figure, namely the number of units deployed.

**2)** Papers were required to report **benefits in the aggregate**, as opposed to exclusively *per vehicle* or *per trip*. These can be straightforward and practical ways to express benefits, because they typically do not require an explicitly stated point of reference – readers are already well-equipped to interpret a result such as 4.6 person-minutes saved per trip (Shah and Wunderlich, 2001). However, using these estimates to calculate nationwide benefits would require assumptions regarding the total number of vehicles or trips in all places where the technology is currently deployed.

3) Papers were required to estimate benefits in relation to the **number of units of ITS deployed** (e.g., the benefits from using electronic toll collection at one toll plaza). These ranged from 1 toll plaza (Burris, 2004) to 430 ramp meters (a metropolitan-level study by Cambridge Systematics, 2001) to a nationwide TSC study (Shrank and Lomax, 2009) undertaken in 2007, when the technology was deployed at 72,255 intersections.<sup>41</sup> This metric is important to allow for increasing the estimate across all deployed units of ITS for a particular technology.

4) Papers were required to provide a **length of time** over which the benefits are reported to accrue. This is reported in almost every paper, and it allowed the final results in this study to be reported as benefits per year. Note that these lengths of time do not always represent the length of time over which empirical data were collected in a study – in some studies benefits are projected over time based on data collected over a shorter sample period. Such projections were deemed acceptable for the purposes of this study.

### **Three Additional Criteria**

In addition to the four basic criteria listed above – relating to magnitude of estimated benefits, number of units deployed, and length of time over which benefits accrue – three additional requirements were established to help determine the suitability of papers for the nationwide benefits calculations.

5) The benefit estimates in each paper were required to refer to a **specific site** or set of sites. It was not required that the deployments actually exist – studies that use simulations to estimate the benefits of a certain technology if it were to be deployed at a certain real site are acceptable. (These studies typically use real street maps and baseline traffic data from the site of hypothetical deployment.) However, studies that use simulations to estimate the benefits of a technology without reference to any particular site of deployment, e.g. Kang and Gillen (1999), were discarded because they lacked a solid enough empirical basis for inclusion in this analysis.

6) Papers used in the calculation were required to meet at least one of the following criteria related to **reliability**:

- Appeared in a peer-reviewed academic journal (e.g. the *Transportation Research Record*)
- Prepared or sponsored by a government agency (e.g. USDOT ITS-JPO)
- Prepared or sponsored by an established research institution (e.g. Texas Transportation Institute)

The purpose of these criteria was to capture only papers of a high professional caliber and those that have been thoroughly reviewed.

7) Estimates of the benefits of **bundles of technologies or other strategies** were discarded. That is, estimates of the *combined* effects of the primary ITS technology *and* another technology or strategy, were not considered desirable or useable within the confines of this study. This was intended to isolate, to the degree possible, the effects of each individual technology. This is distinct from the issue of synergies mentioned elsewhere in this report: the concern here is not that one technology enhances the effect of another, but rather that the benefit estimates in some studies pick up effects that are due exclusively to another technology.

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<sup>41</sup> ITS Deployment Statistics Database, 2007 survey results, Research and Innovative Technology Administration of the U.S. Department of Transportation, <http://www.itsdeployment.its.dot.gov/Default.asp>.

## ***Final Review***

Papers meeting all seven of the above criteria were then reviewed to further ensure that their estimation procedures and results were credible. They were then grouped according to the technology they covered.

## **Benefit Categorization and Monetization**

This section details and discusses the values used to convert benefits measurements from each study reviewed into monetary terms, and to scale down the resulting monetized values to a per-unit-deployed, per-year basis. The objective of this exercise is to make benefits estimates comparable across studies by translating results into common terms, and employing a standardized set of values and assumptions in monetary calculations. The techniques used to estimate the original results provided in each paper remain the product of the individual paper itself. Furthermore, since the values used in the calculation of these ITS benefits are based upon existing literature, they represent the evaluations and benefits determinations produced within the confines, and at the time, of that research. This means that future research and analysis of ITS benefits may lead to noticeably different results from those presented in this report. Results from studies of ITS benefits are reported in various forms in the literature, often rendering comparison among evaluations from different studies difficult. A first potential point of discrepancy between studies is simply the units in which results are expressed. In this analysis, we identify a set of unique “metrics” used to measure ITS benefits across all the studies to be assessed quantitatively, as listed in Table 24 (page 143). Metrics are intended to be conceptually orthogonal; they cannot be reduced to or converted among one another. Each represents a “lowest common denominator” for expressing an effect of ITS deployment purporting non-trivial economic impact – whether economic benefits or dis-benefits. Metrics in the papers reflect safety, mobility, environmental, efficiency, productivity, or utility benefits to society. All of the measures identified in Table 24 clearly have economic implications, though some are of ambiguous or highly variable value. In many cases, however, an accepted or recommended value (or range of values) with established precedent in the relevant economic literature can be found to approximate the societal impact of a unit change in the metric. Discussion or calculation of the value associated with a unit change in each metric is captured in the Benefit Categorization and Monetization Section.

A study may report findings as either a unit change in a metric (e.g., “a travel time reduction of 30,000 person-hours of travel over the six-month period”) or as a percentage change from an initial condition (“a 15% reduction in fatal crashes at the affected intersections”). Results may be reported on a per-unit basis (e.g., “a 7% reduction in crashes per camera-equipped intersection”), or, more commonly, as a lump-sum estimate covering the entire scope of deployment (“a 9% reduction in travel-time delay on the three-toll-plaza corridor”). Alternatively, a study may assign a monetary value to the estimated benefits, according to the authors’ own means of valuation.

Where possible, benefits were extracted from the studies and recorded in the form of absolute amounts of one or more of the unique metrics discussed below, as opposed to monetary values. It was sometimes necessary to perform one of the following procedures in order to derive an absolute amount from the results as reported in the study:

- Calculation of a change in quantity, based on a percentage change and a baseline amount (e.g., converting a 23% reduction in average travel time delay into person-hours of delay reduction. If initial average travel time delay were reported at 10,000 person-hours on the roadway segment, calculated benefits would be 2,300 fewer person-hours of delay over the time period.)
- Converting units to a metric (e.g., converting avoided emissions of CO<sub>2</sub> from metric tons to kilograms)

- Non-trivial conversions to a metric (e.g., studies quantifying travel time changes may report results in vehicle-hours or person-hours; since both measures pertain to the same type of benefit, vehicle-hours were converted to person-hours using a standard assumption about average vehicle occupancy rates.)

Benefits expressed in quantities are monetized using the standardized per-unit monetary value assigned to the relevant benefit metric.<sup>42</sup> The standardized per-unit monetary values of each metric are shown in the final column of the table in the appendix.

Where studies report results in monetary terms only, these monetary values are adjusted from year-of-calculation (or nominal) dollars to reflect current (2009) price levels, using the Consumer Price Index for All Urban Consumers (CPI-U), then recorded along with the other benefits.

## Core Variables and Assumptions

As noted above, once the results reported in subject papers are expressed in terms of the metrics listed in the appendix, benefits are monetized according to a standardized per-unit economic value of each metric. This section discusses how these values are determined or calculated.

### Safety

Safety benefits of ITS technologies are typically quantified and reported in terms of crashes reduced or avoided. Studies may report a reduction in overall crashes following deployment, or further specify the distribution of avoided crashes according to severity (fatal, injury, or property damage only). The value of crashes avoided used for this analysis follows USDOT guidance on the subject, which is based upon evaluation of the comprehensive societal cost associated with a traffic crash.<sup>43</sup> The recommended economic value for prevention of a traffic fatality as of November 2009 was \$6.0 million. Recommended values for non-fatal injury crashes are calculated as fractions of the value of a fatality, according to the severity levels defined in the MAIS (Maximum Abbreviated Injury Scale). These costs are shown in Table 6.

Data provided by the National Highway Traffic Safety Administration (NHTSA) are used to weight the value of each MAIS severity by its relative incidence in 2004 crash statistics, producing a weighted average crash-cost of approximately \$61,819. This weighted average crash-cost is applied to results from studies reporting safety effects in terms of “crashes.” Similarly, studies that report a change in “injury crashes” are assigned an incidence-weighted average cost value for MAIS levels 1-5 (\$28,690). “Killed or seriously injured” (KSI) crashes are valued with a weighted average crash-cost from MAIS levels 3-6 (\$48,451). Studies reporting results in terms of a reduction in fatal crashes are valued according to MAIS 6, and non-injury crashes are assigned the MAIS 0 value shown below.

<sup>42</sup> “Unit” here refers to unit of a metric, e.g., one person-hour as a measure of time savings, whereas “unit” as in “benefit per unit-year” refers to unit of *deployment*, e.g. one ramp meter.

<sup>43</sup> The calculation of the societal cost of a crash includes property damage, medical and legal costs, time lost due to related travel delay, and other direct costs, as well as the intangible costs of injuries, such as pain and suffering. See Joel Szabat, “Treatment of the Economic Value of a Statistical Life in Departmental Analyses – 2009 Annual Revision,” USDOT Office of the Secretary of Transportation, March 18, 2009.

**Table 6. Monetized Societal Value of Traffic Crashes by Severity Level**

MAIS Level	Severity	Fraction of VSL	OST <sup>44</sup> Recommended Cost (\$2009)
<b>MAIS 0</b>	Non-Injury	--	\$3,170
<b>MAIS 1</b>	Minor	0.002	\$12,063
<b>MAIS 2</b>	Moderate	0.0155	\$93,487
<b>MAIS 3</b>	Serious	0.0575	\$346,807
<b>MAIS 4</b>	Severe	0.1875	\$1,130,891
<b>MAIS 5</b>	Critical	0.7625	\$4,598,956
<b>MAIS 6</b>	Fatal	1	\$6,031,418

**Mobility**

Time spent in vehicle travel or congestion delay is associated with an opportunity cost; guidance on the valuation this time (measured in person-hours) is provided by the Office of the Secretary of Transportation (OST), and reflects travelers’ willingness to pay to avoid travel time delay.<sup>45</sup> One person-hour of travel time savings is assigned the OST-recommended value for urban travel, which is based upon the average hourly wage rate (about \$26.23, in current-year dollars). Personal travel (which accounts for 94.4% of urban travel) is valued at 50 percent of the average hourly wage rate, and business travel (5.6% of urban travel) is valued at 100 percent of the hourly wage rate, producing a passenger travel value of travel time savings of \$13.85 per person-hour. Travel time savings for commercial motor vehicle travel is associated with a higher value (\$22.50 per person-hour), reflecting the comprehensive cost of operations to the motor carrier lost per hour of travel time delay.<sup>46, 47</sup> These values are used independently where studies specify the quantity travel time savings accruing to each of these traveler groups separately. Where studies report only total travel time savings or increases, a weighted average value of time for urban travel (\$14.17) is applied. Weights are commensurate with the share of total vehicle miles of travel (VMT) attributable to the two vehicle types in urban areas.<sup>48</sup>

Studies may quantify travel time savings or delay reduction in vehicle-hours rather than person-hours. In such cases, conversions to person-hours are made by multiplying by vehicle occupancy. According to the 2001 National Household Travel Survey, average vehicle occupancy for personal vehicle travel was

<sup>44</sup> Office of the Secretary of Transportation

<sup>45</sup> Emil H. Frankel, “Revised Departmental Guidance: Valuation of Travel Time in Economic Analysis,” USDOT Office of the Secretary of Transportation, February 11, 2003.

<sup>46</sup> It is assumed here that the portion of large-truck travel made for purposes other than commercial is negligible.

<sup>47</sup> Vehicle occupancy for commercial motor vehicles is assumed to be equal to 1.

<sup>48</sup> Trucks make up only about 3.4% of the total vehicle fleet (Federal Motor Carrier Safety Administration, 2005), and travel by single-unit and combination trucks accounted for 3.7% of total urban VMT in 2007 (Federal Highway Administration, *Highway Statistics 2007*, Table VM-1). The adjustment to the value of travel time savings is additionally important in light of the fact that many of the studies finding significant mobility-related benefits are evaluating ITS deployments on freeways and interstates (e.g., electronic toll collection, ramp metering), where truck travel is heaviest.

approximately 1.63 persons per vehicle.<sup>49</sup> Thus, the economic value per vehicle-hour of urban travel time savings is taken to be approximately \$23.10.

