# NYSERDA TRANSPORTATION PROGRAM
# CASE STUDY:

# KLD’s Adaptive Control Decision Support System for Traffic Management

***Final***

Prepared For:

**New York State Energy Research and Development Authority (NYSERDA)**
Albany, NY

Jennifer Phelps, NYSERDA Project Manager

Prepared By:

**Industrial Economics, Incorporated (IEc)**
Cambridge, Massachusetts

Cynthia Manson, Project Manager

NYSERDA Contract 32883 January 2017

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# 1. Introduction

In 2013, New York State's transportation sector consumed more than 1,032 trillion Btus of energy, or 43 percent of the total energy consumed in the state. Approximately 92 percent of transportation energy consumption came from petroleum products. As a result of its reliance on the combustion of petroleum products, New York's transportation sector was responsible for 75 million metric tons of $CO_2$-equivalent emissions in 2013, or 42 percent of all fuel-borne greenhouse gas emissions in the state.[1]

Within this context, NYSERDA's Transportation Program has identified several objectives:

- To reduce and diversify the energy consumed by the transportation sector;
- To minimize greenhouse gas emissions; and
- To create economic development opportunities in New York State.[2]

The current Transportation Program builds on decades of research conducted with state and federal funding. Beginning in 2016 with the transition to NYSERDA's Clean Energy Fund (CEF), the Transportation Program adopted three focus areas: electric vehicles, public transportation, and mobility management. The project described in this case study – KLD Associates' Adaptive Control Decision Support System for Traffic Management – aligns with the mobility management focus area.

Adaptive traffic controls are software systems that change or adapt traffic signal timing across multiple intersections based on real-time detection of traffic flow. In contrast, fixed-time systems change signal timing according to preset schedules (e.g., weekday rush hour vs. mid-day), and actuated systems change signal timing based on vehicle detection at a single intersection (e.g., maintaining a green light on the busiest street until a vehicle approaches on the cross street). Adaptive traffic controls offer several benefits over those of fixed-time or actuated systems by optimizing traffic flow, including that of vehicles, bicycles, and pedestrians, in areas where traffic patterns are highly variable. Examples of these benefits include:

- Improved traffic flow and associated reductions in travel time, congestion, fuel consumption, and air pollution;
- Shorter wait times for pedestrians as a result of real-time detection;
- Increased ability to grant priority to public transit and emergency vehicles by changing signals along transit routes instantaneously; and

[1] The remaining 58 percent of emissions from fuel consumption are associated with the residential (18 percent), commercial (13 percent), industrial (six percent), and electric generation (22 percent) sectors. NYSERDA. 2015. Patterns and Trends – New York State Energy Profiles: 1999–2013. October 2015. http://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Patterns-and-Trends.

[2] NYSERDA. 2015. Transportation Program: Product Development, Product Demonstration, and Product Deployment, Program Theory and Logic Model Report. August 2015.

- Reduced effort and field exposure required to set and maintain signal timings, and associated risk reductions for engineers and technicians.

As shown in Exhibit 1, NYSERDA funded multiple traffic control system projects between 1999 and 2016. The focus of this case study, however, is an adaptive control commercialization project carried out by KLD Associates (KLD) between 2011 and 2014. During those four years, KLD, a traffic and transportation engineering company headquartered in Islandia, New York, received $376,347 in funding from NYSERDA to enhance, generalize, and commercialize its Adaptive Control Decision Support System (ACDSS), which was originally developed in 2011 for use in New York City.

