



IDEA

**Innovations Deserving
Exploratory Analysis Programs**

SHRP 2 RELIABILITY IDEA PROGRAM

Proximity Information Resources for Special Events

Final Report for
SHRP 2 Reliability IDEA Project L-15B

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June 2012

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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This IDEA project was funded by the Second Strategic Highway Research Program (SHRP 2).

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FINAL REPORT
for
SHRP 2 Reliability IDEA

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ACKNOWLEDGEMENTS

The contractor and authors of this report wish to express their gratitude to the National Academy under the Transportation Research Board's (TRB's) Innovations Deserving Exploratory Analysis (IDEA) Program for their financial support for this grant. We would like to thank our panel of experts: Jim Chung of George Washington University, Sue Knapp of KFH Group, and Lester Young of EC&S Associates. We would like to acknowledge the following organizations for their interest in our project: The Bethesda Urban Partnership, ITS America, and The Washington Nationals Baseball Franchise. We would like to especially express our gratitude to the following individuals for their time and interest in our project: Jonathan Aberman, Dave Mulholland of the National Park Service, and James Austrich of the Washington, D.C. Metropolitan Police Department. A very special thank you is dedicated to Marc Hitzig, Festival Director and Ambassador John Malott, President and CEO of the Japan-America Society of Washington, DC for allowing us to conduct experiments at their annual Sakura Matsuri Japanese Street Festival.

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EXECUTIVE SUMMARY

The initial IDEA proposal described the development of a mobile application to assist in management and communications during large events, such as events hosted at the National Mall. The concept was coined PRISM for PProximity Information System for Mobility during special events. The PRISM team was unified through common experiences while attending special events in the Washington DC area. At these events, critical information related either to health, sanitation (restrooms), first aid, guidance, or mobility (parking, shuttles, and recommended driving routes) were frustratingly difficult to obtain. Many times event specific information such as the program, timetables and navigation of booths and stages were also inconveniently conveyed by event organizers. Stage I of the project consisted of sharing the PRISM concept, and its motivations to a number of potential stakeholders and experts. Through collaboration with this group, the PRISM concept was refined, and revealed that event organizers were similarly frustrated by the lack of objective information about the size and disposition of the crowd attending the event, and by lack of means to communicate with them, particularly in emergency situations. By the completion of Stage I, a number of smartphone applications had emerged to service conference venues, delivering a portion of the event specific information envisioned by the original PRISM concept. Although commercial applications were emerging, a significant market gap was identified for a communication and management system for special events that performed the following functions:

- Measure crowd size, density, and movement. Automated methods to assess crowd metrics are notably absent in the market.
- Transform these crowd metrics data into usable information for event management. A crowd management information stream is a welcome addition to emergency management tools.
- Provide an authorized communication channel for authorities and event managers to communicate to event attendees, particularly in the event of emergencies but could also be used for more venue and program information.
- Ensure that this communication link is robust and fail-safe so that it is available in emergencies even when cellular communications fail.

On the recommendation of the expert panel, the stage II PRISM initiative was realigned to focus effort on the market gaps identified above. Building on the core detection technology developed by Traffax Inc., the PRISM team planned to demonstrate the first two functions identified in the gap analysis: collecting crowd metrics and transforming the base data into a meaningful information stream for event management. The goal was to demonstrate such capability within the remaining time and fiscal constraints of project.

Stage II activities consisted of a number of small data collection experiments and prototype software development that led up to a major demonstration in cooperation with Sakura Matsuri, a cultural festival held annually in Washington, DC in conjunction with the Cherry Blossom Festival. Sakura Matsuri provided a compact venue with crowd densities similar to that of large National Mall events. Typical attendance at the one-day festival is estimated at 30,000 to 60,000; large enough to adequately exercise the Traffax pedestrian monitoring equipment. The Japan American Society of Washington DC (JASW) collaborated with the PRISM team, sharing many of the same needs identified by Stage I collaborators, particularly identifying the need for an objective source of real-time crowd metrics without having to rely on subjective crowd observations and estimates. With the cooperation of the JASW, the team was able to deploy its prototype PRISM system during the one day event and demonstrate many of the key features of the re-focused concept.

The JASW demonstration illustrated a number of capabilities and provided insight into a number of issues. Crowd monitoring was demonstrated using a deployment of 11 portable sensors at strategic locations such as entrances, crossroads, and stages. Data from the sensors was delivered in real-time to a monitoring station and was post-processed for in-depth analysis. Additional data streams from social media (Twitter and Flickr), simulated data streams reflecting the availability of space in nearby parking garages, and the location of a roving medic were integrated into the real-time monitor display. Key findings of the demo included:

- Traffax core monitoring technology was able to capture relative volume of pedestrians at entrances as well as at various locations and attractions within the festival. Although sensor range and placement need to be further optimized, the basic sensing capability was affirmed.
- Integrating social media sources such as Twitter and Flickr provided further dimension and color to the real-time monitoring system.

- Simulated data feeds for parking capacity and key personnel locations demonstrated extensibility of the system to provide a broad-based event monitoring platform.
- The data architecture relied on a cloud-based information publishing and subscription model that abstracts data integration. This approach minimized application complexity, eased the development of a custom display, and has the potential to greatly enhance reliability.

In depth post-processed data analysis of sensor data provided detailed information on the size, location, and movement patterns of festival attendees. Key accomplishments and findings included:

- The distribution of attendees determined by sensor data agreed favorably with the portions inferred from same-day ticket sales data provided by JASW.
- The estimated sampling rate of attendees was 1.5% to 2.0%. Uncertainty of actual festival attendance, discriminating attendees from passersby, and varying antenna detection characteristics limited the precision of this estimate.
- Detailed trip patterns from the sensor data revealed the time and sequence of visits to various locations and attractions at the festival. Based on this data, the relative attractiveness of various festival locations and attractions was analyzed.
- Attendance patterns such as time of entry, time of exit, and length of stay were extracted from the trip pattern analysis. The data sample was of sufficient density to create an animated simulation of the sampled trips which provided a visual representation of the level of activity at the festival.

After briefing the expert panel on the results of the festival demonstration, the following conclusions, recommendations and guidance were offered.

- The basic crowd monitoring capability was demonstrated. Although tweaks and improvements can be made, the essential capability is available. Enhancements, such as further data analysis and visualizations, which increase the utility of derived information or make such information actionable by potential clients is critical for market success.
- Primary concern is to identify market potential and clients. Sakura Matsuri, proved to be a successful demonstration yet it has limited revenue potential. Large events, commercial real estate, and various other potential niche clients were discussed.
- Current period of reduced capital investments and improvements puts greater emphasis on planning, creating a potential market for use of crowd metrics to show need and justify capital spending.
- Customized applications to be used at special events or in other potential markets, will require expertise within the respective industry, emphasizing the need to collaborate and partner with prospective clients.

The feedback from the expert panel guided the strategic development of a business plan targeted at creating industry specific products in partnership with identified partners/clients. The plan allows for incremental development and investment to minimize risk as market potential is fully understood. Primary commercialization risk is not technology, but monetization of the product and service. Although a clear need exists for large events, it is unclear whether existing event budgets are adequate to drive the market. Complimentary markets such as public / private sector capital planning analysis, pedestrian behavior studies associated with commercial real estate, and pedestrian monitoring for transit agencies may be viable markets.

In order to clearly articulate the the PRISM concept the research team invested in the production of a short video that captures intent of the system, as well as the results of the demonstration. Readers are encouraged to review the video which is made available online at <https://www.box.com/s/51bnickn2sscfxp4glib>.

CHAPTER 1: IDEA PRODUCT

As a result of the Stage I efforts and through experience gained in Stage II of the project, the PRISM concept is focused on providing a monitoring and management system for use during large events, such as events hosted at the National Mall. The PRISM concept presented in the original IDEA proposal was the result of shared experiences by team members at large events which created either anxiety or frustration when critical information was inadequate or difficult to obtain. Such information may be event specific (such as programs, timetables, and locations), but also ancillary information critical to any situation, such as health and first aid, sanitation (restrooms), navigation and guidance, and mobility options (parking, shuttles, transit, and recommended driving routes). The concept was coined PRISM for PRoximity Information System for Mobility during special events, a catch-all phrase for better situational awareness during large events. The Stage I investigation revealed that event managers were as thirsty for situational awareness on the size and disposition of the crowd of attendees, as the crowds were for better understanding of services and logistics. Although a few companies had begun to produce smart-phone applications that distributed special event information to attendees, no services were available to provide situational awareness to event managers. With this understanding, and acting on the advice from our expert panel, the product of the PRISM IDEA was refocused into the following objectives.