**Environmental**

Environmental effects of ITS deployments are measured in terms of emissions reduced or avoided. Harmful emissions associated with the gasoline and diesel fuel are greenhouse gases (of which carbon dioxide accounts for 97%) and criteria pollutants (particulate matter, nitrogen oxides, sulfur oxides, and volatile organic compounds). Emissions of these substances result from both production and distribution of fuel (“upstream emissions”), as well as from fuel consumed in vehicle travel (“tailpipe emissions”). Tailpipe emissions of carbon dioxide scale approximately linearly with the number of gallons of fuel consumed. In the case of criteria pollutants, however, emissions rates depend upon a variety of factors – including, importantly, engine efficiency and vehicle speed.

**Table 7. Monetized Societal Value of Emissions Avoided**

Substance	Value of Emissions Reduction (\$2009/ton)
Carbon Dioxide (CO <sub>2</sub> )	\$20.80
Carbon Monoxide <sup>50</sup> (CO)	\$0.00
Nitrogen Oxides (NO <sub>x</sub> )	\$4,164
Particulate Matter (PM)	\$175,114
Volatile Organic Compounds (VOCs)	\$1,768
Sulfur Dioxide (SO <sub>2</sub> )	\$17,084

The monetized values of emissions are based upon EPA estimates of environmental costs per metric ton of each pollutant (based upon health- and welfare-related damages incurred or avoided).<sup>51</sup> These values are applied directly to the results of studies which report environmental effects as changes in the levels or emissions of individual pollutants.

<sup>49</sup> Pat S. Hu and Timothy R. Reuscher, “Summary of Travel Trends: 2001 National Household Travel Survey,” Federal Highway Administration, December 2004.

<sup>50</sup> EPA and USDOT NHTSA, “Proposed Rulemaking To Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Proposed Rule,” *Federal Register*, Sept. 2009, p. 49506, Table II.F.1-1.

<sup>51</sup> With the exception of carbon monoxide, values for all criteria pollutants are consistent with those provided by the Environmental Protection Agency and the Energy Information Administration (see *Annual Energy Outlook 2007*), adjusted to reflect current price levels. Values for carbon dioxide and carbon emissions reflect adjustments made by the EPA that were most recently employed in Final Regulatory Impact Analysis for the Corporate Average Fuel Economy Standards, National Highway Traffic Safety Administration (March 2009), Table VIII-5.

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For studies which instead quantify environmental effects in terms of changes in fuel consumption, an average emissions value per gallon is calculated and applied. The environmental impact of a gallon of fuel consumed is variable since, as noted above, criteria emissions are not linearly related to fuel consumption. Criteria emissions rates per vehicle mile of travel for the typical vehicle mix on urban roadways at various speeds of travel were obtained from estimates developed for regulatory impact analysis of the Corporate Average Fuel Economy Standards.<sup>52</sup> Using the estimated average fuel economy for this vehicle mix, total emissions costs per gallon were calculated for speeds between 5 and 65 miles per hour. Emissions costs as a function of speed decline from \$1.02 to \$0.90 per gallon in the range of 5 to 43 miles per hour, then rise in the range of 43 to 65 miles per hour. The average value across this distribution is \$0.93 per gallon. This value was used to approximate the environmental cost per gallon of a change in fuel consumption, because it intersects the smoothed curve of the emissions distribution at speeds of about 10 and 60 miles per hour (i.e., appropriate to both congested and free-flow urban traffic).

## **Efficiency**

### **Vehicle Throughput**

Vehicle throughput refers to the number of vehicles which cross a segment of roadway during a period of time. A change in vehicle throughput has ambiguous economic impacts. Increased throughput itself does not directly create economic benefit or dis-benefit, though it may be associated with or result from other quantifiable economic effects. First, increased throughput may be caused by an increase in demand for travel along the roadway segment. This may be a response to either a (perceived or real) decline in travel time along the roadway segment (that is, effectively, a perceived increase in available roadway supply), or to an increase in the utility of travel along the segment. To the extent that either of these are the cause of increased throughput, benefits of the change can be expressed using a separate measurement (i.e., the value of travel time or utility changes). Secondly, increased throughput may be the result of decreased congestion along the roadway; benefits from this change will also be quantified in terms of travel time savings. Changes in throughput may be associated with an environmental impact, but this change can, again, be fully expressed in terms of the values of fuel consumption and emissions changes. Furthermore, the direction of this change would not necessarily be evident, since emissions rates vary according to vehicle speed; an increased number of vehicles per unit time may actually result in fewer emissions, based upon initial speed conditions on the roadway segment.

### **Speed**

Similar to throughput, the net economic effect of an increase in average vehicle speed along a roadway segment is ambiguous. The economic value of a change in the speed of traffic may be fully captured in terms of other metrics such as travel time savings or emissions reductions, or it may carry additional safety and other implications.

### **Ridership and Trip-Making**

Increased ridership (such as for a transit system) does not constitute a pure economic benefit. Increases in ridership stem from one of two sources: mode shift or increased trip-making. Either or both of these changes may produce economic benefits or dis-benefits quantifiable in terms of other metrics discussed above: for example, mode shift from personal vehicle travel to transit travel may produce a change in aggregate fuel consumption or travel time; increased trip-making may have the effect of increasing aggregate emissions or increasing utility. However, the net economic impact of these effects for a given increase in ridership *a priori* is unclear. Thus, if studies measure the effects of a change in ridership in the case of the particular deployment in terms of the metrics discussed above, these results are preferred in calculations. Otherwise, changes in ridership are noted, but no attempt is made to monetize these results.

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<sup>52</sup> Values generated by the Environmental Protection Agency's MOBILE-6.2 model, as employed in the Final Regulatory Impact Analysis for the Corporate Average Fuel Economy Standards, National Highway Traffic Safety Administration (March 2009).



## **Productivity**

### **Cost Savings**

Valuation of pure cost savings estimates is straightforward: dollar values are deflated from nominal reported results (given in year-of-estimation dollars) to reflect current price levels (2009 dollars) using the consumer price index (CPI-U) for the relevant year(s).

Cost savings also accrue to travelers from fuel savings in personal vehicle travel. In the cases where studies specify a change in aggregate fuel use, the societal cost saving per gallon is taken to be the average retail price of fuel over the period of the study, net of state and federal taxes.<sup>53</sup> (The latter represent a transfer payment, from which no net economic benefit is derived.) Historical fuel prices data are taken from the Energy Information Administration's nationwide annual average nominal retail gasoline price series, and are converted to real prices using the consumer price index series for motor fuel prices.<sup>54,55</sup>

### **Utility**

Changes in utility indisputably have economic benefit: such changes directly contribute to or detract from societal well-being; furthermore, utility effects are the primary impetus and influence which underlies decision-making and behavior. It is not reasonable to assign a single value to utility in the same way that an average value is assigned for assessment of a unit of travel time savings; people have various preferences that do not necessarily converge on some hypothetical value. For isolated instances of choice, economists may attempt to derive a representative distribution of utility by evaluating subjects' "willingness to pay." Willingness to pay for a particular situation, however, is not a straightforward measure to obtain; thus, unless studies arrive independently at such an estimation (for example, a means of valuation associated with an increase in customer satisfaction), this analysis does not account for benefits reported in terms of utility changes into the monetization procedure.

### **Scale Variables**

In addition to calculating monetized benefits by applying the standardized values described above to each study's results, this analysis applies these findings to suggest an order-of-magnitude of the benefits of the installed base of ITS deployments in each technology category. Information on the existing stock of ITS installments was obtained from the Intelligent Transportation Systems ITS Deployment Tracking survey results.<sup>56</sup> Monetized estimates of benefits per unit-year are multiplied by the existing number of units currently in operation to obtain an approximation of the total societal benefit attributable to the particular ITS application.

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<sup>53</sup> That is, in cases where the change in aggregate fuel consumption is unambiguous, a distinction is made from studies which estimate, for example, travel time savings on a roadway segment on which a resulting increase in travel demand could offset some or all of the change in fuel use attributable to this efficiency increase.

<sup>54</sup> Available on the EIA website: [http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MG\\_RT\\_US&f=A](http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MG_RT_US&f=A).

<sup>55</sup> Bureau of Labor Statistics website: <http://www.bls.gov/CPI/>.

<sup>56</sup> ITS Deployment Statistics Database, 2007 survey results, Research and Innovative Technology Administration of the U.S. Department of Transportation, <http://www.itsdeployment.its.dot.gov/Default.asp>.

## The Benefit Estimation Model

Estimating the benefits attributable to ITS deployment was done through a linear modeling procedure. This methodology estimated the annual benefit from one unit of ITS deployment according to each study and then applied this across the total deployment captured in the ITS Deployment tracking survey. As such, ITS technology benefits are estimated for deployment across the entire U.S., regardless of the level of network or region covered in the underlying estimating paper.

Nearly all of the available reports estimate the benefits of individual projects, which are typically of limited scale and geographical extent. Using these estimates as inputs in a linear calculation of aggregate benefits can be a concern for several reasons:

1. Due to the limited scale of the projects studied in these reports, the results may not pick up the possible effects of increasing or *decreasing returns to scale*.<sup>57</sup> For example, Retting (2001) estimates that Red Light Camera enforcement at 11 of 125 signalized intersections in Oxnard, California reduced crashes at signalized intersections (throughout the city) by 7%. It is unclear, however, whether the next 11 red light cameras deployed in the city would result in a crash reduction of similar magnitude. It is possible that 11 cameras were a sufficient deterrent against red-light running in general for the majority of would-be violators,<sup>58</sup> and additional cameras would not yield as great a benefit. This would be an example of decreasing returns to scale. Conversely, it is possible that 11 cameras really only deterred a small portion of would-be violators, and that each additional camera would yield a more dramatic crash reduction. This would be an example of *increasing returns to scale*. In either case, Retting's benefit estimate would not be representative of subsequent deployments within Oxnard, and the calculation of aggregate benefits based on that estimate would require a more complex quantitative model.
2. Since the projects studied in the reports tend to represent the first deployment of a technology within a given geographical area, they may tend to be in locations where they are thought to be most needed (or most effective). For example, Gains et al. (2003) evaluate a pilot study in Britain in which speed enforcement cameras were installed on roadways where crashes occurred most often. Similarly, in a study on the potential benefits of an advanced traveler information system in Seattle, Wunderlich, et al. (2000) select as their study area a corridor that has "among the worst" delay and congestion in the metropolitan area and the most views of its congestion map on the Washington DOT website (p. 35).

It is possible that this type of prioritization of deployment would translate into progressively lower *marginal* benefits over time, simply due to the decreasing magnitude of the problems that subsequent deployments would be intended to mitigate.<sup>59</sup> Thus, deployments that are among the earliest within a given geographical area would tend to produce annual benefits that are *greater* than the average of all deployments nationwide (because some of the deployments included in this average would be among the later ones within their geographical area). Yet the linear extrapolation technique used in this study relies on the assumption that the benefits produced by the sample deployment are *representative* of the average deployment nationwide. Thus, linear extrapolation based on the estimated benefits of earlier projects such as those cited above, which are suspected to be the most effective, may produce an upwardly biased estimate of aggregate benefits.

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<sup>57</sup> The term "decreasing returns to scale" refers to a scenario in which the benefits produced by each additional input decreases as more inputs are added. In this case, it means each additional unit of technology deployed produces a lower level of benefits than the previous unit. Correspondingly, "constant returns to scale" means each additional unit produces the same level of benefits, and "increasing returns to scale" means each additional unit deployed produces a greater level of benefits.

<sup>58</sup> Retting (2001) recognizes the "spillover effect" of cameras.

<sup>59</sup> The marginal benefit of [X] with respect to [Y] refers to the change in X resulting from one additional unit of Y, controlling for all other factors. In this case, the marginal benefit (of deployment) refers to the additional benefit resulting from one additional unit of deployment, given a certain existing deployment level.