**Exhibit 1. Traffic Control System Projects Funded by NYSERDA**

| Year | Project | Funding Amount |
|---|---|---|
| | **Product Development Projects** | |
| 1999 | **KLD** developed the IMPOST (Internal Metering Policy to Optimize Signal Timing) traffic control algorithm. (With separate funding from NYCDOT, KLD later expanded upon IMPOST to develop ACDSS.) | $275,000 |
| 2000 | Building on its previously developed signal timing method, "Alternate Time Band Sequence (ABTS) Method for One-Way Arrivals," **Traftek, Inc.** pursued efforts to formulate the ABTS signal timing policy for two-way street networks and develop a software product suitable for wide-scale deployment. This project was not completed. | $215,705 |
| 2005 | **KLD** developed a graphic user interface for IMPOST to support future commercialization efforts of the program. | $100,000 |
| 2011 | **KLD** enhanced and generalized ACDSS to be capable of commercial deployment in a wide range of traffic management systems. | $376,347 |
| | **Demonstration Projects** | |
| 2012 | **Rhythm Engineering** demonstrated the InSync adaptive control system on Long Island. The project was decommissioned due to site concerns. | $274,702 |
| 2014 | **TransCore** installed SCATS (Sydney Coordinated Adaptive Traffic System), another adaptive control program, along a busy commuting and retail arterial in White Plains, NY, to demonstrate the benefits of the system. | $249,082 |
| | **Decision-Making Tool Projects** | |
| 2016 | **Rensselaer Polytechnic Institute (RPI)** created a tool to help decision-makers decide whether adaptive control is appropriate for a given corridor or intersection. | $75,000 |

ACDSS is an evolution of IMPOST (Internal Metering Policy to Optimize Signal Timing), a traffic control algorithm created by KLD with funding from NYSERDA in 1999 and expanded with NYSERDA funding in 2005. Following those projects, KLD developed ACDSS with funding from the New York City Department of Transportation (NYCDOT) for use in New York City's "Midtown in Motion" project, which aimed to reduce congestion in Midtown Manhattan by enabling real-time traffic management. ACDSS improves traffic flow by optimizing traffic signal patterns to respond to changing traffic volumes, as determined by strategically placed detectors (e.g., sensors, video cameras, E-ZPass readers). The software can be set up to run autonomously or, if desired, to require approval for traffic signal changes from a centralized traffic control operator (see Exhibit 2). The Midtown in Motion project was highly successful, as KLD reported reductions in drivers' annual fuel consumption of 89,000 gallons and a 10 percent improvement in travel time on streets within the 110-block project area following ACDSS implementation.[3]

