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16. ABSTRACT

Deploying innovations in transportation products and services to Stage 5 of the product development process represents a growing challenge for the California Department of Transportation's (Caltrans) Division of Research and Innovation (DRI). This technical agreement focused on communicating the promise of select products and services through outreach and promotion in an effort to gain broader knowledge, understanding, and acceptance of the innovations leading to their adoption by Caltrans and the transportation community at-large. Attention is given to outreach and promotion of ROSA-CRP which addresses integration of traffic collision data packaged in a web-based analysis tool utilizing the Continuous Risk Profile approach to improve identification of high collision concentration locations, and the California Center for Innovative Transportation's (CCIT) portfolio of Caltrans sponsored projects including the Mobile Century and Mobile Millennium projects that opened the door to the use of GPS smart phones as traffic probes for determining real-time traffic flows.

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**CALIFORNIA CENTER FOR INNOVATIVE TRANSPORTATION
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY**

PROMOTING RESEARCH RESULTS AND NEW TECHNOLOGIES: MAKING THE CASE FOR ACCELERATED DEPLOYMENT

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**CCIT RESEARCH REPORT
UCB-ITS-CWP-2011-3**

california center for innovative transportation
UNIVERSITY OF CALIFORNIA, BERKELEY



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Final Report for Research Technical Agreement C806 / 65A0306

July 2011

PROJECT FACT SHEET

Title:	Promoting Research Results and New Technologies: Making the Case for Accelerated Deployment
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Contract No.:	RTA C806 / 65A0306
Performance Period:	July 2008 – November 2010
Project Cost:	\$171,000

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Anything innovative is not easily done and that includes the deployment of new transportation projects, products, and services. Perhaps no one can appreciate the difficulties associated with deployment more than our principal sponsor at Caltrans, Larry Orcutt, who has steadfastly championed the development of the Roadway Safety Analysis (ROSA) package for high collision concentration location (HCCL) identification and analysis. To you we offer our deepest gratitude. We are also thankful for the guidance and support of our other Division of Research and Innovation colleagues Juan Araya, Hamid Ikram, Fred Yazdan, Rebecca Boyer, and Randy Woolley.

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Finally, we thank Annie Schuler and Beth Muramoto for their assistance in compiling and formatting this document.

ABSTRACT

Deploying innovations in transportation products and services to Stage 5 of the product development process represents a growing challenge for the California Department of Transportation's (Caltrans) Division of Research and Innovation (DRI). This technical agreement focused on communicating the promise of select products and services through outreach and promotion in an effort to gain broader knowledge, understanding, and acceptance of the innovations leading to their adoption by Caltrans and the transportation community at-large. Attention is given to outreach and promotion of ROSA-CRP which addresses integration of traffic collision data packaged in a web-based analysis tool utilizing the Continuous Risk Profile approach to improve identification of high collision concentration locations, and the CCIT portfolio of Caltrans sponsored projects including the Mobile Century and Mobile Millennium projects that opened the door to the use of GPS smart phones as traffic probes for determining real-time traffic flows.

ACRONYMS USED

Average Annual Daily Traffic (AADT)

California Center for Innovative Transportation (CCIT)

Caltrans Division of Research and Innovation (DRI)

Continuous Risk Profile (CRP)

Federal Highway Administration (FHWA)

Global Positioning System (GPS)

High Collision Concentration Location (HCCL)

National Cooperative Highway Research Program (NCHRP)

Traffic Accident Surveillance and Analysis System (TASAS)

Traffic Investigation Report Tracking System (TIRTS)

Transportation Systems Network (TSN)

TASAS Selective Accident Retrieval (TSAR)

Research Technical Agreement (RTA)

Roadway Safety Analysis (ROSA)

Safety Performance Function (SPF)

Sliding Moving Window Method (SMW)

State Highway Operation and Protection Program (SHOPP)

State Transportation Improvement Program (STIP)

EXECUTIVE SUMMARY

This document represents the final report for a Caltrans - California Center for Innovative Transportation (CCIT) project, Technical Agreement 65A0306. The goal of this project, *Promoting Research Results and New Technologies: Making the Case for Accelerated Deployment* was to accelerate, via outreach and promotion, the deployment of promising projects of importance to the Caltrans Division of Research and Innovation.

Three categories of outreach and promotion -- (i) internal, (ii) external, and (iii) a mix of both -- have been used to organize this document and to illustrate differences in the application of each type using guidance from Report 610, the NCHRP guidebook on communicating the value of transportation research.

Originally proposed project work plan included four broadly defined tasks: 1) selection of the project for accelerated deployment, 2) assessment of the business/operational need for accelerated deployment, 3) internal and external promotion of the project, and 4) establishment of a framework to assess the value of accelerating deployment.

Early on in the project DRI provided background information on a short-list of potential projects for internal promotion including WeatherShare, Responder, IRIS, Fog Detection, and Identification of High Collision Concentration Locations (HCCL) Using the Continuous Risk Profile Approach (CRP). DRI directed CCIT to focus attention on accelerated deployment of CRP (later called ROSA-CRP) based upon the research findings in the December 2008 California PATH report, *Methods for Identifying High Collision Concentration Locations for Potential Safety Improvements* ((UCB-ITS-PRR-2008-35) (1) and the July 2009 SafeTrec report, *The Continuous Risk Profile Approach for the Identification of High Collision Concentration Locations on Congested Highways* (UCB-ITS-TSC-2007-6-Updated July 2009) (2).

DRI also directed CCIT to maintain flexibility to provide deployment assistance – particularly external outreach and promotion – for in-progress, high profile, innovative projects including Mobile Century and Mobile Millennium. This sharpened focus of the project from the four broadly defined tasks to emphasize outreach and promotion with special attention given to ROSA-CRP.

Outreach and promotion for the Mobile Century and Mobile Millennium projects included the creation of project fact sheets, websites, video segments, and posters to broadly communicate the value and significance of using smart phones as traffic probes to a range of external audiences including other transportation agencies, the media, and to the public at-large.

Also requested by DRI was the creation of mixed audience outreach and promotion materials highlighting the portfolio of CCIT projects sponsored by Caltrans. This included the production of the 2008-2009 CCIT Biennial Report of activities, a services brochure emphasizing the movement of transportation innovations from research to real-world implementation, the development of a CCIT website (<http://www.calccit.org>) highlighting CCIT's unique academic-public-private partnership approach to accelerating deployment, as well as project specific fact sheets.

Accelerated deployment of CRP focused largely on internal outreach and promotion to Caltrans district offices. The emphasis of the Caltrans internal effort was orientation and training on the use of the web-based database and analysis tool called **ROSA – ROadway Safety Analysis**. ROSA combines the existing sources of traffic collision data available from the Traffic Accident Surveillance and Analysis System (TASAS) with the analysis capabilities of the Federal Highway Administration (FHWA) *SafetyAnalyst* software package for HCCL identification, but uses CRP as the methodology.

In addition to providing functions currently available within TIRTS, ROSA offers important new functions that dramatically improve and modernize the traffic collision data and report tracking system. The aim of the advanced functionality within ROSA is to enhance communication among safety engineers and planners to optimize financial and human resource utilization while also improving highway safety.

This report summarizes ROSA-CRP and its functionality and identifies the next step toward Caltrans adoption, now underway as Technical Agreement 65A0373, *Experimental Evaluation of the Continuous Risk Profile (CRP) Approach to the Current Caltrans Methodology for High Collision Concentration Location Identification*.

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BACKGROUND

Originally proposed, the goal of *Promoting Research Results and New Technologies: Making the Case for Accelerated Deployment* was to facilitate and accelerate, via outreach and promotion, the deployment of transportation research and innovation. A key objective was to assist the Caltrans Division of Research and Innovation (DRI) promote promising – cutting edge, high profile – transportation products and services through Stage 5 of the Caltrans project development process shown in Figure 1.

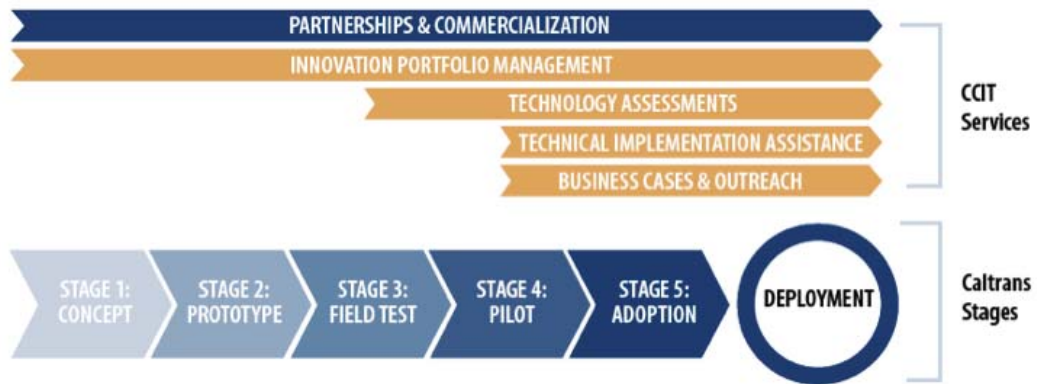


Figure 1: Caltrans-DRI five stages of research and CCIT services.

To achieve this objective, and the ultimate goal of the technical agreement, four broadly defined tasks were identified:

1. Project/product review and selection
2. Business case development
3. Development of internal and external promotional materials and events
4. Development of an economic framework to assess the value of research

Critical to accomplishing these tasks was that the projects or products considered for inclusion in the technical agreement be, a) readily identified by their ability to solve a serious transportation issue, b) intuitively promise a significant benefit over cost, and c) possess a high likelihood for deployment success by DRI.

From the outset, however, these criteria posed a significant challenge to progress. DRI provided early background information for a short-list of candidate projects/products including WeatherShare, Responder, IRIS, and Fog Detection. The final determination directing CCIT to make Identification of High Collision Concentration Locations Using the Continuous Risk Profile Approach the focus of the technical agreement was made by DRI.