3. The fact that many of these reports are on technologies that were fairly new at the time (as opposed to mature) means that the benefit estimates do not reflect subsequent refinements either in the technologies themselves or in their use.
4. It is unclear to what degree the benefits of a particular technology are dependent upon the unique set of existing characteristics belonging to the location of deployment. That is, the benefits of a particular ITS project, or even of a given unit of deployment, may not be representative of the benefits of similar projects in other locations. In the case of transit signal priority, for example, Wang et al. (2007) observe that

*because performance of a signal control strategy is closely related to traffic conditions, surrounding land use, traffic regulations, and roadway network geometry, comprehensive impacts of TSP systems on transit and other vehicles are case specific and difficult to generalize. (p. 13)*

The degree of variation in benefit estimates by location for a given technology often cannot be readily gauged from the literature, due to differences in the metrics used in the various studies (as well as methods). Such variation presents a clear source of concern and possible error in calculating aggregate benefits.

USDOT Federal Highway Administration's "Regulatory Benefit-Cost Analysis of Proposed Rulemaking Real-Time System Management Information Program" (2006) is an example of a study that uses location-specific data in an aggregation model. Like the present report, FHWA's analysis is based on an earlier smaller-scale study, in this case an evaluation of a freeway monitoring system in the Atlanta metropolitan area with traveler information, freeway management, and incident management applications. For this technology, benefits are expected to accrue to the entire city, rather than smaller areas surrounding some particular physical unit of deployment such as an ETC-equipped toll plaza.<sup>60</sup> But instead of treating each metropolitan area single unit of deployment and extrapolating by multiplying Atlanta's benefits by the total number of cities expected to adopt the technology, a linear weighting procedure was employed based on the assumption that citywide benefits were directly proportional to citywide vehicle-miles traveled – e.g. a city with double the VMT of Atlanta would be estimated to accrue double the benefits from the technology. In other words, the FHWA study performs a linear extrapolation based on *VMT*. In contrast, this study report performs a linear extrapolation based on *units of deployment*.

5. One location-specific characteristic of particular importance is the existing level of deployment of other technologies within a given area. Cambridge Systematics (2001) notes that it is important to have
 

*a thorough understanding of [...] the interaction and synergies between different components, both within deployments as well as across deployments (this will facilitate the consideration of the benefits of integrated ITS deployments, as well as the avoidance of double-counting of benefits).*

For example, Birst and Smadi (2000) determine that the integration of a freeway management system in Fargo, North Dakota with a traffic signal coordination system on adjacent arterials "compounded the benefits" of the freeway management system – the travel time and speed benefits of the freeway management system more than doubled.

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<sup>60</sup> This is the chief reason why FHWA's approach was not adopted in the present report. It was determined that the technologies examined here should not be assumed to be strongly related to citywide variables, because their intended effects are mostly confined to smaller areas surrounding individual physical units of deployment. VMT data for these smaller areas were generally unavailable.

It is not feasible to acquire information on exogenous ITS deployment levels in the geographical areas studied in the literature at the specific times of the studies. Therefore, any generalizations based on the results of these studies would have to rely to some extent on the assumption that the existing deployment levels of other technologies in the areas studied in the literature are representative of deployment levels in all areas where the technology under consideration is deployed.

In light of these observations, three general types of information can be identified that would ideally be incorporated into the model of aggregate nationwide benefits, if such information was available for each study being reviewed and for each deployment nationwide.<sup>61</sup>

- 1. Magnitude of existing costs.** This would be some measure of congestion, emissions, or safety-related costs within a given area. Examples of these metrics are described in the Benefit Categorization and Monetization section of this report.
- 2. Scale of existing ITS deployment *in the study area*.** This refers to the technology being researched, as well as any other technologies that may be thought to affect the performance of that technology either positively or negatively. This would be measured in units of technology deployed.
- 3. Level of technology.** This information, which may be qualitative or quantitative, would provide some indication of the level of technological refinement of the units to be deployed. For example, it would be important to know whether ramp meters in a given area are coordinated. Similarly, it might be useful to include data on the maximum distance at which certain types of TSP hardware are capable of granting priority.

Although these categories are not exhaustive, they address many of the concerns discussed above, and including these types of information would produce a more realistic model of aggregate nationwide benefits. The studies reviewed for this report, however, did not report this information on a consistent basis. FHWA's ITS Deployment Analysis System (IDAS) is an example of a more complex system that incorporates additional variables into its benefits calculation model. These variables include the level of technology, as well as existing congestion levels, accident rates, emission rates, and fuel consumption levels.

It is important to note that the introduction of additional variables into the model used in this study would mean it is no longer an extrapolation model. As such, in order to calculate aggregate nationwide benefits, information would be required on each individual deployment, or perhaps each group of deployments at the city or local level.

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<sup>61</sup> Or at least each set of deployments within a given metropolitan area.

## Benefits Calculation Equation

The following equation was used to calculate nationwide benefits of a given technology:

$$B_N = B_S * (U_N/U_S) * (1 \text{ year}/T_S)$$

Where:

**B<sub>N</sub>** = Monetary magnitude of annual nationwide benefit of technology

**B<sub>S</sub>** = Monetary magnitude of benefit of technology as estimated in the study

**U<sub>N</sub>** = Number of units deployed nationwide

**U<sub>S</sub>** = Number of deployed units responsible for the benefit reported in the study

**T<sub>S</sub>** = Length of time over which benefits reported in the study accrue

Note that the subscript “N” denotes a nationwide variable, and the subscript “S” denotes a study-level variable. See below for further explanation of the equation terms. The term **U<sub>N</sub>/U<sub>S</sub>** scales the benefit reported in the study, **B<sub>S</sub>**, to the national level. The term **1 year/T<sub>S</sub>** annualizes **B<sub>S</sub>**, i.e., it adjusts **B<sub>S</sub>** in such a way that **B<sub>N</sub>** represents benefits accruing over exactly one year.

### Terms of the Equation

The following are descriptions of the terms of the formula, along with some related methodological notes.

**B<sub>N</sub>**: Magnitude of annual nationwide benefit of technology (\$).

This is the number to be calculated.

**B<sub>S</sub>**: Magnitude of benefit of technology as estimated in the study (\$).

This has already undergone the conversion and monetization process described in the Benefit Categorization and Monetization section.

**U<sub>N</sub>**: Number of units deployed nationwide.

These numbers were obtained from RITA’s ITS Deployment Statistics Database, using the latest available date (2007, except where noted). They are presented in

Table 8.

**U<sub>S</sub>**: Number of deployed units responsible for the benefit reported in the study.

This, in other words, is the number of deployed units to which the reported benefit is attributed. Note that these are not necessarily the same as the number of deployed units for which empirical data were collected in a study – the benefits reported in the studies are often extrapolations based on data collected on a smaller sample of units.<sup>62</sup> Such extrapolations were deemed acceptable for the purposes of the nationwide benefits calculation, so long as the corresponding number of deployed units was provided.

**T<sub>S</sub>**: Length of time over which the benefits in the study are reported to accrue.

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<sup>62</sup> In the case of Council et al. (2005), the reverse is true -- benefits are reported *per unit-year* based on data collected on multiple sites and years.

This value is reported in almost every paper. Note that this value does not always represent the length of time over which empirical data were collected in a study – in some studies benefits are projected over time based on data collected over a shorter sample period. Such projections were deemed acceptable for the purposes of the nationwide benefits calculation. The metric  $T_S$  was converted to an annual figure for the nationwide benefits calculation.

**Table 8. Nationwide Deployment Statistics Used for Benefits Calculations**

<b>Technology</b>	<b># Units Deployed Nationwide (<math>U_N</math>)</b>	<b>Unit type</b>	<b>Year of Deployment Count</b>
<b>Transit Signal Priority</b>	3,214	Intersections	2007
<b>Red Light Camera</b>	960	Intersections	2007
<b>Traffic Signal Coordination</b>	72,255	Intersections	2007
<b>Ramp Metering<sup>63</sup></b>	2,045	Ramps	2007
<b>Electronic Toll Collection</b>	590	Toll plazas	2007
<b>Electronic Toll Collection</b>	3,501	Toll lanes	2007
<b>Traveler Information Systems</b>	5,825	Dynamic Message Signs	2007, 2006 <sup>64</sup>

## Results and Literature Discussion

A description of the benefit estimation methodologies employed in the literature, followed by results and a discussion of the calculations and analyses performed for this report is presented next. Results are then summarized and compared across technologies. Finally, these results are used to produce estimates of the total annual nationwide benefits of each technology over time (i.e., from 1997-2007).

Note that the results presented in this section do not necessarily represent comprehensive estimates of all benefits either within a benefit category or across all benefit categories. For example, reported environmental benefits may not consider every criteria pollutant for which emissions reduction benefits

<sup>63</sup> Due to peculiarities in the data from the RITA ITS Deployment Statistics database, the 2007 nationwide ramp meter deployment in Table 4 was taken from California Department of Transportation (2007). For details on this subject, refer to the section titled *Nationwide Benefits over Time*.

<sup>64</sup> The total number of DMS deployed nationwide includes the number of portable DMS deployed on highways as reported in 2006, the last year for which this measure is available.

accrue. Similarly, the reported total annual nationwide benefit may include mobility benefits but exclude related benefits accruing in the environmental category.

## Electronic Toll Collection

### *Literature Methodology:*

Most of these studies use a combination of real-world data and simulations. For example, Wilbur Smith (2001) collects data including “traffic counts, transactions at the toll plaza, transaction times by various vehicle categories and payment types, [and] queue lengths,” and uses the TOLLSIM microscopic simulation model to estimate “traffic operation conditions at each toll plaza [...] in terms of queues, average delay time and vehicles processed by vehicle class and payment type” (ES-2).

### *Results:*

**Table 9. Benefits per Unit-Year, Electronic Toll Collection (\$2009/unit-year)**

Reference Information	Unit of Deployment	Mobility Benefits per Unit-Year	Environmental Benefits per Unit-Year	Fuel Cost Benefits per Unit-Year	Total Benefits per Unit-Year
Saka and Agboh (2002)	toll plaza	--	\$4,923	--	\$4,923
Wilbur Smith Associates (2001)	toll plaza	\$1,739,907	\$53,021	\$141,533	\$1,934,460
Al-Deek et al. (1997)	Lane	\$172,155	--	--	\$172,155
Gillen et al. (1999)	toll plaza	\$1,655,369	\$85,437	\$262,867	\$2,003,673

**Table 10. Annual Nationwide Benefits, Electronic Toll Collection (\$2009/unit-year)**

Reference Information	Unit of Deployment	Annual Nationwide Mobility Benefits	Annual Nationwide Environmental Benefits	Annual Nationwide Fuel Cost Benefits	Total Benefits per Unit-Year	Total Annual Nationwide Benefits
Saka and Agboh (2002)	toll plaza	--	\$2,904,283	--	\$4,923	\$2,904,283
Wilbur Smith Associates (2001)	toll plaza	\$1,026,544,897	\$31,282,254	\$83,504,391	\$1,934,460	\$1,141,331,542
Al-Deek et al. (1997)	Lane	\$602,714,686	--	--	\$172,155	\$602,714,686
Gillen et al. (1999)	toll plaza	\$976,667,898	\$50,407,594	\$155,091,362	\$2,003,673	\$1,182,166,854

The nationwide Mobility benefit estimates for the three ETC studies reporting them are all roughly comparable, although there is a substantial gap between Al-Deek et al. (2001) and Gillen et al. (1999). One notable difference between the two estimation procedures is that Al-Deek's only includes benefits accruing to users of *dedicated* ETC lanes. This may be viewed as a source of downward bias in the nationwide estimate because it excludes benefits accruing to travelers in other lanes. The effect may be substantial – in Wilbur Smith Associates (2001), an estimated 36% of the total annual delay-saving benefits of ETC on the New Jersey Turnpike were reported to have accrued to non-E-ZPass users. However, this difference in estimation procedure may also be viewed as a source of upward bias, because the nationwide lane count used for extrapolation refers to *all* lanes with ETC “capabilities,” which includes lanes that accept both manual and ETC transactions. Further complicating matters is the fact that Al-Deek's estimate does not capture the total benefits accruing to ETC users because it only measures queuing delay, which excludes direct savings on transaction time. The net effect of these methodological differences on the benefits estimates reported by Al-Deek and the nationwide benefit estimates reported above is ambiguous both in direction and magnitude.

It should also be noted that Wilbur Smith Associates (2001) offers separate time-savings estimates for passenger cars and for trucks, and the monetary values above account for this distinction based on the assumptions described in the Benefit Categorization and Monetization section. The Mobility benefit would rise by 2.4% if trucks and automobiles were treated as identical, as they are for the other studies.