- **Estimate crowd size, density, and movement building on the core detection technology developed by Traffax Inc, a core team member of PRISM. Automated methods to assess crowd metrics are notably absent in the market, and provide a basis from which to build and market a broader based system.**
- **Transform these crowd metrics into usable information. The initial target is for event management personnel who have responsibility for crowd management, safety, and emergency operations. These metrics may also be transformed into information to satisfy the attendees need for situational awareness.**
- Provide an effective communication channel to attendees at events. The channel would be used to communicate safety critical information from authorities and event managers to event attendees in the event of emergencies, but would also convey event specific information, and ancillary information directly to attendees.
- Insure that this communication link is robust and fail-safe so that it is available in emergencies, and when crowd densities are such that cellular communications are saturated and fail.

Stage II activities focused on demonstrating the first two objectives, **as bolded above** – and the first two objectives form the basis for a viable market entry point. After establishing a minimal viable product, additional functionality can be incrementally developed and deployed to address the remaining two pillars of the PRISM concept – as well as provide common event information similar to the first generation of smart phone applications for conferences that have emerged in the past 18 months.

Existing event management relies primarily on expertly trained personnel providing feedback on conditions through voice communications channels. Methods to communicate with the crowds are limited to human interaction and decades old technology of loud-speaker (public-address) systems, and sirens. The latter limit the amount of information and granularity of instruction. A common example shared with the PRISM team is the need to direct crowds to storm shelters along the National Mall in the event of inclement weather. The distributed nature of the shelters makes general notifications through traditional means inefficient. The location and entrances to the shelters need to be communicated (as they are not visually apparent to visitors), and need to be customized to the location of the attendee. Likewise, as these shelters reach capacity, emergency personnel need to redirect people to other shelters. This process relies on observations by personnel in constant voice communication with the command center. Assessing the quantity of people occupying the National Mall is at current a manual process. Any aids that provide automated feedback on the size, disposition, and trajectory of the crowd are welcome from an event managers' point of view.

As a corollary, attendees, particularly those with young families, are also attune to such dangers, and would be better equipped to respond, and be more at ease at the event if such information was readily available. The reader is referred to a use-case scenario conveyed in the Stage I report of a family attending a science-fair festival on the National Mall for additional insight on information critical to attendees.

Although the work of the IDEA program in Stage II was focused on developing and demonstrating the capabilities of the first two objectives highlighted above, that of measuring crowd metrics and transforming it into useable information, these also build a platform to address objectives three and four – that of communicating directly to the crowd. The initial target is a product for event managers, and builds on core capabilities of Traffax Inc. in monitoring technology. The commercial target is a quickly deployable crowd monitoring system with real-time information and post-event analytics.

The deployed sensors needed to support crowd monitoring also provide the platform to develop robust communications directly to crowds in the event of an emergency as well as for normal event information.

Each sensor contains a multi-function standardized field processor, currently dedicated only to sensing crowd metrics. Field processors can support multiple sub-processes related to relaying information in various modes, in addition to their core task of crowd metrics. Various modes of communication could be implemented such as:

- Sensors could provide WiFi data connectivity. This service could provide, for example, a stand alone web server for information or as a conduit back to event management web pages or other data assets.
- The sensor's Bluetooth™ sub-system, currently dedicated to crowd sensing, can also simultaneously support other services. Similar to WiFi, the resulting data connectivity could be used to drive various methods of conveying information such as proximity marketing (but instead of advertisements, event essential information), or to convey SMS and MMS (text and photos) directly to cell phones in the crowd.
- Sensors could drive displays, such as LCD screens, to provide event attendees not only schedule and venue information, but also serve to direct in the event of an emergency.
- If audio peripherals are connected to the sensors, audio warnings and alerts could be relayed to the crowd.
- The physical case of the sensor (or its realization of a piece of event furniture) can be used to display static information (such as sign-up information for text alert messages) or even display Q-R codes to direct attendees to appropriate information portal on the web.

This PRISM approach to augmenting communication via re-use of field processor capacity provides the authenticated communications channel between authorities and/or event managers to the attendees. Furthermore, this method greatly enhances reliability, providing fail-safe, redundant data and messaging channels. The ubiquity of smartphone technology and its evolutionary products provide an environment in which most pedestrians have a dedicated communications, computing, and data storage device. Such devices provide multiple opportunities to connect to provide vital information. Cellular communications links to these mobile platforms remain vulnerable under high demand conditions such as a dense crowd at an event. This effect is compounded during an emergency. A lesson learned from recent disasters is that text and social media appear more resilient than voice connections in times of disaster due to their store and forward nature. Voice connections require either real-time QOS on packet networks, or switched analog circuits, both of which are quickly overwhelmed. The PRISM concept extends this messaging capability, leveraging the multi-channel communications nature of most mobile devices as well as its field processor to provide redundant communications paths, so that in the event the cellular networks are overloaded or inoperable, data connectivity to the event attendee can still be maintained.

Lastly, the PRISM approach provides the opportunity to provide location specific information. Data delivered by a field processor, either through wireless data links, or through visual or audio feeds, are geographically limited, providing the ability to customize the message within the vicinity of the sensor. Additionally, digital data can be geo-coded such that smart phones with GPS reception can filter information specific to their location. Such abilities provide additional tools to direct pedestrians to safety specific to their location.

Safety sells to organizers, convenience satisfies attendees, and overall efficiency gains for events will sustain the business model.

CHAPTER 2: CONCEPT AND INNOVATION

The concept of PRISM is described in the previous section. A key innovative aspect brought by the PRISM team was the ability develop, deploy and manage the PRISM application in such a manner that it is non-complex to users, and adapts easily to new user requirements. Three key areas are integrated to accomplish that goal and to form the basis for a marketable solution. This includes (1) Traffax's ability to detect crowd metrics using its core Bluetooth monitoring technology, (2) transforming the base detections into information that can be consumed easily by event managers, and (3) using a framework that allows for quick deployment, development and customization.

ABILITY TO DETECT CROWD METRICS

The ability to detect the size, distribution and movement of a mass of people is built on Traffax Inc.'s technology which discerns movement based on re-identification of electronic signatures emitted by consumer devices with embedded Bluetooth™ wireless communications subsystems. Already commercialized for the vehicle market, this technology provides a means to directly sample travel time, estimate the number of vehicles traversing a path, and determine the pattern of movement among a network of roadways. Similarly, since many consumer electronic devices are carried on-person, much of the same functionality is possible for pedestrian movements.

The system works through sampling a portion of travelers, i.e. those travelers with a consumer electronic device detectable using the Bluetooth™ pedestrian monitoring (BPM) technology. This process allows for an approximate 5% random sample based on result of roads and highways. Technical research and development during Stage II consisted of adapting and optimizing existing sensor technology for use in pedestrian and crowd environments, and assuring that many of the principles of Bluetooth™ traffic monitoring from the vehicle world are valid for pedestrian environments.

The compact nature, low power, and standardized Bluetooth™ technology also provide development paths to enhance the system. During the festival, sensors were deployed quickly, were unobtrusive, and were, for the most part, invisible to attendees. Sampling percentage at the festival was estimated at 1.5% to 2%. Due to the standardization of the operating platform, the sensor is also adaptable for other functions. For example, a communications hub for Wi-Fi could also be hosted (to provide a communications path to attendees) while the platform still serves its primary sensing objective. The low power and small footprint allow the technology to be integrated into a standardized piece of furniture (such as a table, bench, trash receptacle, shade structures, etc.). This could ease deployment and improve antenna placement.

TRANSFORMING DATA INTO CROWD INFORMATION

The ability to detect crowds and their movement using BPM technology forms the building blocks of the PRISM concept. The ability to transform the data into meaningful information, either in real-time or for after-action reports is critical. It allows the concept to graduate from an interesting lab experiment to a useful commercial tool which can be implemented and leveraged for crowd management.

A portion of the Sakura Matsuri live demonstration included the display of pedestrian volumes (as detected) which are proportional to actual volumes entering the festival. The use of BPM data for crowd measurements (as opposed to movement of pedestrians or vehicles along confined pathways) required additional research into appropriate placement of sensors as well as appropriate data reductions and algorithms to extract information in an unconstrained movement environment. Whereas vehicles on a roadway or pedestrians in urban environments are constrained to known paths and boundaries, large events may allow crowd movement in many directions simultaneously. In the former, sensors need only to be placed at diversion points, whereas in the latter sensors may need to be deployed to create a two dimensional grid in order to capture the crowd movement. Fences and buildings at the festival helped to channelize a portion of the pedestrian flow, easing the challenge of sensor placement and analysis.

Data collected during the festival was analyzed for trip patterns. From these patterns, proportion estimates were made of the number of attendees that entered and exited through various gates, the disposition and size of the crowd throughout the day, the relative attractiveness of locations and attractions within the festival, the peak periods for entry and exit, and the estimated time visitors spent at the festival. Trip data also formed the basis of a simulation of the festival providing a visual, animated representation of festival activity.