DRI's decision to proceed with CRP was based on the findings of the December 2008 California PATH report, *Methods for Identifying High Collision Concentration Locations for Potential Safety Improvements* (UCB-ITS-PRR-2008-35) (1) and the July 2009 SafeTrec report, *The Continuous Risk Profile Approach for the Identification of High Collision Concentration Locations on Congested Highways* (UCB-ITS-TSC-2007-6-Updated July 2009) (2). More about the factors leading to the selection of CRP will be discussed in the section on ROSA-CRP.

At the time CRP was selected to be the focus of the technical agreement in December 2009, DRI brought additional clarity to the project by focusing the four broadly defined tasks to emphasize outreach and promotion for in-progress projects including ROSA-CRP and the CCIT project portfolio. As a result, outreach and promotion associated with the execution of technical agreement presorted here was divided into three categories.

Category I, illustrated by ROSA-CRP, represents outreach and promotion largely internal to Caltrans. Category II, illustrated by Mobile Century and Mobile Millennium, represents outreach and promotion largely external to Caltrans. Category III, illustrated by the CCIT project portfolio sponsored by Caltrans, represents outreach and promotion at a mix of both internal and external audiences.

This document is organized to provide a discussion of each of the outreach and promotion categories described above, with the most extensive discussion given to Category I where approximately sixty percent of the technical agreement budget was utilized.

Sections of the document addressing outreach and promotion of ROSA-CRP include a discussion of the method, navigation of the technical and institutional pathways necessary to successfully achieve deployment, and a description of the functionality of ROSA.

CATEGORY 1: INTERNAL AUDIENCES

OUTREACH & PROMOTION OF ROSA-CRP WITHIN CALTRANS

INTRODUCTION: CRP "THE METHOD"

Reducing the estimated 200,000 collisions that occur annually on California highways, and the potential tort liability they represent, is a high priority for Caltrans. Though resources devoted to collision investigations and improvements are significant, the statewide economic picture demands that more be done with less.

A promising new method for monitoring traffic collision data called the Continuous Risk Profile (CRP) approach, proposed by Chung et al. in July 2009 (2) not only showed the potential for improvements in highway safety, but also demonstrated significant resource savings both in terms of dollars and time spent on collision investigations.

In brief, CRP offers a number of advantages over the existing methods for detecting high collision concentration locations including the current Sliding Moving Window (SMW) method used by Caltrans for more than 30 years. Specifically, CRP does not require segmentation of the roadway under investigation, nor does spatial correlation in the data affect the results of a collision analysis.

Though highly technical in its foundation, the bottom line message is that CRP significantly reduces the number of false positive results (i.e., identifying a site as an high collision concentration location when it is not) when compared to the SMW method (See Table 1). This directly translates into fewer sites requiring a safety investigation and the redirection of limited financial and human resources to higher priority locations where investment in collision countermeasures would demonstrate the greatest improvement in public safety. (2)

Given the potential improvement to public safety coupled with significant monetary and labor savings it's clear to see why DRI would want to accelerate adoption of the CRP approach statewide.

The challenge for CCIT was to navigate CRP from a promising concept demonstrated at small scale on 413 miles of freeway in one Caltrans district to a multi Caltrans district pilot test leading to statewide adoption.

To address the challenge CCIT forged an internal collaboration with the Deployment Branch of DRI to develop an outreach and promotion roadmap to guide the statewide deployment. Essential to the roadmap was the development of a set of deployment questions that would be used as the framework for building an internal outreach and promotion strategy. The set of roadmap questions included:

- Who are users of CRP?
- How would they benefit?
- What current problem is being addressed?
- What is innovative about CRP?

- Is there competition to CRP?
- What is the track record of comparable solutions?
- What prevents CRP from being implemented right away?
- Is procurement involved?
- Are standards and specifications required?
- Are there salient operational, institutional, or legal implications?
- How significant is the challenge posed by these implications?
- Have previous efforts presented CRP to a wide audience of practitioners and decision-makers?
- Have previous efforts identified customers and stakeholders, inside and outside of Caltrans?
- Have previous efforts identified potential business/operations models to introduce CRP into daily practice?
- Have previous efforts quantified the costs and benefits to Caltrans and society?

Arriving at the list of roadmap questions above was driven by a review of previous Caltrans sponsored research addressing the problem of HCCL identification, a review of internal documentation evaluating performance of the current Caltrans HCCL procedure and recommendations for improvement – both short and long term, and finally extensive conversations with Caltrans traffic safety professionals statewide.

This wealth of information was then methodically processed using new guidance on communicating the value of transportation research described in the 2009 National Cooperative Highway Research Program (NCHRP) Report 610. (3) Specifically employed by CCIT was the communications process (Context → Strategy → Content → Channels → Style) and associated methods described in NCHRP, Report 610.

In effect, NCHRP Report 610 became the roadmap, or operational framework, utilized by CCIT for all three categories of project outreach and promotion.

PATHWAYS TO ACHIEVING ROSA-CRP ADOPTION

To tackle the internal outreach and promotion questions raised during CCIT's application of the communication process described in NCHRP, Report 610 it became evident that two distinct pathways would be needed to achieve successful statewide adoption of ROSA-CRP.

One pathway would need to address outstanding technical issues surrounding CRP as the procedure of record to be utilized throughout Caltrans for HCCL identification in the future.

The second pathway, viewed as more qualitative and perhaps less tangible, but no less significant, would need to address institutional barriers associated with the widespread implementation of a new procedure that would replace one with more than a 30 year history. Also included here is the added dimension posed by what has incorrectly been labeled as competition to the CRP approach, namely the FHWA *SafetyAnalyst* program.

ADDRESSING THE TECHNICAL ISSUES PATHWAY

Responding to issues relating to the first pathway involved creating a stronger technical foundation for adoption of CRP by applying the approach to an expanded list of highway routes from multiple Caltrans districts, and to experimentally compare via simulation the outcomes of CRP versus SMW analyses. The scope of this effort was determined to be beyond the outreach and promotion scope of the project being reported here, which led to the creation of Technical Agreement 65A0373, *Experimental Evaluation of the Continuous Risk Profile (CRP) Approach to the Current Caltrans Methodology for High Collision Concentration Location Identification* currently underway by CCIT. The primary goal of 65A0373 is to quantitatively demonstrate the efficacy of CRP as a state-of-the-practice approach for HCCL identification. Results from the project are anticipated in March 2012.

ADDRESSING THE INSTITUTIONAL ISSUES PATHWAY

Issues associated with the second pathway to CRP adoption, namely institutional barriers, are summarized here and organized thematically by issue.

UNDERSTANDING WHAT CRP "IS"

Chief among the institutional barriers to Caltrans' adoption of CRP is achieving an understanding of what CRP "is" and how it relates with to the current Caltrans HCCL process.

The current Caltrans HCCL method (SMW), imbedded in TASAS the legacy system database for the analysis of Table C and Wet Table C, shown in Figure 2, has a 30-year institutional history.*

Overcoming the inertia associated with transitioning from a familiar, well-established procedure to a new one, regardless of the benefits, can be difficult particularly when the new method is not well understood by the intended users.

*Note: Readers of this report requiring detailed information about TASAS, Table C and Wet Table C should review the *Table C Task Force Summary of Task Force's Findings and Recommendations* dated September 2002. (4)

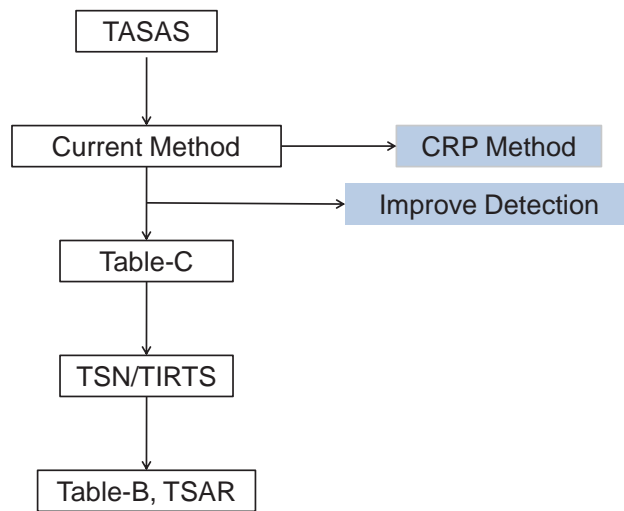


Figure 2: Relationship of CRP to the Caltrans TASAS legacy system database and the Table C, Wet Table C methodology for HCCL identification.

In the case of CRP, Caltrans safety engineers have long recognized that the SMW method suffers from a high false positive rate (i.e., identifying sites for safety investigation when one is not needed). (4)

However, in spite of this, there has been reluctance to embrace CRP as the Caltrans HCCL method of record due concern that CRP has been tested on only 413 miles of roadway. The limited number of CRP test miles has raised the issue of whether the method would filter out so-called "true hotspots" presently identified by SMW, leaving Caltrans vulnerable to potential litigation.

Although previous research conducted by Chung et al. (2) demonstrated that CRP detected all of the true hotspots identified by SMW as summarized in Table 1, CCIT recognized that a multi-district experimental evaluation of CRP and SMW was needed to create confidence in the method among Caltrans traffic safety professionals. To more fully establish the efficacy of CRP for HCCL identification and analysis, CCIT is now performing an experimental evaluation of CRP and SMW under Technical Agreement 65A0373.

Miles Examined	Accident Hotspots (HCCL)	Expected HCCLs using SMW method	Expected HCCLs using CRP method
413 miles	9 sites	62 sites	20 sites
False positives		53 sites	11 sites

Table 1: Comparison of SMW and CRP true hotspot and false positive counts for a 413-mile test section of California freeway. Note that the CRP method located all true hotspots and significantly fewer false positives compared the SMW approach.

Perhaps more importantly, it was clear from meetings with Caltrans headquarters and district staff that confidence in CRP had less to do with the miles tested, than having a complete theoretical understanding of the method. In effect, that which could not be understood would be rejected.