In addition to the Mobility benefit estimate, Al-Deek et al. (2001) also reports a 251% increase in throughput (1,255 vehicles per hour) and a 194% increase in capacity (1,055 persons per hour) in a dedicated ETC lane. These findings suggest that ETC may bring dramatic improvements in the area of efficiency.

In the Environmental category, benefits for Wilbur Smith Associates (2001) and Gillen et al. (1999) were comparable, and they were 5% and 8% as high as the Mobility benefits, respectively. Thus, based on this limited evidence, emissions benefits from ETC appear to be roughly proportional to the Mobility benefits. The environmental benefit estimate for Saka and Agboh (2002) is far lower because, unlike the others, it does not include CO<sub>2</sub> reduction benefits, which account for the vast majority of the total Environmental benefit in the other studies.

Although the Mobility benefits estimated by Wilbur Smith Associates (2001) and Gillen et al. (1999) are very close, Gillen's Fuel Cost benefit estimate is nearly double Wilbur Smith's. One possible explanation is that baseline speeds were higher in Wilbur Smith than in Gillen, though no data are available to confirm this.

## Ramp Metering

### *Literature Methodology:*

The Ramp Metering literature, which was one of the sparser of those reviewed for this study, contained a mix of empirical and simulation-based studies. Cambridge Systematics (2001) is an extensive empirical report on an experiment in which all ramp meters were turned off for five weeks. The study uses probe vehicles to collect travel time data, traffic detectors for traffic volume data, a crash database for statistical safety analysis, transit travel time and ridership data for transit impact analysis, and surveys for analysis of traveler attitudes and behavior. In addition, data on weather, pavement conditions, light conditions, construction activity, and incidents were collected as control variables. Kang and Gillen (1999), on the other hand, estimate travel delay, fuel consumption, and emissions using an entirely simulation-based approach.



It is important to note that these studies and all others that were reviewed in the Ramp Metering category, are system-wide, meaning they account for offsetting effects that occur on ramps. This is designed to ensure that the estimated benefits are not the result of shifting congestion off the highway.

### **Results:**

While the Mobility benefits reported for Cambridge Systematics (2001) appear roughly comparable to those of Shrank and Lomax (2009), it should be noted that this is due almost entirely to the fact that the Cambridge Systematics estimates include the benefit of the increase in travel time *reliability* as well as the reduction in travel time. When travel time reliability improves, travelers respond by leaving less “buffer time” (Shrank and Lomax, 2009), or extra time allotted to travel in anticipation of potential non-recurring delay. The benefit of travel time reliability is reported in person-hours of buffer time. (For the monetary estimates below, person-hours of buffer time are valued equally to person-hours of travel time. Nevertheless, there is some disagreement in the literature on this point [Cohen and Southworth, 1999].) In the Cambridge Systematics study, the increase in travel time reliability is reported to save more than 100 times the number of person-hours saved in travel time.

The vast difference between the two studies’ benefit estimates for travel time savings (Cambridge Systematics’ is less than 1% of the Shrank and Lomax’s) appears peculiar, especially in light of the fact that Shrank and Lomax’s estimate is an extrapolation based on the results of the Cambridge Systematics study, which was performed in the Minneapolis-St. Paul metropolitan area. This difference is due to the fact that Shrank and Lomax’s nationwide benefits extrapolation, unlike the one developed in this study, utilized a weighting procedure based on the congestion levels in the areas served by ramp meters and the number of lane-miles served by the ramp meters. (Higher values of either of these measures translated into heavier weights.) Based on a rough comparison of the geographical distribution of ramp meter deployment and the congestion ranking tables in Shrank and Lomax (2009), it can be seen that ramp meter deployment is concentrated in metropolitan areas that well outrank the Twin Cities in both total and per-traveler travel time delay.<sup>65</sup> (Los Angeles, San Francisco, and San Diego alone account for 70% of total national deployment.) Additionally, based on the deployment data, it would not be surprising if ramp meter deployment were found to be concentrated in areas where each meter serves more lane-miles than in the Twin Cities, although data sufficient to demonstrate this hypothesis are not readily available. Thus, by accounting for locational variation in two key variables, Shrank and Lomax produced a nationwide estimate of ramp metering benefits that is far greater, and presumably more accurate, than the simple extrapolation of the Twin Cities study performed in the present report.

The finding that Safety benefits outweigh Mobility benefits is a surprise, as ramp metering is generally viewed foremost as an enhancer of mobility. Fatal, injury, and PDO crashes accounted for 75%, 20%, and 5% of the total benefit respectively. The monetary estimate of Safety benefits is highly sensitive to small changes in the number of fatal crashes in the sample, and of course to the monetary values assigned to each crash type. Nevertheless, there is apparently no compelling reason to reject the finding.

The relatively modest negative Environmental benefit in the Cambridge Systematics study is due to congestion created on the ramps, which results in net increases in NO<sub>x</sub> and CO<sub>2</sub> emissions. As noted above, all estimates reported in both ramp metering studies are system-wide, meaning they are net benefits and they account for any offsetting effects occurring on ramps.

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<sup>65</sup> ITS Deployment Statistics Database, 2007 survey results, Research and Innovative Technology Administration of the U.S. Department of Transportation, <http://www.itsdeployment.its.dot.gov/Default.asp>.

**Table 11. Benefits per Unit-Year, Ramp Metering (\$2009/unit-year)**

Reference Information	Unit of Deployment	Mobility Benefits per Unit-Year	Environmental Benefits per Unit-Year	Fuel Cost Benefits per Unit-Year	Safety Benefits Per Unit-Year	Total Benefits per Unit-Year
Cambridge Systematics (2001)	<b>metered ramp</b>	\$85,600	-\$13,053	-\$38,612	\$106,473	<b>\$140,407</b>
Shrank and Lomax (2009)	<b>metered ramp</b>	\$133,799	--	--	--	<b>\$133,799</b>

**Table 12. Annual Nationwide Benefits, Ramp Metering (\$2009/unit-year)**

Reference Information	Unit of Deployment	Annual Nationwide Mobility Benefits	Annual Nationwide Environmental Benefits	Annual Nationwide Fuel Cost Benefits	Annual Nationwide Safety Benefits	Total Benefits per Unit-Year	Total Annual Nationwide Benefits
Cambridge Systematics (2001)	<b>metered ramp</b>	\$175,052,000	-\$26,693,385	-\$78,961,540	\$217,737,285	<b>\$140,407</b>	<b>\$287,132,315</b>
Shrank and Lomax (2009)	<b>metered ramp</b>	\$273,618,955	--	--	--	<b>\$133,799</b>	<b>\$273,618,955</b>

## Red Light Cameras

### *Literature Methodology:*

The studies in this category estimate benefits by comparing crash and violation data from before and after the deployment of cameras. Unlike the other categories reviewed here, none of these studies obtain results from simulations, due to the difficulty of modeling the causal relationships between RLCs and driver behavior, and between driver behavior and crash rates. Although the procedures used in these studies are credible and make use of some amount of control data, they generally do not control directly for other factors within the given area of deployment that may produce changes in the number of crashes, most likely due to a lack of available data.<sup>66</sup> It is not clear to what extent this detracts from the credibility of these studies compared to those in other technology categories. Resolving this issue is outside the scope of this project, but the potential concern is worth noting here.

It is difficult to know the appropriate geographical extent of RLC benefit analysis. Some of the studies report citywide benefits, while others report benefits only at camera-equipped intersections.<sup>67</sup> There is reason to believe there may be citywide benefits even for limited deployments, due to “spillover” effects – increased reluctance to exceed speed limits or run red lights at all signalized intersections. Such effects have been documented (Retting et al., 2008), and one option would be to apply the documented magnitudes of the effects to the results of studies that only report benefits at camera-equipped intersections.

There are, however, reasons to doubt the existence of a linear relationship between the number of cameras deployed and spillover effects produced. (As discussed earlier, marginal spillover effects may attenuate once a certain percentage of drivers perceive a high risk of incurring a penalty.) Thus, although attempting to include spillover effects in benefit estimates decreases the risk of underestimation, it may also dramatically increase the risk of overestimation.

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<sup>66</sup> These might include economic conditions, fuel prices, or weather. (Retting and Kyrychenko, 2002, p. 1823)

<sup>67</sup> Newstead and Cameron (2003) report benefits within 2 km of camera-equipped intersections.

**Results:**

**Table 13. Benefits per Unit-Year, Red Light Cameras (\$2009/unit-year)**

Reference Information	Unit of Deployment	Safety Benefits Per Unit-Year	Total Benefits per Unit-Year
Retting and Kyrychenko (2002)	intersection	\$224,303	<b>\$224,303</b>
Council et al. (2005)	intersection	\$42,393	<b>\$42,393</b>
Ruby and Hobeika (2003)	intersection	\$1,224,846	<b>\$1,224,846</b>
Washington and Shin (2005)	intersection	\$65,205	<b>\$65,205</b>
Washington and Shin (2005)	intersection	-\$35,451	<b>-\$35,451</b>

**Table 14. Annual Nationwide Benefits, Red Light Cameras (\$2009/unit-year)**

Reference Information	Unit of Deployment	Annual Nationwide Safety Benefits	Total Benefits per Unit-Year	Total Annual Nationwide Benefits
Retting and Kyrychenko (2002)	Intersection	\$215,330,745	<b>\$224,303</b>	<b>\$215,330,745</b>
Council et al. (2005)	Intersection	\$40,697,435	<b>\$42,393</b>	<b>\$40,697,435</b>
Ruby and Hobeika (2003)	Intersection	\$1,175,852,233	<b>\$1,224,846</b>	<b>\$1,175,852,233</b>
Washington and Shin (2005)	Intersection	\$62,596,357	<b>\$65,205</b>	<b>\$62,596,357</b>
Washington and Shin (2005)	Intersection	-\$34,032,674	<b>-\$35,451</b>	<b>-\$34,032,674</b>

The papers selected for the calculations of nationwide RLC benefits report a broad range of results. There are several possible explanations for some of the outliers, but a straightforward examination and comparison of the papers' methodological characteristics does not provide any compelling reasons to narrow the range of monetary benefit. Ruby and Hobeika (2003) estimate the greatest benefit by far – more than five times higher than the next highest estimate, by Retting and Kyrychenko (2002).<sup>68</sup>

The most prominent difference between Ruby and Hobeika (2003) and the other selected RLC papers is that Ruby and Hobeika separate benefits by crash type – fatal, injury, and property-damage-only. Accordingly, the figures above for that paper were calculated with different monetary values assigned to fatal, injury, and property-damage-only crashes. The figures for the other papers listed above, on the other hand, were calculated by multiplying the total number of crashes avoided by an average of the

<sup>68</sup> Ruby and Hobeika additionally report a 60% decrease in red-light violation.

monetary values for each crash type, weighted by nationwide crash proportions (see Benefit Categorization and Monetization section). (Thus, for the purposes of this report, crashes reduced in the other papers are assumed to take on the same proportions by type as total crashes nationwide.)

If Ruby and Hobeika's results for the three crash types had been summed together into one total crash figure, and the benefits calculated by the same procedure as the other papers, the per-unit-year and annual nationwide benefits would have come out to \$494,559 and \$474,776,470, respectively – less than 50% of the benefits as originally calculated. This discrepancy is due to the fact that the ratio of fatal to non-fatal crashes within that study is greater than the proportion of fatal to non-fatal crashes nationwide – that is, RLCs prevent a disproportionately large number of fatal crashes. Since each fatal crash is considered to be roughly 190 times as costly as a PDO and injury crash combined, even a seemingly slight difference in crash proportions – in this case, less than 2 percentage-points – can produce dramatically different results in monetary terms.

It is possible that the higher proportion of fatal crashes observed in the Ruby and Hobeika's study was simply due to chance and a small sample size (80 crashes, 2 of which were fatal). This then magnified the effect on the results due to the vast gap between the monetary valuations of fatal and non-fatal crash reductions. Still, it remains a possibility that Ruby and Hobeika's results could be representative of RLCs nationwide, meaning that RLCs actually do prevent a disproportionately large number of fatal crashes compared to injury and property-damage-only crashes. The distribution of the effects of RLCs among crash rates of different types is a subject for possible future research.

