IBM’s Smarter Cities Challenge

Boston

Report

IBM

Contents

1. Executive summary

Introduction

Boston, Massachusetts, was one of the 33 cities selected to receive a Smarter Cities® Challenge grant from IBM in 2012 as part of IBM's citizenship efforts to build a Smarter Planet™. Since the program's inception in 2010, more than 40 cities have received Smarter Cities Challenge grants, and many have already made great progress on the road to becoming more instrumented, interconnected and intelligent. During three weeks in June 2012, a team of six IBM experts worked to deliver recommendations on a key challenge identified by Mayor Thomas M. Menino and his senior leadership team: help achieve Boston's climate and traffic improvement goals by unlocking, sharing and analyzing transportation data.

The challenge

Boston collects a significant amount of data from many sources that could be quite useful to researchers, developers, transportation engineers, urban planners and, above all, citizens. This data, though, often is isolated in various departments, exists in multiple formats and is not fully exploited. To achieve its climate and transportation goals, Boston needs timely, local, accurate information about city transportation conditions.

Specific transportation challenges include:

- **Reducing carbon emissions** associated with automobile travel: Boston's automobile traffic accounts for about 25 percent of the city's carbon emissions. The mayor's Climate Action Plan[6] calls for significant greenhouse gas reduction.
- **Analyzing and reducing vehicle miles traveled (VMT):** This contributes to reducing traffic congestion and carbon dioxide (CO_2) emissions.
- **Providing data for residents** to make intelligent choices about transportation alternatives: With access to reliable transportation information, citizens can make more intelligent decisions about their travel alternatives, including ones that can reduce VMT, such as bicycles, public transit and walking. These, in turn, can reduce traffic congestion and advance climate goals.

The underlying challenge involves unlocking, sharing and analyzing multi-modal transportation data, along with visualization to communicate information to the public and various stakeholders, especially:

- **Manual traffic count data at intersections:** This data currently does not exist in a consumable digital form; hence, it is not standardized, shared or easily accessible.
- **Inductive loop traffic count data:** This data currently is not shared or analyzed. As a result, it is not exploited to its full potential and is not accessible to citizens and others.
- **Camera video data:** This data currently is not shared, and often is not recorded or analyzed, therefore camera data is not fully leveraged.

Although various City stakeholders have their own missions and momentum, the benefits of unlocking, sharing and analyzing data offer motivation to overcome any organizational barriers.

Overview of findings and recommendations

Based on extensive interviews and discussions with about 75 key participants, the IBM Smarter Cities Challenge team found that individual departments within the City of Boston government are focused on their mission to provide particular services to constituents. As is the case in many cities, Boston's departments tend to manage their own data for their own purposes, missing many benefits that would come from sharing their data more broadly. Requirements and desires vary widely across organizations, from straightforward improvements to sophisticated analytics:

- The Mayor's Office of New Urban Mechanics values innovation and is eager to have a prototype to demonstrate to citizens.
- Two organizations within the Boston Transportation Department are key stakeholders:
  - The Policy and Planning organization desires shared multi-modal data to make better, more data-driven policy decisions and a friendlier, standard method for managing the manual traffic count process.
  - The Traffic Management Center receives inductive loop and video camera data but uses an intentionally isolated network (because of the critical nature of traffic signal control), so that data currently does not benefit other departments.

- The Environmental and Energy Services Cabinet would like to improve the process to share and analyze transportation data because traffic affects the City's climate goals. The department wishes to determine its baseline measurements and the improvements achieved over time.
- The Department of Innovation and Technology (DoIT) is motivated to unlock, share and analyze transportation data. It manages the platforms that deliver online citizen services.
- Citizens desire timely, local, accurate transportation information to make appropriate transportation choices and improve their quality of life.

The team also observed that Boston has extensive instrumentation to collect traffic data, but, in general, the various departments and systems are not interconnected. This presents obstacles to realizing intelligent traffic solutions.

The IBM Smarter Cities Challenge team's recommendations focus on interconnecting the various traffic data systems to establish a common data model and platform to enable intelligent applications through analytics and visualization. The roadmap includes forward-thinking, longer-term recommendations such as video analytics, simulation and benchmarks with other cities. The recommendations fall within four key themes:

- **Unlocking data:** Includes a common data model that aligns with recognized standards and online submission of manual traffic count data in a standard format
- **Sharing data:** Includes an automated process to transfer traffic count data from the Traffic Management Center to DoIT, online access to manual traffic count data that already exists and many visualization techniques
- **Analyzing data:** Includes easy online access to, and visualization of, important transportation data for Boston residents, a smarter traffic control infrastructure, multiple forms of analytics, CO_2 emission estimates and benchmarks with other cities
- **Future vision:** Includes consolidating video cameras across departments, a comprehensive infrastructure for a smarter traffic control system, advanced analytics, and visualization and an architecture and long-term roadmap to gradually establish the entire infrastructure with state-of-the-art technologies

Mayor Menino recognizes that climate goals and automobile traffic improvements are interconnected. The IBM Smarter Cities Challenge team expects that these recommendations will lead to new insights into Boston's transportation system that will guide more data-driven policy decisions and intelligent choices for residents that can lead to improvements in quality of life.

Highlights

- The City of Boston has already invested in substantial infrastructure for transportation instrumentation. Multiple sources provide data with great potential value if that data is unlocked, shared and analyzed.
- The City of Boston has substantial opportunity to make strides toward its climate and transportation goals by interconnecting the various traffic data sources and sharing data across departments to benefit multiple stakeholders. These include the Department of Transportation, the Environmental and Energy Services Cabinet, real estate developers, consultants and citizens.
- Increased interconnection and data sharing can enable more sophisticated analytics that can lead to more intelligent systems that benefit urban planners, transportation engineers, law enforcement agencies and citizens. DoIT is poised to lead this integration effort.
- Boston's DoIT organization has excellent geographic information system (GIS) skills. They already have released several applications, such as Citizens Connect[11], Street Bump[7] and Boston Food Truck[8]. DoIT also possesses the ability to visualize big data in a consumable way.
- In addition to offering recommendations, the IBM Smarter Cities Challenge team worked with the City to develop a working prototype that demonstrates the benefits of unlocking, sharing, analyzing and visualizing data. The initial prototype was completed during the three-week period.
- This Smarter Cities Challenge involved collaboration with a university – Boston University professors and PhD candidates contributed in several areas, especially in developing the prototype.

2. Introduction

A. The Smarter Cities Challenge

In 2010, IBM Corporate Citizenship launched the Smarter Cities Challenge to help 100 cities around the world over a three-year period become smarter through grants of IBM talent. Boston, Massachusetts, was selected through a competitive process as one of 33 cities to be awarded a Smarter Cities Challenge grant in 2012. Since the program's inception in 2010, more than 40 cities have received Smarter Cities Challenge grants, and many have already made great progress on the road to becoming more instrumented, interconnected and intelligent.

During a three-week period in June of 2012, a team of six IBM experts worked in Boston to deliver recommendations that address key issues for Mayor Thomas M. Menino.

B. The challenge

The City of Boston wants to make the most effective use of transportation data. Boston collects a significant amount of data from many sources that could be quite useful to researchers, developers, transportation engineers, urban planners and, above all, citizens. This data, though, often is isolated in various departments, exists in multiple formats and is not fully exploited. To achieve its climate and transportation goals, the City of Boston needs timely, local, accurate information about city transportation conditions.

Specific transportation challenges include:

- **Reducing carbon emissions** associated with automobile travel: Boston's automobile traffic accounts for about 25 percent of the city's carbon emissions. The Mayor's Climate Action Plan[6] calls for significant greenhouse gas reduction.
- **Analyzing and reducing vehicle miles traveled (VMT):** This contributes to reducing traffic congestion and carbon emissions.
- **Providing data for residents** to make intelligent choices about transportation alternatives: With access to reliable transportation information, citizens can make more intelligent decisions about their travel alternatives, including ones that can reduce VMT, such as bicycles, public transit and walking. These, in turn, can reduce traffic congestion and advance climate goals.

The underlying challenge involves unlocking, sharing and analyzing transportation data, along with visualization to communicate information to the public and various stakeholders, especially:

- **Manual traffic count data at intersections:** This data currently does not exist in a consumable digital form so it is not standardized, shared or easily accessible.
- **Inductive loop traffic count data:** This data currently is not shared or analyzed. As a result, it is not exploited to its full potential and is not accessible to citizens and others.
- **Camera video data:** This data currently is not shared, and often is not recorded or analyzed, therefore camera data is not fully leveraged.

Although various stakeholders have their own missions and momentum, the benefits of unlocking, sharing and analyzing data – as demonstrated in the prototype – offer motivation to overcome any organizational barriers.

C. Process

To address these challenges, the IBM Smarter Cities Challenge team gathered a comprehensive view of:

- The existing data that the City collects
- How that data is used today
- The current inhibitors to fully exploiting this data
- Other available data sources
- The City's vision for transportation improvements that can contribute to environmental improvements

In addition, the team worked with the City to better understand organizational inhibitors to unlocking, sharing and analyzing data. The team then applied its knowledge and expertise in the areas of transportation optimization, data analytics, machine-to-machine communication, video analytics, physical security, environmental protection and municipal government to recommend actions for short-term and long-term benefits.

To convince various stakeholders to release and share their own data, it is useful to emphasize the short-term benefits that can improve the daily operations of the current stakeholders. In particular, when data is shared and aggregated, the original data owner not only can provide data, but also consume shared data, leading to improved operations. For this purpose, these recommendations include plausible data analytics and visualization, such as detecting faulty sensors and discovering traffic patterns.

The team also provided a roadmap for the City and a recommendation for benchmark comparisons to other "Smarter Cities" to facilitate continuous improvements toward Boston's climate and transportation goals.

3. Context for recommendations

A. Stakeholders

Like many municipal governments, the City of Boston has numerous departments organized by function and the services they provide. This enables the City to focus on providing the services expected by citizens, but it can lead to "silos" and isolation that can present obstacles to unlocking and sharing data. As has been illustrated in other Smarter Cities Challenge reports, sharing data is valuable for governments and citizens. In Boston, various stakeholders have their own missions and perspectives.

Key stakeholders for this Smarter Cities Challenge include:

- **Mayor's Office of New Urban Mechanics:** The mission of this department is to offer civic innovation focused on delivering transformative City services to Boston's residents[1]. From the perspective of the department, this mission can best be accomplished by broad data sharing across all City departments and extending to other agencies outside the City. The New Urban Mechanics office values innovation and is eager to have a prototype to demonstrate to citizens.
- **Boston Transportation Department:** The mission of this department is to promote public safety, manage the City's transportation network and enhance the quality of life for residents[1]. Two areas of the Transportation department are key stakeholders for this Smarter Cities Challenge:
  - **Policy and Planning:** This organization sets transportation policies for the City of Boston and has launched the Boston Complete Streets initiative[2] with the goal of designing and operating streets that are multi-modal, environmentally friendly and smart in their use of new technology. It would like shared data to make better, data-driven policy decisions.
  - **Traffic Management Center:** This organization oversees the expansion, operation and maintenance of Boston's Traffic Management Center. It receives inductive loop data from 845 signalized intersections and video data from 120 traffic monitoring cameras[1] which could be valuable to other stakeholders, but it is not shared today. This organization uses an intentionally isolated network because of the critical nature of traffic signal control. One result of this isolation is that the inductive loop traffic data is not shared with other departments. In addition, the video data from traffic cameras is not recorded because the department does not have sufficient staff to manage and maintain stored video data. (For example, if the video data is stored, then the staff would need to respond to public records requests for this data.) Because of this, video camera traffic data is not shared with other departments.
- **Environmental and Energy Services Cabinet:** This department is responsible for carrying out the Mayor's Climate Action Plan[6] which was developed after a year-long collaborative process with leaders throughout the community. The City of Boston's goal is to reduce greenhouse gas emissions by 25 percent by 2020 and 80 percent by 2050. To achieve these goals, the department is pursuing green buildings and transportation improvements. The transportation policies and data are largely within the purview of the Transportation department, although transportation directly affects the Environmental and Energy Services Cabinet. It wishes to determine its baseline measurements and the improvements achieved over time.
- **Department of Innovation and Technology (DoIT):** DoIT is the City's enterprise technology organization and focuses on connecting the city, engaging and empowering citizens, improving business processes, working collaboratively and continuously innovating[1]. The DoIT staff has had recent successes in connecting various departments, and they are motivated to unlock, share and analyze transportation data, which is an area that has not been interconnected. They manage the platforms that deliver online citizen services, including the geographic information system (GIS) platform that was used in the prototype built during this Smarter Cities Challenge engagement. They are in the process of building a federated video system that could integrate camera data from silos into a shared repository to benefit many government organizations and the citizens of Boston.

- **Citizens:** Although the consumers of transportation data include various City departments, researchers and practitioners, the ultimate consumers and beneficiaries of unlocked, shared and analyzed transportation data will be the residents of Boston. Timely, local, geographically oriented, accurate, comparable transportation information will empower citizens to make appropriate transportation choices and improve their quality of life.

B. Current state

The City of Boston has a significant amount of instrumentation related to transportation and traffic, including inductive loops, manually gathered traffic counts, video cameras, GPS and others. In addition, other agencies, including the State of Massachusetts and the Central Transportation Planning Staff (CTPS), a part of the regional Metropolitan Planning Organization, have other transportation-related data that is relevant to the City of Boston, such as pneumatic tube traffic counts and mass transit data.

The Mayor's Climate Action Plan[6] includes goals to reduce CO_2 emissions and provide information for residents and commuters to make choices about transportation. The Mayor's Office of New Urban Mechanics wants to provide practitioners, researchers and residents with more timely, local, geographically oriented, accurate, comparable information about transportation conditions in Boston.

The City of Boston has established aggressive environmental goals, including a 25 percent reduction in greenhouse gas emissions by 2020. Reducing Vehicle Miles Traveled (VMT) is an important action to reach this goal, yet the City currently has no way to analyze VMT.

"We don't have a standard way equally represent data on all modes of travel. We hope that one of the outcomes is a new standard to collect and use data."

— Vineet Gupta, Director of Policy and Planning, Boston Transportation Department

The City of Boston has a wealth of instrumentation, but many opportunities exist for interconnection among agencies and departments, so that data which is already is collected can be used to generate useful information for all parties. For example, the Traffic Management Center receives traffic count information from inductive loops and video cameras, but this data is not shared with other departments that could find value in it. Other departments, such as police, libraries and schools, also have video cameras, but the information is not shared. Data from manual traffic counts occurs on a relatively low-frequency basis (as compared to automated data sources), and typically when new development projects are proposed, but the data often is captured in the form of printed (and occasionally electronic) reports. In either case, the data is intended for human consumption, not digital processing.

"We want to create and set a standard that is immediately usable and transferable to other cities."

—Chris Osgood, Co-Chair, Mayor's Office of New Urban Mechanics

This leads to the challenge of unlocking, sharing and analyzing data so that the instrumentation that exists can be interconnected and contribute to intelligent traffic solutions. This, in turn, leads to environmental and economic benefits. Hence, the efforts to unlock, share and analyze existing traffic data are significant to the City's environmental goals.

C. Prototype

The City requested a demonstrable prototype to illustrate the potential of the recommended actions. The IBM team partnered with Boston University and the City's DoIT to build a citizen-facing prototype to demonstrate the capabilities that can be enabled through implementation of the team's recommendations.