In addition to data from sensors, event information must also be integrated (such as known timetables of events and performances) to understand why and when pedestrian traffic is surging or receding. An example from the festival demonstration was the large influx of attendees immediately following the completion of the Cherry Blossom Parade. Additional data applicable to the festival include location and availability of parking, and social information shared by the crowd in the form of pictures or status updates via Twitter. Social data feeds add color and dimensionality to the system.

AN ADAPTABLE AND EXTENSIBLE APPLICATION FRAMEWORK

Agile Media Ventures led the development of the software engine to access data, transform it to meaningful information and display it in an intuitive and adaptable map-based view. Although no individual piece or module of the software development was unique to the PRISM project, the data architecture used to support the development of PRISM software was innovative in allowing for maximum flexibility and extensibility. The architecture was based on an information publish and subscribe (Pub/Sub) mechanism which is beginning to take hold for integration intensive web applications. Whereas traditional integration intensive apps rely on a myriad of well-documented application programming interfaces (APIs), each of which has to be ported and implemented in each module, the PRISM model makes use of a data publisher and subscription mechanism which abstracts this task to a third party messaging system. This greatly simplifies the integration of applications by minimizing the complexity of information sharing. The publish and subscribe data model has long been used to distribute news and social media by simplifying user access to thematic topics so that they do not have to search various web sites. The same concept is now applied to data streams consumed by other applications. Rather than keeping track of a multitude of APIs, each module either contributes to and/or extracts data from a defined data stream. The interface to the data stream is standardized, and secured. This allows for independent development of modules and capabilities with the minimum of integration complexity.

Within the PRISM demonstration, each module ran independently and its data interchange was consolidated to the publish/subscribe interface available from a third-party software-as-a-service provider called *PubNub*. Such flexibility not only greatly conserved development resources, but also allowed for rapid adjustments, even on the day of the demonstration. The efficiency of the architecture is evident in the ability to quickly prototype the overlay of social media (Twitter and Flickr) to provide color and depth to situational awareness, and to integrate other data feeds such as the simulated parking garage capacity, WMATA train service API, and location of critical personnel module. A visual representation of the data flow model used in the festival demonstration is shown in Figure 1.

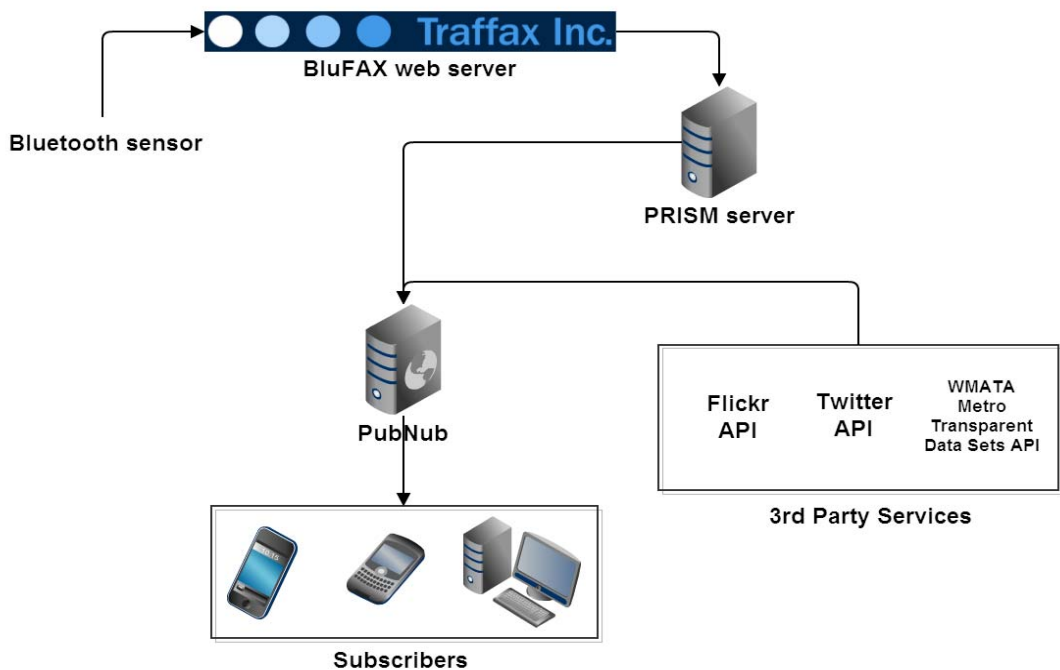


FIGURE 1 Information flow model of the PRISM Demonstration

CHAPTER 3: INVESTIGATION

Based on the outcome of the Stage I investigation, the Stage II work plan was developed consisting of the following overall phases.

1. Design and Execute Proof of Concept
2. Envision 1st Generation and End Product
3. Develop Viable Commercialization Plan

Chapter 3 reports on the design, execution, and result of the proof of concept which culminated in the demonstration at the Sakuri Matsuri festival. After action briefings and feedback with the JASW and the expert panel help shape the vision for a commercial product, and ultimately shaped a business plan for continued commercialization as reported in chapters 4 and 5 respectively.

The demonstration performed in cooperation with the Japan America Society of Washington DC (JASW) on Saturday April 14, 2012 encapsulated the first of the three phases above. Preparation for the Sakura Matsuri demonstration was preceded by several experiments and development efforts.

TRAFFAX PEDESTRIAN MONITORING DEVELOPMENT

Prior to the PRISM project, the base Traffax monitoring technology had been demonstrated on at least two occasions for pedestrian use. One was for a pedestrian dispersion study from a New York City PATH Train station near the site of the World Trade Center. The second was monitoring the exodus of the crowd after the 4th of July fireworks demonstration in Washington DC along 7th Street to support evacuation simulations. Both were minor in terms of size, and the pedestrians were constrained to sidewalks or known paths. The planned demonstration for Sakura Matsuri differed in scale, as well as topography. Rather than known paths, the festival grounds allowed for freedom of movement, though constrained by a boundary fence. The primary significance is that sensor detection footprints during the planned demonstration were not physically or logically constrained by topography or pre-existing routes, and had to be carefully designed and managed in order to extract crowd movement information.

In preparation for deployment for the Sakura Matsuri festival, the PRISM team ran a series of experiments to characterize the detection properties of the Traffax sensor within the pedestrian environment anticipated at the festival. These experiments attempted to isolate the detection range and other properties under controlled conditions. In summary the experiments consisted of:

- Measuring the range of various configurations of sensors and antennas in an open area to determine the sensor's ability to discriminate the general location of a detected target.
- Recording pedestrian activity within a known environment to confirm detection rates of the Traffax technology for pedestrians, and estimate sensor response in a target rich environment.

There were two primary findings of these experiments.

- (1) The experiments confirmed previous experience that the expected detections rate for pedestrians should be consistent with that experienced with vehicles – roughly 5% of the traffic stream. It was difficult to find ground truth data for pedestrians. Although no reference count of students were available, experiments run at the University of Maryland Student Union indicated that the detection rate was generally proportional to the observed volume of students.
- (2) The detection range of the Traffax standard sensor would need to be adjusted for pedestrians. Prevailing design for highways created a substantially larger detection zone radius of roughly 500 feet, which is needed to detect high-speed targets. If used in pedestrian environments, the spatial resolution afforded by the large detection zones would diminish the ability to discern pedestrian foot traffic patterns. The primary finding of preliminary experiments was anticipated detection range by sensor class, antenna gain and antenna height as shown in Table 1. This information resulted in the development of a Class 2 sensor with a 1dB Omin antenna with an anticipated detection range of 100 feet when ground deployed, and approximately 200 feet when elevated. This sensor was used during the demonstration.

TABLE 1 Nominal Pedestrian Detection Range

	On Ground	Elevated > 6'
Class 1 Radio 1 dB Omni antenna	130	450
Class 2 Radio Isotropic Antenna	60	100

In addition to antenna range and sensitivity to height, interference characteristics, and repeatability of inferred travel time and dwell time were also assessed. Fuller details of these preliminary experiments are available in Appendix A.

DEVELOPMENT OF CENTRAL SOFTWARE AND DISPLAY

An important part of the festival demonstration was to display crowd metrics in real-time and integrate it with other forms of information critical to event management. To this end, Agile Media Ventures led the development of a prototype system. The prototype integrated several sub-systems using a new data management model. These efforts included:

Pedestrian Monitoring Data Processor

This module accepted the base detection data delivered by the Traffax sensors and created crowd metrics in real-time. Detections captured via Traffax BluFAX sensors were packaged into bundles and forwarded to a PRISM server. The PRISM server was a cloud-hosted Linux server running custom software developed with node.js and supported by a local Redis key/value data store. Data collected on the PRISM server was analyzed as it was received and converted into simple, human-readable messages that were published to a specific channel on *PubNub*, a cloud-hosted publish/subscribe messaging service for building real-time applications. The resulting information was portrayed as detection rate graphs, which reflected relative volume of pedestrians at the various sensors. The real-time aspects of pedestrian monitoring included detection rates at each sensor, and monitoring the data stream for specific electronic id's which signified the presence and location of critical personnel. Crowd circulation patterns were performed as post-processing.