The large difference between the second highest benefit estimate (Retting and Kyrychenko, 2002) and the three lower estimates might be due to the fact that only Retting and Kyrychenko's estimate includes "spillover" effects occurring at other intersections throughout the study area. It is unclear, however, whether these spillover effects are actually powerful enough to produce a discrepancy of this magnitude. (Retting and Kyrychenko do not attempt to isolate the spillover effects from the total effects.) In addition, it must be noted that Ruby and Hobeika's estimates also do not include spillover effects, yet they are far greater than Retting and Kyrychenko's (even accounting for the aforementioned crash-type proportion issue).

Another methodological distinction between Retting and Kyrychenko (2002) and the rest of the studies is that Retting and Kyrychenko make use of regression analysis. Nonetheless, it is not clear how, or to what degree, this should have influenced their benefit estimates. This is a subject for possible future research.

Finally, the other somewhat unexpected result of note is the negative benefit reported by Washington and Shin (2005). More peculiar perhaps is the fact that this estimate is reported in the same paper as the positive benefit listed above, which is derived from a separate analysis on a different study area. Washington and Shin attribute the net dis-benefit to an increase in rear-end collisions, "presumably due to a relatively larger number of drivers braking suddenly to avoid a possible violation and fine" (3). They speculate that the difference in the results from the two study areas might be due to "the combination of relatively high approach speeds and the lagging left-turn phasing" in the higher-performing study area (117).

## Traffic Signal Coordination

### Literature Methodology:

Most of the reports in this category are based on simulations. Notable exceptions, however, are two entirely empirical before-after studies: Skabardonis (2001) estimates an average 11.4% travel time reduction across 76 TSC projects, and Banerjee (2001) estimates a 21.4% delay reduction as a result of 375 TSC-equipped intersections in Los Angeles.<sup>69</sup>

### Results:

**Table 15. Benefits per Unit-Year, Traffic Signal Coordination (\$2009/unit-year)**

Reference Information	Unit of Deployment	Mobility Benefits per Unit-Year	Total Benefits per Unit-Year
Shrank and Lomax (2009)	intersection	\$3,827	\$3,827

**Table 16. Annual Nationwide Benefits, Traffic Signal Coordination (\$2009/unit-year)**

Reference Information	Unit of Deployment	Annual Nationwide Mobility Benefits	Total Benefits per Unit-Year	Total Annual Nationwide Benefits
Shrank and Lomax (2009)	intersection	\$276,544,507	\$3,827	\$276,544,507

A range of estimates could not be obtained for TSC benefits, because only one TSC study was found that met all the criteria for nationwide extrapolation. This was Shrank and Lomax (2009), a broader nationwide congestion study called the *Urban Mobility Report*, which also contains benefit estimates discussed in the Ramp Metering results section of the present report.

In order to preserve internal consistency, the same extrapolation procedure was performed on Shrank and Lomax's TSC benefit estimates as was performed on all other estimates selected for analysis in this report, despite the fact that in this instance the estimate was nationwide to begin with. The resulting extrapolated estimate, shown above, is substantially lower than the one originally reported by Shrank and Lomax. This is due to the lower monetary value per person-hour assumed in this study, as well as differences in the data sources and metrics used for the calculation of nationwide TSC deployment.<sup>70, 71</sup>

<sup>69</sup> Skabardonis (2001) was not used for the analysis in this report because it did not include benefits in amount form. Banerjee (2001) was not used because it did not report benefits in aggregate form.

<sup>70</sup> See Benefit Categorization and Monetization section.

The other TSC studies reviewed were eliminated as candidates for nationwide extrapolation for a variety of reasons, the most common being that they did not report aggregate benefits and presented benefits in percentage form only, rather than absolute amounts.

It should be noted that there is some evidence of environmental benefits associated with TSC, though none of these papers meet the criteria for nationwide extrapolation. For example, Unal et al. (2003) estimate the effect of TSC on per-trip HC and NOx emissions for four different vehicle models in both congested and non-congested settings. The greatest effects for both pollutants were found under the uncongested scenario with the 1998 Chevrolet Venture: 59% and 57% decreases in HC and NOx emissions, respectively.

There is also some evidence of fuel saving benefits resulting from TSC, though these papers did not meet the criteria for nationwide extrapolation. Rakha et al. (2000) perform a simulation and conclude that “the level of traffic signal coordination can result in major reductions in fuel consumption and vehicle emissions (in the range of 50 percent)” (p. 65).<sup>72</sup> In a separate TSC paper, Rakha et al. (2000) estimate a fuel reduction of 1.6% due to a cross-jurisdictional TSC system. In this paper, they mention the role of speed variability in TSC-related fuel savings: their method “explicitly considers that although different speed profiles exhibit the same average speed, they may result in very different fuel consumption and emission rates, depending on the amount of speed variability about this average” (p. 43).

## Transit Signal Priority

### *Literature Methodology:*

Reports in this category typically collect data from transit vehicles and from the TSP systems themselves. Analysis of these data is often supplemented by a simulation. Wang et al. (2008), for example, obtain travel time data using in-vehicle GPS data loggers, and gather TSP request frequency from Transit Priority Request Generators (a roadside device that communicates with the traffic signal controller). A simulation, along with recorded video images, is used to gauge the potential offsetting effect of TSP on other traffic. (This effect is found to be insignificant.)

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<sup>71</sup> See p. B-38 in Shrank and Lomax (2009). They use lane-miles as their deployment metric, whereas this report uses number of intersections, as provided in RITA’s ITS Deployment Statistics Database.

<sup>72</sup> They do note, however, that the result is “less significant” if cross-street traffic is considered.

**Results:**

**Table 17. Benefits per Unit-Year, Transit Signal Priority (\$2009/unit-year)**

Reference Information	Unit of Deployment	Mobility Benefits per Unit-Year	Total Benefits per Unit-Year
Lehtonen and Kulmala (2002)	intersection	\$13,149	\$13,149
Wang et al. (2008)	intersection	\$46,666	\$46,666

**Table 18. Annual Nationwide Benefits, Transit Signal Priority (\$2009/unit-year)**

Reference Information	Unit of Deployment	Annual Nationwide Mobility Benefits	Total Benefits per Unit-Year	Total Annual Nationwide Benefits
Lehtonen and Kulmala (2002)	intersection	\$42,260,073	\$13,149	\$42,260,073
Wang et al. (2008)	intersection	\$149,986,037	\$46,666	\$149,986,037

Only two TSP papers met all the criteria for nationwide extrapolation: these were Lehtonen and Kulmala (2002) and Wang et al. (2008). Wang’s estimate is more than three times greater than Lehtonen and Kulmala’s, and the reason for the gap is not immediately apparent based on the information presented in the papers. Potential sources of variation in results among studies include differences in ridership, existing congestion levels, and number of TSP-equipped vehicles.

It is important to note that the benefit estimates in these reports typically relate to transit only, i.e., they do not adjust for offsetting effects on other vehicles. Wang tests for these offsetting effects and finds them to be statistically significant. However, in the case of at least one other TSP study, offsetting effects were found to be substantial, even resulting in negative net benefits in some categories.<sup>73</sup>

The other TSP studies reviewed were eliminated as candidates for nationwide extrapolation for a variety of reasons. There was a tendency among these papers, more so than in any of the other technology categories, to present *per-trip* or *per-vehicle* benefits. This should not be surprising, given that the benefits of this technology accrue to transit, a domain in which vehicle counts, trip counts, trip times, and traveler counts can be known with great precision. Moreover, as previously noted, these are reasonably intuitive and convenient ways of expressing benefits. For the purposes of the nationwide extrapolation procedure used in this report, however, they are worthless unless accompanied by fleet sizes or daily trip counts. These are typically not reported.

<sup>73</sup> Southampton University and the University of Portsmouth Transport Research Laboratory for the Hampshire County Council (1999).



# Traveler Information Systems

## Literature Methodology:

Nearly every study in this category is based on simulations, due to the inherent difficulty of isolating the relatively small effect of improvements in information from the multitude of other variables affecting aggregate measures of mobility. Simulations in this category require information or assumptions regarding the percentage of drivers who adjust their routes according to disseminated information, as well as the effectiveness of such adjustments. The Volpe Center (2008) notes

*the extreme difficulty of estimating the time-savings benefits of traveler information, as this is very context-specific. [In particular,] travelers who adjust their routes or departure times according to reports of delays and congestion sometimes save time, but often do not because of outdated information or rapidly changing conditions. (40)*

It is not immediately clear how closely the simulations capture these complexities.

Only one TIS study was found that met all the criteria for nationwide extrapolation. This was Smith and Perez (1992), which estimated a Mobility benefit of \$93,237 per DMS-year, which was extrapolated to \$543,102,791 in annual nationwide Mobility benefits.<sup>74</sup> Smith and Perez also noted 5% and 13% increases in VMT and speed, respectively, from a deployment of 74 DMS.

## Results:

**Table 19. Benefits per Unit-Year, Traveler Information Systems (\$2009/unit-year)**

Reference Information	Unit of Deployment	Mobility Benefits per Unit-Year	Total Benefits per Unit-Year
Smith and Perez (1992)	DMS	\$93,237	\$93,237

**Table 20. Annual Nationwide Benefits, Traveler Information Systems (DMS) (\$2009/unit-year)**

Reference Information	Unit of Deployment	Annual Nationwide Mobility Benefits	Total Benefits per Unit-Year	Total Benefits Nationwide
Smith and Perez (1992)	DMS	\$543,102,791	\$93,237	\$543,102,791

<sup>74</sup> It is important to note that these figures refer only to “incident-related effects” (63).

In addition to the typical scarcity of papers reporting aggregate benefits in amount form, two other issues made it particularly difficult to locate papers suitable for nationwide extrapolation in the TIS category:

- 1) Unlike the other categories studied in this report, TIS is not inherently linked to any particular type of deployment unit – whereas Ramp Metering is linked with metered ramps, TSP with intersections, ETC with plazas or lanes, etc. Moreover, due to the nature of the product being delivered, the “quantity” produced by a given technology within a study area may bear very little relation to the number of units deployed, which is often fixed at 1, as in the case of 511 systems or a website.

The only unit of TIS deployment deemed feasible for extrapolation purposes in this report was the Dynamic Message Sign, as the number of DMS deployed would seem to be strongly related to the amount of information disseminated and the amount of benefit ultimately accrued. Constraining the TIS analysis in this report to DMS effectively eliminated vast bodies of TIS literature from the pool of potential data sources.

- 2) More so than in any of the other categories, TIS studies tended to estimate the benefits of bundles of complementary technologies such as TSC (Birst and Smadi, 2000) or RM (Shah and Wunderlich, 2001). Moreover, technologies *within* the TIS category were also typically bundled together in the studies: for example, Jeannotte et al. (2001) estimate the benefits of a program that included DMS, Highway Advisory Radio, a telephone information service, and a website. It was not always possible to obtain or derive from these studies an estimate of the isolated effect of DMS.

## Summary of Results

Table 21 contains the range of annual nationwide benefit estimates for each benefit category within each technology, as calculated based on results obtained from the literature. The final two columns show the range of *total* nationwide benefit estimates for each technology, summing across all benefit categories estimated in a given paper. The table yields the following observations:

- In the Mobility category, ETC appears to produce the greatest annual benefits nationwide, with a high estimate of over \$1 billion. ETC is followed by TIS, TSC, RM and TSP in descending order.
- In the Environmental category, ETC produces positive benefits, while RM produces negative benefits due to the delay it causes on the ramps.
- Results in the Safety category are less conclusive due to the large range observed in estimates of RLC benefits. The Safety benefits of RM are in the lower part of that range.
- In the Fuel Cost category, ETC produces greater benefits than RM. RM produces negative net benefits due to the delay it causes on the ramps.