Because this Smarter Cities Challenge engagement was only three weeks in duration — with the first week spent primarily in gathering details about the City's current state, requirements and desires — incorporating a prototype required a very aggressive schedule. To stay on schedule, the scope of the prototype initially was limited to demonstrating how to unlock, share and visualize the inductive loop and manual count data that is not accessible today (sample data of both types existed for a few intersections). As the prototype progressed, the team also incorporated pneumatic tube counts and demonstrated additional analytics and visualization techniques.

This prototype was completed within the three-week engagement period and included an initial implementation of a common data model, population of an aggregated traffic count database with more than one million records and several visualizations of analyzed data. Figure 1 provides an overview of the prototype.

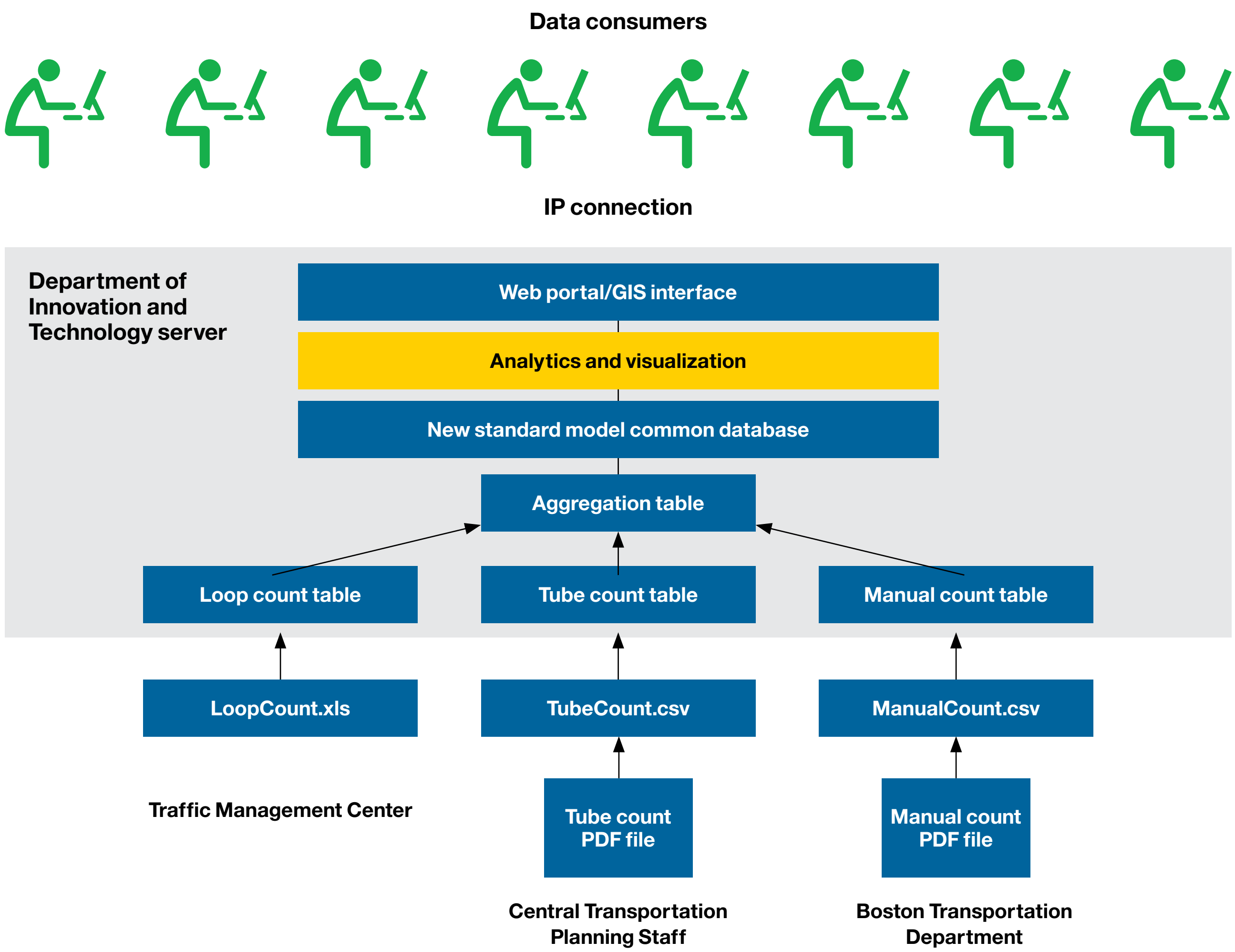

Figure 1
Prototype platform

[Re: prototype]: "… a new, fresh, original, engaging, delightful application that we can show citizens."

—Chris Osgood, Co-Chair, Mayor's Office of New Urban Mechanics

The prototype demonstrated what could be accomplished with currently available data: inductive loop counts, pneumatic tube counts and manual counts. Although data records for inductive loops and pneumatic tubes were collected at different intervals, the team could see similarities between traffic flows recorded by inductive loops at an intersection with those recorded on nearby roads by pneumatic tubes. This demonstrates the possibility of increasing data accuracy by combining various types of sensor data.

Using data analytics, the team extracted six traffic patterns from existing pneumatic tube count data. Those patterns are: commuting, going-home, early-bird, night-owl, anomaly and busy streets. Commuting streets have peak hours in the morning and afternoon. Going-home streets peak in the afternoon, whereas early-bird streets peak in the morning. Night-owl streets have more traffic at night than during the rest of the day. Anomaly streets have a traffic burst during a short interval (possibly caused by false sensor data). Busy streets have heavy traffic from the morning to late afternoon.

Pneumatic tube counts can also be used to visualize the hourly changes of traffic on average weekdays. This visualization helps identify how the traffic flows throughout the day.

The prototype was instrumental in demonstrating the short-term value that can be achieved from unlocking, sharing and analyzing existing data and it provided a sound basis for the future vision.

D. University partnership

Another novel aspect of this Smarter Cities Challenge was a formal university partnership. The City of Boston's proposal included Boston University as a participant in the engagement. This added some complexity to the project, but it offered benefits that included the input and ideas of Boston University professors and PhD candidate students who contributed to the project. In particular, PhD candidate (Geography, specializing in environmental issues) Conor Gately served as the full-time project manager for Boston University during the engagement. All Boston University participants are listed in Appendix A.

E. Overview of recommendations

The potential scope of an overall solution is broad, involving other agencies beyond the City of Boston. The scope of this particular Smarter Cities Challenge focuses on recommendations about the use of manual traffic count data and inductive loop data for near-term actions, because these data sources are most accessible from the existing infrastructure and present a solid foundation for analytics and visualization. The engagement scope also includes strategic recommendations about next steps toward longer-term solutions, especially in the area of video camera data.

The IBM Smarter Cities Challenge team's recommendations are categorized according to the three main themes of unlocking, sharing and analyzing transportation data, plus a fourth theme of future vision. They address several topics, including environmental actions, privacy, benchmarking and long-term vision.

1. Unlocking data

a) Adopt a common data model that supports multiple types of input data.
b) Align data with recognized standards.
c) Aggregate data from multiple sources.
d) Prescribe manual traffic count format and deliverables to consultants.
e) Enable online submission of manual traffic count data.

2. Sharing data

a) Institute an automated process to transfer inductive loop traffic count data from the Traffic Management Center to DoIT to enable online access to this data by multiple consumers.
b) Enable online access to manual traffic count data that already exists (make this data accessible to multiple consumers).
c) Ensure that reasonable security and privacy policies, procedures and controls are incorporated in data sharing, especially for personally identifiable information.

3. Analyzing data

a) Enable easy online access to, and visualization of, important transportation data for residents of Boston in multiple ways through multiple channels.
b) Establish a smarter traffic control infrastructure that uses existing and new data sources to enable new applications that enable multiple parties to offer value to multiple consumers.
c) Provide traffic data analytics for extracting, transforming, and loading traffic data to verify the accuracy of aggregated traffic sensor data and to provide various reports that are useful for the city's operation.
d) Provide CO_2 emission estimates based on traffic data analytics.
e) Provide visualization to view the data generated by the various types of data analytics, categorized into three topics: as-is, analytical and what-if.
f) Perform benchmarks with other cities, and share best practices.

4. Future vision

a) Consolidate video cameras that are isolated in departmental "silos" by establishing a federated video infrastructure managed by DoIT, considering camera network design, servers, storage, platforms and standards.
b) Create a comprehensive infrastructure for a smarter traffic control system that collects data from multiple sources.
c) Create a framework that incorporates pedestrian and bicycle counts with motor vehicle counts.
d) Use multiple data sources to validate other data sources.
e) Create an architecture and long-term roadmap to gradually establish the entire infrastructure with state-of-the-art technologies for networks, servers, storage, sensors and video cameras. The roadmap should include:
   - Technology migration plans that include using one form of sensor to augment and validate other forms of sensors
   - Gradually replacing older traffic measurement and control technologies with more efficient, accurate technologies, such as IP and wireless-based systems, GPS and video analytics
   - Building a network infrastructure with high-bandwidth fiber optic connections and a well-designed topology to ensure flexibility and scalability for aggregated traffic data from multiple sources (including video), thus enabling a smarter traffic control system for real-time analytics and visualization
   - Collaboration with universities and businesses to improve traffic data analytics and optimization to fully utilize multi-modal data that is collected from various sources and improve traffic control and associated services to make Boston a Smarter City

F. Roadmap

The roadmap in Figure 2 represents the evolution of the ecosystem for transportation solutions for the City of Boston, beginning with short-term recommendations and progressing to the longer-term forward-thinking vision.

This roadmap illustrates evolutionary progression:

1. Using "**unlocked**" data, the common data model offers a path toward alignment with recognized standards.
2. **Sharing** data advances the focus from individual data sources to the consolidated data and application platform.
3. Data **analysis** enables new intelligent applications and visualizations.
4. The **forward-thinking** future vision enables new ideas to be realized, and advanced analytics and applications to be implemented, leading toward a smarter traffic management system in Boston.

An expected outcome of this roadmap is increased **consumer value** for researchers, government, businesses and, especially, citizens.

G. Goals and objectives

Table 1 illustrates the goals and objectives of this Smarter Cities Challenge from a technological perspective. Within the domain of transportation and the scope of this project, the goals in the first row of the table are supported by the objectives in the remaining rows, from the highest layer of visualization to the lowest layer of the infrastructure. The columns on the right specify whether the corresponding items are included in the demonstration prototype or rather are incorporated in the roadmap for the future. (See the "Roadmap" section for an ecosystem roadmap and Recommendation 4d for additional details about the future vision roadmap).

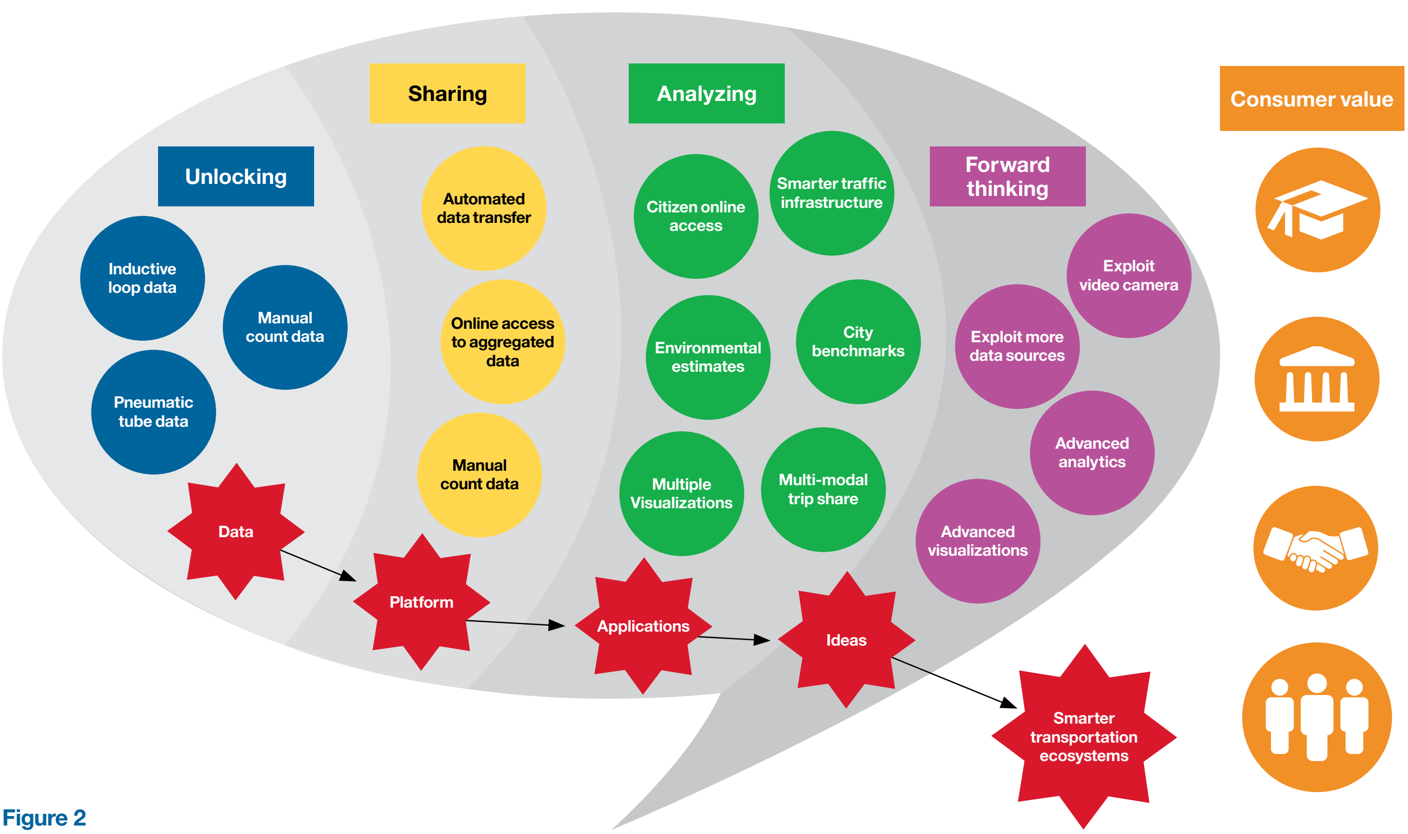

Figure 2
Ecosystem roadmap

Table 1: Goals and objectives from a technological perspective

Component	Example capabilities	In prototype	In roadmap
Goals	• Unlock data • Share data • Analyze data	✓	✓
	• Future vision roadmap		✓
Visualization	• Intersection traffic view • Traffic count displays from multiple data sources, including the three data sources (inductive loops, manual counts and pneumatic tube counts) demonstrated in the prototype • Histograms of car, bicycle and pedestrian traffic at intersections, including colored intersection display of manual counts	✓	✓
Analytics	• Peak hour and in/out directional flows • Road classification based on distribution of traffic volume and patterns • Travel conditions with state indicators described in the common data model for roads and intersections • Video camera-based vehicle counts • CO_2 heat map based on traffic density and CO_2 measurements	✓	✓
	• Standards-based traffic state indicators • Inductive loop sensor fault detection • Traffic growth rate estimation • Travel time estimation to particular landmarks • Traffic simulation technologies to support urban planning • Alternative routes computation • Estimation of travel time to particular landmarks • Estimation of areas lacking sensors based on sensors in adjacent areas • Distribution of trips between pedestrians, bicycles and motor vehicles		✓
Data	• Inductive loop traffic counts • Manually collected traffic counts • Pneumatic tube traffic counts • Common data model • Aggregated data from sources listed above	✓	✓
	• Video cameras • Mobile devices • GPS data from public and private vehicles • BigBelly waste collection • Parking data • Hubway bike sharing • Electric vehicle charging stations • Mayor's 24-Hour Hotline/Citizens Connect • Public transit data • Regional highway data • EZPass transponders • Alignment with recognized standards • Manual count online submission		✓
Instrumentation	• Inductive loops • Existing manual count reports • Pneumatic tube counts	✓	✓
	• Video cameras • GPS • Public transit data • Others		✓

4. Recommendations

Recommendation 1: Unlock data

Existing data can be unlocked by defining a common data model that offers a path toward alignment with recognized standards and serves as a basis for aggregating data from multiple sources.