**Exhibit 2. Conceptual Diagram of ACDSS Operation**

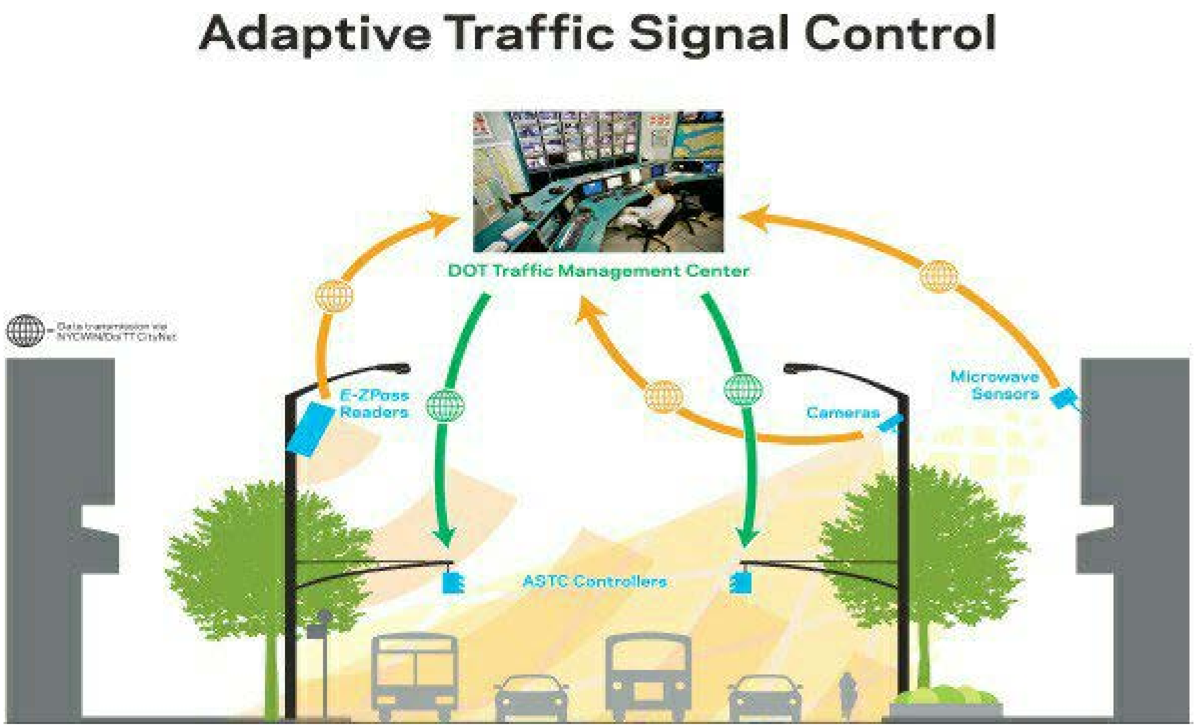


**Image source: The City of New York Office of the Mayor. "Mayor Bloomberg announces new, real-time traffic management system to reduce congestion in Midtown Manhattan." Press release, July 18, 2011.**

KLD's final project report to NYSERDA indicates that the company was able to generalize the ACDSS system's interfaces and functionalities, prepare industry-standard documentation and installation guides, and successfully commercialize ACDSS, culminating with deployment to a number of cities outside of New York City. Although many other adaptive traffic management tools are already on the market (see Section 2.2), ACDSS offers increased flexibility as a result of its ability to interface with a wide range of hardware systems and operate either autonomously or with input from a centralized traffic control operator.

To support commercialization of ACDSS, in addition to providing funding for development efforts, NYSERDA helped to connect KLD with its current business partner TransCore, a transportation logistics software and service company. TransCore is currently responsible for marketing ACDSS, which can be easily integrated with TransCore's widely-used TransSuite Advanced Traffic Management System.

Exhibit 3 provides additional detail on the focus of this case study. In particular, the primary intent is to understand the market development impacts of the project, including benefits achieved to date and the potential for future benefits in other market segments or applications.[4]

[3] NYSERDA. 2013. Enhancement and Generalization of Adaptive Control Decision Support System into a Commercial ITS Solution - Final Report. August 2013.

**Exhibit 3. Evaluation Scope**

| Evaluation Question | Data Sources and Analytic Methods |
|---|---|
| 1. To what extent did KLD leverage non-NYSERDA investment? | • Review of the information provided by KLD to NYSERDA as part of NYSERDA's standard follow-on reporting requirements<br>• Interviews with TransCore, KLD, and NYSERDA<br>• Verification of findings using market research, information provided by the New York State Department of Transportation (NYSDOT), and interviews with the acting chair of White Plains' Transportation Commission and Dr. Yeganeh Hayeri and Dr. Costa Samaras, experts in traffic management systems |
| 2. How many ACDSS installations are there within and beyond New York State? | |
| 3. To what extent are decision-makers aware of adaptive control technologies, including ACDSS, and their benefits? | • Online market research<br>• Interviews with TransCore, KLD, NYSERDA, the acting chair of White Plains' Transportation Commission, and Dr. Yeganeh Hayeri and Dr. Costa Samaras<br>• Through parallel market characterization effort, survey of transportation companies in New York State about their interest in and use of connected infrastructure |

The following sections of this report discuss the evaluation questions, methods, and findings in detail. Section 2 summarizes the results of the case study analysis for each of the three evaluation questions listed in Exhibit 3. Section 3 then examines the strategic implications of those findings, including the potential for successful adaptive control traffic system projects in new markets, effective approaches that NYSERDA can build on, and remaining barriers to the adoption of adaptive traffic control systems that NYSERDA could address. Section 3 also proposes additional metrics that NYSERDA could use to evaluate future projects, in the context of rapidly evolving technologies and market conditions.

[4] This case study is part of a suite of six case studies with an overall purpose of: (1) highlighting important transportation research and development accomplishments in New York State; (2) understanding the role that the Transportation Program played in achieving those outcomes; and (3) informing Transportation Program strategy by identifying effective approaches that NYSERDA can build on and remaining market barriers to address.