Graphical Display of Event Information on Festival Maps

For Sakura Matsuri, a prototype map-based display was developed using the Google Maps JavaScript API to display all of the data that was aggregated via *PubNub* in real-time. Data that contained location information was displayed as an overlay on the map. Data with no geographic information (e.g. status updates on Twitter labeled with hashtag #Sakura Matsuri) were simply displayed in a list on the right side of the interface. The map featured an overlay of the festival map created by the sponsor. This display demonstrated the ease with which custom interfaces could be rapidly prototyped, and generated independently using the publish/subscribe data model. See FIGURE 2 for a depiction of the map based interface used during the demonstration.

Parking Garage Capacity Simulation Module

As a demonstration of how other sources of mobility data could be integrated, a module that simulated the receipt of data from adjacent parking garages was developed. The simulated data reflecting the parking capacity of the facility was published to *PubNub* via a mobile application developed using PhoneGap. The display application subscribed to the channel, simulated picking up parking information provided by the parking facility, and then portrayed that information in the map view. This, along with the integration of the WMATA data, demonstrated the capacity to integrate data from existing mobility data systems.

Integration of WMATA Data from Open API

The Washington Metropolitan Area Transit Association (WMATA) manages the local fixed rail transit and provides an API which developers can use to access real-time status of stations and trains. A module was created that published WMATA data from the API to the *PubNub* channel, which was then displayed on the graphical interface. The module utilized the Rail Station Prediction method of the WMATA Transparent Data Sets API to include real-time train arrival information for those stops in/around Sakura Matsuri. This demonstrated the ability to convert existing API based resources into data channels within the PRISM data architecture.

Hand-held, Roving Personnel Monitoring and Data

A module was created that allowed the simulation of monitoring the whereabouts of critical personnel. The module was loaded on a smartphone through means of a mobile web page. The user of the smartphone application could input data, take photos, or collect other information. One of our team members used the app on her iPhone to post periodic updates on what was going on at the festival. Information gathered through this channel went directly from the user's mobile device to PubNub, which was then automatically forwarded to interested subscribers, such as our prototype application described previously. During Sakura Matsuri, this application was used in the 'roving medic' demonstration.

Social Media Portals

Crowd-sourced data, such as text and photos, is becoming an increasingly abundant source of information. Modules were developed that monitored *Flickr* and *Twitter* for geo-referenced data within the boundaries of the festival. For Twitter and Flickr, their respective APIs were used to forward relevant tweets and images to *PubNub*. Once in a *PubNub* channel, the display picked up the relevant data and displayed appropriately.

Combined, these modules comprised the central software that was demonstrated at the Sakura Matsuri festival. This central software combined with the refinements in pedestrian sensing form the basis for the first generation end product.



FIGURE 2 Map Based Interface Used During Sakura Matsuri Demonstration

With the equipment and software readied, the system was prototyped at the annual Sakura Matsuri Japanese cultural festival on April 14, 2012. The Sakura Matsuri festival provided an environment that mimics the crowd densities seen at major events typical of locations such as the National Mall. Attributes of the festival include:

- Approximately 40,000 attendees within seven hours
- Part of a larger 1 million visitor Cherry Blossom Festival
- The festival grounds encompass approximately a half mile along Pennsylvania Ave in Washington DC, as well as portions of intersecting streets
- The grounds are fenced, with 5 entrances/exits, four stages, and over 1 mile of vendor booths and attractions
- The event is served by four metro stations, creating one of the largest ridership days of the year (in combination with Cherry Blossom Activities)

This environment provided an opportunity to confirm the PRISM concept. JASW organizers were interested in objective estimates of crowd size, attendance patterns, and relative attractiveness of the various themed areas of the festival. The deployment of Traffax sensors was planned to capture crowd metrics. The festival presented unique challenges for the deployment, processing, and estimation of crowd movement. A full report on the challenges and results of assessing crowds metrics using Traffax technology at Sakura Matsuri (SM) are available in a separate report, available on request and also accessible on an internet share at <https://www.box.com/s/51bnickn2sscfxp4glib>.

HIGHLIGHTS AND LESSONS LEARNED

Highlights and lessons learned are summarized below.

Eleven Traffax sensors were deployed at the festival as shown in Figure 3. Sensors B, C, F, J, and H were co-located at entrances/exits to the festival. Sensors A, G, E, and K were located near stages. Sensors D and I were at crossroads where the crowd would need to traverse to attend other areas of the festivals.



FIGURE 3 Traffax sensor deployment at festival

The configuration of the sensors was guided by the early experiments. Each sensor was configured with a Class 2 transceiver and a 1dB gain antenna, developed specifically for pedestrian use as previous described. Sensors were deployed along with other temporary structures (fences and booths) on the day of the festival. Some sensors were placed directly on the ground and secured to fences while others were placed about three feet off the ground on top of barrels used as stays for booths at the festival. Sensor deployment required less than one hour, as did retrieval at the end of the day. It was discovered that sensor detection range was impacted by crowd density and/or height to a degree greater than anticipated by preliminary experimentation. Sensors placed directly on the ground consistently detected fewer attendees

than sensors with three feet of elevation, plus the overall detection range of either ground or barrel mounted sensors was less than anticipated based on preliminary experiments, possibly attributed to the density of the crowd. **A primary lesson learned from the festival was that a sensor integrated into standard festival furniture (such as table, shade, or trash receptacle) could ease deployment, provide greater flexibility for placement, simplify permitting, and more easily provide elevation to the sensor antenna.** Any such design could also take into account future plans to integrate crowd communication capabilities, including audio and visual as well as electronic communication.

Each sensor performed as designed. Detection rates were proportional to anticipated traffic. Figure 4 is an example from Sensor B placed at the northwest gate. The pattern of detections is consistent with known activities. The festival started at 11:00 AM. Up until 10:30 AM, pedestrians were free to traverse Pennsylvania Avenue north to south. At 10:30 AM, the festival fence was closed restricting cross traffic, and then festival gates opened at 11:00 AM. The noon lunch, Cherry Blossom parade conclusion, and festival ending times are also called out in Figure 4.

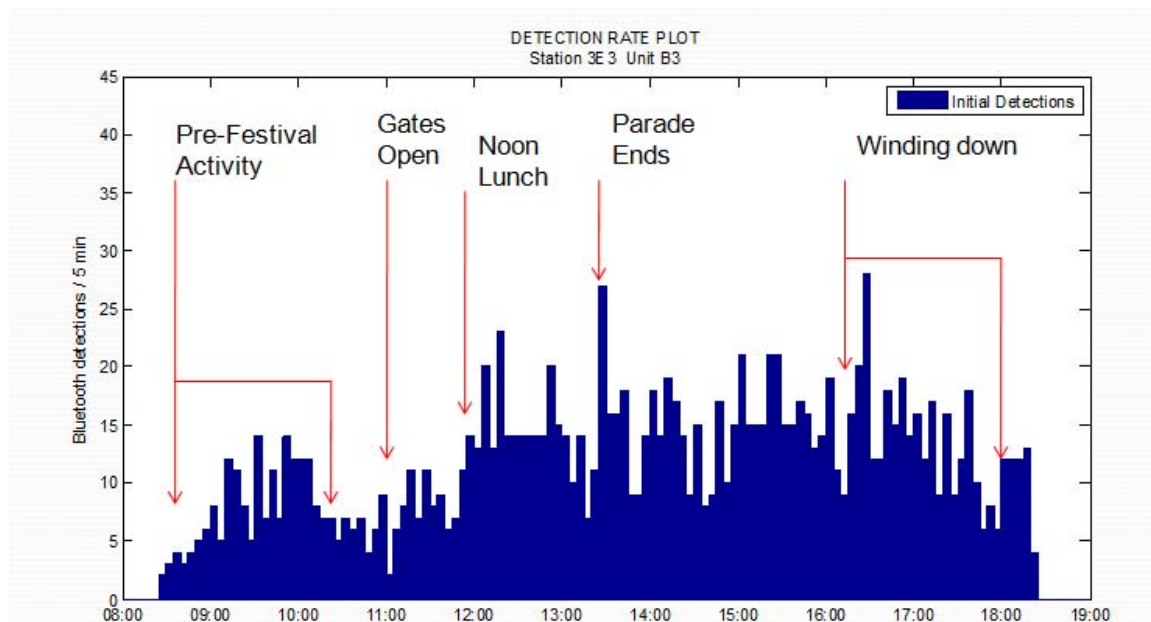


FIGURE 4 Sample detection rate plot for sensor B

Comparison of attendees based on gate receipts from same day ticket sales (comprising over half of all attendees) were consistent with sensor detection counts at each entry gate as shown in Table 2. Ticket sales by gate were the most objective data for comparison. Accurate pedestrian counts are difficult to obtain except when crowds are channeled through turnstiles. No such opportunity was available at Sakura Matsuri. In the absence of ground-truth data for pedestrian, confidence in the system is established with available data (as shown in Table 2) and through experience with vehicle monitoring. On roadways, Traffax technology has been verified with various sources of ground-truth data since its emergence in 2008.