Recommendation 1a: Adopt a common data model that supports multiple types of input data
The City should adopt a common data model that supports multiple types of input data and enables this data to be aggregated in a common repository that is available to multiple agencies.

Scope and expected outcomes

The common data model should:
- Enable simple consumption of traffic count data by setting expectations for data quality and error checking
- Easily provide data that is commonly needed by applications, without inundating them with unnecessary details
- Enable entitled users who want to see details about a data source to access those details
- Facilitate the process to import, process and manage data for IT staff

The common model is required for data integration. Moreover, it should be:
- Continuously reviewed with respect to user requirements and as sources of data change over time
- Aligned with additional relevant standards according to consumers' requirements

This can lead to the following outcomes and benefits:
- The data becomes useful to most consumers in its current state, while still enabling users to drill down to details, and is easy to maintain.
- The data becomes general purpose – unlocked from the source. In the prototype, the common data model was mapped to four different data sources.
- The data becomes aligned with standards and prescribes error-handling semantics. The applications can rely on a specified level of data consistency.
- The structure can be used to incorporate additional traffic data – beyond traffic counts and traffic volume, and even other types of data – into the IT infrastructure of the city.

The cost of inaction is that data is likely to remain isolated without the opportunity to aggregate data from multiple sources.

Proposed owner and stakeholders	Suggested resources needed
Owner: Department of Innovation and Technology **Stakeholders:** Mayor's Office of New Urban Mechanics; Boston Transportation Department; Department of Innovation and Technology	Once the data model is defined, the Department of Innovation and Technology can facilitate continuous maintenance at medium cost.
Dependencies	**Key milestones, activities and timeframe**
None	**Short term:** Initial data model is already implemented in prototype. **Medium term:** Review it every six months for traffic count purposes and enhance the model for other traffic measures as necessary.

Priority status
High

Recommendation 1b: Align data with recognized standards

The City should identify and adopt appropriate traffic and transportation standards. This will enable the City to leverage work performed by standards bodies and more easily interchange data with other agencies and other cities.

Scope and expected outcomes

All parts of a city affect one another. No department can work effectively in isolation. For example, traffic incidents on the road, managed by the Traffic Management department, might affect public safety, water management and environment monitoring. Similarly, external events can affect traffic. For example, a broken water pipe might affect traffic flow and prompt the traffic department to act.

This raises the issue of how participants can share common information about the domain unambiguously. For example, a road condition, such as congestion, is used by traffic personnel, the fire department, electrical utility companies, the mayor's office, citizens, civil contractors and IT companies that implement intelligent transportation systems.

Standards enable unambiguous reference to concepts related to the traffic and transportation domain. A primary benefit of using standards is that the collected data is more consumable.

Today, information typically is exchanged among transportation departments and external government agencies using the DATEX II standard, and between government agencies using the National Information Exchange Model (NIEM) standard. The format for information exchange is the Common Alerting Protocol (CAP) standard.

Information exchanged with DATEX II systems is composed of several basic elements:
- Road and traffic-related events (called "traffic elements"), such as accidents, obstruction and road-related weather conditions
- Operator actions, such as road network management and roadside assistance
- Advisories to commuters
- Impacts that describe five possible road state values: free flow, heavy, congested, impossible and unknown
- Non-road-event information, such as service disruption and parking
- Elaborated data that represents data derived or computed from raw measured data
- Measured data that represents direct measurement from equipment

The team recommends that "Impacts" and "Elaborated/measured data of flow" (also called count or traffic volume) be incorporated in Boston's common data.

NIEM prescribes how data elements, such as time, data, organization, address and vehicle type, should be structured. Although relevant to Boston in the long term, because of broad support by the US government, this standard can be considered in subsequent versions of the common data model.

CAP prescribes a specific format for representing messages, expressing details about the origin of a message, its priority and its content. The team recommends that CAP be a format in which Boston's data is disseminated.

The cost of inaction is that the City of Boston might find it more difficult to exchange data with other cities and agencies who adopt recognized standards.

Appendix D describes the standards that were considered.

<table>
<tr><th colspan="2">Recommendation 1b: Align data with recognized standards (continued)</th></tr>
<tr><th>Proposed owner and stakeholders</th><th>Suggested resources needed</th></tr>
<tr><td>Owner: Department of Innovation and Technology

Stakeholders: Mayor's Office of New Urban Mechanics; Boston Transportation Department; Department of Innovation and Technology</td><td>A staff member from the Department of Innovation and Technology can be responsible for standards alignment and liaise with individual departments about domain-dependent standards, such as traffic standards.</td></tr>
<tr><th>Dependencies</th><th>Key milestones, activities and timeframe</th></tr>
<tr><td>Recommendation 1a</td><td>Short term:
• Begin to adopt the standards identified, namely CAP and portions of DATEX II.

Medium term:
• Review standards alignment in conjunction with reviews of the common data model.</td></tr>
<tr><th colspan="2">Priority status</th></tr>
<tr><td colspan="2">High – this activity should be performed concurrently with implementing the common data model</td></tr>
</table>

Recommendation 1c: Aggregate data from multiple data sources
A common data model enables data from multiple sources to be combined. The City should aggregate traffic and transportation data from various data sources to provide a richer data set that enables richer analytics and visualization.
Scope and expected outcomes
Timely availability of aggregated traffic data is critical for consumers to make accurate decisions. The City of Boston is fortunate to have a rich set of instrumentation to collect traffic data from a variety of sources. A critical decision that City authorities need to make is which sensors to use to get traffic data. A multitude of techniques exist that vary in accuracy, coverage and cost to install and maintain, as well as how they can complement one another. Traffic measurement and data acquisition have received much attention with technologies, such as inductive loop and pneumatic tube counters since the 1960s; video image analysis since the 1970s; floating car data since the 1990s; data mining of telecommunication data since the 2000s; and the currently popular GPS-based devices. Even if a city starts with one preferred sensor type (such as inductive loops), over time, technology presents more options that can work synergistically (such as mobile phones). Consequently, a city that plans to use traffic data soon finds that it must make, and continuously re-assess, its choice among multiple sensor types for increased returns on its investments. The only practical way that the City of Boston can make the most of its available instrumentation is to aggregate data into a common format. However, prescribing a common data format or model must be balanced between what a majority of consumers want and what existing data sources provide. The IBM Smarter Cities Challenge team has defined a data model after discussion with the current consumers (beginning with discussions about preparing a prototype), and recommends that this data model be periodically reviewed with respect to evolving consumer requirements and new data sources. The expected outcome and primary benefit of data aggregation is the ability to share data from multiple sources, which can lead to more intelligent analytics and visualizations. The cost of inaction is that the common data model defined in Recommendation 1a would not be exploited to its full potential, leading to difficulty in data sharing. The aggregation itself would be performed on integration platforms that already are available within the City's Department of Innovation and Technology. The team also recommends a platform roadmap that considers aggregation requirements.

Proposed owner and stakeholders	Suggested resources needed
Owner: Department of Innovation and Technology **Stakeholders:** Mayor's Office of New Urban Mechanics; Boston Transportation Department; Department of Innovation and Technology	The aggregation approach has already been demonstrated for three traffic count data sources in the prototype. The Department of Innovation and Technology can facilitate continuous updates to data aggregation based on the technology roadmap.
Dependencies	**Key milestones, activities and timeframe**
Recommendation 1a	**Short term:** • It is already demonstrated in the prototype. **Medium term:** • Proceed according to the ecosystem roadmap.

Priority status
High

"If, going forward, we can standardize the manual counts and store them individually, then it will make it much easier to access and share that data."

—Don Burgess, Manager, Traffic Management Center, Boston Transportation Department

Recommendation 1d: Standardize manual traffic count data format

The City should define the format and method used to submit manual traffic count data so that this data can be captured electronically and aggregated with data from other sources.

Scope and expected outcomes

Traffic count data applies to specified intersections and is gathered by consultants hired by developers who propose new development projects. The City of Boston also occasionally hires consultants to perform traffic counts for targeted intersections. Currently manual counts are the only way to collect data on pedestrians and bicycles.

The primary expected outcome is evolution from the current system, in which the traffic count data is submitted in a format chosen by the consultant, to a standard format. This standardization serves as an enabler for Recommendations 1e and 2b. Taken together, these recommendations unlock and share manual traffic count data, which benefits the City, consultants and developers by making this data easily accessible and saves time and effort for all parties.

Because this recommendation enables related recommendations described earlier, the cost of inaction is that the current state of locked, inaccessible data would be maintained — that is, manual count data would remain locked in paper and PDF files and would not be accessible to the consumers who could benefit from easy access to the data.

Proposed owner and stakeholders	Suggested resources needed
Owner: Boston Transportation Department **Stakeholders:** Traffic Management Center; consultants hired by developers and by City of Boston to perform manual traffic counts	Relatively low cost – could be accomplished by staff directive. Requires that the transportation department is prepared to receive data in the standard format, so a small amount of staff time is required.
Dependencies	**Key milestones, activities and timeframe**
None	**Short term:** • Prescribe the new format for manual traffic count data, based on selected effective date, through appropriate mechanism (ordinance, staff directive). **Medium term:** • Verify that standard is adopted correctly. **Long term:** • Exploit the new standard data (see Recommendations 1e and 2c).

Priority status

Medium

"All we need is to systematize this data collection."

—Vineet Gupta, Director of Policy and Planning, Boston Transportation Department

Recommendation 1e: Enable online submission of manual traffic count data

The City should provide a web application or web portal to enable consultants, hired by developers or by the City, to submit manual traffic counts, in standard format, to the City electronically.

Scope and expected outcomes

During discussions with consultants, they indicated that their preferred container format for traffic count data is a spreadsheet. The web portal should be access-controlled to ensure that only approved users can submit data.

Expected outcomes are a more efficient method for submitting manual traffic counts, which saves resources for consultants and the City, and more efficient storage of the manual traffic count data, which today exists in paper or PDF form. This recommendation also enables Recommendation 2b. Taken together, these recommendations unlock and share manual traffic count data, which benefits the City, consultants and developers by making this data easily accessible, saving time and effort for all parties.

The cost of inaction is that the current state of locked, inaccessible data would be maintained — that is, manual count data would remain locked in paper and PDF files and would not be accessible to the consumers who could benefit from easy access to this data.

Proposed owner and stakeholders	Suggested resources needed
Owners: Boston Transportation Department; Department of Innovation and Technology **Stakeholders:** Traffic Management Center; consultants hired by developers and by the City of Boston to perform manual traffic counts	This is a relatively low-cost implementation. It is straightforward and can use existing Department of Innovation and Technology computing resources and requires a relatively small amount of staff time. The Transportation department should provide a list of authorized users and user credentials must be communicated to the consultants who will use the system. Education and training for consultants is likely to be required, however, based on our discussions with consultants, they already are familiar with similar processes so training should be minimal.
Dependencies	**Key milestones, activities and timeframe**
Recommendation 1d Although it does not strictly depend on Recommendation 1a, it should use the recommended common data model.	**Short term:** Build a prototype web application/portal and perform a pilot with selected consultants. Refine the system based on their feedback. **Medium term:** Begin migration from the current submission process to online submission with a target date to switch to online submission only. Incorporate the data into the common data model and data warehouse. **Long term:** Maintain and enhance the system as required.

Priority status

Medium

Recommendation 2: Share data

Sharing data advances the focus from individual data sources to the consolidated data and application platform.

Recommendation 2a: Share inductive loop data with online access

The City should institute an automated process to transfer inductive loop traffic count data from the Traffic Management Center to the Department of Innovation and Technology to enable online access to this data by multiple consumers.

Scope and expected outcomes

The Traffic Management Center should create "loop count auto sender" software that generates loop count report files and places these on an FTP server at specified time intervals (presumably 15 minutes). DoIT should create a "loop count auto receiver" that obtains these files from the FTP server and populates the historic database in the smarter traffic system. The aggregated view of loop counts can then be generated and published on a web portal by a report generator. The consumers can obtain loop count reports via online access or view the loop count data via various visualization tools (described in other recommendations). This is illustrated in Figure 3.

The expected outcome and primary benefit is the ability to share data that currently is available only to the Traffic Management Center. The cost of inaction is that this data would remain isolated from other users who can obtain value from it.

Proposed owner and stakeholders	Suggested resources needed
Owners: Boston Transportation Department; Department of Innovation and Technology **Stakeholders:** Traffic Management Center; Infrastructure and Applications at Department of Innovation and Technology	**Traffic Management Center:** Engage a software contractor to implement the "loop count auto sender." The cost is low. Compare the costs of generating this data in the common data model format by the software contractor versus DoIT. **DoIT:** 1. Create the "loop count auto receiver." The cost is low. 2. Populate loop count data into the system, store in the historic database, and create an aggregated database that leverages the existing data warehouse. Overall cost is high, but portions have already been implemented in the prototype. 3. Create web-accessible report generator. Cost is low.

Dependencies	Key milestones, activities and timeframe
Recommendations 1a, 1b and 1c	**Short term:** Copy loop count data from the existing software system in the Traffic Management Center to comma-separated value (.csv or spreadsheet) files, and use FTP to transfer the data to DoIT. DoIT populates the data using the common data model, stores the data in the historic database, creates an aggregated view of the common data model and generates data to be used by the analytics and visualization tools and the report generator tool. **Long term:** Integrate with the VidSys PSIM system for camera data.