# 2. Project Outcomes

The following sections discuss each of the three evaluation questions in detail. First, Section 2.1 highlights the extent to which KLD leveraged non-NYSERDA investment to continue or expand the company's efforts. Section 2.2 then discusses ACDSS deployment to date and remaining barriers to widespread adoption. Finally, Section 2.3 describes the extent to which decision-makers are aware of adaptive control technologies in general, and ACDSS in particular.

## 2.1 Leveraged Investment

This evaluation first considered the extent to which KLD leveraged non-NYSERDA investment to continue or expand its efforts. Interviews with KLD clarified that ACDSS itself arose out of leveraged investment. KLD leveraged external investment from NYCDOT to expand upon its initial work with NYSERDA on IMPOST (Internal Metering Policy to Optimize Signal Timing); with NYCDOT's support, KLD created the original ACDSS, tailored for Midtown Manhattan. The original ACDSS for Manhattan covered 110 blocks and enabled traffic engineers in the city's Traffic Management Center to identify and unplug bottlenecks to smooth the flow of traffic. As part of the ACDSS deployment, 100 microwave sensors, 32 traffic video cameras, and E-ZPass readers at 23 intersections were used to measure traffic speeds.[5]

Following the ACDSS deployment in Manhattan, NYSERDA invested additional resources to assist KLD with commercialization of the system for other locations. NYSERDA's funding was used to generalize the ACDSS interface and software. The commercialized version of ACDSS allows for dual modes of operation (e.g., autonomously or with an operator behind the controls, as was used in Manhattan) and, key to its successful commercialization, can interface with a range of hardware systems. This allows ACDSS to operate within and across jurisdictions with different traffic management systems and equipment.

In addition to leveraging the initial investment to create ACDSS, KLD was also able to leverage TransCore's extensive sales network to commercialize and deploy the system. This relationship was particularly important as KLD did not have established product marketing experience or a network large enough to ensure successful deployment, whereas TransCore was already an industry leader with sales of a competing adaptive control system, SCATS, and TransCore's own TransSuite traffic management software.[6] Since then, TransCore has integrated ACDSS into its TransSuite intelligent transportation systems (ITS) package and continues to market the two systems together; as described in the next section, ACDSS deployments are widespread, extending across the country and to international locations. However, the market for adaptive traffic control technologies remains crowded, with many similar products available. Illustrating this point is the fact that TransCore continues to market both ACDSS and SCATS.

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[5] New York City Department of Transportation. 2012. NYC DOT Announces Expansion of Midtown Congestion Management System, Receives National Transportation Award. June 2012. http://www.nyc.gov/html/dot/html/pr2012/pr12_25.shtml

[6] SCATS is an older adaptive control system that has been in use for decades. In contrast to ACDSS, which is designed to work with a variety of hardware systems, SCATS requires specific hardware to be installed.

KLD has also been able to leverage its position in the adaptive traffic control market to explore broader traffic management opportunities. KLD noted that NYSERDA's support has given KLD the credibility to be a key, respected market player beyond adaptive control products and independent of TransCore. As a result, KLD is now expanding its business into new technologies. As one example, NYSERDA and NYSDOT are currently working with KLD (independent of TransCore) to test the feasibility of using connected vehicles and adaptive controls to enable "eco-driving" (e.g., optimizing acceleration and deceleration with respect to downstream traffic signals to decrease fuel consumption and emissions) in New York City and Arcadia, CA.[7]

## 2.2 ACDSS Installations

As a result of its partnership with TransCore, KLD has successfully deployed ACDSS both nationally and internationally. To date, since the end of NYSERDA's funding, the system has been installed at more than 370 intersections across the U.S., in the following locations:[8]

- Multiple locations in Staten Island, NY, including along Victory Blvd. and Bayonne Bridge
- Manhattan, NY
- Arcadia, CA
- St. Louis, MO
- Overland Park, KS

An additional 395 intersections, located both within and beyond the U.S., will use ACDSS by the end of 2016. These include additional locations in New York City and Arcadia, CA, as well as new installations in Flushing, NY, and Riyadh, Saudi Arabia.[9] ACDSS has potential for further expansion in areas with variable, high-volume traffic patterns, such as municipalities with busy downtown areas, stadiums, concert venues, and airports.