TABLE 2 Comparison of gate receipts with sensors detections

Station	GATE RECEIPTS		BT Detections	
	\$	% of total	#	%
C	5981	27%	1622	28%
B	5803	26%	1432	25%
H	3396	15%	1051	18%
J	3719	17%	722	12%
F	3472	16%	1004	17%
	22321	100%	5831	100%

A trip analysis was performed that examines the time and location that unique Bluetooth devices were observed. For example, a unique device may be first observed at entrance gate F, and then proceed past sensors E, D, G and H, in that order, creating a trip chain of FEDGH, with associated time stamps at each sensor. Trips may have any number of sensors in the chain. A pedestrian may also loop back to a sensor, so that a sensor may appear more than once in a trip chain.

The trip analysis led to several overall findings. The general pattern of arrival and departure is shown in Figure 5 for the festival. Peak attendance was from 12:30 to 4:00PM. Further analysis indicated an average duration of visit of approximately two hours.

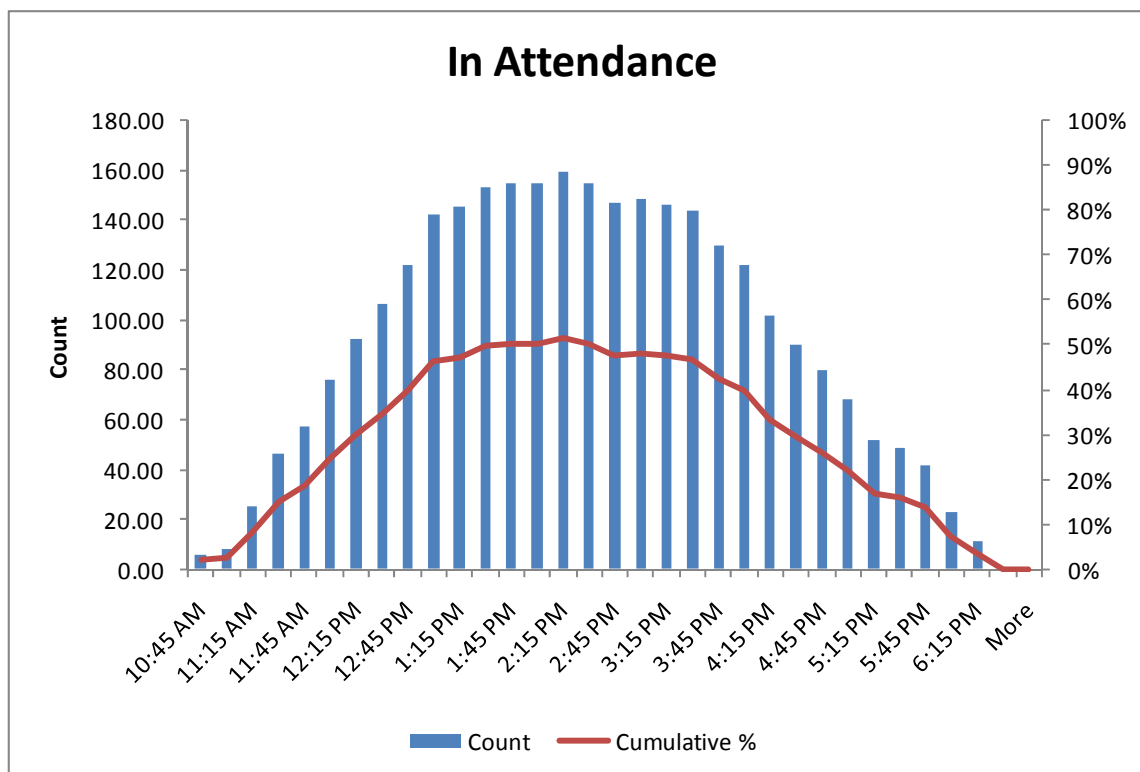


FIGURE 5 Attendance pattern of the festival

Event organizers expressed interest in assessing the relative attractiveness of various venues within the festival. In one such analysis stations were grouped to represent various areas within the festival. Sensors A, B, and C were grouped representing the western end of the festival where traditional folk attractions (both stage and booth) were available. Sensors D and G were grouped representing the central portion of the festival where many food vendors occupied booths. Sensors E and F were grouped representing a major entrance and attractions along its leg. Sensors H, I and J were grouped in the east section of the festival where several pop culture attractions were available. Sensor K at the far-east end of the grounds was near a pop culture stage and a beer garden. The chart in Figure 6 represents the relative attraction of these various areas presented as a ‘sand-diagram’. In this stacked line chart, the distance between the line for a specific area and the line below it is proportional to the volume of attendees at that area. For example, the distance between the green line (representing sensors D and G) and the red line (representing sensor A through C) is proportional to the number of attendees observed at sensors D and G. The thickness of the bands between by the various lines portrays the relative attractiveness of the various festival areas.

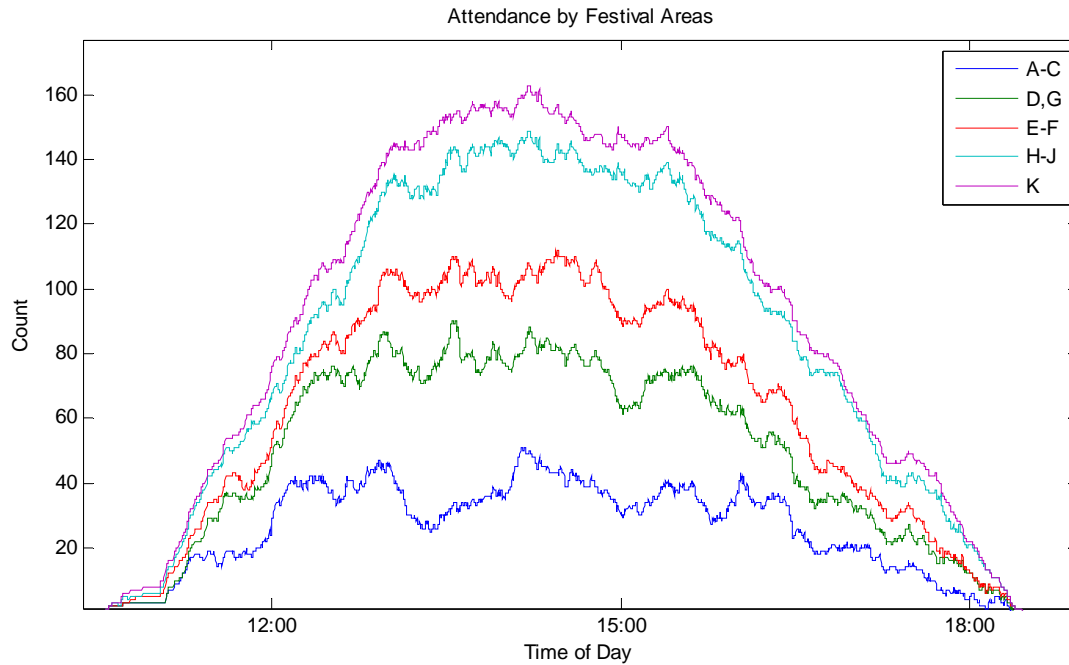


FIGURE 6 Relative attractiveness of various locations at the festival

The density of Traffax data was such that an animated simulation of attendees was able to be created showing the general movement of festival goers from arrival to departure.

In short, the sensor captured an estimated 1.5% to 2% of attendees based on gate receipt counts. Better deployment (particularly raising the height of the antenna) may increase this sampling percentage. However, current sampling was sufficient to characterize crowd movement. The data was able to capture relative volume of attendees, when and where they arrived and exited, and the distribution of attendees at various attractions.

CHAPTER 4: Plans for Implementation

The demonstration at Sakura Matsuri vetted the technology sufficiently so that technical risks are manageable and a development path can be adequately characterized to support special events. Crowd metrics extracted from the sensor data were the primary interest of JASW organizers. The business model, financing and cash flow were the primary topics of discussion and feedback in follow up meetings with the expert panel. Demonstrated utility and capacity to evolve to the full featured PRISM concept were the primary interests of a follow up meeting with the United States Park Police.