Priority status

High

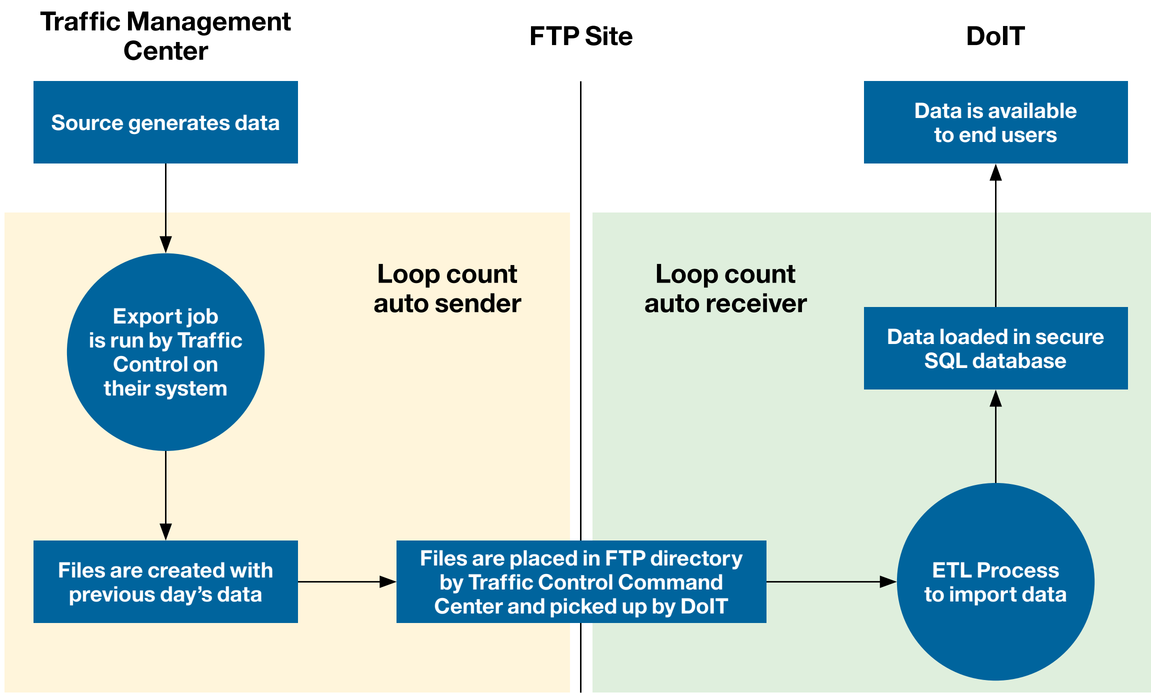

Figure 3
Overview of inductive loop data sharing

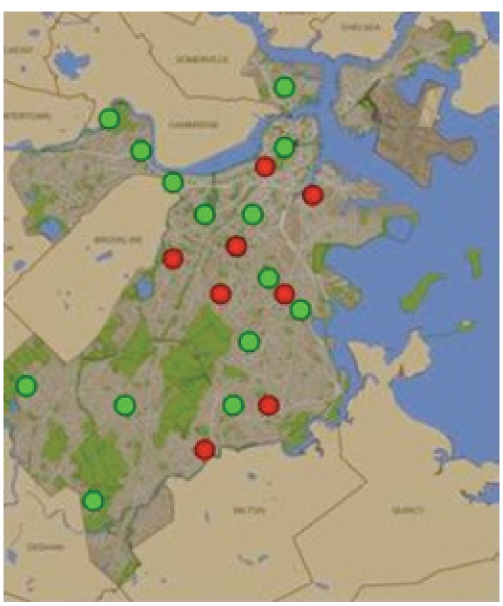

Figure 4
Example of simplified intersection manual count status

Recommendation 2b: Enable online access to manual traffic count data to multiple consumers

The City should enable online access to manual traffic count data that already exists, make this data accessible to multiple consumers and visualize the data. This enables developers to determine what traffic studies are required. It also enables the City to target intersections where studies should be updated.

Scope and expected outcomes

Using the common traffic data access mechanism suggested by Recommendations 1a and 1c, implement the ability to extract all manual traffic count data. Using this data, implement a visualization on the existing GIS system that identifies all city intersections and visually distinguishes those intersections that have a valid (recent) traffic count from those intersections that do not have a valid traffic count (as illustrated in Figure 4). The GIS application should enable an intersection to be selected and clicked to display the standardized representation of the manual count data – including vehicles, bicycles and pedestrians – for that intersection (as detailed in Recommendation 3e). Pedestrian and bicycle counts should be represented and accessible online.

The audience for this data includes at least the Department of Transportation, traffic engineers, developers and consultants. It might also be interesting to citizens. Therefore, the application should be hosted in the appropriate portal, possibly with other citizen-facing GIS applications, or on the restricted-access portal for the City of Boston, developers and consultants.

Expected outcomes include streamlining and reducing cost and effort associated with manual traffic counts. For example, the City, developers and consultants can rapidly determine whether a valid count already exists for a particular intersection so that they can focus on intersections that require new counts. The City also can more efficiently and effectively select intersections for which counts would be beneficial, either when new development projects are proposed or when the City hires its own consultants to perform counts at intersections for which new data is desirable.

The cost of inaction is that manual traffic count data that is unlocked via Recommendations 1d and 1e will not be fully exploited because it would not be shared with multiple consumers who can benefit from it.

Proposed owner and stakeholders	Suggested resources needed
Owners: Boston Transportation Department; Department of Innovation and Technology **Stakeholders:** Traffic Management Center, Department of Transportation; consultants hired by developers and the City to perform manual traffic counts	Once the dependent recommendations are implemented, this recommendation becomes a low-cost implementation. It is straightforward and can use existing Department of Innovation and Technology computing resources. It could use the existing GIS platform and existing data platforms that are results of the dependent recommendations so it should require a small amount of staff time. The transportation department should provide a list of authorized users — user credentials must be communicated to the consultants who will use the system. Training and education should not be required as this will be a straightforward web application.
Dependencies	**Key milestones, activities and timeframe**
Recommendations 1a, 1c, 1d and 1e	**Short term:** Determine the audience with whom the City wishes to share this data, such as consultants, developers or citizens. **Medium term:** Following implementation of the dependent recommendations, implement the web portal that provides the manual traffic count information (both raw data and GIS visualization) based on the aggregated data in the common database. **Long term:** Update and maintain the system as required.

Priority status

Medium

Recommendation 2c: Ensure data privacy
The City should ensure that reasonable security and privacy considerations about policies, procedures and controls are incorporated in data sharing, especially for personally identifiable information.
Scope and expected outcomes
Privacy, with respect to personally identifiable information (PII), is a core value that can be obtained only with appropriate policies, procedures and associated controls to ensure compliance with requirements. The Department of Innovation and Technology especially needs to consider the strong correlation that exists between data security and privacy. The National Institute of Standards and Technology (NIST) has published a document called "Security and Privacy Controls for Federal Information Systems and Organization"[4] that should be used as a guide to define the appropriate policies, procedures and associated controls for the City. To obtain the best results, it is important to share internal best practices with citizens, and make them feel confident that their data is managed in the correct way, regardless of how data is collected (manually, video cameras, websites and so on). As expected outcomes, the City should define and document internal policies, procedures and controls. The City should share portions of these documents with the stakeholders (City departments, law enforcement agencies and citizens) to create a chain of trust and good behaviors about how PII is managed. Inaction could impact the City's reputation, as privacy considerations become increasingly important.

Proposed owner and stakeholders	**Suggested resources needed**
Owners: Law department **Stakeholders:** All departments that manage PII as part of their regular work; citizens	The cost of this task is relatively low. It might include brief engagements with external consultants for specific issues. To obtain the best results, it is important to define a core team that consists of a City project manager who is empowered to coordinate other departments and representatives of the Law and DoIT departments and the security organizations within various other departments, such as law enforcement.

Recommendation 2c: Ensure data privacy (continued)	
Dependencies	**Key milestones, activities and timeframe**
Security and privacy policies must take into account applicable legislative, regulatory, ethical and organizational requirements, such as OMB A-130, Public Law 100-235 and the Privacy Act of 1974.	**Short term:** 1. **Create a Strategic Security and Privacy Plan:** It should ensure that security and privacy are addressed systematically and is consistent with the objectives and mission of the City and other stakeholders. 2. **Perform security and privacy policy analysis and create definitions:** Identify the rules that are necessary to ensure that the security objectives (such as confidentiality, integrity and availability) are met. Specifically, security and privacy policies identify the conditions under which data access, storage and transmission operate. **Medium term:** 3. **Secure solutions integration:** This requires applying the appropriate combination of technical and non-technical security services to the system for a cost-effective, robust, user-friendly, effective, interoperable solution. 4. **Security and privacy awareness, education and training:** This process informs users and stakeholders about threats to the systems, the measures to protect the systems from those threats and the proper security and privacy procedures for implementing and maintaining the protection measures. **Long term:** 5. **Security and privacy management:** This is a continuous administrative security activity that incorporates procedural and technical security features. Management procedures should be reviewed periodically and updated as needed so that system security is maintained if a contingency situation arises. 6. **Security and privacy assessment and testing:** These tests are performed in the later stages of system development and operation or after modifications, upgrades or changes in connectivity.
Priority status	
Medium	

Recommendation 3: Analyze data

Data analysis enables new intelligent applications and visualizations.

Recommendation 3a: Make transportation data available to residents

The City should enable easy online access to, and visualization of, important transportation data for residents of Boston, in multiple ways through multiple channels.

Scope and expected outcomes

The primary way that residents would obtain transportation data is via online access.

As Recommendations 1 and 2 are implemented via Recommendation 3b, data becomes available to three components: the count data analytics engine, visualization and search engine, and online traffic report generator. Once data is obtained and analyzed, multiple visualization techniques are provided to residents through interfaces demonstrated in the prototype and defined in Recommendation 3e, using the data analytics generated from Recommendation 3c.

The benefit of this recommendation is that citizens have easy access to relevant data that enables them to make intelligent choices about transportation alternatives. The cost of inaction is that data will not be unlocked and shared for Boston residents, hampering the city's efforts to reduce traffic congestion and meet its climate change goals.

Proposed owner and stakeholders	Suggested resources needed
Owners: Boston Transportation Department; Department of Innovation and Technology **Stakeholders:** Infrastructure and Applications, Department of Innovation and Technology	The cost of this recommendation is covered in Recommendation 3b, if the City considers only the online access components, because analytics and visualization expertise can be obtained through collaboration between the City and universities. The visualization cost is generally proportional to the sophistication of the analytics and visualization, and can be reduced by involving third parties who develop analytics and visualization that can be used by the City and others.
Dependencies	**Key milestones, activities and timeframe**
Recommendations 1a, 1c, 1d and 1e	**Short term:** Provide online access through a web portal using the manual count submitter and traffic report generator defined in Recommendation 3b. **Medium term:** Use a partial implementation of the count data analytics to generate visualized traffic data through a web interface via the visualization and search engine defined in Recommendation 3b. **Long term:** Incorporate video data federation and analytics into the visualization and search engine defined in Recommendation 3b.

Priority status

High

Recommendation 3b: Establish infrastructure to enable new applications

The City should establish a smarter traffic control infrastructure that uses existing and new data sources to enable new applications so that multiple parties can offer value to multiple consumers.

Scope and expected outcomes

Establish an infrastructure, as illustrated in Figure 5, to enable traffic applications that expose application programming interfaces (APIs) to the service departments and agencies to enable application development.

The infrastructure should include the following components:

1. **Loop data auto sender:** Software component in the Traffic Management Center that sends inductive loop data files from the Traffic Management Center to DoIT via automated FTP (see Recommendation 2a)
2. **Tube data auto sender:** Software component at Central Transportation Planning Staff (CTPS) that sends State of Massachusetts road tube count data from CTPS to DoIT via automated FTP
3. **Loop data auto receiver:** Software component in DoIT that receives the inductive loop count data from the Traffic Management Center via automated FTP (see Recommendation 2a)
4. **Tube data auto receiver:** Software component in DoIT that receives the State of Massachusetts road tube count data from CTPS via automated FTP
5. **Web portal:** Facilitates online access to data defined in this recommendation
6. **Historic database for existing count data:** Relational database that has three tables, each of which stores the original data from the original sources:
    a. Inductive loop count table
    b. Manual count table
    c. Tube count table
7. **Manual count submitter:** Web-based interface tool that enables users to input the manual count data based on its original format
8. **Standard data model aggregator:** Data warehouse component that aggregates data from each original table in the historical database and stores it in the aggregated database, based on the common data model described in Recommendation 1a
9. **Aggregated database for standardized data model:** Stores the new, formatted data based on the common data model
10. **Count data analysis engine:** Uses the count data queried from the aggregated database and performs traffic data analysis
11. **Federated video infrastructure:** Could be the current VidSys Physical Security Information System (PSIM) that DoIT is exploring. The PSIM will poll the videos from cameras dispersed in isolated networks and place the content in a DoIT system to make it available for analytics and multipurpose usage, such as security and traffic control. This assumes that the PSIM system provides a geo-based and time-synchronized video indexing engine; otherwise, these functions need to be implemented. This is an engine that provides the synchronization of the timing for video from various sources and creates indices based on the geolocation. A primary use of the federated video infrastructure is to aggregate multiple cameras owned by multiple stakeholders and use video analytics to perform traffic counts. By sharing cameras, investments in deploying new cameras are reduced.
12. **Video analytics engine:** Integrated with the VidSys PSIM to perform traffic data analytics and generate data used for online access and by the visualization tools. This engine should provide APIs to enable the visualization tools to provide traffic video viewers and web portal access for data consumers.
13. **Traffic report generator:** Web-based application that generates traffic reports for consumers. The report generator should provide data from various data sources:
    a. Raw data from the historical database in the original format of the inductive loop count, manual count and tube count
    b. Aggregated data from the common database in the standardized format
    c. Analyzed data from the count data analytics engine
14. **Visualization and search engine:** Provides real-time geo-spatial and historical views of traffic data with a search engine for indexing the location, time, source and other data, enabling consumers to have easy online access to all relevant data. The tool displays the diagrams or videos on the web portal.

The benefit of developing this infrastructure is the ability to build the analytics and visualizations that make data consumable for citizens and other stakeholders. The cost of inaction is that applications could not share a common infrastructure, resulting in duplicated, and possibly inaccurate, data, infrastructure and maintenance costs.