WHERE ROSA FITS IN THE EXISTING CALTRANS PROCEDURE

To address this barrier, CCIT initiated an extensive on-site outreach and promotion campaign to traffic safety professionals in all twelve Caltrans district as well as Caltrans headquarters. Rather than bring all 170+ Caltrans safety professionals up to speed on the statistical underpinnings of CRP, of interest to few, CCIT adopted a practical strategy focusing on the **RO**adway **S**afety **A**nalysis (ROSA) web-based software application toolkit that incorporates CRP.

Shifting attention to ROSA (Figure 3) and its analytic capabilities enabled CCIT to actively engage Caltrans safety professionals in the process of better understanding CRP while also providing them with an opportunity to add new functional features to the application that would increase both the efficiency and effectiveness of the work they perform.

In effect, CCIT turned the conversation from equations and statistical methods to one emphasizing modernization, simplification, and resource optimization driven by the input of traffic safety professionals at the ‘where the rubber meets the road’ level.

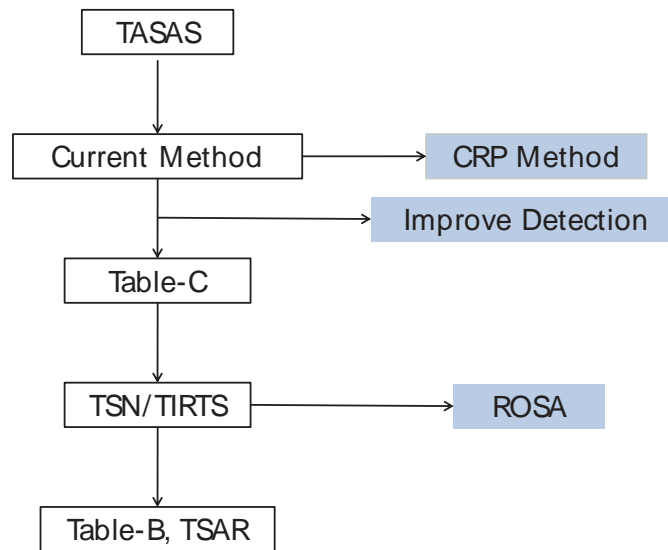


Figure 3: Relationship of ROSA to the Caltrans TASAS legacy system database and Table C, Wet Table C.

For example, safety engineers can currently perform standard Table C, Table B, and TIRTS analyses to collect statistics about an accident site before conducting a field investigation. However, the existing system lacks the analytic flexibility, desired by investigators, to accommodate custom analyses in a timely manner.

As an example, a request to locate where rear-end type collisions occur during the AM and PM peak periods within a 20 mile freeway corridor over a period of years, would require many hours of effort by an investigator. The same request, using ROSA, would be completed within a few minutes.

ROSA also enables safety engineers to attach GPS-referenced digital images of an investigation site as well as the as-built construction drawings. Consolidation of the various sources of site investigation information in ROSA not only increases the analytical power available to investigators, but also streamlines documentation that can be invaluable during litigation. Using ROSA, investigators can also graphically visualize where safety improvement projects have been implemented with respect to the site under investigation.

ROSA has been widely accepted among, and in fact, endorsed by, safety engineers for its user friendliness, analytic features that expedite routine tasks, and making essential information needed for safety analysis available with just a few clicks of a mouse. (See Table 3.)

Summarized in Table 2 are the results of a five-question survey administered during each on-site district orientation and training for ROSA-CRP between December 2009 and November 2010. A total of 86 respondents, representing all twelve Caltrans district

offices, completed the survey.

ROSA Survey Questions	1 (Strongly Disagree) to 5 (Strongly Agree)
1. Statewide implementation of ROSA/CRP should be a high priority for Caltrans.	4.55
2. Use of ROSA/CRP will aid me in the performance of my Caltrans duties.	4.48
3. Inclusion of STIP/SHOPP info in ROSA is a value-added benefit.	4.67
4. I would like to begin training on the use of ROSA-CRP as soon as possible.	4.36
5. Reclassification of the current Caltrans Highway Rate Groups is necessary.	4.24

Table 2: Summary of ROSA-CRP survey results obtained from 86 traffic safety professionals representing all twelve Caltrans district offices.

Also gleaned from the surveys were common and noteworthy responses given by traffic safety professionals concerning the features of ROSA they found to be most beneficial as well as suggestions for new features to be added. Table 3.

	Common Responses	Noteworthy Responses
Most Beneficial Aspects of ROSA	<ul style="list-style-type: none"> • Reduction of false positives • Real-time ability to see and analyze data results faster/more accurately • User-friendly system with quick responses • Significant improvement form current Oracle-based system • Inclusion of completed and under-construction projects • Inclusion of STIP and SHOPP is very beneficial 	<ul style="list-style-type: none"> • Everything about ROSA is so easy to use and understand! • Almost instantaneous identification of hotspots – huge time saver! • The fact that it's here; we're in dire need of moving beyond the Oracle system
Additional Features to Include in ROSA	<ul style="list-style-type: none"> • Redo the rate groups • Collision diagram that improves upon current ACD Caltrans program • Ramps and intersections, motorcycles and bikes • Street or aerial view • Photo log • Use of SWITRS for real-time analysis • Minor projects in addition to STIP/SHOPP • Previous investigations 	<ul style="list-style-type: none"> • Implementation of historical reports to allow for easy access to past investigations of the subject locations under study • Giving access to other engineers to view TIRs would be helpful • Expand the types of collisions • Pictures!

Table 3: Summary of common and noteworthy written comments given by survey respondents.

A summary of ROSA functions, demonstrated to traffic safety professionals at each on-site orientation and training session, is presented in the section on ROSA "The Tool".

ADDRESSING THE COMPETITION

FHWA SAFETYANALYST, FEDERAL HIGHWAY SAFETY MANUAL & CRP

Second only to understanding what CRP "is" the next significant institutional barrier to adoption of ROSA-CRP is the perception that a comparable competing product has already been deployed and is available for widespread use.

The so-called competitor is the *SafetyAnalyst* program developed by FHWA as a one-size fits all solution for collision analyses and safety improvement prioritization. The purpose of the *SafetyAnalyst* program is to use available data sources to review the entire roadway network of a given highway agency and identify and prioritize sites for detailed investigation and subsequent countermeasure implementation. The system utilizes Safety Performance Functions to drive the ranking process.

The Safety Performance Function (SPF) is an observed mathematical relationship of an explanatory variable (in most cases, average annual daily traffic (AADT) volume) and collision frequency. To develop an SPF, one needs to have (a) AADT, (b) traffic collision data, and (c) the start and end post-mile of different roadway classification groups. Currently Caltrans classifies highways into 67 groups and there is no systematic way of getting this information except by running Table B with the group breakdown option checked. An example of a Caltrans SPF is shown in Figure 4.

SPFs are regression models for estimating the predicted average crash frequency of individual roadway segments – the parameters in an SPF can be estimated using different methods.

The *SafetyAnalyst* software developed by FHWA comes with default SPFs that have been developed using data from multiple states. The SPFs within *SafetyAnalyst* can be replaced with SPFs developed specifically by a given transportation authority.

Based upon how much the observed value deviates from the SPF, the software can detect hot spots and rank them. Then, based upon the collision modification factor (CMF) of a countermeasure, *SafetyAnalyst* can be used to assist a safety engineer in selecting a countermeasure. The most up to date CMFs are publicized by FHWA at <http://www.cmfclearinghouse.org/>.

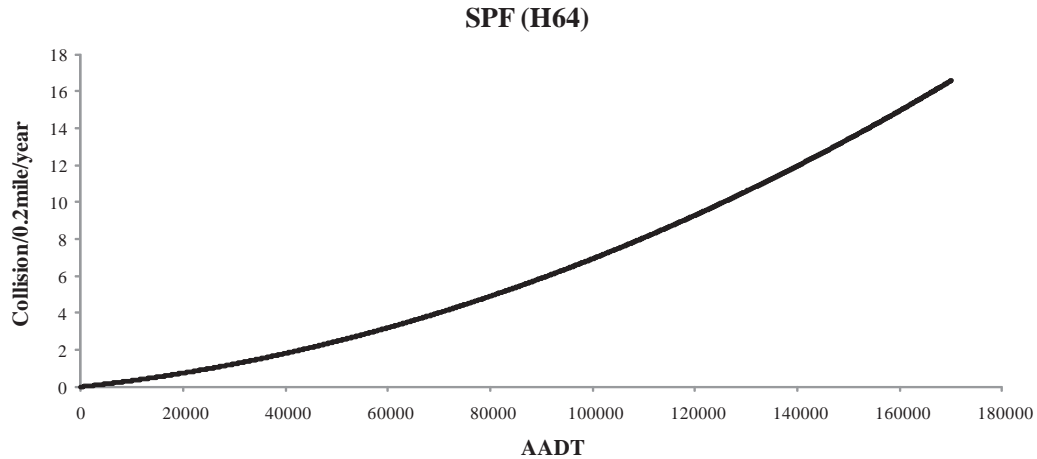


Figure 4: Example of Caltrans SPF for Highway Group 64

ROSA-CRP also uses SPFs in the ranking process. What is frequently misunderstood is that in order to effectively use either *SafetyAnalyst* or ROSA-CRP, unique SPFs for each highway classification group (or appropriate subset thereof) will need to be developed by Caltrans. Also misunderstood is that both ROSA-CRP and *SafetyAnalyst* use HCCL identification methods that are consistent with the Federal Highway Safety Manual (FHSM). Caltrans' adoption of ROSA-CRP would be not in conflict with the procedures in the HSM.

The logic behind the CRP method is consistent with the procedures proposed in the Federal Highway Safety Manual (FHSM) for HCCL identification. Within the FHSM, the Sliding Moving Window Method (SMW) and Peak Searching (PS) methods are presented. SMW, PS, and CRP each represent different HCCL screening methods.

The Sliding Moving Window Method (SMW) and PS methods can be used in *SafetyAnalyst*. ROSA however, can utilize SMW, PS, and CRP.

When the SMW method is used, the collision rate within a fixed window size is compared with to a selected performance measure described in Table 4-2 of the FHSM. When the PS method is employed, the roadway segment is subdivided into windows of similar length. The size of the windows used by the PS method start of 0.2 miles and increase gradually until finally reaching the full length of the roadway under investigation. For each window, the selected performance measure is calculated. By contract, utilization of CRP filters noise contained in the collision data using a weighted moving average technique and then plots the collision risk profile continuously along the highway.