There are however, barriers to adaptive control system installation, none of which are specific to ACDSS:

- **Licensing and installation costs may be high for some municipalities,** especially at a time when municipal transportation budgets are limited.[10] According to research conducted by Rensselaer Polytechnic Institute (RPI), upfront costs for adaptive control systems can range from \$20,000 to \$80,000 per intersection.[11] The U.S. Department of Transportation conducted a survey of adaptive traffic control system users in 2010 and found that the median installation cost was

[7] NYSERDA. 2016. Connected Eco-Driving for Adaptive Signal Control. March 16, 2016.

[8] Interview with William McShane, CEO of KLD Associates. Conducted June 13, 2016.

[9] Ibid.

[10] Interview with Tom Soyk, Acting Chair of the White Plains Transportation Commission. Conducted July 21,2016.

[11] Rensselaer Polytechnic Institute, Department of Civil and Environmental Engineering. 2016. Decision-Making Tool for Applying Adaptive Traffic Control Systems, Final Report. Report Number 16-12. Prepared for NYSERDA. March 2016. (6)

approximately $45,000 per intersection.[12] Routine system maintenance for all types of adaptive control systems may incur additional costs.

- **Benefits of adaptive control systems do not accrue directly to the municipalities investing in those systems**. Instead, drivers, who may come from other municipalities, benefit most directly from fuel savings, travel time reductions, and other quality-of-life improvements. Municipalities may therefore have difficulty justifying the costs of installing adaptive control systems, particularly at intersections where a high proportion of drivers come from other jurisdictions.

- **Traffic signal management is not standardized across municipalities**; for example, police departments manage traffic signals in some municipalities while professional engineers manage traffic signals in other municipalities. The installation of adaptive controls over a large area or across municipal boundaries therefore requires coordination with multiple stakeholders in multiple jurisdictions. Furthermore, installations in all municipalities are likely to require coordination with NYSDOT, which typically manages traffic signals on state roads. This level of regional coordination may be difficult for municipalities to pursue.

In addition to barriers to adaptive control systems in general, current market conditions may, in some cases, delay further ACDSS adoption. The adaptive traffic management landscape is evolving quickly, with many competitors and potentially disruptive emerging technologies, such as connected vehicles. In particular, the crowded market serves as a barrier to deployment of ACDSS. RPI summarized nine currently available systems in a recent report to NYSERDA (Exhibit 4). Several of these systems, such as SCATS, have been in use for decades and thus benefit from widespread familiarity. In addition, one interviewee noted that the uncertain landscape surrounding connected infrastructure has delayed investments in adaptive control systems as some municipalities opt to postpone investment until they know how emerging technologies will interface and interact with different traffic control systems.[13]

[12] U.S. Department of Transportation. Intelligent Transportation Systems Joint Program Office, Knowledge Resources. "Costs Database." http://www.itscosts.its.dot.gov/ITS/benecost.nsf/ID/5A53F0D1919AA5EE8525798300819B6E?OpenDocument&Query=CApp.

[13] Interview with Yeganeh Hayeri, Assistant Professor at Stevens Institute of Technology's School of Systems and Enterprises. Conducted June 14, 2016.

**Exhibit 4. Comparison of Mainstream Adaptive Traffic Control Systems**

| Adaptive System | Goal |
|---|---|
| ACS-Lite | Adjusts timing on a cycle basis |
| Adaptive Control Decision Support System (ACDSS) | Minimizes delay, manages queues, provides diamond interchange control via switchable plug-ins |
| Automated Traffic Surveillance and Control (ATSAC) | Adjusts timing on a cycle basis |
| InSync | Minimizes queues and delay time |
| QuicTrac | Minimizes delay, congestion via local volume collecting data controllers |
| Real Time Hierarchical Optimized Distributed Effective System (RHODES) | Responds to natural behavior of traffic flow |
| Split Cycle Offset Optimization Techniques (SCOOT) | Minimizes delay with relative importance on stops |
| Sydney Coordinated Adaptive Traffic System (SCATS) | Minimizes delay, stops, and travel time |
| TranSuite | Minimizes delay, stops, and travel time |
| Source: Rensselaer Polytechnic Institute, Department of Civil and Environmental Engineering. 2016. Decision-Making Tool for Applying Adaptive Traffic Control Systems, Final Report. Report Number 16-12. Prepared for NYSERDA. March 2016. Table 1. | |