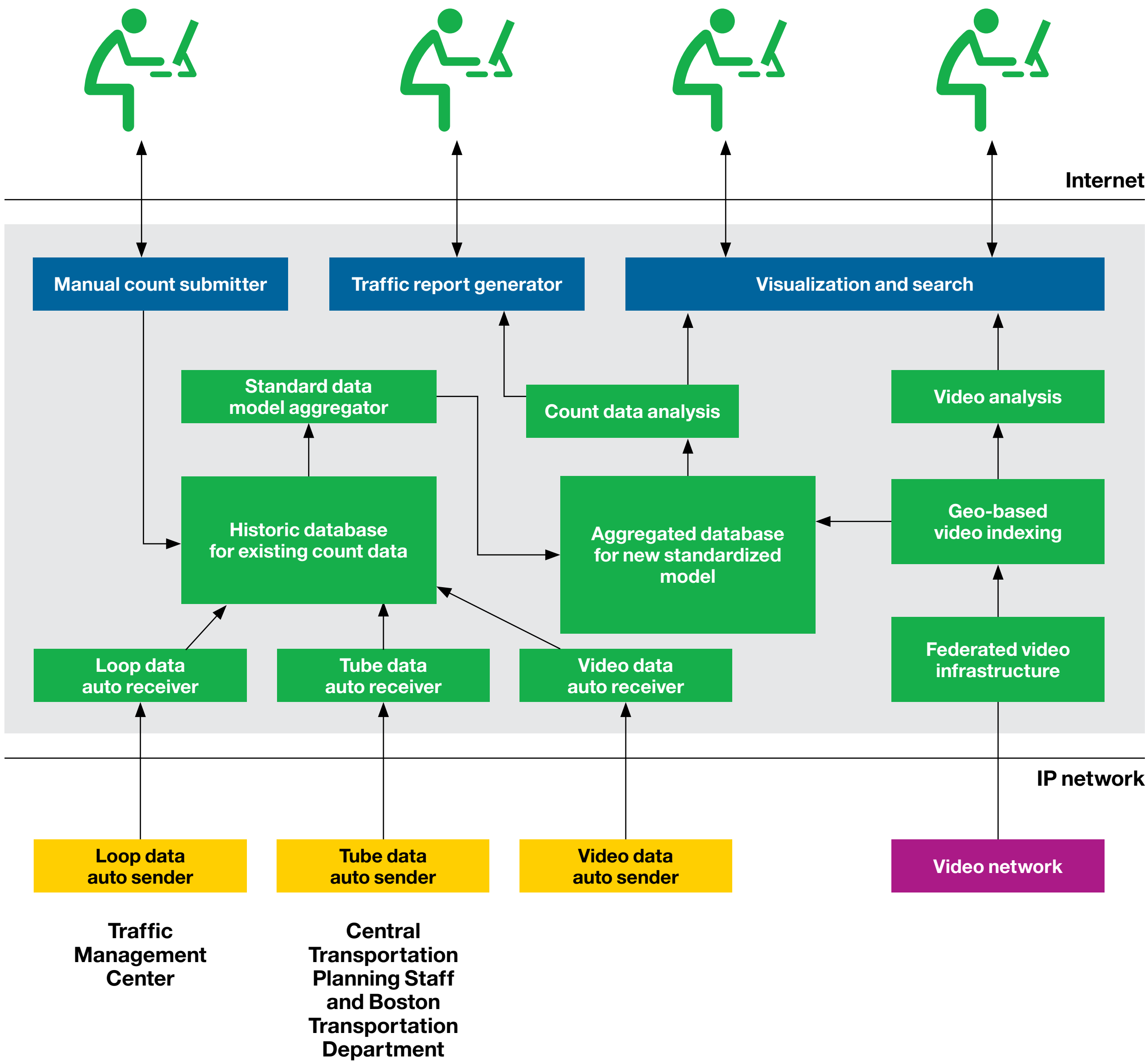

Figure 5
Smarter traffic control infrastructure

Recommendation 3b: Establish infrastructure to enable new applications (continued)	
Proposed owner and stakeholders	**Suggested resources needed**
Owners: Boston Transportation Department; Department of Innovation and Technology **Stakeholders:** Data producers, including Traffic Management Center; Legal department; public safety departments; CTPS; MBTA	DoIT is primarily responsible for this implementation, and the City might want to involve third-party vendors, consultants and university experts. The cost is high.
Dependencies	**Key milestones, activities and timeframe**
Depends on most other recommendations	**Short term:** Implement components 1-10 and a portion of component 14 for traffic counts data only. **Medium term:** Implement component 11. **Long term:** Implement components 12-13 and the remainder of component 14 with video integration.
Priority status	
High	

Recommendation 3c: Provide traffic data analytics

The City should provide traffic data analytics for extracting, transforming and loading traffic data to verify the accuracy of aggregated traffic sensor data and to provide various reports that are useful for the City's operations.

Scope and expected outcomes

The analytics presented in this recommendation address only data that the City currently collects. The scope of these analytics includes defining standard procedures essential for removing noise, identifying false sensor data, verifying data accuracy and providing insights to manage traffic. Analytics that address future data sources, such as cameras, are described in Recommendation 4c.

Outcomes include:

1. Aggregated data that is of higher quality than data provided by other traffic data providers — the City has direct access to inductive loop, tube count and manual count data that, when pre-processed with basic analytics, is more reliable than raw data
2. Basic tools to detect broken or anomalous sensor devices, enabling the City to leverage its investment in sensors and act as a trusted data provider
3. Insights for managing traffic that include:
   - Peak hours on each street and in/out directional flows of traffic in the city
   - Road classification based on distribution of traffic volume and patterns
   - Travel conditions with state indicators described in the common data model for roads and intersections
   - CO_2 heat map based on traffic density and measurement data
   - Standards-based traffic state indicators
   - Inductive loop sensor fault detection
   - Traffic growth rate estimation
   - Traffic simulation technologies to support urban planning
   - Alternative routes computation
   - Estimation of travel time to particular landmarks
   - Estimation of un-sensed areas based on sensors in adjacent areas
   - Distribution of modes

Additional outcomes include efficiency increases for data collection and visualization, the ability to incorporate new technologies and the possibility to share data and analytic skills with other cities.

Figure 6 depicts one of the demonstration prototypes of time-series sensor data analytics that can be used to classify roads (by time-series clustering algorithms) according to their average weekday temporal distribution of traffic volume. The team discovered six traffic patterns on the streets that were analyzed and referred to as commuting, going-home, anomaly, early-bird, night-owl and busy streets. This is also an example of analytical visualization described in Recommendation 3e.

As the City of Boston collects data from various sources, skills in analyzing that data and using it to optimize the City's operations are essential. Analytics classes include:

1. Time-series sensor data analytics
2. Data mining and machine learning
3. Geospatial-temporal data analytics
4. Large-scale combinatorial optimization
5. Privacy-preserving data mining
6. Simulation with emphasis on traffic and CO_2 distribution

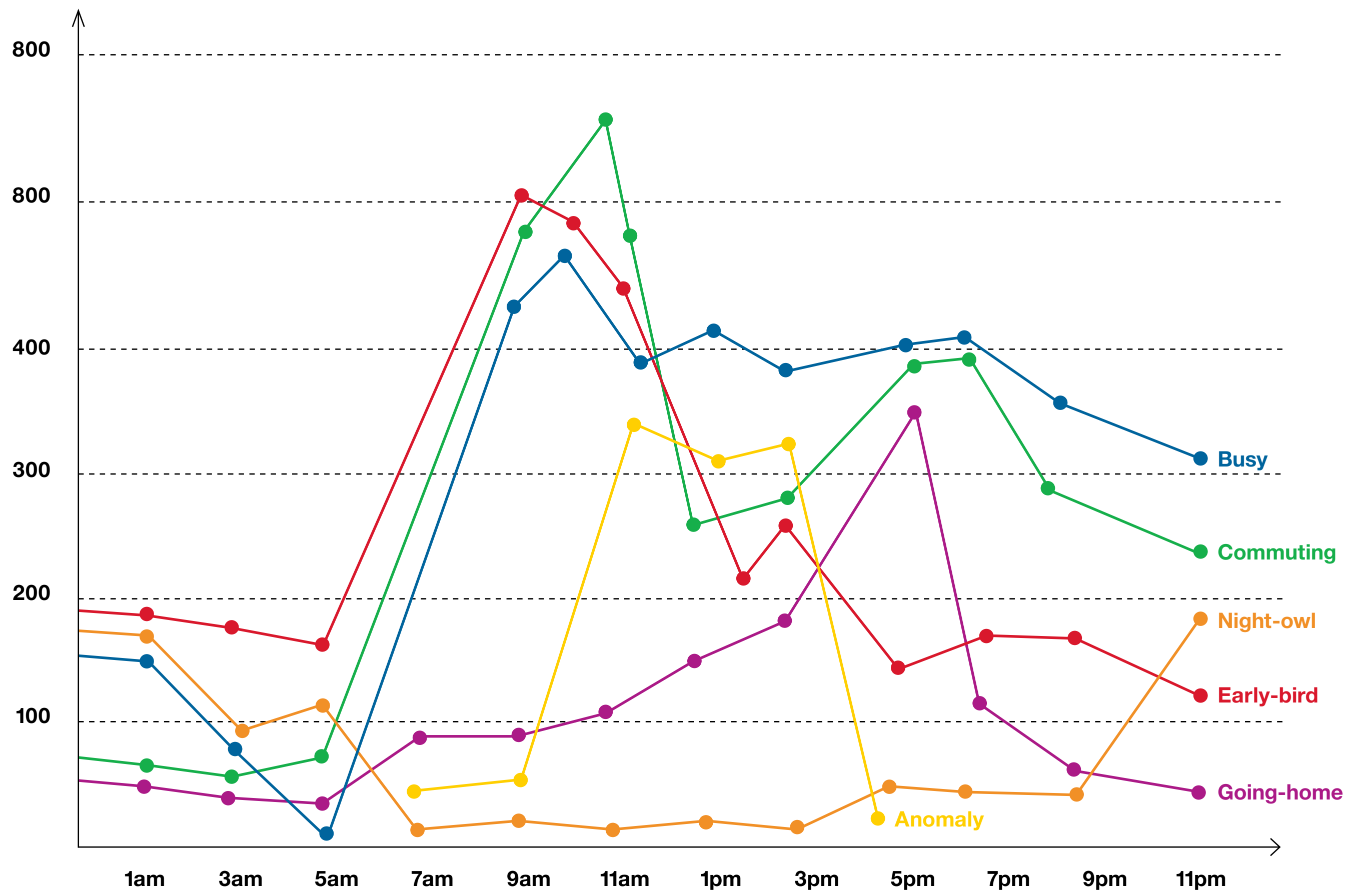

Figure 6
Time series traffic data for six representative traffic patterns

Recommendation 3c: Provide traffic data analytics (continued)

Scope and expected outcomes (continued)

Mature methods in time-series sensor data analytics, data mining and machine learning are widely available as open source products, such as R, scikit-learn in Python or Weka in Java. Commercial products also exist.

Geospatial-temporal data analytics is a flourishing research topic, and, although commercial software exists, support from researchers in academia and businesses might be required. The same can be said about privacy-preserving data mining.

For large-scale combinatorial optimization, some knowledge in linear programming and mixed-integer programming is essential. Advanced and reliable commercial products in this field are widely available.

Although methods for traffic simulation and its connection to CO_2 emissions are not yet mature, research results in traffic simulation for vehicles and multi-modal transportation simulation exist.

Costs of inaction on this recommendation would be:
1. Accumulation of unreliable data that consumes resources to collect, store and manage
2. Lost opportunities for increased efficiencies of operation in many departments of the City
3. Lost opportunities for insights to support policies to manage traffic to meet environmental goals

Proposed owner and stakeholders	Suggested resources needed
Owners: Mayor's Office of New Urban Mechanics should organize ideas for analytics and the data that should be collected. Each data owner is a stakeholder because the analyzed data can be used to improve each data owner's operations (that is, data producers can also be data consumers). For example, the Traffic Management Center can obtain cleaned and analyzed data that can be used to help locate faulty inductive loops.	To handle the complexity of analytics, a Data Analytics team might be formed by the Mayor's Office of New Urban Mechanics. This team could determine insights from data that is aggregated from various data sources. The team could work with various City departments to define reports that could improve efficiency, collaborate with researchers and develop analytics that could be used by other cities. A project manager from New Urban Mechanics should be assigned to coordinate a team that is responsible for maintaining and collecting data from sensor devices (such as inductive loops). An expert in GIS and an expert in data analytics should participate. Academic experts in data mining, analytics and optimization can contribute to this recommendation. The cost is medium.
Dependencies	**Key milestones, activities and timeframe**
Recommendations 1b and 1c	**Short term:** Publish data obtained from sensor devices with documentation about the data properties. **Medium term:** Document standard procedures to infer missing data and filter abnormal data. **Long term:** Publish the results of data analytics with visualization methods as described in Recommendation 3e.

Priority status

High

Recommendation 3d: Provide carbon dioxide (CO_2) estimates

The City should provide CO_2 emission estimates based on traffic data analytics to inform decision making about actions to mitigate climate change.

Scope and expected outcomes

Transportation accounts for about one-fourth of Boston's greenhouse gas (GHG) emissions. In 2008, it was estimated that all vehicles in Boston and the MBTA operations emitted a combined 2.3 million tons of carbon dioxide.

Using traffic data analytics, the City should calculate the estimated CO_2 emissions at specific intersections, then, using the count data from a particular intersection, correlate the CO_2 emissions based on observed CO_2 measurements.

Outcomes include the ability to determine CO_2 emissions across the city and the ability to report and visualize this data to help citizens make intelligent choices about transportation alternatives, as depicted in Figure 7. By understanding the amount of CO_2 emissions associated with transportation related activities, the City can make informed decisions about actions to mitigate climate change.

The cost of inaction includes obstacles to achieving the City's climate goals as expressed in the Mayor's Climate Action Plan. Additionally, inaction could potentially bring significant economic disruption to the city because climate changes could directly impact the harbor and associated low-lying areas, ultimately impacting residents' quality of life.

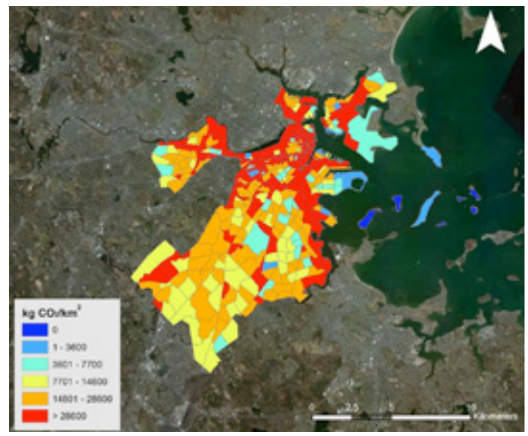

Figure 7
Example of CO_2 visualization

Courtesy Boston University; Source: Brondfield, M.N., Hutyra, L.R., Gately, C., Raciti, S.M., Peterson, S.A. (2012), "Modeling and validation of on-road CO2 emissions inventories at the urban regional scale," *Environmental Pollution*

Proposed owner and stakeholders	Suggested resources needed
Owner: Environmental and Energy Services Cabinet **Stakeholders:** Traffic Management Center; Infrastructure and Applications, DoIT; Boston University	A project manager from the Environmental and Energy Services Cabinet should be assigned to coordinate a team to work with DoIT to develop this calculation and associated visualization. Academic experts in CO_2 emissions and climate change can contribute to this recommendation. The cost is low because it is based on existing traffic data.
Dependencies	**Key milestones, activities and timeframe**
Recommendations 1, 2a, 3a and 3c	**Short term:** Correlate the CO_2 emissions to the traffic data model. **Medium term:** Observe and report on CO_2 emissions trends across City of Boston intersections. **Long term:** Report on progress to achieve CO_2 goals.

Priority status

High priority based on Mayor's Climate Action plan that includes a goal to reduce CO_2 emissions by 25 percent by 2020

Recommendation 3e: Provide visualization for data generated by analytics
The City should provide visualization techniques for viewing the data generated by the various types of data analytics.
Scope and expected outcomes
The visualization for data types, such as those listed in Table 1, can be grouped into three categories: as-is, analytical and what-if: 1. As-is visualization is intended to display various time-series sensor data that provides information about the state of each sensor device and the corresponding state of roads where the sensors are located. The outcome is visualization for the data that is collected from pneumatic tubes, inductive loops and manual counts, with other data sources in the future. Benefits include improving the City's operations and levels of service. The cost of inaction is high because accumulated data cannot be utilized without as-is visualization. Figure 8 is an example of as-is visualization of the traffic volume of a road. 2. Analytical visualization is intended to obtain a comprehensive view of the traffic conditions in the City. Benefits include the ability to discern traffic patterns for streets that have instrumentation or, based on data generated by analytics, produce traffic estimates for streets without sensor data. This enables data-driven decisions about strategies to reduce congestion and decrease VMT and associated greenhouse gas emissions. Figure 9 consists of four images at six-hour intervals from a series of images that spans 24 hours. It illustrates a combination of as-is visualization and analytical visualization of the dynamic nature of traffic in Boston. 3. What-if visualization is intended to display the results of proposed actions and policies for transportation, such as reducing parking spots, reducing travel lanes and closing streets. Benefits include the ability to predict traffic and the ability to evaluate traffic policies.