The only difference between the SMW and PS methods is the way these methods segment the freeway. An advantage of the CRP approach is that segmenting of the roadway is unnecessary since it employs continuous evaluation of risk along the length of the corridor.

ROSA VS SAFETYANALYST

A common criticism of the *SafetyAnalyst* software, reported by safety professionals who have attended workshops on its use, is the lack of user friendliness associated with the system. Were Caltrans to adopt use of the *SafetyAnalyst* package, users may be reluctant to utilize it due to difficulties experienced when attempting to perform analyses with the product. Counter to this is the approach CCIT has employed with ROSA-CRP which has actively involved users throughout development of the toolkit inclusive of the statistics used to generate reports.

	Safety Analyst	Roadway Safety Analysis
Developed by	FHWA	Caltrans Engineer and UCB
Type	workstation	web based
Annual license fee for Caltrans	\$15,000 per station or \$25,000 for site	None
Network Screening Tool	SM and PS	Currently CRP, but SM and PS can be used.
Economic Appraisal	Uses CMF. Ready to use.	Uses CMF. Module not yet included.
Can it be used to document findings from site investigation?	N.A.	Yes
Can it be used to locate STIP and SHOPP location?	N.A.	Yes
Ability to attach GPS referenced site images with a site	N.A.	Yes
Ability to conduct corridor wide safety analysis	N.A.	Yes
Can the functions within the application be modified to meet Caltrans needs?	Maybe.	Yes
Is the method used in the software consistent with the method explained in Highway Safety Manual?	Yes	Yes
Does it use SPF?	Yes	Yes

Table 4. Comparison of FHWA SafetyAnalyst to UCB/Caltrans ROSA HCCL analysis application software.

Finally with regard to *SafetyAnalyst* is the cost. As currently marketed, the fee for a single workstation or site license for *SafetyAnalyst* is \$15,000 and \$25,000 per year, respectively.

Additionally, the product requires installation, estimated at \$350 per workstation. Also for consideration is the need for maintenance and upgrading of the product in the future.

ROSA, by contrast, is a web-based application developed collaboratively by a Caltrans engineer and researchers from the University of California. The current version of ROSA works with the current Caltrans SPFs, and like *SafetyAnalyst*, ROSA can be used with other SPFs. ROSA minimizes Caltrans' cost by offering a web-based product, owned by Caltrans that can be easily maintained and upgraded from a single location like CCIT.

Perhaps most importantly, ROSA-CRP effectively eliminates the need for paper documentation and recordkeeping saving both space and labor, while also providing the flexibility to produce customized reports specific to the needs of investigators.

Table 4 provides a comparison of *SafetyAnalyst* features to those of ROSA.

DESCRIPTION OF ROSA “THE TOOL”

This section features a "user's-eye" view of ROSA-CRP highlighting the functionality and ease of use of the tool.

Authorized users may access the ROSA-CRP demonstration site at: <http://www.safetrec-demo.berkeley.edu/rosa/>

1. SPECIFYING THE INVESTIGATION SITE

Selecting year, date, and route information is easily obtained via dropdown menus customized to meet the needs of each Caltrans district. After selecting the route, the user can see the starting and end point on the map. The user may also use the pushpin feature on the map to define the start and end points of the route for analysis. With the route defined, a user can see the CRP graph for the section by clicking the “Show CRP” button. This graphically shows the result of the CRP analysis. If the user has a sub-section to analyze in detail from the CRP graph, clicking the starting and end point on CRP graph in select mode will produce the analysis for the sub-section (Figure 5).

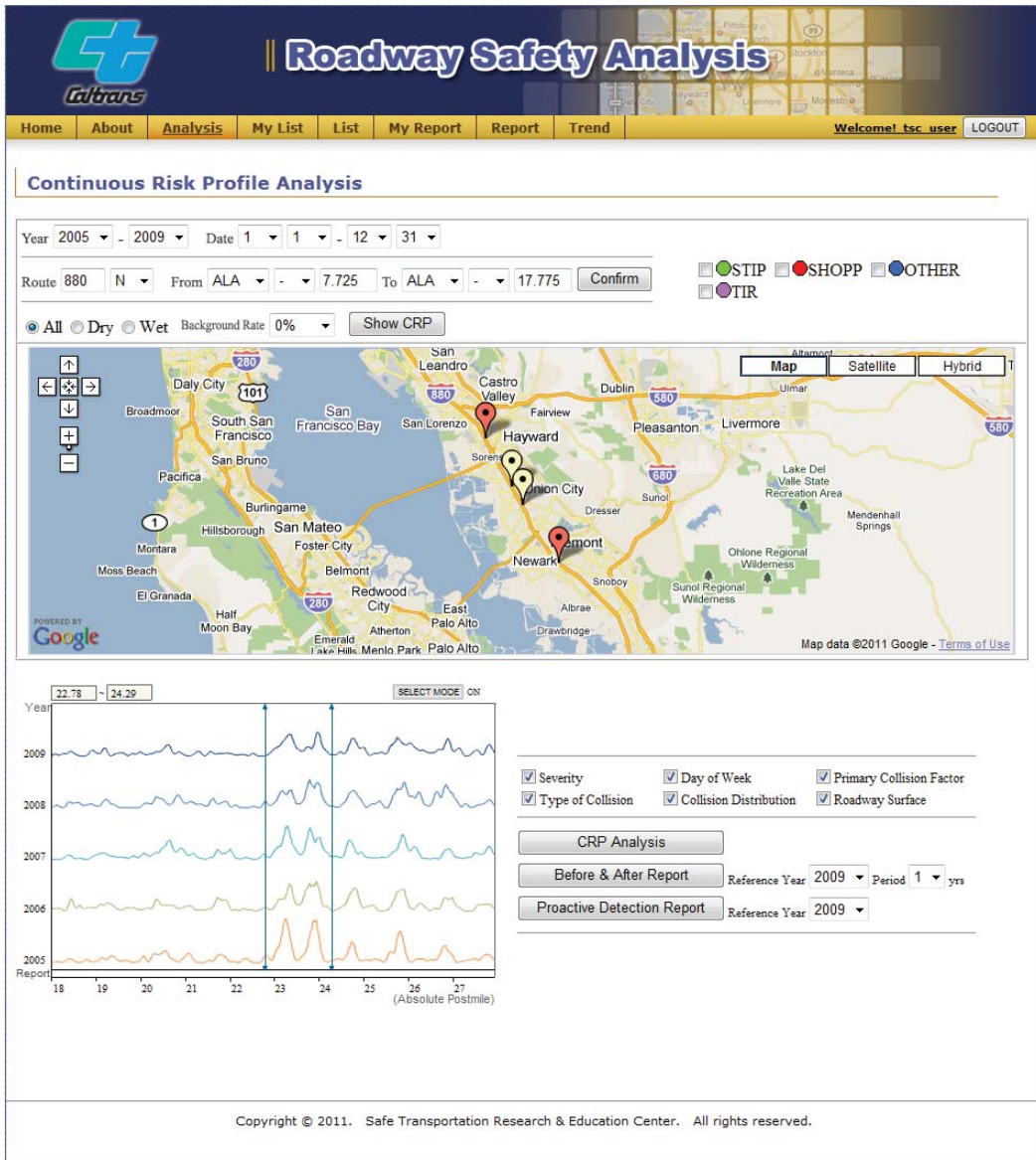


Figure 5: Specifying the investigation site. The red pushpins represent the complete roadway segment under analysis. The yellow pushpins represent a sub-section for detailed analysis.

2. VIEWING STIP AND SHOPP PROJECT INFORMATION

A feature universally requested by safety engineers was the addition of STIP and SHOPP project information to ROSA. This function provides users with a history of STIP and SHOPP projects occurring within the roadway segment under analysis (Figure 6).



Figure 6: Display of STIP and SHOPP project information within the roadway segment of interest. STIP projects are presented by green dots. SHOPP projects represent red dots. Clicking on a dot will generate a bubble depicting the relevant project history.

3. GRAPHICAL REPRESENTATION OF CRP ANALYSIS RESULTS

The CRP analysis function dramatically reduces the time required to analyze the data from days or hours to just minutes. The result shows location information including route, period, post mile and collision count. The user can download collision data information for the selected section and period into an Excel spreadsheet file. Also depicted is the CRP graph for the most recent year, the percent collisions by time of day, and CRP graphs and safety performance functions for the selected period (Figure 7).