**Table 21. Summary – Annual Nationwide Benefits at 2007 Deployment Levels (\$2009)**

	Mobility		Environmental		Fuel Cost		Safety		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High
<b>ETC</b>	\$602,714,686	\$1,026,544,897	\$2,904,283	\$50,407,594	\$83,504,391	\$155,091,362	--	--	\$2,904,283	\$1,182,166,854
<b>RM</b>	\$175,051,077	\$273,619,082	-\$26,693,605	-\$26,693,605	-\$78,962,219	-\$78,962,219	\$217,736,931	\$217,736,931	\$273,619,082	\$287,132,183
<b>RLC</b>	--	--	--	--	--	--	-\$34,032,674	\$1,175,852,233	-\$34,032,674	\$1,175,852,233
<b>TSC</b>	\$276,544,507	\$276,544,507	--	--	--	--	--	--	\$276,544,507	\$276,544,507
<b>TSP</b>	\$42,260,073	\$149,986,037	--	--	--	--	--	--	\$42,260,073	\$149,986,037
<b>TIS</b>	\$543,102,791	\$543,102,791	--	--	--	--	--	--	\$543,102,791	\$543,102,791

## Nationwide Benefits over Time

Estimates of the annual nationwide benefits of each technology from 1997 to 2007 were calculated by multiplying the benefits per unit-year by the nationwide deployment counts obtained from RITA's ITS Deployment Statistics Database. This is the same calculation performed to obtain the annual nationwide benefits reported earlier, although those calculations used only 2007 deployment data. The yearly deployment figures are presented in Table 22. It is worth noting the some technologies did not begin to be captured within the survey until after 1997. There are also missing values in the deployment sequence due to years without a survey. In these instances data was filled in using the average of the previous and next year's survey results. Figure 24 and Figure 25 depict the low range and high range estimates, respectively, based on the low and high per-unit-year benefit estimates.

**Table 22. Nationwide Deployment Levels (1997-2007)**

Year	ETC-capable plazas	ETC-capable lanes	TSC intersections	TSP intersections	RLC intersections	Metered Ramps <sup>75</sup>	DMS
1997	--	1,069	50,962	--	--	2,649	--
1998	--	--	--	--	--	--	--
1999	--	--	--	--	--	--	--
2000	570	2,721	61,179	1,251	278	2,335	3,177
2001	--	--	--	--	--	--	--
2002	670	3,505	67,632	2,073	550	2,161	5,133 <sup>76</sup>
2003	--	--	--	--	--	--	--
2004	792	3,928	75,806	2,888	1,276	2,303	5,535
2005	730	3,862	73,295	--	--	1,424	5,301
2006	686	3,737	80,110	2,891	1,182	1,660	5,949
2007	590	3,501	72,255	3,214	960	2,045	5,825

The results in this section rely on the same assumptions as those in the previous section. Since these results involve the projection of benefits over many periods, they rely especially heavily on the assumption that annual nationwide benefits change over time in proportion to deployment levels, i.e., benefits per unit-year remain constant over time for each technology.

<sup>75</sup> The ramp meter deployment levels reported in RITA's ITS Deployment Statistics database for years 2005-2007 were adjusted to produce the figures that appear in Table 21. According to RITA's figures, deployment grows dramatically between 2004 and 2005 and then stays roughly constant from 2005 to 2007. This appears to be due primarily to a peculiar reported increase of over 3,000 meters for one particular agency, California Department of Transportation (Caltrans) District 7, which serves Los Angeles and Ventura Counties. It is noted that a 2007 Caltrans Ramp Metering Annual Report states a total deployment of only 870 meters. This discrepancy demonstrates that there are occasional errors that can affect the ITS Deployment Tracking reporting.

The fact that nationwide deployment remains at a similar level through 2007 may be explained by the fact that the Caltrans District 7 deployment level remains at *precisely* the same level during those years – this is likely due to the survey's use of auto-fill during these years, whereby a given agency's deployment level is reported by default to be identical to the previous year's.

It is unclear why RITA's database reported such a vast increase in 2005 for this agency. In any event, for the purposes of this report, it was deemed appropriate to make an informed adjustment to the survey data.

Thus, the figure from the 2007 Caltrans document (870 meters) was used to calculate the 2007 nationwide ramp meter deployment level reported in Table 18. The 2005 and 2006 deployment levels in Table 18 assume a linear trend in Caltrans District 7's deployment level between 2004 and 2007.

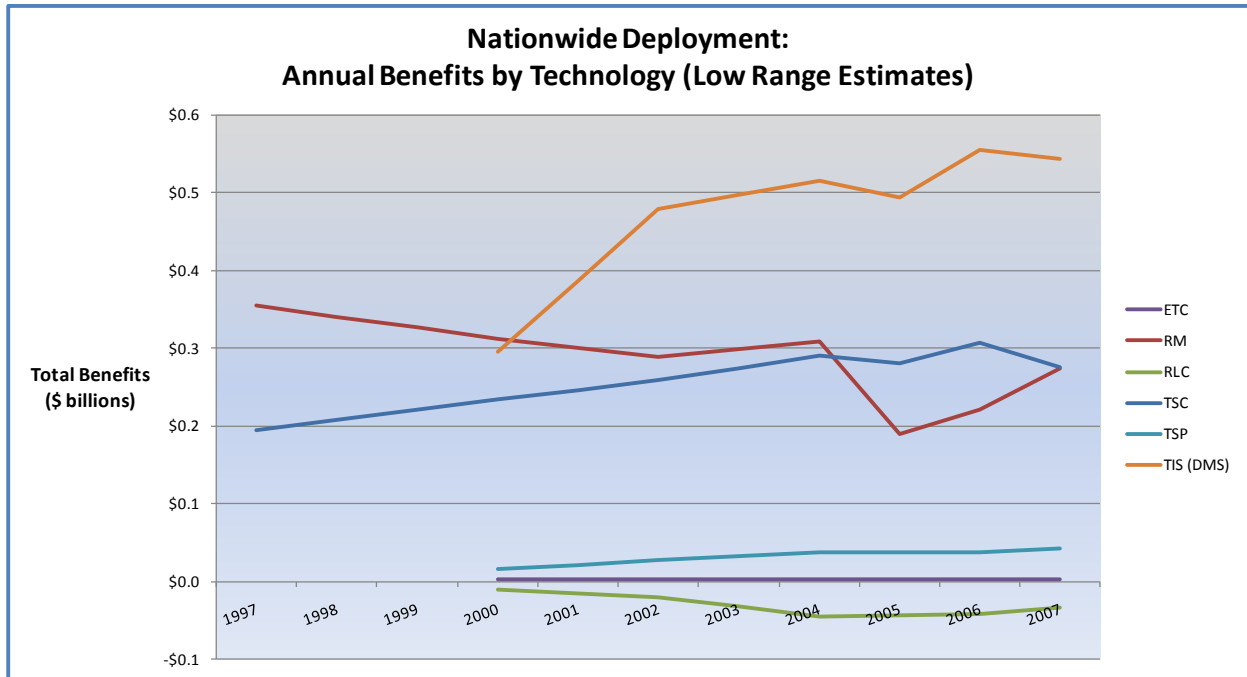
<sup>76</sup> The DMS count for this year does not include portable DMS deployed on arterials.

The high range estimates and low range estimates differ dramatically not only in terms of the magnitude of the benefits, but also in terms of the *relative* benefit levels among technologies:

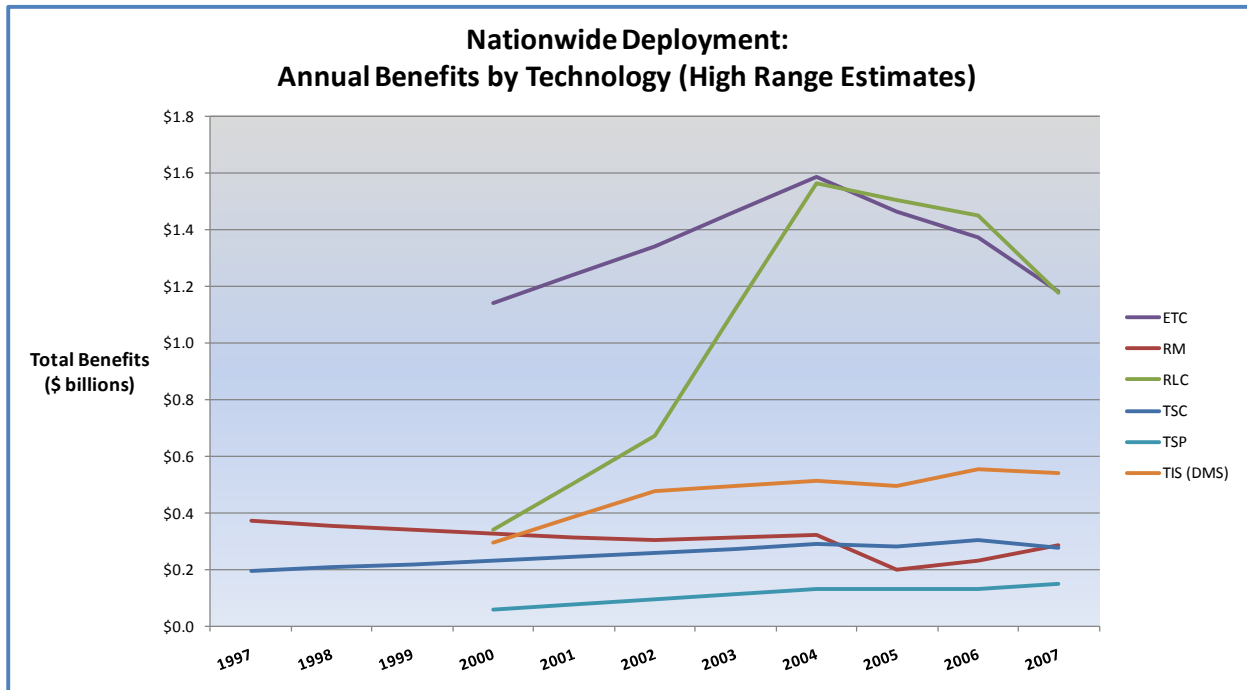
- In the low range estimates, TIS produces the highest benefits – nearly double the benefits produced by the next highest technology, TSC. It is worth noting, though, that in 2000, the first year for which TIS data were available, TIS produced slightly less benefits than RM – annual TIS benefits grew dramatically over the following years, peaking in 2006. Meanwhile, annual TSP benefits remained below \$50 million throughout the study period, ETC benefits remained below \$4 million, and RLC net benefits were negative.
- In the high range estimates, on the other hand, ETC and RLC produced the highest benefits by far. In 2007, each produced greater than double the benefits of the next highest technology, TIS. Both RM and TSC produced benefits lower than TIS generally between \$200 million and \$400 million, and they were followed by TSP, which remained below \$200 million.

Table 23 contains observations on the trends in annual benefits of each technology. As seen in Figure 24 and Figure 25, there are no common trends across technologies or high/low estimates. Indeed, in some cases benefits have been declining in more recent years, while they have remained static for others. The level of deployment plays a central role in the pattern of these benefits, so any changes in methodology or technology definitions in the survey will have a direct effect on these numbers. If these downward trends are not entirely due to survey issues, then this would yield some interesting questions that might be worth answering in future research.

**Figure 24. Benefits of ITS Technologies over Time (Low Range Estimate)**



**Figure 25. Benefits of ITS Technologies over Time (High Range Estimate)**



**Table 23. Observations on Benefit Trends, by Technology**

<p><b>Electronic Toll Collection</b></p>	<p>Annual benefits grew by around 40% between 2000 and 2004, but they have declined substantially since. The magnitude of the decline depends on which deployment metric is used for the extrapolation: the number of toll <i>plazas</i> with ETC capability has declined by more than 25%, returning nearly to 2000 levels, whereas the number of ETC <i>lanes</i> has declined by a more modest 11%. The source of the decline in deployment levels, and thus benefit levels, may be due to changes in the structure of the survey, or that it is capturing a shift towards open road tolling, whereby toll plazas are no longer required. This would be a useful subject for possible future research.</p>
<p><b>Ramp Metering</b></p>	<p>Annual benefits have remained fairly constant over time. (The apparent drop in benefits in 2005 may be related to the peculiar data for that year and the adjustment procedure described earlier in this section.)</p>
<p><b>Red Light Cameras</b></p>	<p>Annual RLC benefits doubled every two years between 2000 and 2004, but have since declined by nearly 25%. This refers to the high range of estimates, in which benefits are positive. This decline is due entirely to a decline in deployment levels. The decline may be an artifact of the survey, but may also be a result of political opposition leading to the removal of cameras. This would also present an interesting area for further investigation.</p>
<p><b>Traffic Signal Coordination</b></p>	<p>Annual benefits grew at a fairly steady pace of about \$70 million per year between 1997 and 2004, but have remained relatively constant in the years since.</p>
<p><b>Transit Signal Priority</b></p>	<p>After more than doubling between 2000 and 2004, annual benefits grew by a more modest 11% between 2004 and 2007.</p>
<p><b>Traveler Information Systems (Dynamic Message Signs)</b></p>	<p>Annual benefits grew by roughly \$100 million per year until 2003; growth has been far more modest since.</p>

## Conclusions: Benefits Estimation

This report estimated the monetized annual nationwide benefits of each of the following ITS technologies:

- Electronic Toll Collection (ETC)
- Ramp Metering (RM)
- Red Light Cameras (RLC)
- Traffic Signal Coordination (TSC)
- Transit Signal Priority (TSP)
- Traveler Information Systems (TIS) – specifically Dynamic Message Signs (DMS)

Benefits were broken down into the following four categories:

- Mobility
- Environmental
- Fuel Cost
- Safety

The results of the annual nationwide benefits calculations are summarized in Table 21. To obtain the basis for these estimates a literature review of more than 80 papers was conducted. Of these papers, 14 passed the selection criteria for use in the annual nationwide benefits calculation.<sup>77</sup> It was found that one of the most common reasons for the elimination of papers as candidates for nationwide benefits calculations was that some crucial piece of data – often a benefit stated in the form of absolute amounts as opposed to percentages – was not provided in the papers despite its presumed availability to the papers' authors. This suggested that the authors made a positive decision to exclude these numbers, perhaps thinking they were not of interest to the intended audience. In the future, if the U.S. DOT ITS Program chooses to contract out research on the benefits of ITS, the resulting report should be requested to include all data items necessary for nationwide extrapolation. This would be an effective and efficient use of funding.