Proposed owner and stakeholders	**Suggested resources needed**
Owner: Department of Innovation and Technology (DoIT should lead visualization efforts and produce appropriate visualization for each stakeholder who provides sensor data) **Stakeholders:** Boston Transportation Department; Traffic Management Center; Mayor's Office of New Urban Mechanics; Environmental and Energy Services Cabinet	• As-is visualization cost is low. It entails knowledge of plotting graphs and basic analytical skills and requires a small amount of IT investment. Such visualization was already demonstrated in the prototype. • Analytical and what-if visualization costs are medium, requiring advanced analytical skills and a medium amount of IT investment. • Each stage of visualization can build on the investments made for the prior stage.
Dependencies	**Key milestones, activities and timeframe**
Recommendation 3c for as-is visualization	Key milestones for as-is are to implement visualization of: 1. Location of sensors and counts (demonstrated in prototype) 2. Faulty inductive loop data 3. Comparisons of inductive loop data with surrounding pneumatic tube counts to verify data accuracy Key milestones for analytical are to implement visualization to determine: 1. Peak traffic hours 2. Traffic patterns 3. Anomalies in traffic patterns 4. CO_2 emissions based on traffic patterns Key milestones for what-if are to implement visualization of: 1. Traffic pattern predictions 2. The effects of traffic policies

Priority status
High priority for as-is visualization, medium priority for analytical visualization, low priority for what-if visualization

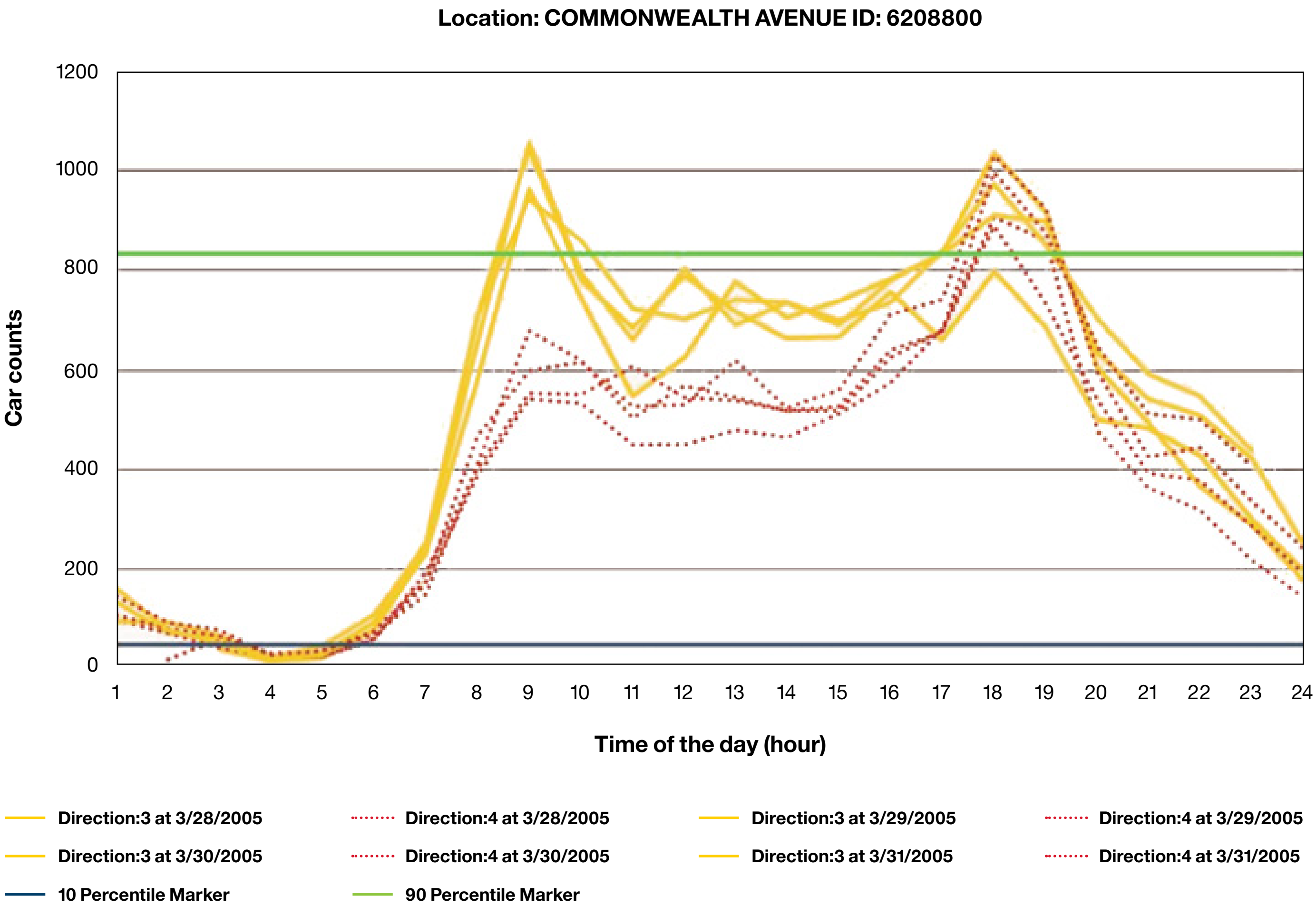

Figure 8
Example of as-is visualization

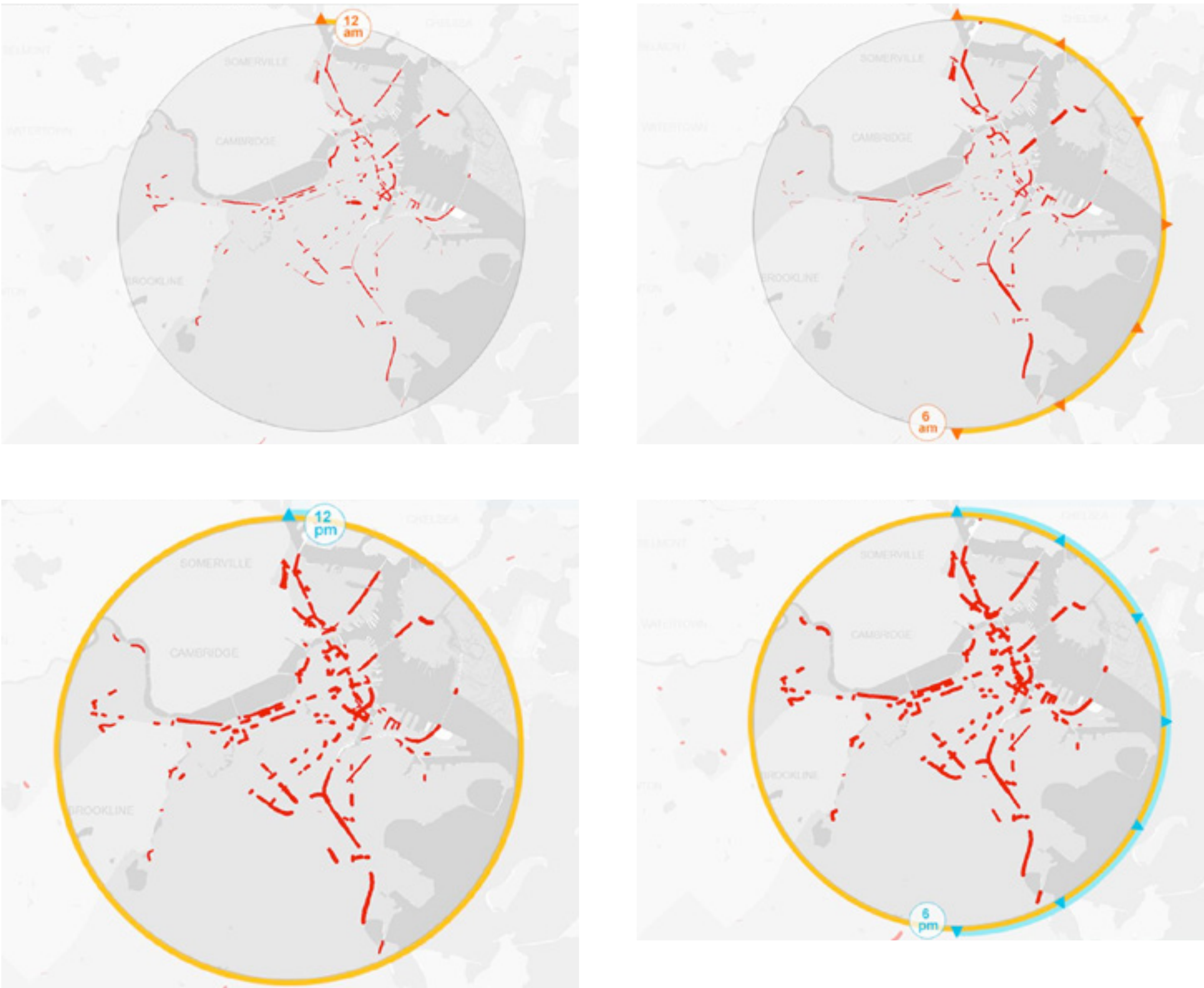

Figure 9
Example of as-is visualization and analytic visualization

Recommendation 3f: Perform benchmarking	
The City should perform benchmarks with other cities and share best practices.	
Scope and expected outcomes	
The City of Boston is a recognized leader among its peer municipalities. By sharing best practices, Boston and other cities can increase the returns on their investments. Boston can increase the benefits from the investments made in IT infrastructure to help reduce VMT and associated greenhouse gas emissions. The City should share the techniques it has employed to unlock, share and analyze traffic data and calculate associated CO_2 emissions. Expected outcomes include: • Recognition of the City of Boston as a thought leader for transportation and environmental solutions • Identification of insights gained from other cities that could be used in Boston • The ability for citizens to see government transparency and collaboration	
Proposed owner and stakeholders	**Suggested resources needed**
Owner: Mayor's Office of New Urban Mechanics **Stakeholders:** Department of Innovation and Technology	An assigned person from the Mayor's Office of New Urban Mechanics should initiate and lead this effort. Minimal resources should be required to implement a tool to share best practices, such as an online open forum. Such forums already exist, such as CityForward[9] and data.gov[10].
Dependencies	**Key milestones, activities and timeframe**
This recommendation depends on progress of most other recommendations because the best practices are gleaned from their implementation. However, existing best practices in other areas could be shared immediately, as appropriate, so the forum for sharing could be put in place now.	**Short term:** Determine best practices already in place within the City of Boston and share these externally. **Medium term:** Benchmark Boston's best practices with respect to those of other cities in the US and around the world.
Priority status	
Medium	

Recommendation 4: Future vision

The forward-thinking future vision enables new ideas to be realized, and advanced analytics and applications to be implemented, leading toward a smarter traffic management system in Boston that serves many consumers, especially citizens.

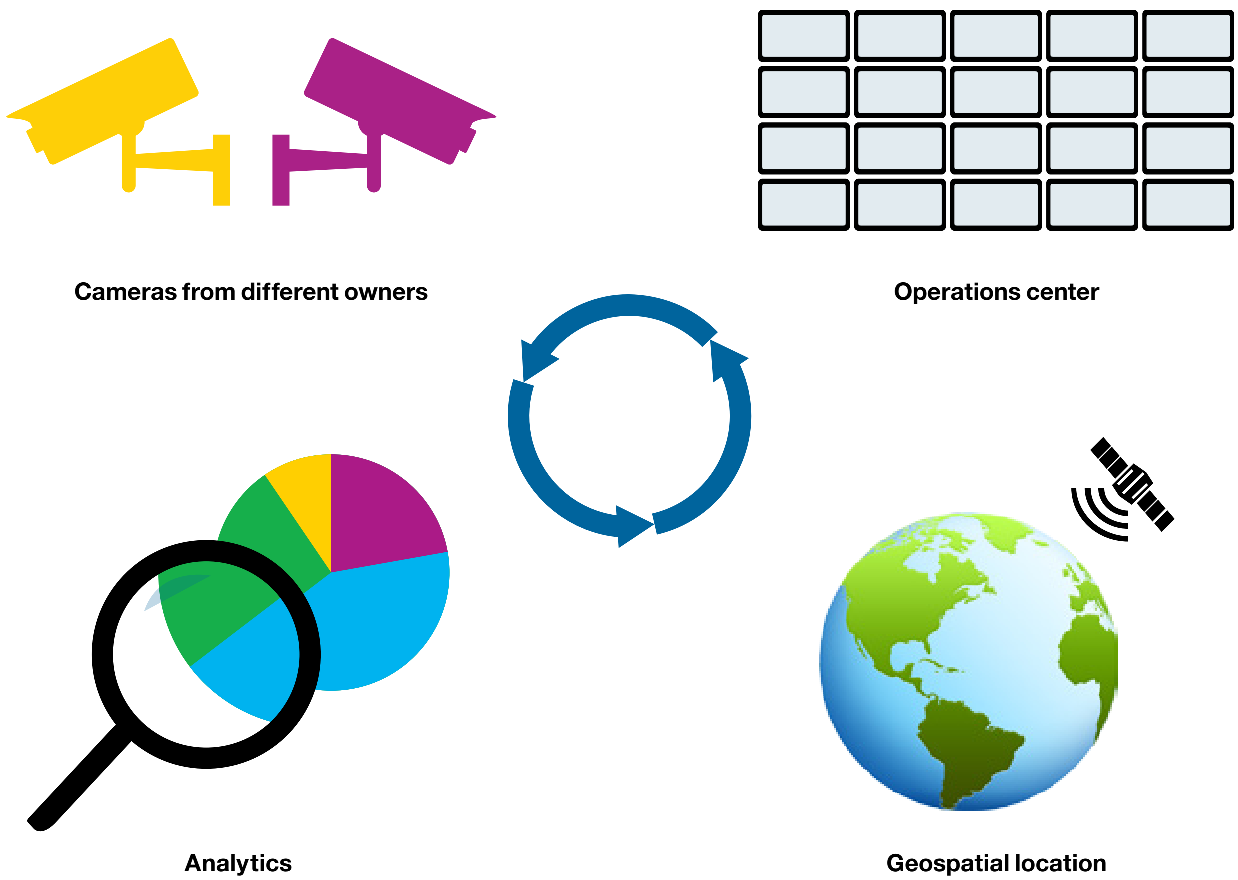

Figure 10
Video camera federation

"A missing component is the inductive loop equivalent to count pedestrians and bicycles automatically."

—Vineet Gupta, Director of Policy and Planning, Boston Transportation Department

"If we shared cameras and used video analytics, then law enforcement agencies could do a better job in a shorter period of time"

—Don Denning, Public Safety Chief Information Officer

Recommendation 4a: Consolidate video cameras

The City should consolidate video cameras that currently are isolated in departmental "silos" by establishing a federated video infrastructure managed by the Department of Innovation and Technology, considering camera network design, servers, storage, platforms and standards.

Scope and expected outcomes

In city surveillance installations, integrators and administrators often face the challenge of integrating several independent surveillance entities into a large-scale system that provides monitoring and administration access to the entire system while still allowing for local management and monitoring.