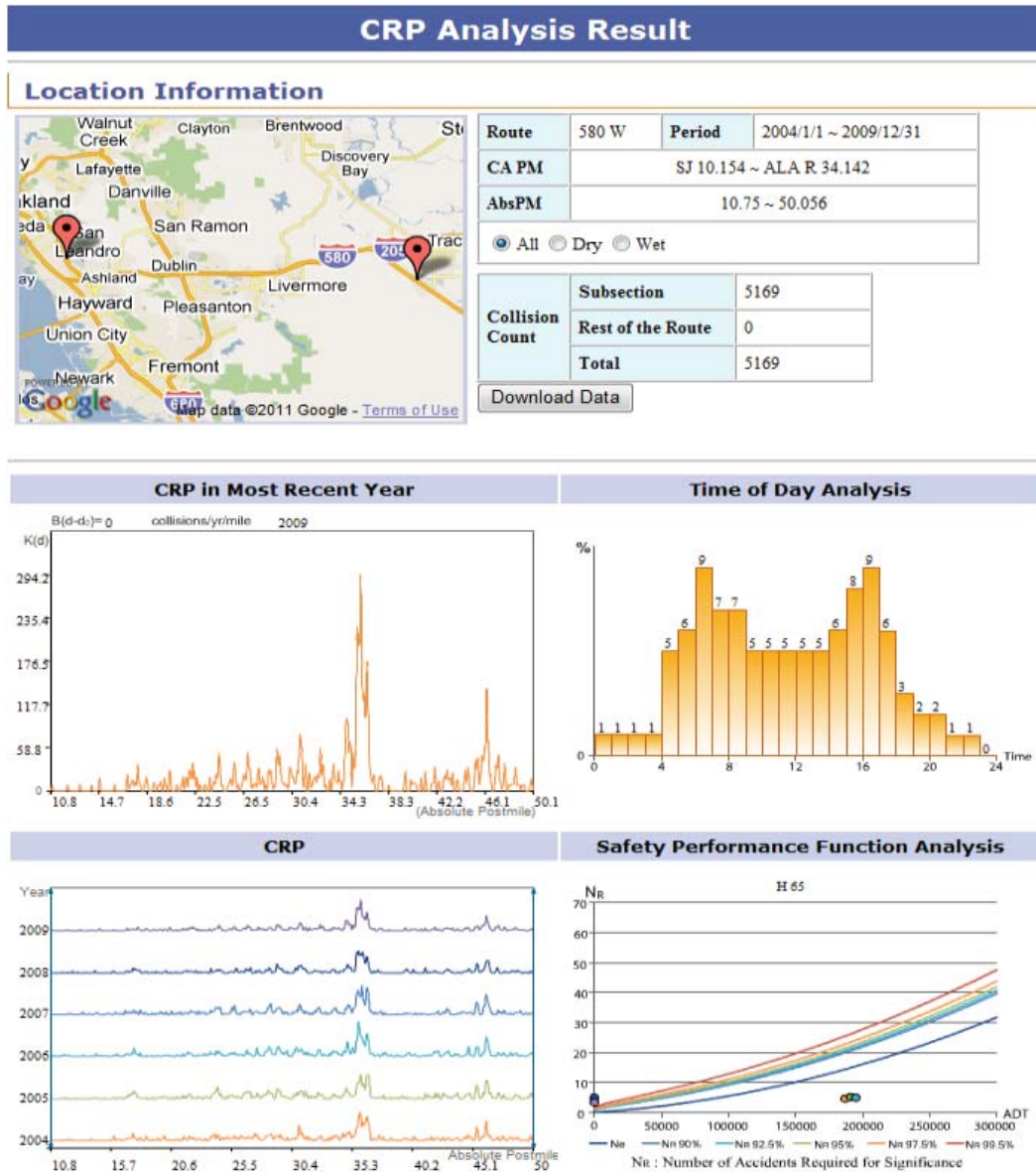


Figure 7: Display of the Selected Route Information, Most Recent Year CRP Analysis, Collision History, and Safety Performance Functions.

4. COLLISION SUMMARY GRAPHS

This function produces bar graphs of data based on TASAS code definitions for the subsection under analysis in left column, and for the complete roadway section in the right column within a few seconds. Producing these graphs was previously a time-consuming task for safety engineers (Figure 8).

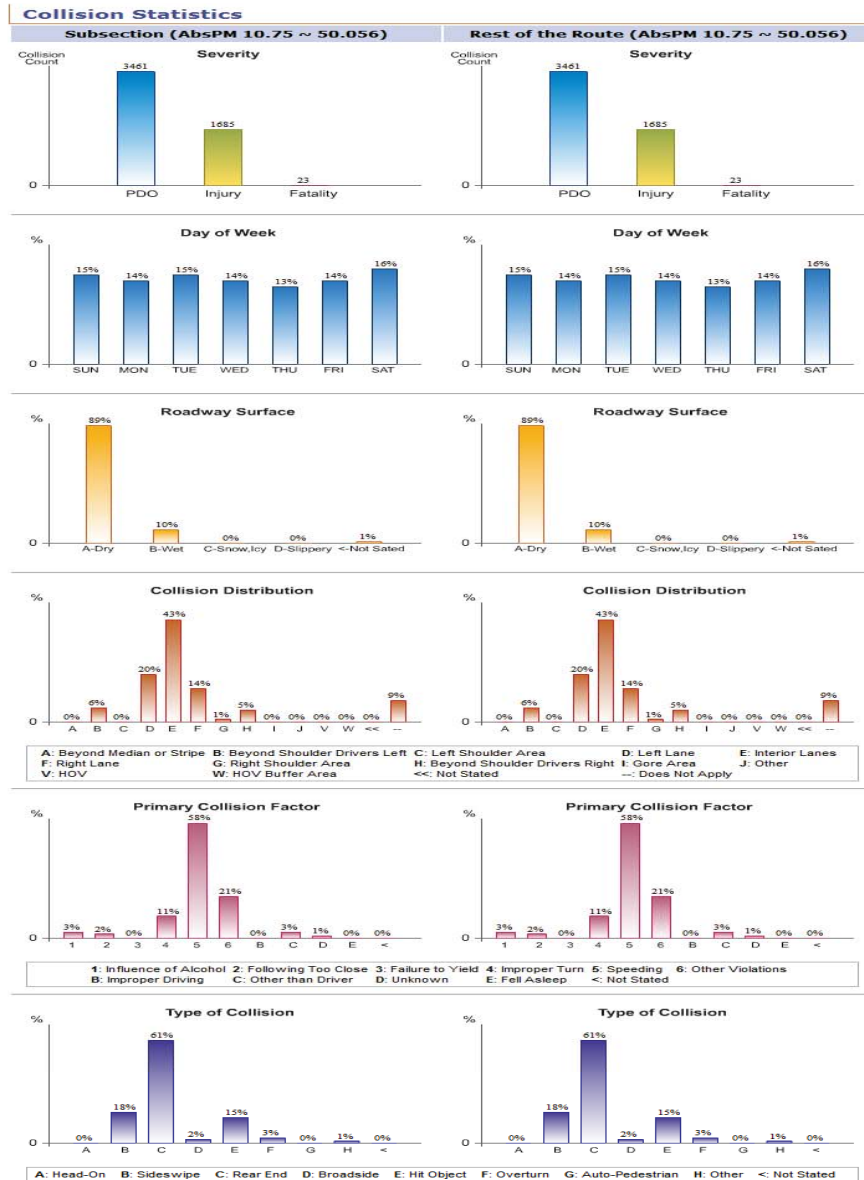


Figure 8: Summary display of Day of Week, Roadway Surface, Collision Distribution, Primary Collision Factor, and Type of Collision for the selected subsection and route under analysis.

5. EXTRACTING CRASH DATA BASED ON SELECTED COLLISION FACTORS

Users can select 5 types of collision factors (time of day, roadway surface, collision distribution, primary collision factor, and type of collision) for analysis. Users can also use this function to analyze dry/wet as well as fatal/injury patterns (Figure 9).

Detailed Analysis

- Collision Factor Analysis

<input checked="" type="checkbox"/> Time of Day	<input checked="" type="checkbox"/> Roadway Surface	<input checked="" type="checkbox"/> Collision Distribution	<input checked="" type="checkbox"/> Primary Collision Factor	<input checked="" type="checkbox"/> Type of Collision
0 ~ 1	<input type="checkbox"/> A - Dry <input type="checkbox"/> B - Wet <input type="checkbox"/> C - Snow,Icy <input type="checkbox"/> D - Slippery <input type="checkbox"/> < - Not Stated	<input type="checkbox"/> A - Beyond Median or Stripe - Left <input type="checkbox"/> B - Beyond Shoulder Drivers Left <input type="checkbox"/> C - Left Shoulder Area <input type="checkbox"/> D - Left Lane <input type="checkbox"/> E - Interior Lanes <input type="checkbox"/> F - Right Lane <input type="checkbox"/> G - Right Shoulder Area <input type="checkbox"/> H - Beyond Shoulder Drivers Right <input type="checkbox"/> I - Gore Area <input type="checkbox"/> J - Other <input type="checkbox"/> V - HOV <input type="checkbox"/> W - HOV Buffer Area <input type="checkbox"/> << - Not Stated <input type="checkbox"/> -- - Does Not Apply	<input type="checkbox"/> 1 - Influence of Alcohol <input type="checkbox"/> 2 - Following Too Close <input type="checkbox"/> 3 - Failure to Yield <input type="checkbox"/> 4 - Improper Turn <input type="checkbox"/> 5 - Speeding <input type="checkbox"/> 6 - Other Violations <input type="checkbox"/> B - Improper Driving <input type="checkbox"/> C - Other than Driver <input type="checkbox"/> D - Unknown <input type="checkbox"/> E - Fell Asleep <input type="checkbox"/> < - Not Stated	<input type="checkbox"/> A - Head-On <input type="checkbox"/> B - Sideswipe <input type="checkbox"/> C - Rear End <input type="checkbox"/> D - Broadside <input type="checkbox"/> E - Hit Object <input type="checkbox"/> F - Overturn <input type="checkbox"/> G - Auto-Pedestrian <input type="checkbox"/> H - Other <input type="checkbox"/> < - Not Stated

Show CRP

- Dry / Wet Pattern Analysis

Show CRP

- Fatal / Injury Pattern Analysis

Show CRP

Save Report

Figure 9. Display of Collision Factor Analysis options and Dry/Wet and Fatal/Injury Pattern Analysis options.

6. PRODUCING & SAVING COLLISION ANALYSIS REPORTS

Upon completing a collision analysis, the user can save all reports and archive them using the My Report/CRP function (Figure 10).

The screenshot shows the 'Roadway Safety Analysis' web application interface. At the top, there is a navigation menu with options: Home, About, Analysis, My List, List, My Report, Report, and Trend. A user is logged in as 'tsc_user'. Below the navigation, there are tabs for 'Before and After', 'Proactive Detection', and 'CRP'. The main content area displays 'My CRP Analysis Result' with a table of 10 entries. Each entry includes a number, date, route, direction, area, period, and buttons for 'VIEW' and 'DELETE'. A pagination control at the bottom of the table shows '<< 1 [2] 3 >>'. The footer contains the copyright information: 'Copyright © 2011. Safe Transportation Research & Education Center. All rights reserved.'