The key observations from the benefits calculations are:

- In the Mobility category, ETC appears to produce the greatest annual benefits nationwide, with a high estimate of over \$1 billion per year. ETC is followed by TIS, TSC, RM and TSP in descending order.
- In the Environmental category, ETC produces greater benefits than RM. RM produces negative net benefits due to the delay it causes on the ramps.

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<sup>77</sup> The Government Accountability Office (2009) finds similar limitations in the literature on the quantified benefits of real-time traffic information systems. In particular, the GAO report notes the challenge of isolating the impacts of a particular technology, and the uncertainty involved in simulations.



- Results in the Safety category are less conclusive due to the large range observed in estimates of RLC benefits. The safety benefits of RM are in the lower part of that range.
- In the Fuel Cost category, ETC produces greater benefits than RM. RM produces negative net benefits due to the delay it causes on the ramps.

Finally, estimates of the annual nationwide benefits of each technology from 1997 to 2007 were calculated by repeating the nationwide benefits calculation using deployment counts for those years, which were obtained from RITA's ITS Deployment Statistics Database.<sup>78</sup> The high and low ranges for these benefits by technology classification are presented in Figure 24 and Figure 25. The following observations were made:

- In the low range estimates, TIS produces the highest benefits – nearly double the benefits produced by the next highest technology, TSC. It is worth noting, though, that in 2000, the first year for which TIS data were available, TIS produced slightly *less* benefits than RM – annual TIS benefits grew dramatically over the following years, peaking in 2006. Meanwhile, annual TSP benefits remained below \$50 million throughout the study period, ETC benefits remained below \$4 million, and RLC net benefits were negative.
- In the high range estimates, on the other hand, ETC and RLC produced the highest benefits by far – in 2007, each produced greater than double the benefits of the next highest technology, TIS. Next in line were RM and TSC, which were each generally between \$200 million and \$400 million, and finally TSP, which remained below \$200 million.

## Caveats

In reviewing the results of this study, several caveats need to be recognized. In particular, the benefits calculation relied critically on the assumption of a linear relationship between deployment levels and benefits. It is highly likely this assumption does not accurately represent the change in benefits as deployment increases. The level of benefits produced by a given unit of deployment may depend on factors such as technological refinements to the basic technology, existing congestion levels in the location of deployment and existing ITS deployment levels in the location of deployment. Indeed, it is quite possible that ITS deployment does not exhibit constant returns to scale. For example, if returns to scale are increasing and the study that forms the basis for extrapolation was performed early on when the deployment level was still low, then the calculation underestimates benefits; alternatively, if returns to scale are *decreasing* and the study was performed early on when the deployment level was still low, then the calculation *overestimates* benefits.<sup>79</sup>

In order to reliably determine whether returns to scale are increasing or decreasing, sample benefit estimates would be required from several points in time spread out from the earliest deployments to the most recent deployments (assuming increasing nationwide deployment levels). It was determined that the number of data points collected from the literature for this report was insufficient to achieve a credible finding regarding returns to scale.

As suggested above, the extrapolation procedure does not account for certain factors that may be sources of variation in benefit levels among individual units of deployment. These factors include:

- The magnitude of existing costs in the deployment area (annual delay, emissions, crashes, etc.)

<sup>78</sup> Deployment counts for certain years were linearly interpolated based on data from surrounding years.

<sup>79</sup> If on the other hand the study was performed fairly recently, the directions of these misestimates are reversed.

- The scale of existing ITS deployment *in the study area*
- The level of technological refinement of the ITS deployment in question

There is reason to suspect that the deployments in the studies selected for analysis in this report are not representative of all deployments nationwide in terms of these factors, in which case the results of this report would exhibit some degree of bias. These factors are discussed in the Benefit Estimation Model section of this report.

## Considerations for Future Research

The caveats discussed for this study suggest areas for possible future research. These include:

- Determinants of regional variation in annual per-unit benefits of ITS technologies.
- The relationship between deployment levels and the marginal benefit of additional units of ITS deployment, both at the local and national levels. The literature review found no specific papers on this topic, making it a promising area for future research.
- Patterns in benefit levels over the course of a technology's lifecycle, at national, metropolitan, and per-unit scales of analysis.

Additionally, research may be conducted to establish a more formal set of criteria for assessing the reliability of benefits estimations obtained both from empirical and simulation-based methods.

# Appendix: Benefits Estimation

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**Table 24. Benefit Metrics**

Metric	Metric Unit	Benefit Category	Value of One Unit Change (\$2009)
customer satisfaction	utils	Utility	--
crash reduction	crashes	Safety	\$61,819.85
injury crash reduction	injury crashes	Safety	\$28,690.44
pdo reduction	pdo crashes	Safety	\$3,170.00
Violations	violations	Safety	--
KSI (killed or seriously injured crashes)	ksi crashes	Safety	\$48,451.18
fatal crash reduction	fatal crashes	Safety	\$6,031,417.82
cost	dollars	Productivity	\$1.00
fuel consumption (cost savings)	gallons	Productivity	\$2.15
fuel consumption (comprehensive)	gallons	Productivity	\$3.10
travel time reduction	person-hours	Mobility	\$14.17
travel time reduction - passenger	person-hours	Mobility	\$13.85
travel time reduction - truck	vehicle-hours	Mobility	\$22.50
fuel consumption (emissions savings)	gallons	Environmental	\$0.95
CO	kg	Environmental	\$0.00
Nox	kg	Environmental	\$4.16
VOCs	kg	Environmental	\$1.77
CO <sub>2</sub>	kg	Environmental	\$0.0208
SO <sub>2</sub>	kg	Environmental	\$17.08
throughput increase	vehicles/hour	Efficiency	--
speed increase	mph	Efficiency	--
Ridership	persons	Efficiency	--
transit trips	trips	Efficiency	--

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*Note: Documents that were selected for use in the calculation of annual nationwide benefits appear below in bold.*

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## 7. Glossary of Terms

**actuated traffic control** – a type of *traffic signal control* based on data collected by traffic detection devices.

**advanced traffic signal control** – a class of *traffic signal control system* characterized by “real-time” optimization of a traffic network, i.e. dynamic response to current conditions. See also: *Traffic Signal Coordination*, *traffic signal control*, *traffic responsive control system*, and *traffic adaptive control system*.

**Automated/Automatic Vehicle Classification (AVC)** – a class of technology designed to determine the type and characteristics of a vehicle, for the purpose of charging an appropriate toll.

**Automated/Automatic Vehicle Identification (AVI)** – a class of technology designed to identify individual vehicles, typically using on-board tags or transponders. Applications include electronic toll collection and stolen vehicle recovery.

**Automated/Automatic Vehicle Location (AVL)** – a class of technology designed to track the location of a vehicle (typically a transit vehicle).

**AVC** – See *Automated/Automatic Vehicle Classification*.

**AVI** – See *Automated/Automatic Vehicle Identification*

**AVL** – See *Automated/Automatic Vehicle Location*

**cellular model** – a business model for firms involved in *probe based data collection*. Firms using this business model collect anonymous location data derived from cell phones. See also: *probe based data collection* and *owned and operated model*.

**central control** – a type of *traffic signal control* architecture in which local controllers perform real-time commands received directly from a *traffic management center (TMC)* (or through an intermediary unit to facilitate communication). The TMC optimizes signal timing based on data it receives from traffic detection devices. See also: *closed loop system*, *advanced traffic signal control*, and *Traffic Signal Coordination*.

**closed loop system** – a type of *traffic signal control system* in which control logic is distributed among three levels: 1) the local controller, 2) the on-street master, and 3) the central computer. The overwhelming majority of currently-deployed *traffic signal control systems* are of this type. The chief limitation of closed loop systems, compared to more advanced technologies, is that control cannot be exercised over intersections under different masters in a unified fashion, so control area boundaries cannot easily be adjusted in response to changing traffic conditions. See also: *central control*, *traffic signal control* and *Traffic Signal Coordination (TSC)*.

**competitive market** – a market in which no supplier has a great degree of market power. This situation tends to occur when there are many suppliers, few barriers facing suppliers attempting to enter the market, and little variation in the product or service offered by different suppliers. Competitive markets are often associated with low prices relative to production costs. See also: *market power*, *monopoly*, and *natural monopoly*.

**constant returns to scale** – See *returns to scale*.

**Contract carrier model** – a business model for firms involved in *probe based data collection*. It is a mix between the *cellular model* and the *owned and operated model*. The model centers on contracts with specific entities, commercial vehicle carriers for example, to provide location data. While some probe information comes from these contracts, the company can also deploy its own probes. See also: *probe based data collection*, *cellular model*, and *owned and operated model*.

**decreasing returns to scale** – See *returns to scale*.

**Dedicated Short Range Communication (DSRC)** – a technology that “allows high-speed communications between vehicles and the roadside, or between vehicles, for ITS; it has a range of up to 1,000 meters.” (USDOT, 2003)

**DMS** – See *Dynamic Message Sign*.

**downstream technology** – See *upstream/downstream technology*.

**DSRC** – See *Dedicated Short Range Communication*

**Dynamic Message Sign (DMS)** – “programmable traffic control devices that can usually display any combination of characters to present messages to motorists. These signs are either permanently installed above or on the side of the roadway, or portable devices attached to a trailer or mounted directly on a truck and driven to a desired location” (Dudek, 2004).

**economies of scale** – cost advantages associated with performing an activity on a larger scale. In particular, if a firm faces a high *fixed costs* and low *marginal costs*, then the total average cost per unit produced will decrease as more units are produced, and the firm will experience economies of scale. See also: *returns to scale*, *input cost*, *fixed cost*, *marginal*, and *natural monopoly*.

**Electronic Toll Collection (ETC)** – a “combination of techniques and technologies that allows vehicles to pass through a toll facility without requiring any action by the driver (i.e., stopping at toll plazas to pay cash)” (FHWA, 1997).

**Emergency Vehicle Preemption (EVP)** – a class of technology designed to improve emergency response time by adjusting the timing of traffic signals when emergency vehicles are approaching or stopped at them. See also: *Transit Signal Priority (TSP)*.

**end-to-end supplier** – See *vertically integrated firm*.

**environmental life-cycle analysis** – the assessment of the comprehensive environmental impact of a product and all activities associated with that product over time, including production, usage, and disposal. See also: *life-cycle cost* and *input cost*.

**equilibrium level of deployment** – See *market saturation*.

**ETC** – See *Electronic Toll Collection*

**EVP** – See *Emergency Vehicle Preemption*.

**fixed cost** – a supplier expense that does not occur on a per-unit or per-transaction basis. Examples include rent and employee salaries.

**fixed-time traffic control** – a simple type of *traffic signal control* based on a pre-programmed timer. See also: *traffic signal control*, *actuated traffic control system*.

**Herfindal-Hirschman Index (HHI)** – a measure of industry concentration, i.e. concentration of market share among a small proportion of suppliers. A higher HHI indicates greater industry concentration. The

Department of Justice considers an HHI of .18 or greater to indicate a “concentrated market.” See also: *market share*, *market power*, *monopoly*, and *oligopoly*.