On the 6th of June, 2012, JASW organizers were briefed on the results of the PRISM demonstration at the festival. On the day of the festival JASW organizers were shown the real-time monitoring aspects. The after-action briefing was designed to summarize the accomplishments of the festival demonstration and to present and discuss the analysis of the collected sensor data. At the briefing JASW organizers inquired if data could be further analyzed to determine aspects of the crowd such as:

- At 2pm (the estimated peak of attendance) how many people were at each sensor?
- During the peak period of noon to 3pm, how many attendees were at the festival, and where were they generally located?
- Can attendee behavior be analyzed in relation to the available attractions? Do the majority of attendees sample all attractions or hang out at a specific venue?

These questions led to further focused analysis of the data, the results of which are included festival report prepared for JASW. Feedback from JASW underscored the market need for a crowd information system (not simply data or sensors), and reinforced that market opportunities would be primarily service-based rather than product or software license based. The enthusiasm for objective information on crowd behavior exemplifies the current state of affairs for event management which relies almost wholly on manual observations for crowd behaviors.

The second meeting with the expert panel convened on June 11, 2012. Minutes from the meeting are available online at <https://www.box.com/s/51bnickn2sscfxp4glib>. Feedback from the panel included the following observations, recommendations and guidance for commercialization:

- The basic crowd monitoring capability was demonstrated at the festival. Although tweaks and improvements can be made, the essential capacity to assess the location, quantity and travel patterns of attendees was demonstrated.
- Enhancements (technical or systematic) that increase the utility of derived information from the data, or make such information actionable by potential clients is critical for market success.
- The primary concern for viability in the market place is not technical, but rather the size of the market, and method of monetization.
- It is likely that any market (event, commercial, government, or otherwise) will be service based or, at a minimum, a turn-key system, and not the sale or licensure of equipment and software.
- In the opinion of the panel, the size of the municipal event market is not sufficient to justify capital investment. Sakura Matsuri, though a successful demonstration, has limited revenue potential. Although the municipal event market may prove a niche category, the PRISM capability of assessing crowd movement needs to expand and/or adapt to other markets to increase market capacity.
- The need for pedestrian and crowd information in the areas of commercial real-estate and capital improvement planning were discussed as potential markets to augment major events.
 - The current period of declining capital investment puts greater emphasis on planning, creating a potential market for use of crowd metrics to show need and justify capital spending.
- Applications, whether event related or other potential markets, will require expertise within the respective industry in order to transform data into appropriate actionable information. This underscores the need to collaborate and partner with prospective clients.
- The perceived limited size of the market and uncertainties of monetization of the service inhibits external funding opportunities. Methods to organically grow capability, or incrementally build on existing products with

limited investment appears the most viable route to commercialization. This may be altered as the potential market is investigated and better understood.

In summary, the expert panel emphasized that the primary commercialization risk is not technology, but monetization of the product and service. Although a clear need exists for large events, it is questionable that the municipal event market is adequate in itself to support a commercial product. Complimentary markets for capital planning, commercial real estate, and other pedestrian monitoring applications (such as for transit) may supplement to produce a viable market. Feedback from the expert panel were primary driven that guided the development of the strategic business plan in the next section.

On the 24th of September, 2012, representatives from the United States Park Police (USPP) were briefed on the results of the PRISM demonstration at the festival, as well as plans and opportunities to move forward. Feedback from the USPP early in the project was critical in shaping the PRISM concept into its overall objectives. At the briefing, a representative of the USPP reviewed the summary findings with an interest in determining possible applications to larger scale events.

- Comments by USPP affirmed that large events managers have an interest in objective crowd monitoring, with many of the same interests as shared by JASW organizers.
- 1-2% detection should be sufficient for crowds of >100,000 people as is typical at major Mall events.
- The 2013 inauguration was discussed as a possible next step in developing and proving the technology. Knowledge of size and dispersion of the crowd is currently limited to video feeds and field observations.
 - Objective crowd metrics alone, similar to the Sakura Matsuri festival would be welcome input for the inauguration.
 - Deployment could be facilitated by mounting on street lights. This is preferred to deployed posts or stands which would be subject to vandalism and would reduce available standing space.
- Use of devices to relay critical information (in the case of emergencies) would provide additional information conduits critical for crowd safety.
- USPP encouraged partnering with existing vendors of crowd management products.

Feedback from USPP affirmed that the technical approach (that of developing crowd metrics first, and then working toward a full communications capability) was viable. The enthusiasm for objective information on crowd behavior mirrored the input from JASW, and USPP's further enthusiasm of seeing the development path for a fail-safe means of communication led to a discussion of continued opportunities for funding and partnering for development. Each sensors positioned for crowd metrics could also provide additional communication paths to attendees such as WiFi, and Bluetooth digital links, or even audio and video displays enabled by the sensors field processors. Multiple information paths provides resiliency in the event of emergencies when cellular voice channels are quickly over-whelmed.

The debriefing with USPP also clarified the use of crowd metrics in providing information to the crowd in the event of emergencies. Crowd metrics from the PRISM system provide situational awareness to the USPP in addition to video cameras and ground personnel. A frequently cited example was directing crowds on the National Mall to designated storm shelters. The crowd metrics could provide volume and location of the crowd relative to existing storm shelters. The communication portion of the PRISM concept could help direct pedestrians to the nearest shelter. Directions would be customized based on the pedestrian's current location, sending them to the near facility.

STRATEGIC BUSINESS PLAN

The PRISM team is anchored by Traffax Inc., a University of Maryland startup established in 2009 to commercialize Bluetooth™ traffic monitoring technology. In 2012 anticipated Traffax revenue is roughly one million dollars, with limited cash flow to fund major development efforts without raising additional capital. Other team members, Michael Belisle Design and Agile Media Ventures, LLC, are small businesses with similar capital constraints. Outside capitol for the PRISM concept is unlikely due to the relatively small market potential, and the general constriction in venture capital due to prevailing economic downturn. Remaining options encompass an incremental approach to development by partnering with clients to produce customized solutions and thereby growing product capacity.

An incremental development approach yields marketable products in discrete steps. As an example, Traffax Inc. is already moving forward with the development of an easily deployable sensor stand – similar in concept to a sensor integrated into festival furniture, such as a shade structure or waste receptacle. Sensor deployment un-tethered to existing

structures is desirable for several roadway monitoring applications, providing an immediate product for one market, while preparing to engage additional pedestrian monitoring opportunities.

Additional incremental technical development opportunities include:

1. Embed WiFi and Bluetooth communications at the sensor to enhance sensor management and reduce telecommunication costs in the near-term, while simultaneously positioning the sensor to serve as a broad-base communications relay mechanism.
2. Embed trip analysis algorithms used to assess crowd metrics into existing analysis software. These tools provide value for various vehicle applications, while creating analysis capacity to engage potential clients and partners for pedestrian monitoring and crowd metrics.

Identifying partners and potential clients will require continued and additional market research. One such opportunity emerged while preparing for the festival demonstration. The original sensor deployment plan included placing sensors at subway stops near the festival. Although permitting and other concerns prevented placement of sensors at subway stations, inquiries led to a dialogue with the Washington Metropolitan Area Transit Authority (WMATA) concerning data needs for capital planning at stations. The dialogue is progressing, and a small demonstration is being planned. This dialogue also resulted in a grant application for data collection and analysis specific to WMATA planning data needs. Such opportunities will build capacity toward the overall PRISM concept. Potential clients that have been identified include the United States Park Police and the Metropolitan Police Department.

In order to clearly articulate the full breadth of the PRISM concept to engage potential clients, partners, and investors, the research team invested in the production of a short video. The video captures the work accomplished at Sakura Matsuri, as well as the larger PRISM concept to develop an event monitoring and communication system. The video is available for viewing online at <https://www.box.com/s/51bnickn2sscfxp4glib>.

CHAPTER 5: Conclusions

Reliability of transportation, which has gained traction for highways, arterials, and even transit and air travel, extends also for pedestrians. Although pedestrian mobility is a critical link in almost every trip, it is especially vital during large events such as those hosted on the National Mall. Performance measures relating to volume, density and trajectory of pedestrians (referred to as crowd metrics) which are critical to managing large crowds are currently estimated primarily by visual observations. Real-time crowd metrics can provide event managers with situational awareness critical to safely managing a large crowd in the event of emergencies such as inclement weather. The PRISM concept takes the first steps in bringing automated measurement capability to the assessment of crowd metrics, bringing the concepts of transportation reliability to the pedestrian mode.