No.	Date	Route	Direction	Area	Period	View	Delete
34	2011-07-08	580	W	SJ 10.154 ~ ALA R34.142	2004 ~ 2009	VIEW	DELETE
33	2011-06-08	580	W	ALA R1.058 ~ ALA R29.274	2000 ~ 2009	VIEW	DELETE
31	2010-11-29	24	W	ALA R5.847 ~ CC R8.046	2008 ~ 2008	VIEW	DELETE
30	2010-11-22	60	W	LA 11.859 ~ LA R29.109	1999 ~ 2008	VIEW	DELETE
29	2010-09-28	880	N	ALA 7.775 ~ ALA 17.775	2007 ~ 2008	VIEW	DELETE
28	2010-09-07	12	E	SOL 7.801 ~ SOL 9.301	2000 ~ 2008	VIEW	DELETE
27	2010-08-02	880	N	ALA 7.775 ~ ALA 17.775	1996 ~ 2003	VIEW	DELETE
25	2010-05-10	880	N	ALA 7.775 ~ ALA 17.775	1996 ~ 2003	VIEW	DELETE
24	2009-10-15	17	N	SCR 0.25 ~ SCL 5.75	2001 ~ 2006	VIEW	DELETE
23	2009-10-15	13	S	ALA 9.954 ~ ALA 13.704	2002 ~ 2006	VIEW	DELETE

Figure 10. Collision Analysis Reports like the one shown can be archived using the My Report/CRP function.

7. ANALYZING COLLISION TRENDS

Users can analyze the collision count trends according by severity, roadway surface, and type of collision. This function shows the trends of collision counts during a user-selected period by route (Figure 11).

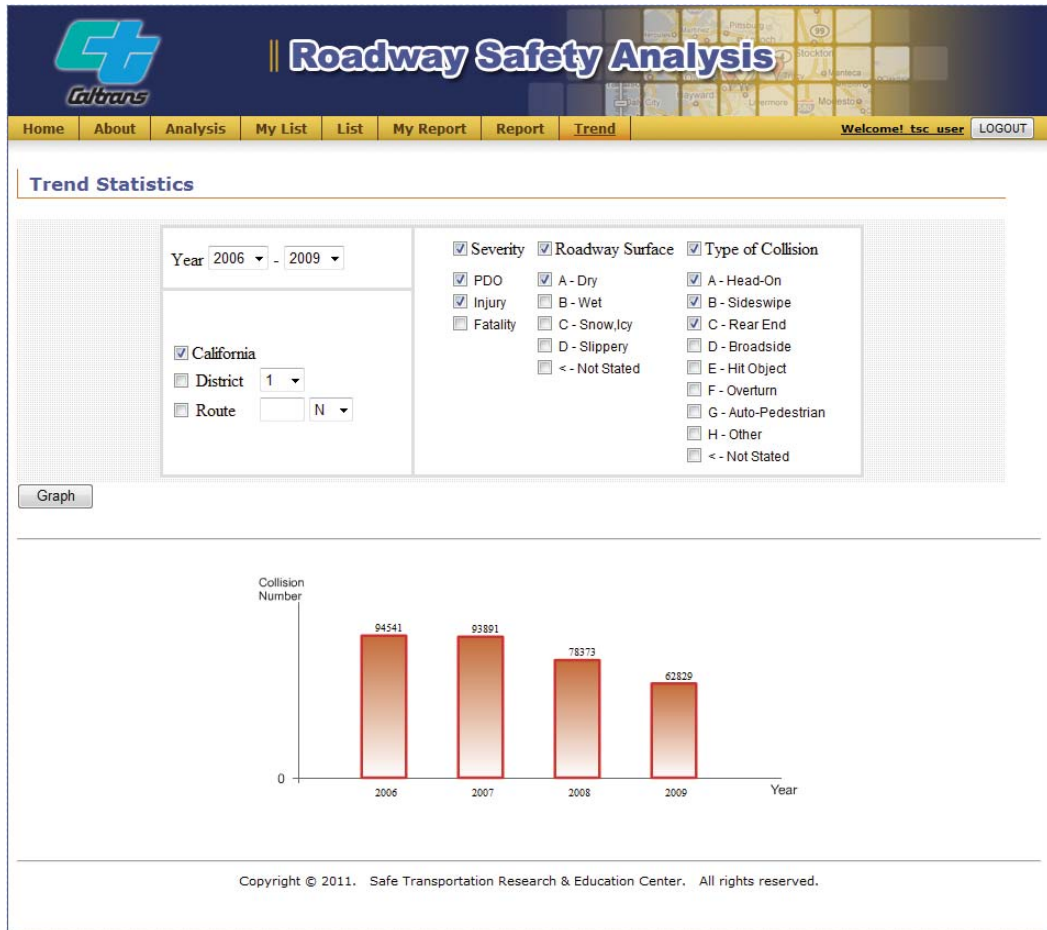


Figure 11: Display of Collision Count Trend options.

ADDITIONAL INTERNAL PROMOTION OF ROSA-CRP

Beyond the promotion of ROSA-CRP to its intended users (safety engineers and traffic operations professionals) through active outreach and engagement, CCIT also developed high-level, overview outreach and promotion materials for widespread distribution to Caltrans management. These materials took three forms.

The first, shown in Figures 12 and 13, consisted of a highlights sheet that includes a project summary, improvements and advantages offered by the product, the readiness of the product for deployment, and metrics for gauging the impact and success of the project.



I-TEAM BRIEF



The Innovation Team (I-Team) at the Caltrans Division of Research and Innovation, in cooperation with its partners, develops proven, ready-to-deploy innovations in methods, materials, and technologies that enable Caltrans to provide the most effective management of public services, resources, and infrastructure.

JUNE 2010
Updated: October 2010

Continuous Risk Profile

A new method of identifying collision hot-spots using the Web-based interface Roadway Safety Analysis

Caltrans continuously analyzes the traffic collisions that occur along its roadways in order to identify sites that might require further safety improvement. Many freeway sites have been improved due to this effort. However, Caltrans understands that the current procedure, called the Sliding Moving Window method, has room for improvement. For example, the Sliding Moving Window method has high false positive rate and often identifies sites that are adjacent to each other. **The Caltrans I-Team supported the development of the Continuous Risk Profile (CRP) method for improved collision data analysis, and the Roadway Safety Analysis (ROSA) Web-based interface to make the use of CRP convenient and easy.**

READY TO DEPLOY

The CRP approach improves the averaging of collision data over the current method. Rather than using a "discrete" approach—averaging data at each segment—CRP uses a "continuous" approach, averaging data at each spot. This approach eliminates small fluctuations while capturing gradual changes in risk throughout the highway, and represents risk reality much more accurately.

NEW AND IMPROVED


- Reduces false positive rates, allowing Caltrans to better utilize its resources by reducing the number of unnecessary onsite safety investigations.
- Graphically produces an easy-to-interpret true risk profile along an extended freeway segment.
- Does not limit the segment length in analyzing traffic collision data, thus effectively capturing the spill-over benefit of a countermeasure to the adjacent sites.
- Can proactively detect sites that display a systematic increase in collision rate over time.
- Employs the ROSA Web-based interface, which was custom-designed to make evaluating traffic collision data with CRP convenient and easy for safety engineers and planners.
- ROSA uses the same input information as the current system.
- ROSA allows users to specify a time period so safety engineers can analyze a segment of freeway over a selected period of several years or several hours.



Figure 12: Front page image of the ROSA-CRP highlights sheet used for high-level communication about the project within Caltrans and the transportation community at-large.

About Continuous Risk Profile

CRP and its Web-based interface ROSA were developed by engineers in District 4 and researchers at Institute of Transportation Studies at the University of California, Berkeley (ITS Berkeley), as an alternative to the existing Sliding Moving Window method used by Caltrans. Both methods use existing Caltrans traffic collision data for input but use different approaches to analyze the data. The current pilot is being administered by the California Center for Innovative Transportation, a research center at ITS Berkeley.




GET STARTED

Contact:
Steve Andrews, UC Berkeley
510.642-5909, sandrews@calccit.org

Learn More

The Continuous Risk Profile Approach for the Identification of High Collision Concentration Locations on Congested Highways, Koohong Chung et al.
<http://www.escholarship.org/uc/item/24m8j57d>



I-TEAM BRIEF

SUCCESSES

- Based on the enormously positive findings of the early research, CRP is expanding its data from two Caltrans districts to a pilot with much larger pool of data from regions across the state.
- Currently, safety managers from nine out of the twelve Caltrans districts have joined the pilot.
- If results of the pilot and other follow-up evaluations further verify CRP's accuracy and value, Caltrans will work to recognize it as an official method for determining high collision concentration locations (HCCL) on state highways.

METRICS

A study conducted on 413 miles of Northern California freeway compared the accuracy of the Continuous Risk Profile and the Sliding Moving Window methods. The study found that the CRP method:

- Reduced false positive rate by 35%.
- Increased to the accuracy rate (true positive) by 300%.
- Increased annual cost savings by 562%.
- Would have increased cost savings by \$4.7 million if the Continuous Risk Profile method had been used instead of the Sliding Moving Window method.

GET READY

ROSA is located at <http://www.safetrec-demo.berkeley.edu/rosa/> and is accessible by authorized users only.

To become an authorized user, you must be part of the pilot. To join the pilot, contact your district manager or call Steve Andrews (see Get Started).

On-site trainings are being conducted throughout the state. Call the number listed under "Get Started" to attend.

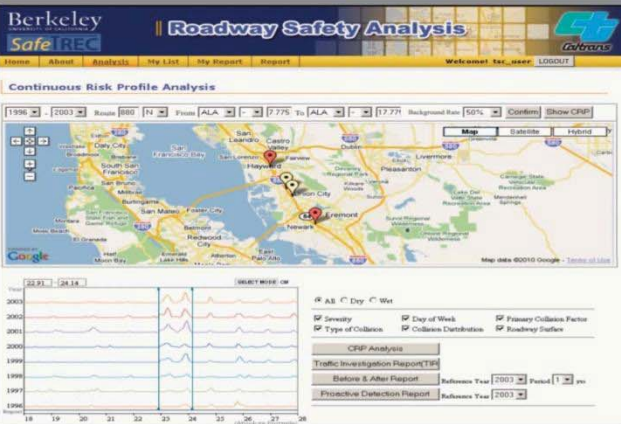


Figure 13: Back page image of the ROSA-CRP highlights sheet used for high-level communication about the project within Caltrans and the transportation community at-large.