Creating a federated video surveillance system enables various stakeholders to share their cameras. Each site in a federated architecture hierarchy can be designed with the performance of the single system and network in mind. To be a part of the hierarchy, each system needs only a network connection to the rest of the hierarchy. This connection can be through a firewall or a router with Network Address Translation (NAT). Each site can run independently, with the ability for the site's local administrators and users to log in, view video from cameras and manage the site, even when the network connection to the federated hierarchy is broken. If the connection to a site in the federated hierarchy is lost, the global users in the hierarchy still can log in and access cameras from all the other sites in the hierarchy that remain online. To minimize the risk of losing network connection to the various sites in the hierarchy, standard methods for implementing network redundancy can be used. This is illustrated in Figure 10.

An expected outcome of this recommendation is that the City's traffic department and law enforcement agencies will be able to quickly access and watch all the cameras placed in the city, whether they are owned by the police department, traffic department, security departments of other public agencies or private real estate owners.

Sharing cameras with multiple stakeholders enables various City departments to view thousands of existing cameras and to consolidate them without needing to install new ones. Using a federated architecture, the law enforcement agencies could record footage from the cameras that currently are outside the law enforcement's camera network, such as traffic cameras. Once built, the new infrastructure will enable citizens, researchers, developers and public and private stakeholders to access it or pay for it as a service. City Hall could become a security system provider, renting the infrastructure (cameras, server, storage and networking) to public and private consumers.

Recommendation 4a: Consolidate video cameras (continued)	
Proposed owner and stakeholders	**Suggested resources needed**
Owner: Department of Innovation and Technology; City departments that own cameras (including Police, Traffic Management Center) **Stakeholders:** City departments that own cameras (including Police; Traffic Management Center); Law Department	Because DoIT already plans to create a federated architecture, using VidSys as the Physical Security Information Management platform, they should direct this integration project. DoIT may need support from vendors or consultants to define the best way to leverage the existing fiber optic and wireless infrastructure and to define the best set of cameras to use.
Dependencies	**Key milestones, activities and timeframe**
Recommendations 2c and 3b The federated architecture enables integration of only IP (digital) cameras; analog cameras or sensors must be connected to IP encoder devices before being linked to the new infrastructure. Security cameras and the security software platform must be compatible with at least one of the two industry standards (PSIA and ONVIF) to simplify the product selection phase and the integration with various command and control rooms, such as the Traffic Management Center and Emergency Management Center. All shared cameras must be synchronized using a common time server.	**Short term:** Define a document of understanding among the law enforcement agencies, Traffic Management Center and DoIT that describes the policy, standards and procedures that will be used in the common infrastructure. The City's Law department should define a contract between the City and stakeholders who want to be linked to the new infrastructure. **Medium term:** Create and expand the existing network (fiber or wireless) to enable new stakeholders to share their cameras. Use the existing GIS platform of the City (ESRI/ArcGIS) as a common database to store the location, owner and type of all the existing outdoor cameras. Provide a common time server to synchronize the time of all shared camera and servers. **Long term:** Leverage the existing cameras with video analytics to provide multiple information to different users (for example, traffic data to the Traffic Management Center, abandoned objects to law enforcement agencies and parking information to citizens).
Priority status	
High	

Recommendation 4b: Exploit multiple existing data sources
The City should create a comprehensive infrastructure for a smarter traffic control system that collects data from multiple sources, including those listed in Table 1.
Scope and expected outcomes
To provide stakeholders more information from multiple sources, a comprehensive infrastructure needs to be established. Based on the near-term infrastructure in Recommendation 3b, data imputation is needed to make multi-modal resources available to the system, as shown in Figure 11. The data processing and imputation component will handle the input from data sources defined in Table 1, then process data in the format of the common data model defined in Recommendation 1a, while adding more data types and updating standards. The new technology of handling "big data" should gradually be added to the existing infrastructure. The data sources listed in Table 1 can be categorized into four types as shown in Figure 11: Transportation Authorities data, mobile data, public data and GIS data. The Transportation Authorities data includes data from video cameras, inductive loops owned by the City and state authorities. This data can be collected by the infrastructure defined in Recommendation 3b. The other three types of data need new input mechanisms to be defined, but the common data model can support these new data types. Sensor data typically is managed by individual organizations. As depicted in Figure 12, a software component, referred to as "auto sender," is needed to periodically load the sensor data and transfer it to the main data aggregation system. The auto sender can be simple or complex, depending on the volume and nature of the data, as well as the IT infrastructure (such as network connectivity) that is available to process it at the source. This data must be received and cleaned by a software component, referred to as the "data cleaner and aggregator." The cleaned and aggregated data can be incorporated into a common model using a variety of techniques, such as data warehousing or data federation, based on the City's technical architecture preference. The prototype used the data warehousing approach, which is extensible to other data sources. The team recommends the City consider implementing state-of-the-art technology for each type and methods to import these additional data types into the system.

Proposed owner and stakeholders	**Suggested resources needed**
Owner: Department of Innovation and Technology **Stakeholders:** Infrastructure and Applications, DoIT	To import multiple data sources into the smarter traffic system, collaboration among the City, academia and citizens is essential. The City should leverage various human resources on a volunteer basis. DoIT must implement the data imputation components in the framework.
Dependencies	**Key milestones, activities and timeframe**
Recommendations 1a, 2c and 3c	**Short term**: Import GPS data into the system for traffic visualization. **Medium term:** Import public data into the system, such as Citizens Connect. **Long term:** Import mobile device data into the system.

Priority status
Medium priority for short term, low priority for medium and long term

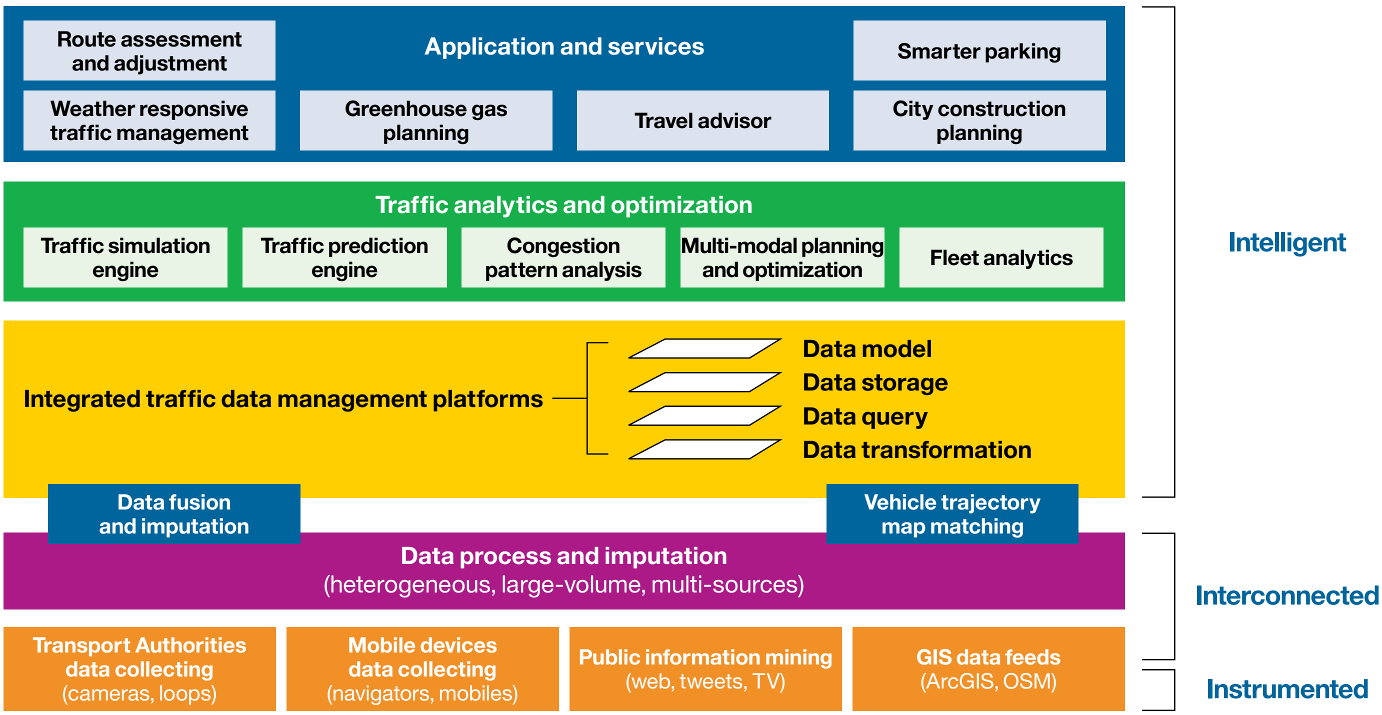

Figure 11
Smart traffic system framework

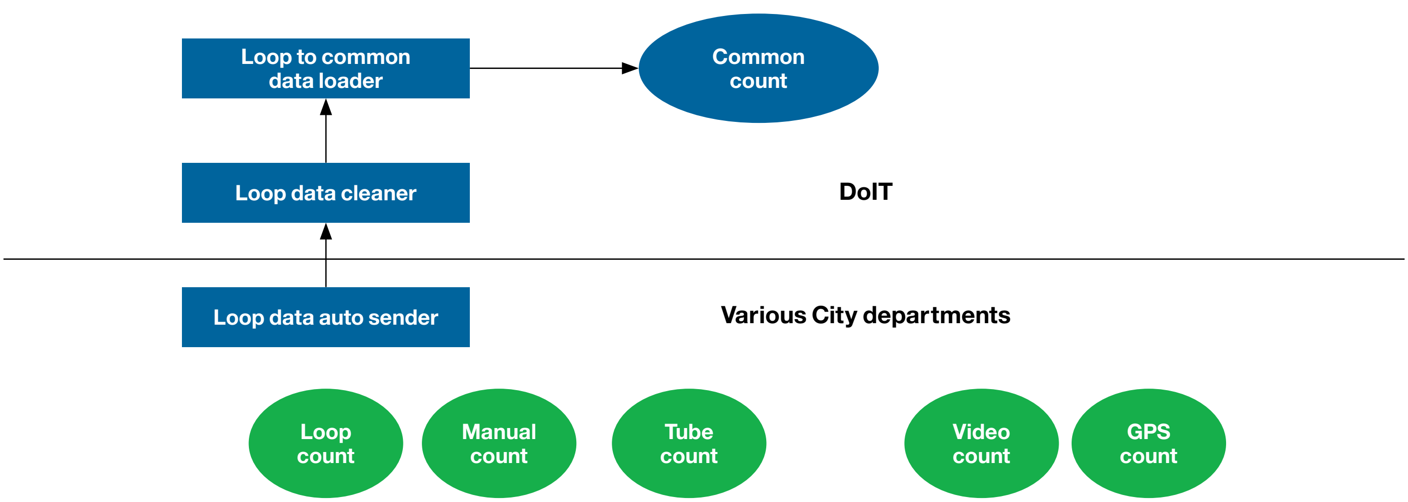

Figure 12
Example of data-loading process for loop counts

> *"Having access to traffic data coming from inductive loops and, in the future, from cameras, and being able to manipulate this data, will be a great step forward for my job."*
>
> —David Knudsen, GIS Analyst, Central Transportation Planning Staff

Recommendation 4c: Use multiple data sources to validate other data sources	
The City should use the various data sources it has to validate one another. This can lead to more reliable data and, over time, elimination of inferior data sources.	
Scope and expected outcomes	
Because existing traffic information comes from various sources at different times, data reliability can be improved by using multiple technologies, such as cameras, GPS or external databases, to validate traffic data. Each data source has its own advantages and limitations. Particular sources might be more reliable at particular times or in specific situations. For example, inductive loops are susceptible to damage from highway construction, and cameras can be limited by weather conditions. Figure 13 illustrates characteristics of two relevant data sources. One benefit, over time, is that it might be possible to reduce the total number of cameras that the City owns and maintains by using one camera for multiple purposes and audiences. Figure 14 illustrates this use of a single camera for multiple purposes, using video analytics.	
Proposed owner and stakeholders	**Suggested resources needed**
Owner: Traffic Management Center **Stakeholder:** all owners of outdoor cameras near an intersection or a street	Use video analytics counting technology to validate the inductive loop counts and/or tube counts. Video analytics can also provide information about speed, vehicle classification and traffic congestion. The same existing traffic cameras could be leveraged with video analytics to provide information for law enforcement agencies (such as abandoned objects, loitering, identifying stolen vehicles and sending alerts when vehicles park in no-parking zones).
Dependencies	**Key milestones, activities and timeframe**
Recommendation 4a	**Short term:** Define the critical intersections that have at least one camera that can be used with video analytics to manage traffic. **Medium term:** Install a video analytics platform that fits with the existing video management systems. Install and tune the analytics software. Use the existing police video system, with the analytics software, to generate traffic count data and origin-destination matrix. Metadata created by the video analytics platform should be indexed to significantly reduce the time required for post-event searches.
Priority status	
High priority for video integration, medium priority for other data sources	

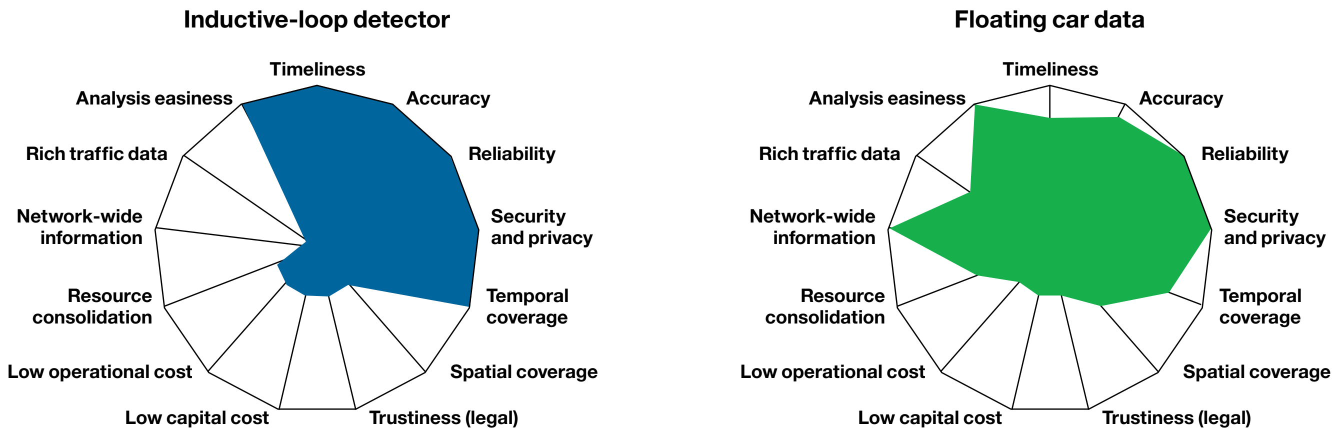

Figure 13
Data source characteristics

Figure 14
Example of video analytics

Recommendation 4d: Create an architecture roadmap	
The City should create a long-term architecture roadmap to gradually establish the entire infrastructure with state-of-the-art technologies for components such as networks, servers, storage, sensors and video cameras.	
Scope and expected outcomes	
The roadmap should include: • Technology migration plans that include using one form of sensor to augment and validate other forms of sensors (for example, use video cameras to augment and validate inductive loops and manual counts) • Gradually replacing older traffic measurement and control technologies with more efficient, accurate technologies, such as IP and wireless-based systems (such as microwave and wireless cameras), GPS and video analytics • Building a network infrastructure with high-bandwidth, fiber-optic backbone connections and a well-designed topology to ensure flexibility and scalability for aggregated traffic data from multiple sources (including video), thus enabling a smarter traffic control system for real-time analytics and visualization • Collaboration with universities and businesses to improve traffic data analytics and optimization to fully utilize multi-modal data that is collected from various sources, and improve traffic control and associated services to make Boston a Smarter City	
Proposed owner and stakeholders	**Suggested resources needed**
Owner: Mayor's Office of New Urban Mechanics **Stakeholders:** Department of Innovation and Technology; Boston Transportation Department; public safety departments (police, fire); Environmental and Energy Services Cabinet	The Mayor's Office of New Urban Mechanics should lead this project and assign a City project manager who is empowered to coordinate other stakeholder departments and collaborate with universities and the private sector. DoIT can acquire and develop technology that supports and implements this roadmap.
Dependencies	**Key milestones, activities and timeframe**
This recommendation depends on most other recommendations.	**Short term:** Define a common City roadmap starting from the best existing technology, practices, policies and controls for each stakeholder department. The roadmap in this report offers guidance. A sustainable collaboration process should be developed with the private sector and universities.
Priority status	
Medium	

5. Conclusion

The City of Boston is forward-thinking and progressive, and Mayor Menino recognizes that climate goals and automobile traffic improvements are interconnected. The City is well-instrumented today, with various data sources related to traffic sensing.