A PRISM system that assists with event management can provide useful tools to event managers to monitor crowds, and direct them appropriately during emergency situations. Such a system, in its initial form, would provide (1) measurements of crowd metrics such as size, density, and trajectory and (2) projection of crowd metrics into meaningful situational awareness, as well as integration of other information streams available for the event and its surroundings. This technology is built on Traffax's core technology to monitor movement based on Bluetooth™ traffic monitoring technology originally developed for vehicle monitoring, but extended for pedestrian environments. Basic crowd sensing combined with contemporary information streams such as the status of available parking, location and load of transit facilities, and social media such as Twitter™ or Flickr™ provides an automated and multi-dimensional information portal to augment situational awareness for management personnel to better respond.

This basic crowd sensing capability relies on a network of deployed sensors whose functionality can be extended to provide for (3) an authenticated message channel to the crowd, and (4) fail safe communications capabilities that directly connect with user electronics to provide emergency and event information. These latter functions provide essential feedback to attendees by leveraging the use of digital messaging capability proliferating through smart phone technology. This provides not only critical safety information, but may also customize the content based on location of the individual. These latter functions, envisioned as an incremental development path for PRISM, augment reliability by ensuring the pedestrians have access to information specific to their location. In emergency situations in which common communications such as cellular voice and data are unavailable, in capability is needed to maximize the safety of event attendees.

A viable business path to a fully featured PRISM system is based on crowd metrics transformed into automated situational awareness for event management. This capability is currently lacking in the market and provides a gap to address with Traffax Bluetooth™ pedestrian monitoring technology. Crowd metrics transformed into easily customizable information screens through use of a resilient publish/subscribe data information architecture, provides rapid development for speed to market and extensibility for future products and functions. This capability was demonstrated at the 2012 Sakura Matsuri festival sponsored by the Japanese American Society of Washington DC (JASW). The demonstration proved the technical aspects of the PRISM concepts, and produced crowd metrics useful to the festival organizers in future planning.

The commercialization potential of the PRISM concept was the primary concern of the expert panel. Although municipal event management is a clear benefit (note that at the finalization of this report news was received of the use of technology similar to Traffax at the 2012 London Olympics), doubts about the adequacy of the size of the market to support a profitable PRISM venture led to discussion of complimentary markets in need of crowd metrics and other PRISM capabilities. Concerns over market size and monetization of the PRISM features led to a recommended commercialization path that focuses on incremental feature development and partnering with clients to build custom solutions, while simultaneously building product capacity for a broader range of PRISM features. This approach is more adaptable to the restricted resources of the PRISM team, while still offering opportunities for revenue either through direct compensation from clients, grant funding (as is being pursued for a transit application in need of pedestrian data), or smaller scale angel investor development efforts.

APPENDIX A

INTRODUCTION

At the onset of Stage II of the NCHRP IDEA project entitled Proximity Information Resources for Special Events (PRISM), a series of base level detection experiments were conducted to refine and optimize Bluetooth™ detection for crowd movements. Recall that the conclusion of Stage I identified three gaps in existing technology pertaining to crowds at special events. The first of these gaps became the subject of the Stage II effort.

Summary of Stage I – Gap Analysis

Stage I of this project, completed in August of 2011, identified three key concepts of the PRISM proposal not currently available in the market. These areas include:

1. Measuring the size, density, location, and trajectory of large crowds.
2. Provide an authenticated communications channel so that emergency personnel can communicate critical information during times of need.
3. Ensure a robust and reliable communications channel to event attendees.

Of these three, the first, that of delivering crowd metrics, is the subject for a stage II effort.

The initial phase of the State II effort is to develop basic crowd sensing capability, building on the existing Traffax technology for sensing and characterizing vehicular traffic using Bluetooth™ (BT) technology. To that end a series of experiments were conducted to characterize antenna radiation patterns, and investigate Bluetooth detection properties peculiar to pedestrians. Through a series of controlled experiments, the antenna range, sensitivity to height, interference characteristics, and accuracy of travel time measures was determined in order to appropriately model *Crowd Metric* capability. This memo summarizes the tests and findings.

EXPERIMENT 1: CHARACTERIZING BLUETOOTH™ DETECTION RANGE

The ability of the BluFAX devices to detect discoverable Bluetooth devices is primarily limited by the power class of the detector, the gain of the antenna on the detector, the installation height, and distance to the Bluetooth probe. The power class of the probe, its antenna, orientation and height also impact detection but are not controllable. In these experiments the probe characteristics remained fixed, typically a cell phone in discoverable mode held at chest height.

Bluetooth devices are rated by power class, either class 1, 2, or 3. The class refers to the power emitted by the radio, and thus impacts the effective operating range in which they can be used. In these tests, class 1 and class 2 devices were tested under the following conditions.

1. Class 1 BT radio, 1 db gain Omni-directional antenna
2. Class 2 BT radio, iso-tropic antenna

In addition to radio type and antenna, the height of the sensor was also varied. In vehicle applications, the optimum height was determined to be about 6-10 feet above ground. This was thought to minimize the line of sight obstructions to BT devices in the vehicle. Height was also tested for pedestrians (with the hypothesis that height of detector may have less of an impact than with vehicles.)

1. ground level – 6 inches from the ground
2. Elevated installation height – 6-10 feet from the ground.

Results

Each combination of BT radio w/antenna and height was tested for nominal range as shown in FIGURE A. 1.

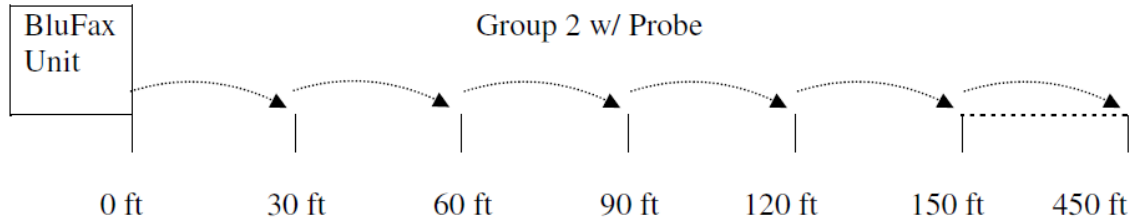


FIGURE A. 1 Diagram of testing

Results of nominal range measurements are shown in TABLE A-1.

TABLE A-1 Nominal detector range in feet

	On Ground	Elevated > 6'
Class 1 Radio 1 dB Omni antenna	130	450
Class 2 Radio Isotropic Antenna	60	100

EXPERIMENT 2: EVALUATING BLUETOOTH™ SENSOR INTERACTION

As a follow up study, BT detectors were tested to determine if the presence of another detector enhanced or degraded detection range. This was tested using two BluFax units, first co-located (see FIGURE A. 2), and then one placed beyond the nominal detection range of the first. Detection ranges specific to the first sensor were tested to determine if the range changed significantly.

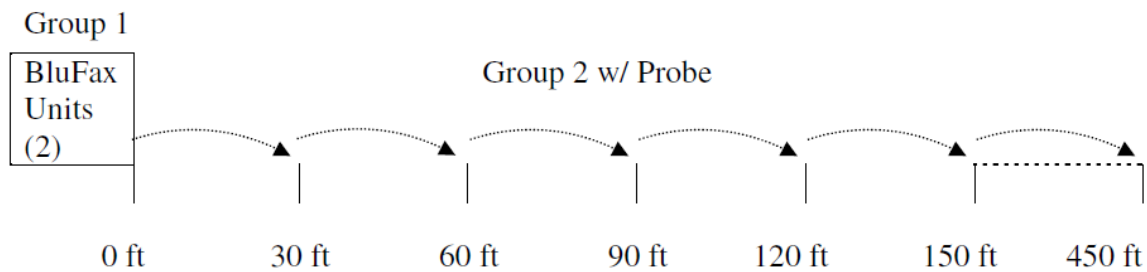


FIGURE A. 2 Two sensors co-located to determine if detection range is impacted

Class II BT configurations with isotropic antenna were used with nominal detection ranges of 90 feet approaching and 20 feet receding. A cell phone was used as a test probe. The position of the cell phone relative to the test figure is a significant contributing factor of the range of the sensors. With the cell phone held at chest height in front of the test subject the detection range facing the BluFax detector was 90 feet. While walking away from the BluFax sensors (see FIGURE A. 4), the detection range was 20 feet. The nominal detection range for approach and egress for the Class II isotropic sensor configuration is shown in FIGURE A. 3.

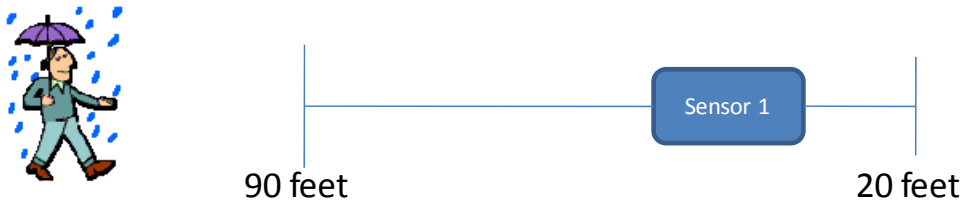


FIGURE A. 3 The detection range of a single BT sensor configured with a Class 2 isotropic antenna.