The second form of high-level outreach and promotion involved presentation of ROSA-CRP as a featured project on the homepage of the CCIT website (<http://www.calccit.org/>). As a featured project, information about ROSA-CRP was immediately accessible to interested Caltrans managers in electronic form.

To provide Caltrans managers, and others, with accessible project information, a twelve month effort was undertaken to develop and implement an architecture for the CCIT website that would accommodate frequent updates that could easily be initiated by project managers as project conditions changed or new milestones were achieved. This effectively eliminated the need for website updates to be performed by a single webmaster as well as the need for specialized website development training.

The third form of high-level outreach and promotion involved the production of a two-minute video overview explaining ROSA-CRP and the motivation for its development. The mp4 format video can be downloaded by going to:

http://gateway.path.berkeley.edu/PATH_Downloads/Video/ROSA/

Production of the overview video required extensive pre- and post-production covering an eight month period. Pre-production included development of the script, screenshots, narration (voiceover), and visual content necessary to produce the video. Post-production included editing, segment timing, and voiceover corrections.

The combination of Category 1 outreach and promotion elements utilized by CCIT to advance deployment of ROSA-CRP has been used by DRI as a model for the internal promotion of other projects including See-Through Bridge Rail, Safety Edge, ShakeCast, Virtual Design Construction, Networked Traveler, Warm Mix Asphalt, Rapid Rehab, and WeatherShare.

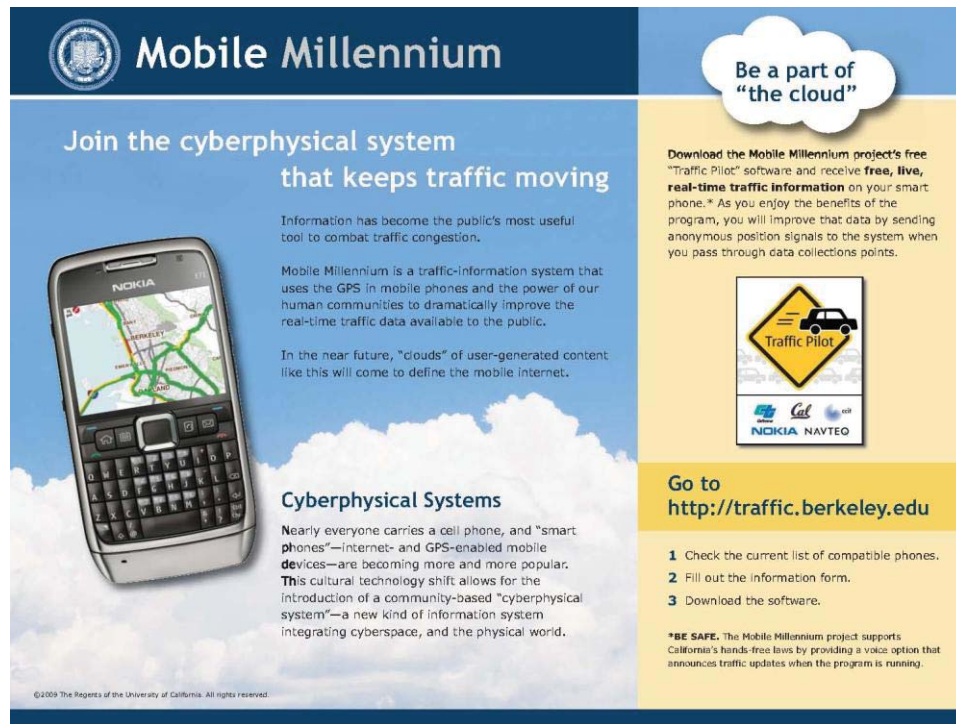
CATEGORY 2: EXTERNAL AUDIENCES

Although ROSA-CRP became the primary focus of this technical agreement, DRI also requested that CCIT assist with the external outreach and promotion of two notable high profile Caltrans sponsored projects Mobile Century and Mobile Millennium. Both projects featured the groundbreaking innovation of using GPS smart phones as traffic probes for real-time traffic flow determination.

To accomplish this, CCIT utilized that assistance of web and print designers, copy editors, and communications specialists to develop a unique “brand” for each project.

Development of the project brands required extensive consultation with the research team as well as the creation of user focus groups.

Focus groups were utilized to assist the CCIT communications team with the development of recruitment materials aimed at engaging and retaining members of the public to be participants in the research effort. Figure 14 is an example of a recruitment flyer for the Mobile Millennium project. Note the flyer includes the URL for the Mobile Millennium website used to provide research participants with near daily updates of the project. (Figure 15.)



The flyer is titled "Mobile Millennium" and features a Nokia smartphone displaying a traffic map. The text on the flyer includes:

Mobile Millennium

Join the cyberphysical system that keeps traffic moving

Information has become the public's most useful tool to combat traffic congestion.

Mobile Millennium is a traffic-information system that uses the GPS in mobile phones and the power of our human communities to dramatically improve the real-time traffic data available to the public.

In the near future, "clouds" of user-generated content like this will come to define the mobile internet.

Cyberphysical Systems

Nearly everyone carries a cell phone, and "smart phones"—internet- and GPS-enabled mobile devices—are becoming more and more popular. This cultural technology shift allows for the introduction of a community-based "cyberphysical system"—a new kind of information system integrating cyberspace, and the physical world.

Be a part of "the cloud"

Download the Mobile Millennium project's free "Traffic Pilot" software and receive **free, live, real-time traffic information** on your smart phone.* As you enjoy the benefits of the program, you will improve that data by sending anonymous position signals to the system when you pass through data collections points.

Go to <http://traffic.berkeley.edu>

- 1 Check the current list of compatible phones.
- 2 Fill out the information form.
- 3 Download the software.

***BE SAFE.** The Mobile Millennium project supports California's hands-free laws by providing a voice option that announces traffic updates when the program is running.

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Figure 14: Image of the Mobile Millennium flyer distributed to individuals interesting in being a pilot study participant.

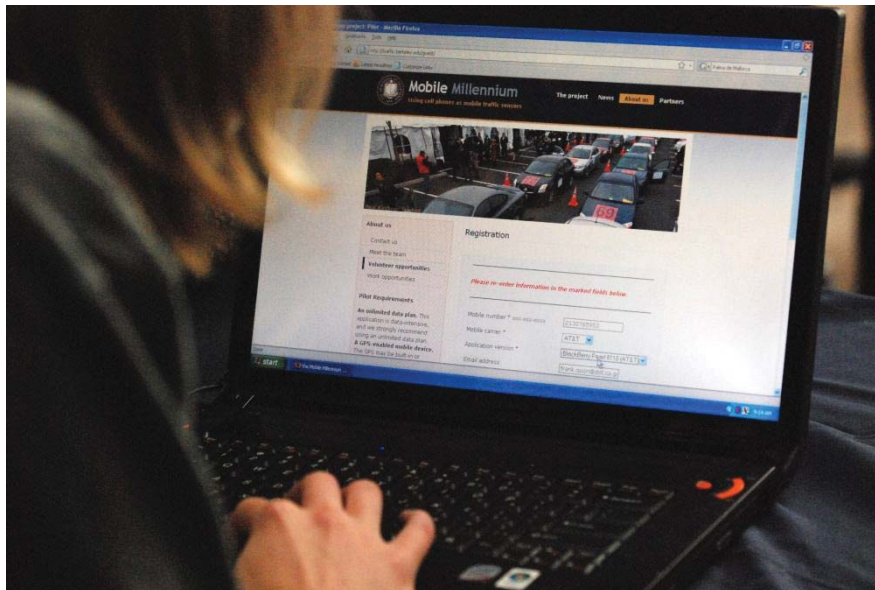



Figure 15: A participant of the Mobile Millennium project utilizing the project website to obtain the latest project news.

Other forms of project “branding” utilized by CCIT for high profile projects like Mobile Century and Mobile Millennium included posters (Figure 16) and project fact sheets (Figure 17) used at conferences and professional meetings to summarize technical features of the projects as well as to promote members of the research partnership.

The suite of external outreach and promotion materials – websites, posters, flyers, and fact sheets were also accompanied by “branded” media spreads such as one presented in the Appendix I published by Information Quarterly featuring the Mobile Millennium project.

Mobile Millennium
Participatory Sensing of Traffic Using GPS Devices
Ryan Herring, Sebastian Blandin, Daniel Wolk, Samitha Samarayake, and Alexandre Bayen
California Center for Innovative Transportation, University of California, Berkeley



The Mobile Millennium traffic filter is available for Nokia and other smartphones that receive traffic information. Available at: <http://traffic.berkeley.edu>

HIGHWAY MODEL

- Dynamics of traffic on highways is modeled by the *Lighthill-Whitham-Richards* partial differential equation (LWR PDE)
- The LWR density model is transformed into a velocity model which is required for GPS sensing, while preserving the physical solution of the PDE.
- Lagrangian (probes) and Eulerian (loops) measurements are integrated through a data assimilation algorithm (Ensemble Kalman Filter) which provides the best estimate given model and observations.

ARTERIAL MODEL

- Goal is to estimate the probability distribution of link travel times, which are modeled as a mixture of Gaussians.
- Distribution parameters are learned from historical data using a probabilistic graphical model framework.
- Learned parameters are shared between similar parts of the road network.
- Graphical model provides inference method to update distributions in real-time.

DATA FILTERING


- Filtering techniques relying on the computation of the *Wokoski-FZ* function (vehicle label) allow for efficient filtering of sensors.
- Online calibration of the filter enables to accurately identify malfunctioning devices.

ROUTING ENGINE

- Optimal routes between an origin and destination based on current and forecasted traffic conditions.
- Variability indicators produced by the traffic estimation models can be integrated to provide fast and reliable routes.
- In-route re-routing via GPS cell phones provides alternate routes to avoid major congestion from unpredictable events (accidents).