## 2.3 Decision-Maker Awareness

Online research and interviews with KLD, TransCore, the White Plains traffic commissioner, and two experts in transportation management systems confirmed that decision-makers are generally aware of the benefits and costs associated with adaptive traffic control systems and view these systems as a viable method to address congestion issues. Many decision-makers are also aware of ACDSS specifically, as a result of its inclusion in TransCore's suite of ITS products.

Decision-makers recognize that systems like ACDSS provide benefits, such as decreasing traffic delays, and understand the locations in which adaptive traffic control systems are likely to achieve the greatest benefits (e.g., locations with highly variable traffic patterns, high pedestrian volumes, difficulty maintaining conventional traffic signal timing sequences, and a centralized traffic system operator). They also understand the primary challenges – cost and interoperability – associated with adaptive control systems. In response to decision-makers' interest, city transportation agencies are beginning to request modular, plug-and-play traffic signal systems so that adaptive traffic controls can be more easily integrated into existing traffic signal systems.

Interviews did highlight three areas where decision-makers could benefit from additional knowledge:

- **Investment in operator training:** Municipal traffic departments need to recognize that adaptive traffic controls cannot immediately address issues related to traffic delays, and may in some cases require time and resources for the traffic operator to learn to operate the program.

- **Investment in detector technology:** It is essential for municipalities to recognize that the effectiveness of adaptive control systems depends heavily on the reliability of the detection systems used, such as sensors or live video feed. One interviewee noted that, in his experience, having live video feed of traffic conditions was particularly important for traffic operators to feel comfortable using the adaptive control system to modify traffic signals.[14]

[14] Interview with Tom Soyk, Acting Chair of the White Plains Transportation Commission. Conducted July 21,2016.

- **Potential implications of emerging technologies:** The emergence of new technologies, such as connected vehicles, is changing market conditions and may therefore influence long-term planning decisions. As municipalities invest in traffic control infrastructure, it will be important for decision-makers to understand how these technologies are likely to interface with adaptive controls.

Concurrently with this case study, NYSERDA's Transportation Program conducted a market characterization survey to explore the interests and priorities of the transportation market in New York State. This survey provides additional detail on decision-makers' awareness and interest in connected infrastructure, which includes adaptive traffic controls. Of the 109 responses received, 16 companies active in the New York State transportation market indicated that they currently work on or use connected infrastructure. An additional 26 companies expressed interest in working with the technology. Complete survey results will be provided in a separate report.

## 2.4 Overall Results

Overall, KLD successfully used NYSERDA's funds to generalize the ACDSS to operate in areas outside of Manhattan. KLD also successfully leveraged non-NYSERDA resources to deploy ACDSS at more than 770 intersections by the end of 2016. This success can be largely attributed to KLD's partnership with TransCore, which was developed following an introduction by NYSERDA, and the interoperability of ACDSS compared to its competitors (such as SCATS), which allows it to work with a variety of municipal traffic management systems. The level of awareness and interest of decision-makers in adaptive control technologies suggests that there is potential for further deployment of ACDSS.

Because the market for traffic control technologies is evolving quickly, particularly related to connected vehicles and infrastructure, NYSERDA and its partners have had to expand their work beyond adaptive controls to focus on the potential interactions between multiple communications-based technologies. For example, NYSERDA and NYSDOT are currently working with KLD to pursue a project that tests the use of connected vehicles with adaptive controls in New York City and Arcadia, CA.[15]

[15] NYSERDA. 2016. Connected Eco-Driving for Adaptive Signal Control. March 16, 2016.