**HHI** – See *Herfindal-Hirschman Index*.

**increasing returns to scale** – See *returns to scale*.

**input cost** – any supplier expense directly required for the production of a given product. (This does not include costs indirectly related to production, such as research and development.) See also: *marginal* and *economies of scale*.

**interoperability** – the ability of multiple systems to function using each other’s equipment or data output. Examples include ETC systems that can handle each other’s transponders, and air traffic control systems that can establish communication with multiple types of airborne equipment.

**knowledge spillovers** – the non-market exchange of technical knowledge and information among individuals working for different firms in the same industry, within the same city or region.

**lifecycle cost** – the sum of all costs associated with ownership of a given product, including purchase, installation, operation, maintenance, and disposal. See also: *input cost* and *fixed cost*.

**lock-in** – an effect characterized by the inability or reluctance of purchasers to switch from a given system to a competing one. Contributing factors may include long product lifecycles, high capital costs, and institutional barriers.

**marginal** – relating to the addition of one more unit. For example, the “marginal benefit” of a given ITS technology refers to the benefit of deploying one additional unit of that technology, given a certain existing level of deployment. Similarly, “marginal cost” may refer to the cost of producing one additional unit of a product, given a certain existing level of production. See also: *economies of scale* and *returns to scale*.

**market consolidation** – a shift in market structure characterized by the increasing dominance of a small number of well-established firms with high *market share*. See also: *market share*, *market power*, *oligopoly*, and *economies of scale*.

**market power** – the influence of a single firm on the market price of a given product. A firm’s market power is typically derived from its *market share*. See also: *market share*, *monopoly*, *natural monopoly*, and *oligopoly*.

**market saturation** – a condition in which all (or nearly all) potential sales of a product have already been made.

**market share** – a firm’s market share is the proportion of the market controlled by that firm. It can be expressed as the ratio of that firm’s sales to the total sales of all firms in the market. See also: *market share*, *monopoly*, *natural monopoly*, and *oligopoly*.

**monopoly** – a market in which there are many purchasers and only one supplier. Monopolies are often associated with excessive market power, high prices relative to production cost, and restricted supply. Markets that have multiple suppliers but still exhibit these properties are often referred to as “monopolistic.” See also: *natural monopoly*, *market power*, *market share*, *oligopoly*, and *monopsony*.

**monopsony** – a market in which there are many suppliers and only one purchaser. This sole purchaser may develop tremendous negotiating power over the suppliers. See also: *monopoly*.

**natural monopoly** – a market that is served by only one supplier due to inherent characteristics of the cost structure, production process, or infrastructure required to supply the product. The great *economies of scale* experienced by the existing supplier, combined with high start-up costs required for new

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suppliers, discourages new suppliers from entering the market, leaving the existing supplier perpetually uncontested. The utilities markets are an example of a natural monopoly. See also: *monopoly*, *monopsony*, *market share*, *market power*, and *economies of scale*.

**oligopoly** – a market in which there are many purchasers and only a few supplier. Like *monopolies*, oligopolies are often associated with excessive *market power*, high prices relative to production cost, and restricted supply. However, these characteristics are thought to be generally less pronounced in oligopolies than in *monopolies*. See also: *market power*, *market share*, and *monopoly*.

**open standard** – a technology or specification that is non-*proprietary* and is intended to be adopted by the overwhelmingly majority of suppliers in a market, so as to promote *interoperability*. See also: *proprietary*, *open-platform architecture and devices* and *interoperability*.

**open-platform architecture and devices:** architecture and devices that are based on an *open standard*. See also: *open standard* and *proprietary*.

**owned and operated model** – a business model for firms involved in *probe based data collection*. Firms using this business model rely heavily on data collected by their own sensors. See also: *probe based data collection*, *cellular model*, and *contract carrier model*.

**perfect competition** -- See *competitive market*.

**probe based data collection** – a type of *HDC* technology that uses various forms of cell phone tracking or GPS based tracking to locate specific vehicles as they move along the roadway. See also: *Highway Data Collection (HDC)* and *sensor based data collection*.

**proprietary** – a proprietary system or technology is one that is patented. The production and sale of proprietary systems and technologies are legally restricted to the owner of the patent, whereas nonproprietary products may be produced or sold by anyone.

**Radio Frequency Identification (RFID)** – a set of technologies that use radio frequencies to identify unique objects (e.g. vehicles) without making physical contact with them. A hardware device identifies objects based on the unique tag affixed to each one.

**Ramp Metering (RM)** – “the deployment of a traffic signal(s) on a ramp to control the rate vehicles entering a freeway facility. By controlling the rate vehicles are allowed to enter a freeway, traffic flow onto the freeway facility becomes more consistent, in essence smoothing the flow of traffic on the mainline and allowing efficient use of existing freeway capacity” (Jacobson et al., 2006).

**Red Light Camera (RLC)** – a system that automatically detects red-light violations at a signalized intersection and takes photographs of the violating vehicle in order to identify the vehicle. Law enforcement personnel may then review the photographs and send a citation to the vehicle’s registered owner.

**regressive tax** – a tax that makes up a greater proportion of income for lower-income taxpayers than for higher-income ones.

**regressiveness** – See *regressive tax*.

**remote pre-clearance** – the practice of automatically performing all necessary measurements and verifications on a truck *before* it arrives at a weigh station, so that the truck may avoid having to stop at the weigh station. See also: *Weigh-In-Motion (WIM)* and *Automated/Automatic Vehicle Identification (AVI)*.

**Request for Proposal (RFP)** – an early step in the procurement process in which the purchaser solicits proposals from sellers to supply a certain product or service. This initiates a competitive process among potential sellers.

**returns to scale** – benefits or dis-benefits associated with expanding the scale of an activity. In this report, the term typically relates to the scale of deployment of a given ITS technology. “Decreasing returns to scale” are said to exist where each additional unit of deployment produces a lower marginal benefit than the previous. Correspondingly, “increasing returns to scale” means each additional unit deployed produces a greater *marginal* benefit, and “constant returns to scale” means each additional unit produces an equal *marginal* benefit. See also: *economies of scale*, *marginal*.

**RFID** – See *Radio Frequency Identification*.

**RFP** – See *Request for Procurement*.

**RLC** – See *Red Light Camera*.

**RM** – See *Ramp Metering*.

**saturation level of deployment** – See *market saturation*.

**SCATS (Sydney Coordinated Area Traffic System)** – a *traffic responsive signal control* technique that makes real-time signal adjustments “in response to variations in traffic demand and system capacity, using information from vehicle detectors, located in each lane immediately in advance of the stopline.” See also: *SCOOT (Split, Cycle, Offset Optimization Technique)*, *traffic responsive signal control*, *Traffic Signal Coordination*, and *advanced traffic signal control*.

**SCOOT (Split, Cycle, Offset Optimization Technique)** – a *traffic responsive signal control* technique that coordinates and optimizes networks of traffic signals “based on detector measurements upstream of the intersection.” (FHWA, 2005) See also: *SCATS (Sydney Coordinated Area Traffic System)*, *Traffic Signal Coordination*, *traffic responsive signal control*, and *advanced traffic signal control*.

**sensor based data collection** – a type of *HDC* technology that typically collects traffic information through inductive loops placed at fixed points underneath the road surface. See also: *Highway Data Collection (HDC)* and *probe based data collection*.

**signal phase** – the period of time during which a traffic signal permits a given set of directional traffic flows. In other words, a signal phase for a given signal is the period of time between the beginning of a green light to the beginning of the next green light. See also: *traffic signal control* and *Traffic Signal Coordination (TSC)*.

**societal value** – the net value of a product, activity, or event, across all members of society. This includes both monetary and non-monetary costs. For example, the societal value of reducing emissions of a certain pollutant includes total monetary savings on medical care – that is, the sum of all health care expenditures prevented, regardless of who would have paid them (individuals, insurance, etc.) – as well as the intangible non-monetary value of the prevention of pain and suffering associated with pollution-related illness.

**Split, Cycle, Offset Optimization Technique** – See *SCOOT (Split, Cycle, Offset Optimization Technique)*.

**Sydney Coordinated Area Traffic System** – See *SCATS (Sydney Coordinated Area Traffic System)*.

**three-distributed computational level** – See *closed loop system*.

**time-based signal control** – a type of conventionally controlled traffic signal system that allows only for fixed, pre-determined signal control plans.

**TMC** – See *Traffic Management Center*.

**TMS** – See *Traffic Management Software*.

**traffic adaptive signal control:** a type of *advanced traffic signal control* that is capable of responding rapidly to detected traffic conditions. Traffic adaptive signal control differs from *traffic responsive signal control* in that it makes “complex adjustments” based on predictive data, rather than selecting from a “menu of signal timing plans” (Selinger and Schmidt, 2009; FHWA, 2005). See also: *traffic signal control*, *advanced traffic signal control*, *Traffic Signal Coordination*, and *traffic responsive signal control*.

**Traffic Management Center (TMC)** – a facility where traffic data and information from many sources is gathered, processed, combined, used for certain decision-making, and disseminated to public agencies, the media, and travelers. See also: *Vehicle Data Collection and Detection (VDC)* and *Traveler Information Systems (TIS)*.

**Traffic Management Software (TMS)** – a class of arterial technology that compiles information received from *VDC* devices and equipment throughout the arterial network, and implements one of several methods for coordinating and managing signals and signs accordingly. See also: *Vehicle Data Collection and Detection (VDC)* and *Traffic Signal Control (TSC)*.

**traffic responsive signal control** – a type of *advanced traffic signal control* that is capable of reacting rapidly to detected traffic conditions. Traffic responsive signal control differs from *traffic adaptive signal control* in that it “selects from a menu of signal timing plans,” rather than making “more complex adjustments” based on predictive data. (Selinger and Schmidt, 2009; FHWA, 2005). See also: *traffic signal control*, *advanced traffic signal control*, *Traffic Signal Coordination*, and *traffic adaptive signal control*.

**traffic signal control** – the practice of controlling the timing of traffic signals. See also: *fixed-time signal control*, *actuated traffic control*, and *Traffic Signal Coordination (TSC)*.

**Traffic Signal Coordination (TSC)** – a tool to provide the ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system” (Koonce et al., 2008). Outcomes are achieved through the adjustments of several key parameters related to the timing of traffic signal changes, including yield points, splits, and offsets. See also: *fixed-time signal control*, *actuated traffic control*, *traffic adaptive signal control*, and *traffic responsive traffic control*.

**Transit Signal Priority (TSP)** – a class of technology designed to improve efficiency and travel time for transit by adjusting the timing of traffic signals when transit vehicles are approaching or stopped at them. See also: *Emergency Vehicle Preemption (EVP)*.

**Traveler Information Systems (TIS)** – a class of technology designed to disseminate up-to-date or real-time information to travelers through various media, including electronic signs, personal communication devices, and the internet. See also: *Vehicle Data Collection (VDC)*, *Highway Data Collection (HDC)*, *Traffic Management Center (TMC)*, and *Dynamic Message Sign (DMS)*.

**TSC** – See *Traffic Signal Coordination*

**TSP** – See *Transit Signal Priority*.

**upstream/downstream technology** – These terms relate to the role of a technology within the larger process of producing and delivering a product or output to an end user. Upstream technologies are designed for tasks that can be thought of as “further” from the end user, e.g. data collection and



processing; downstream technologies are designed for tasks that can be thought of as “closer” to the end user, e.g. dissemination of traffic information.

**VDC** – See *Vehicle Data Collection and Detection*.

**Vehicle Data Collection and Detection (VDC)** – a class of arterial technologies designed to collect vehicle-related data, such as traffic volumes, vehicle classification, speed, density, and occupancy. These data are collected using devices such as loop detectors, cameras, and radar sensors. See also: *sensor based data collection* and *probe based data collection*.

**vertically integrated firm** – a firm that controls all (or a large portion) of the components or steps involved in producing or supplying a given product or service. In the ITS industry, an example would be a supplier of TMS that also produces and sells the hardware and equipment required to collect necessary data and operate the software. See also: *input cost*.

**Weigh-in-Motion (WIM)** – a class of technology designed to weigh vehicles without requiring them to stop. See also: *remote pre-clearance*.

**WIM** – See *Weigh-in-Motion*.