Much of the data gathered from existing sensors, though, is not fully exploited, because many data sources are not interconnected and, therefore, the potential intelligence that can be gleaned from the data is not realized. The IBM Smarter Cities Challenge team's short-term recommendations focus on unlocking, sharing and analyzing data that already is collected.

Unlocking data involves standardizing the data format and collecting data from the various sources in a common repository, as demonstrated in the prototype that was developed for this IBM Smarter Cities Challenge. Once the data is standardized, it can be more easily shared, also as demonstrated in the prototype. This aggregated, shared data enables more sophisticated analytics and visualization to be performed, to provide new insights to guide actions (such as traffic signal timing optimization, public works project scheduling and traffic condition information for citizens that enables them to choose appropriate transportation options).

Longer-term recommendations include increased use of existing and new video cameras and other data sources, such as regional transportation data, citizen input and GPS data from City vehicles to enable more advanced analytics and further insights into Boston's transportation system. These recommendations enable more data-driven policy decisions to reduce vehicle miles traveled (VMT) and congestion, and they enable intelligent choices for residents that can lead to improvements in quality of life.

Beyond technology recommendations, the team believes it is important to sustain and enrich the collaboration among City government, universities and the private sector — to serve the citizens — which this Smarter Cities Challenge catalyzed.

In summary, the City of Boston has built a strong foundation from which it can build new capabilities, as described in these recommendations, to demonstrate leadership in the intertwined areas of addressing climate change and improving transportation performance as a truly Smarter City.

6. Appendix

A. Acknowledgements

The IBM Smarter Cities Challenge team gratefully thanks the many citizens of Boston, all of the organizations that opened their doors and invited us to attend their meetings, and all of the individuals who modified their busy work schedules to have conversations with us during our three weeks in the city. The vision and findings in this report reflect the contributions of many people who offered ideas, explanations, feedback and critiques.

Name	Organisation
Conor Gately	Boston University
Linda Grosser	Boston University
Lucy Hutyra	Boston University
Christos Cassandros	Boston University
Mark Crovella	Boston University
Jonathan Wu	Boston University
Julia Fleck	Boston University
Yuting Chen	Boston University
Yanfeng Geng	Boston University
Yasaman Khazaeni	Boston University
Natali Ruchansky	Boston University
Mohamad Elgharib	Boston University
Janusz Konrad	Boston University
Michael Dettelbach	Boston University
Prakash Ishwar	Boston University
Ted Grunberg	Boston University
Luis Caro-Campos	Boston University
Tom Testa	Boston University
Scott Peterson	Central Transportation Planning Staff
David Knudsen	Central Transportation Planning Staff
Mayor Thomas M. Menino	City of Boston
Mitch Weiss	City of Boston
Jim Alberque	City of Boston
Paul Kresser	City of Boston
Curt Savoie	City of Boston
Claire Lane	City of Boston

Name	Organisation
Donald Denning	City of Boston
Rich Oliver	City of Boston
Vineet Gupta	City of Boston
Tom Tinlin	City of Boston
Susan Hirl	City of Boston
Don Burgess	City of Boston
Jim Hunt	City of Boston
Carl Spector	City of Boston
Patricia Boyle-McKenna	City of Boston
Nigel Jacob	City of Boston
Chris Osgood	City of Boston
Kevin Parker	City of Boston
Kris Carter	City of Boston
John Guilfoil	City of Boston
Jim Fitzgerald	City of Boston
Meredith Weenick	City of Boston
Karen Connor	City of Boston
Daniel Rothman	City of Boston
Prataap Patrose	City of Boston
Mike Ross	City of Boston
Caroline Driscoll	City of Boston
Susan Wang	City of Boston
Jose Gonzalez	City of Boston
Amanda Wall	City of Boston Police Department
Kristopher Reichlen	City of Boston Police Department
Jake Sion	Cornell University
Guy Buso	Howard/Stein-Hudson Associates
Alexandra Siu	Howard/Stein-Hudson Associates
Josh Robin	Massachusetts Bay Transportation Authority
Mark McNeill	Massachusetts Bay Transportation Authority
Brian McKeon	Massachusetts Bay Transportation Authority
Candace Brakewood	Massachusetts Institute of Technology
Chris Haigh	Thompson Island Outward Bound
Michael Hall	Tetra Tech

B. Team biographies

Alberto Giacomel
Physical Security IT Specialist,
IBM Global Technology Services
Milan, Italy

Alberto Giacomel is a pre- and post-sales physical security engineer, working with clients to research, design, sell and deliver new integrated physical security solutions, such as access control, video surveillance and intrusion detection systems. These security solutions include projects in both the public sector (city and transportation) and private sector (banks and manufacturing sites) throughout Europe. Giacomel has been a technical focal point for digital video surveillance solutions over IP and for the IBM video analytics solution called IBM Video Correlation and Analysis Suite (IBM VCAS). He has collaborated with various universities and many industry R&D departments to engineer new innovative security solutions to IBM customers.

Cathleen Finn
New England Manager,
IBM Corporate Citizenship
and Corporate Affairs
Boston, Massachusetts,
United States

Cathleen Finn manages IBM's philanthropic initiatives across four states, including this IBM Smarter Cities Challenge engagement. She has held various roles in information systems and served as a senior internal consultant completing international consulting engagements. Finn graduated with honors with a dual Bachelor of Arts in Mathematics and Psychology from Boston University, and earned a Master of Arts in Conflict Resolution from the University of Massachusetts Boston, receiving an award for academic excellence.

Brent Miller
Senior Technical Staff
Member and Master Inventor,
IBM Intellectual Property
North Carolina, United States

Brent Miller is a Senior Technical Staff Member and Intellectual Property Solutions Engineer in IBM's Research/Corporate Headquarters organization, which is responsible for all IBM patent and technology licensing. He is a technical leader for the technology licensing team, which makes non-commercialized, leading-edge IBM technologies available to clients through custom licensing agreements. Previously at IBM, Miller served as Chief Architect for the Tivoli brand's autonomic computing business unit. He also led several software development teams in pervasive computing, printers, mobile computers and network computing. He was designated an IBM Master Inventor in 2010. Miller has been with IBM for more than 28 years, including several years working on mobile technologies and the past two years identifying IBM Research technologies that can be applied to IBM Smarter Planet solutions.

Raymond Rudy
Research Scientist,
IBM Research
Tokyo, Japan

Raymond Rudy is a member of the Analytics and Optimization group of IBM Research in Tokyo, where he is actively pursuing research in the theoretical aspects of algorithm techniques, data mining and optimization. His work on theoretical aspects of algorithms is mainly on the analysis of Quantum Computation and Information (QCI), which is a novel computation that exploits quantum mechanical phenomena. The experiences of working with advanced math tools for QCI have inspired him to apply them to solve real-world problems. In IBM Research, Rudy has been working with clients in telecommunication and manufacturing industries on geospatial-temporal analytics, sensor data analytics and power optimization. His latest research deals with tracking vehicles from their sequences of noisy GPS points related to mobility pattern recognition and traffic sensing.

Biplav Srivastava
Senior Researcher
and Master Inventor,
IBM Research
New Delhi, India

Biplav Srivastava is a Senior Researcher at IBM Research in New Delhi, India. He has 17 years of experience in industrial and academic research, as well as commercial software development in both India and the US. Srivastava has deep expertise in artificial intelligence, services and sustainability, and a proven track record of high-quality innovation in the global business environment. At IBM, he achieved recognition for his patent work, including IBM Master Inventor in November 2011 and a Corporate Award in 2012. Outside IBM, Srivastava is recognized as a world-class researcher in his areas of expertise. He has published more than 75 research papers, including a range of significant forums in his fields. Srivastava actively participates in professional services, including organizing conference tracks, workshops and as a Program Committee member for more than 50 events.

Steven Wysmuller
Environmental Management System leader,
IBM Global Services
New York, United States

A respected leader in environmental sustainability for nearly 12 years, Steve Wysmuller currently serves as the Environmental Management System leader for IBM Global Services. He is also a Program Manager of Environmental Affairs and Compliance at IBM Global Services, following five years in IBM's Corporate Environmental Affairs department. As an experienced global team manager, Wysmuller has been recognized by the U.S. Environmental Protection Agency as a "strategic thinker" and helped IBM win the EPA's SmartWay Transport Partnership award in 2007. Prior to his work with IBM, he served as Project Engineer at TRC Companies Inc. and as Project Analyst at Technology Team Inc.

Jane Xu
Distinguished Engineer,
IT and Wireless Convergence,
IBM Research
California, United States

Jane Xu is a Distinguished Engineer at IBM Watson Research Center, focusing on the research of IT and Wireless Converged Systems. She is the leading architect of the Machine to Machine (M2M) architecture. Xu leads the IBM worldwide efforts to create a reference architecture of the IBM Smarter Planet Blueprint Common Architecture which covers Smarter Planet applications, including Smarter City and Smarter Transportation. She also works on the Wireless Net Work Cloud project, an IBM pioneer version of the Cloud Radio Access Network in collaboration with the IBM China Research Lab. Xu is a member of the IBM Academy of Technology. In 2008, she was inducted into the Hall of Fame of the Women in Technology International, becoming the fourth Chinese woman with this honor among the 96 worldwide female scientists. She is also a senior member of the Institute of Electrical and Electronics Engineers. Xu received her PhD in Computer Science from the University of Southern California.

C. References

1 City of Boston; www.cityofboston.gov
2 National Complete Streets Coalition; www.completestreets.org
3 United States Department of Transportation – Protecting Our Transportation Systems: An Information Security Awareness Overview; www.fhwa.dot.gov/publications/research/operations/its/jpo98005/protecttrans.pdf
4 NIST – Security and Privacy Controls for Federal Information Systems and Organizations; http://csrc.nist.gov/publications/drafts/800-53-rev4/sp800-53-rev4-ipd.pdf
5 "Smarter city data model standards landscape, Part 2: Transportation"; www.ibm.com/developerworks/industry/library/ind-smartercitydatamodel2
6 City of Boston, "A Climate of Progress (2011 Update)"; www.cityofboston.gov/Images_Documents/A%20Climate%20of%20Progress%20-%20CAP%20Update%202011_tcm3-25020.pdf
7 City of Boston, Street Bump mobile application; www.cityofboston.gov/DoIT/apps/streetbump.asp
8 City of Boston, Boston Food Truck Schedule; www.cityofboston.gov/business/mobile/schedule-tabs.asp
9 City Forward; www.cityforward.org
10 data.gov; www.data.gov
11 City of Boston, Citizens Connect; www.cityofboston.gov/doit/apps/citizensconnect.asp
12 Bradshaw, Hallenbeck, McIntosh, Washington State Transportation Center, University of Washington, Washington State Department of Transportation Advanced Traveler Information Systems Business Plan, www.wsdot.wa.gov/research/reports/fullreports/461.1.pdf
13 DATEX Deployments, www.datex2.eu/datex-node
14 Institute of Electrical and Electronics Engineers, IEEE 1512 Public Safety Early Deployment Projects, http://grouper.ieee.org/groups/scc32/imwg/pubsaf.pdf
15 NTCIP Deployment: Projects, www.ntcip.org/library/projects/
16 Battelle Memorial Institute, "A Report to the ITS Standards Community ITS Standards Testing Program, For TMDD and Related Standards as Deployed by the Utah Department of Transportation"

D. Traffic standards

This appendix describes all of the traffic standards considered for Recommendation 1b (align data with recognized standards).

Standard	Examples of supported concepts	Current deployments
Advanced Traveler Information Systems (ATIS), SAE 2354	Messages defined for traveler information, trip guidance, parking, mayday (emergency information)	International standard (SAE) with traction in North America; gaining momentum in the US; Nebraska, Washington and Minnesota are planning support; see Washington State Department of Transportation Advanced Traveler Information Systems Business Plan[12] for details
DATEX II	Traffic elements, operator actions, impacts, non-road event information, elaborated data and measured data	European standard; version I deployed in several European countries; DATEX II deployment appears to be gaining momentum in several European countries; see DATEX Deployments[13] for details
IEEE 1512	Common incident management message sets for use by emergency management centers, traffic management, public safety, hazardous materials and entities external to centers	International standard; early deployments include Washington D.C., New York City and Milwaukee; see IEEE 1512 Public Safety Early Deployment Projects[14] for details
National Transportation Communication for ITS Protocol (NTCIP) 1200 Series	Currently thirteen data dictionaries defined, including object definitions for dynamic message signs, CCTV camera control, ramp meter control and transportation sensor systems	US-specific standard; according to NTCIP website, several cities and states in the US have NTCIP projects under way; see NTCIP Deployment: Projects[15] for details
Service Interface for Real Time Information (SIRI)	Information exchange of real-time information about public transportation services and vehicles	European-specific standard; based on best practices of various national and proprietary standards from across Europe
Traffic Management Data Dictionary (TMDD)	OwnerCenter, ExternalCenter, Device, DateTime, Dynamic Message Sign, Event, Generic, Organization and RoadNetwork	International standard (ITE and AASHTO) with traction in North America; in early stages of deployment in the US; TMDD is backed by U.S. Department of Transportation and multiple vendors (including Transcom and Siemens); multiple state departments of transportation are planning to move to TMDD in their next revision (including Florida and Utah); see "A Report to the ITS Standards Community ITS Standards Testing Program, For TMDD and Related Standards as Deployed by the Utah Department of Transportation"[16] for TMDD testing details from Utah


MAINE
Portland
Gulf of Maine
Laconia
Concord
Portsmouth
Manchester
Lowell
Nashua
Boston
Massachusetts Bay
Brockton
Cape Cod
Worcester
Providence
New Bedford
Nantucket Island
RHODE ISLAND
NEW HAMPSHIRE

IBM Corporate Citizenship & Corporate Affairs
1 New Orchard Road
Armonk
NY 10504

Produced in the United States of America
January 2013