FIGURE A. 4 Test subject with cell phone held at chest height while walking away from test station (egress).

The impact of co-located sensors on the nominal detection ranges is illustrated in FIGURE A. 5. The approaching range to Sensor 1 remained constant, while the egressing range was measured at 5 feet. Due to the variability observed in measurements, the results were deemed inconclusive.

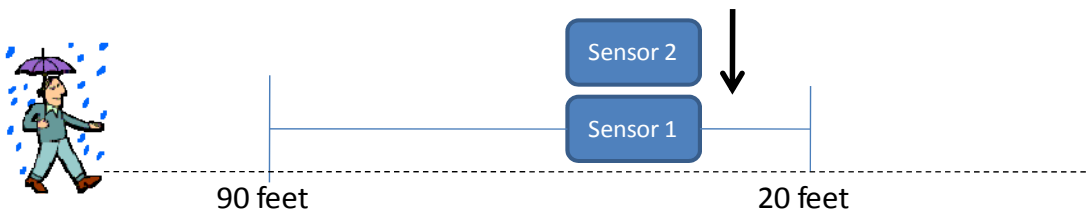


FIGURE A. 5 Test result of collated sensor.

A second test with sensor 2 placed 160 feet was conducted. The results are illustrated in FIGURE A. 6. The detection ranges on approach were measured to be 90 feet, and 10 feet on egressing from sensor 1.

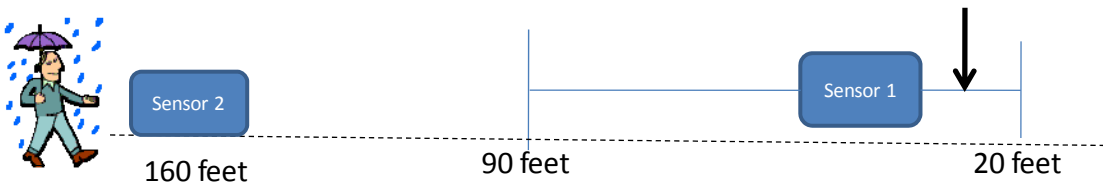


FIGURE A. 6 Test result of second sensor placed beyond the detection range of first sensor.

EXPERIMENT 3: DWELL TIME

In order to validate the accuracy of BT derived travel time, two test scenarios were established. In the first, the dwell time within a single sensor’s detection zone was measured by noting the time of the first detection and the time of the last detection. This time span was then compared to the anticipated dwell time (the time it took the subject to traverse the 90 foot approach to the 20 foot egress) as measured with a stop watch as illustrated in FIGURE A. 7.

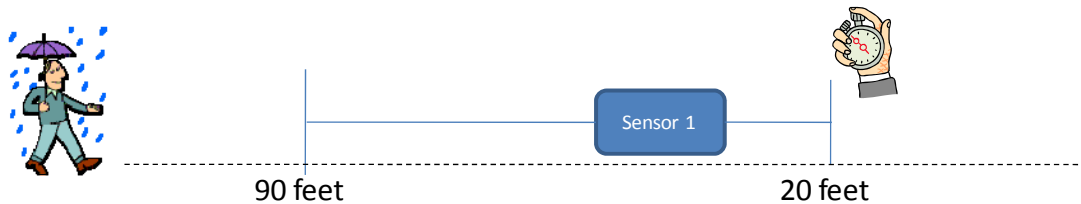


FIGURE A. 7 Dwell time experiment – Scenario 1.

The results of the dwell time experiment are shown in TABLE A-2. As shown in the table, the results for any given trial could be in error, but on average the dwell time was accurate.

TABLE A-2 Results of dwell time experiment

Trial #	Dwell Time (seconds)	
	As measured by BT Sensor	As measured by Stop watch
1	56	32.7
2	26	22.5
3	20	23.2
4	20	23.6
5	26	30.1
6	30	31.7
Avg	29.7	27.3

A second experiment was run in which the traversal time between two sensors was measured and compared to the traversal time estimate based on the BT data as shown in Figure A. 8. Two sensors were placed 200 feet apart. The subject was timed from the point he passed sensor A to the point he passed sensor B. The measured time was compared to the time observed by the recorded BT data.

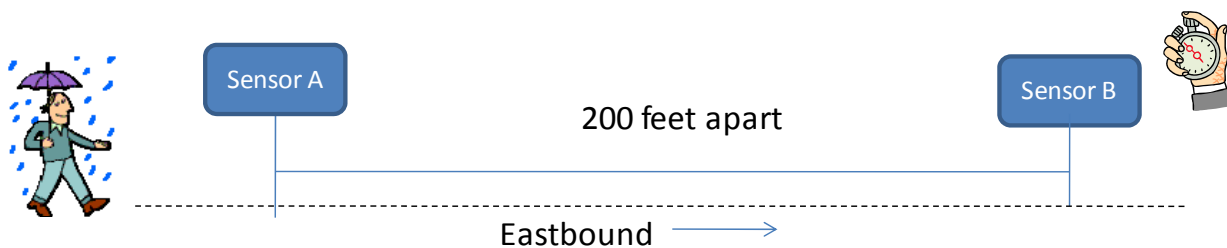


Figure A. 8 – Dwell time experiment – Scenario 2.

The BT travel time results are shown in TABLE A-3. The time to traverse A to B was calculated from BT data in the following manner. At both Sensor A and Sensor B, the time corresponding to the first and last observation of the subject as he passed the respective sensor was recorded (in GMT). The average of the first and last observation at each sensor was calculated, and designated as the estimated time when the subject passed the respective sensor. The difference between these times is the traversal time as estimated via BT data. As shown in TABLE A-3, when traveling WB (westbound), BT consistently underestimated traversal time. While traveling EB (eastbound), BT consistently

overestimated traversal time. This phenomenon led to further investigation. The dwell time at Sensor A was consistently larger than the dwell time at Sensor B for the test subject, leading to the hypothesis that the detection range of Sensor B was significantly less than that of Sensor A. The variability of sensor detection range was tested in Experiment 4.

TABLE A-3 Results of traversal experiment.

Trial	Direction	Sensor A			Sensor B			Time to Traverse A-B (seconds)	
		First Observed	Last Observed	Average	First Observed	Last Observed	Average	Via BT Data	Stopwatch
1	WB	16:26:37	16:27:02	16:26:49	16:26:08	16:26:13	16:26:11	39.0	47.2
3	WB	16:34:04	16:34:19	16:34:11	16:33:30	16:33:35	16:33:33	39.0	45.4
5	WB	16:39:12	16:39:48	16:39:30	16:38:43	16:38:59	16:38:51	39.0	45.1
7	WB	16:44:36	16:45:02	16:44:49	16:44:07	16:44:17	16:44:12	37.0	44.7

Trial	Direction	Sensor A			Sensor B				
2	EB	16:35:11	16:36:02	16:35:37	16:36:35	16:36:45	16:36:40	63.5	43.2
4	EB	16:41:05	16:41:36	16:41:20	16:42:19	16:42:24	16:42:21	61.0	43.9
6	EB	16:46:34	16:47:15	16:46:55	16:47:58	16:48:03	16:48:00	66.0	44.2

EXPERIMENT 4: VARIABILITY OF SENSOR DETECTION RANGE

The results of Experiment 3 led to the hypothesis that significant variability may exist between Bluetooth™ radios. To test this hypothesis, the detection range of four Bluetooth Class II radios were tested as in Experiment 1. The nominal range to cutoff with the sensor on the ground and at chair height was measured. All distances shown in TABLE A-4 were approaching the sensor, with the Bluetooth device held in front of the subject, and facing the sensor. The sensor was rotated 90° at each height to determine any sensitivity to orientation. The results are shown in TABLE A-4. Other than the difference at chair height for sensor B, orientation of 0 degrees, the variation between Class II sensors was insignificant. All distances shown in TABLE A-4 were approaching the sensor, with the Bluetooth device held in front of the subject, and facing the sensor.

Note that the results from the previous data collection (Experiments 1-3) were inconsistent with the results for any of the Class II sensors in that a detection range of 90 feet was never achieved with the sensor placed on the ground – puzzling.

TABLE A-4 Results of Sensor Range Repeatability Test

Height	Orientation	Nominal Range to Cut-off			
		Sensor A	Sensor B	Sensor C	Sensor D
On Ground	0°	20 ft	30 ft	30 ft	30 ft
	90°	20 ft	30 ft	20 ft	30 ft
On Chair	0°	100 ft	55 ft	100 ft	100 ft
	90°	110 ft	125 ft	120 ft	120 ft