**Exhibit 5. Results Summary**

<table>
<tr><th>Progress Achieved</th><th>Gaps in Achievement</th></tr>
<tr><td colspan="2">Evaluation Question 1: To what extent did KLD leverage non-NYSERDA investment?</td></tr>
<tr><td>Midtown in Motion demonstrated KLD’s ability to leverage external investment for adaptive control technologies. Since then:<br>• NYSERDA connected KLD with TransCore, allowing KLD to leverage TransCore’s sales network to deploy ACDSS.<br>• NYSERDA’s funding provided KLD with the credibility needed to become a key market player. KLD has since expanded its work to include connected vehicles.</td><td>The crowded market for adaptive controls, which includes competitor technologies also marketed by TransCore, limits the potential deployment of ACDSS.</td></tr>
<tr><td colspan="2">Evaluation Question 2: How many ACDSS installations are there within and beyond New York State?</td></tr>
<tr><td>More than 370 intersections across the U.S. currently use ACDSS, and an additional 395 intersections, both in the U.S. and internationally, will install ACDSS by the end of 2016. These installations are or will be located in.:<br>• New York City, NY<br>• Flushing, NY<br>• Arcadia, CA<br>• St. Louis, MO<br>• Overland Park, KS<br>• Riyadh, Saudi Arabia</td><td>Remaining barriers to deployment, which are not specific to ACDSS, include:<br>• High cost - Installation requires significant investment for licensing and maintenance. DOT estimated average cost per intersection of $40,000 in 2010; RPI’s 2016 decision-making tool analysis estimates average cost of $20,000 to $80,000 for various systems.<br>• Benefits and costs accrue to different parties - Although the benefits of adaptive control systems have been proven, these benefits generally accrue to drivers, not municipalities.<br>• Multi-jurisdiction collaboration - Traffic signal management is not standardized across jurisdictions, requiring coordination between multiple stakeholders across municipalities.<br>Barriers specific to ACDSS deployment include the highly competitive and quickly evolving market for adaptive and connected infrastructure.</td></tr>
<tr><td colspan="2">Evaluation Question 3: To what extent are decision-makers aware of adaptive traffic control technologies, including ACDSS, and their benefits?</td></tr>
<tr><td>Decision-makers are generally aware of the benefits and challenges associated with adaptive control systems:<br>• Adaptive controls are understood to work best in locations with:<br>o Highly variable traffic patterns<br>o Difficulty maintaining conventional signal timing sequences<br>o Safety concerns (e.g., high pedestrian volumes)<br>o A centralized traffic operator<br>• To address cost and interoperability challenges, transportation agencies are beginning to design systems to be modular (“plug-and-play”).</td><td>Decision-makers could benefit from additional knowledge sharing in three areas:<br>• Using adaptive traffic controls may require time for training to learn how to operate the system.<br>• The effectiveness of adaptive control systems depends on the reliability of detection systems used (e.g., sensors, video).<br>• Emerging technologies (e.g., connected vehicles) are changing market conditions and may influence long-term planning.</td></tr>
</table>

# 3. Strategic Implications

The results of this case study indicate that there are several effective approaches NYSERDA can build on for future traffic management projects. To best support the expansion of adaptive traffic control systems, NYSERDA could:

- **Focus on communities with variable traffic patterns and the ability to coordinate regional transportation efforts:** Adaptive traffic controls may not be appropriate for all communities. Among communities interested in pursuing adaptive control, NYSERDA should focus on those that have:
    - Variable traffic patterns and/or safety concerns (e.g., stadiums/event centers, airports, retail centers, highway interchanges);
    - Difficulty maintaining conventional signal timing sequences;
    - Centralized traffic operators to learn and manage the adaptive system; and
    - Experience coordinating regional transportation efforts.

- **Support holistic traffic management, recognizing that adaptive control systems are one of many options available to municipalities:** Because adaptive traffic controls may not be appropriate for all communities, NYSERDA could work with interested communities to improve traffic flow and reduce fuel consumption by using a variety of lower-cost options. Municipalities have a number of traffic management tools available to them, including:
    - Retiming traffic signals to better align with daily traffic patterns (e.g., morning rush hour, afternoon, evening rush hour, and off-peak);[16]
    - Coordinating traffic signals across intersections and municipalities;[17]
    - Scheduling routine maintenance of traffic detection equipment;[18] and
    - Changing traffic signals (e.g., introducing flashing yellow left turn arrows at intersections).[19]

- **Communicate the societal benefits of traffic improvements to decision-makers as a way of justifying investment:** While the cost of adaptive traffic control systems can be high, the benefits to society of these systems may outweigh the cost. A key challenge, however, is that many of these benefits do not accrue directly to the municipalities investing in the system. Instead, drivers (perhaps from other municipalities) benefit most directly from travel time reductions and other quality-of-life improvements. Existing data sets may help to communicate some of these benefits

[16] U.S. Department of Transportation – Federal Highway Administration. 2002. Managing Traffic Flow through Signal Timing. January/February 2002. https://www.fhwa.dot.gov/publications/publicroads/02janfeb/timing.cfm

[17] U.S. Department of Transportation. 2003. By Implementing Coordinated Signal Timing on the Arterial Network in Syracuse, New York Total Fuel Consumption was Reduced by 9 to 13 Percent, Average Fuel Consumption Declined by 7 to 14 Percent, Average Vehicle Emissions Decreased by 9 to 13 Percent. September 2003. http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/A9953A0DFDDA7B4885256E9B0052FB24

[18] University of Southern California. 2016. Traffic-Actuated Signals. October 2016. http://illumin.usc.edu/197/traffic-actuated-signals/

[19] New York State Department of Transportation. 2011. Introducing the Flashing Yellow Left Turn Arrow. 2011. https://www.dot.ny.gov/regional-offices/region9/repository/InfoSheet2.pdf

to municipalities interested in improving residents' quality of life. For instance, a 2014 study from the Texas A&M Transportation Institute estimates that the value of travel delay is $17.67 per hour of person travel and $94.04 per hour of truck travel.[20] These figures can be multiplied by the estimated reduction in travel time resulting from the use of adaptive controls or other traffic management systems to estimate societal benefits. While these benefits will not accrue directly to the municipal departments that are investing in the system, quantification may help to better communicate the magnitude of the benefits to decision-makers.

- **Encourage partners to develop technologies that respond to changing market dynamics:** Interviews with KLD and TransCore confirmed that the market for adaptive control systems is evolving rapidly as new technologies emerge. NYSERDA should continue its current efforts to support the development of technologies that respond to these changing market dynamics (e.g., KLD's integrated adaptive traffic control and connected vehicle project). By doing so, NYSERDA's partners can stay competitive and continue to leverage resources to explore new technologies.

Although the three evaluation questions considered in this case study provided a high-level overview of program impacts, NYSERDA could consider tracking additional metrics to evaluate the success of future adaptive traffic control projects, particularly in regards to the consideration of emerging technologies. Specifically, NYSERDA could ask project partners to report on their progress in:

- Entering a new market (e.g., feasibility studies or demonstrations completed; business models developed);
- Disseminating information and facilitating knowledge sharing for long-term planning (e.g., reports published; participation in steering committees, focus groups, and/or conferences); and
- Reducing installation costs for adaptive control systems through improved technology interoperability, modular design, innovative detection methods, or other strategies.

Overall, the lessons learned from KLD's development and deployment of ACDSS suggest that NYSERDA can build on and expand traffic management efforts in municipalities across the state to improve travel efficiency and reduce fuel consumption associated with delays. The market for traffic management technologies is changing rapidly, however, so to be most effective, NYSERDA should encourage its partners to work towards innovative, holistic traffic management solutions. Given the rapid evolution of the market, technology solutions should also prioritize interoperability and flexibility (e.g., modular design), as successfully demonstrated by KLD's ACDSS.

[20] Texas A&M Transportation Institute. 2015. 2015 Annual Urban Mobility Scorecard. August 2015. https://mobility.tamu.edu/ums/

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