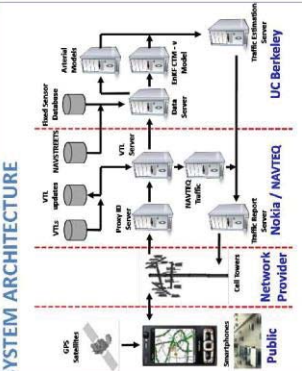
CHALLENGES

- Distributed models for traffic flow on large transportation networks and junction modeling.
- Estimation techniques to circumvent lack of accurate road geographical information
- Wired Lagrangian/Eulerian sensing
- Spatially aware sampling and privacy
- Real-time, online traffic estimates
- Validation methods and accuracy evaluation
- Tradeoff between estimation accuracy and privacy management



GPS data from mobile devices significantly advances the quality and quantity of traffic information available for the transportation network.


SYSTEM ARCHITECTURE



DEPLOYMENT

Mobile Millennium


- Field operational test
- Initial deployment in the whole San Francisco Bay Area
- Over 4,000 downloads
- Arterial and highway traffic estimation



Mobile Millennium deployment area

100 Mobile Century vehicles

- Experiment
- Started February 8, 2008
- 150 UC Berkeley students driving 100 vehicles for 10 mile loops in 880 in California for eight hours
- Prototype system deployment
- Conclusion: 3-5% penetration rate is sufficient to estimate the state of traffic





Connecting People





california center for innovative transportation



Institute of transportation studies

Figure 16: An example of a Mobile Millennium poster utilized at conferences and professional meetings to highlight technical elements of the project as well as to promote members of the research partnership. Note the placement of the Nokia and NAVTEQ corporate logos along with Caltrans and the University of California, Berkeley.

MOBILE MILLENNIUM FACT SHEET



November 2008



Objectives at a glance:

Build and launch a new cell-phone-based traffic monitoring system.

Announce free downloadable traffic information software for the public.

Teach the public about how the system works, including the software interface and state-of-the-art privacy protections.

Collecting Traffic Data from Mobile Probes

The potential of cell phones to operate as traffic data collection devices has been considered by the Intelligent Transportation Systems (ITS) community for several years. Government agencies currently deploy networks of infrastructure-based traffic sensors that are expensive to install and maintain. Leveraging the existing infrastructure of commercial cellular networks could drastically cut the ongoing costs of

traffic monitoring and expand coverage to thousands of miles of highways and urban arterials for which sensors are not currently a viable option. On February 8, 2008, Nokia and the University of California, Berkeley demonstrated the reconstruction of traffic on highways using cell phones by running an experiment, nicknamed *Mobile Century* for its 100 cars traveling in 10-mile loops on I-880 for 8 hours, which amounted to

2% of traffic. During the experiment, GPS-equipped Nokia N95 phones sent traffic information in a privacy-protecting system capable of broadcasting traffic information in real time on the internet. The successful experiment, funded by the California Department of Transportation (Caltrans), led to the development of a pilot system, called *Mobile Millennium*, to make this technology available to the public.

What is Mobile Millennium?



In a partnership between Nokia, NAVTEQ, and UC Berkeley, coordinated by the California Center for Innovative Transportation (CCIT) and supported by the U.S. Department of Transportation and Caltrans, researchers have constructed an unprecedented traffic monitoring system capable of fusing GPS data from cell phones with data from existing traffic sensors. The research and development phase of this project

was dubbed *Mobile Millennium* for the potential thousands of Early Adopters who will participate in the pilot deployment, launching in November, 2008. *Mobile Millennium* will cover not only highways, but also the arterial network, where there is currently almost no sensing infrastructure. The software will work on Nokia and non-Nokia phones, and the public will be able to download it free of charge. It will gather data in a privacy-

preserving environment, relying on *Virtual Trip Lines* technology, a data-sampling paradigm that anonymizes the GPS-based position information and aggregates it into a single data stream. The aggregated data is then encrypted and sent to a computer system, which blends it with other sources of traffic data and broadcasts this real-time, data-rich information back to the phones and to the internet through a user-friendly interface.

CALIFORNIA CENTER FOR INNOVATIVE TRANSPORTATION
UNIVERSITY OF CALIFORNIA BERKELEY · 2105 BANCROFT WAY, SUITE 300 · BERKELEY, CA 94720-3830
PHONE: (510) 642-4522 · FAX: (510) 642-0910 · HTTP://WWW.CALCCIT.ORG

Figure 17: Front page image of a fact sheet for Mobile Millennium used to disseminate project information to a wide audience.

CATEGORY 3: INTERNAL & EXTERNAL AUDIENCES

Last among the outreach and promotion materials produced by CCIT for DRI were those designed to communicate with both internal and external audiences.

In this category are the CCIT website (<http://www.calccit.org>) (Figure 18), CCIT 2008-2009 Biennial Report (<http://www.calccit.org/?page=resources>), CCIT services brochure (Figure 19) and CCIT project fact sheets (Figures 20-28). These collectively present high-level information highlighting the mission, values, organization, and capabilities of CCIT to successfully accelerate deployment of DRI research.

The screenshot shows the homepage of the California Center for Innovative Transportation (CCIT). The header includes the CCIT logo and the ITS Berkeley logo. The navigation menu lists: Home | Projects | Services | Resources | News & Events | About Us. The main content area is divided into two columns. The left column, titled 'Featured Projects', contains three project cards: 'Mobile Millennium', 'Continuous Risk Profile for Roadway Safety Analysis', and 'Hybrid Traffic Data Roadmap: 3rd Party Data Procurement'. The right column, titled 'News & Events', contains three news items: 'Questions & Answers to Unaggregated Data RFP', 'Unaggregated Data RFP', and 'Questions & Answers to Research Proposal Solicitation'. Below the featured projects is a 'Mission' section. The footer contains contact information for CCIT and a link to the intranet.

california center for innovative transportation
UNIVERSITY OF CALIFORNIA, BERKELEY

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Featured Projects

Mobile Millennium
The potential of cell phones to operate as traffic data collection devices has been considered by the Intelligent Transportation Systems (ITS) community for several years. With the Mobile Millennium project, researchers have constructed an unprecedented traffic monitoring system capable of fusing GPS data from cell phones with data from existing traffic sensors. It will be accessible to the public via free software that is compatible with Nokia and non-Nokia smartphones.

Continuous Risk Profile for Roadway Safety Analysis
This project compares and experimentally evaluates the identification of high collision concentration locations determined by the current Caltrans methodology (Sliding Moving Window (SMW)) to those identified using the novel Continuous Risk Profile (CRP) approach.

Hybrid Traffic Data Roadmap: 3rd Party Data Procurement
This project seeks to develop a roadmap to procure traffic data from a third party and demonstrate an efficient use of alternate traffic data sources to complement existing detection systems that are installed and operated by the California Department of Transportation (Caltrans). This project proposes a systematic framework to evaluate the role of micro-simulation in the development of Corridor System Management Plans.

News & Events

Questions & Answers to Unaggregated Data RFP
On May 9th, the California Center for Innovative Transportation (CCIT) requested proposals for the provision of unaggregated point-speed data for highways I-15 and I-880 within the state of California. ...

Unaggregated Data RFP
Please find the subject Request for Proposals attached to this message. The California Center for Innovative Transportation (CCIT) requests proposals for the provision of unaggregated point-speed data for highways I-15 and...

Questions & Answers to Research Proposal Solicitation
CCIT has responded to the submitted questions as indicated in section 4.3 of the research proposal solicitation. The responses are as follows: Q1) Are you requiring the winner of this award to purchase...

Mission
The California Center for Innovative Transportation (CCIT) accelerates the implementation of research and the deployment of technical solutions by practitioners to enable a safer, cleaner and more efficient surface transportation service.
See more about Our Services here.

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[Login to the Intranet \(Password Required\)](#)

Figure 18: The homepage of the CCIT website. Note the three featured projects including Mobile Millennium and ROSA-CRP.

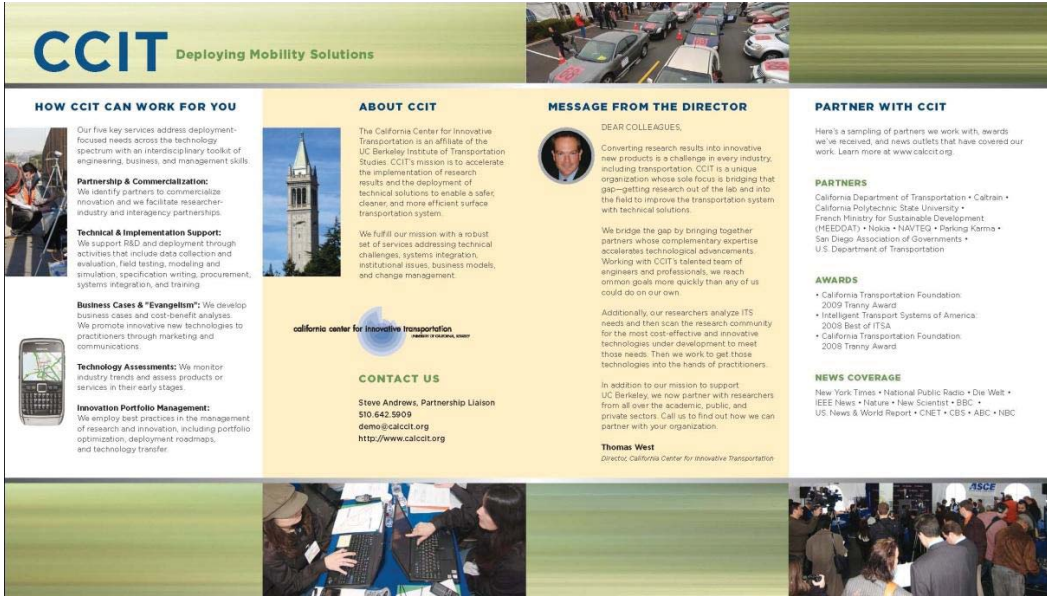


Figure 19: Inside image of the CCIT tri-brochure promoting the creation of partnerships.

FACT SHEET INDEX

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Testbed Integration and Maintenance of Berkeley Highway Laboratories (BHL)



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Project Budget:
\$ 580,421

Project Start Date:
June 1, 2009

Project End Date:
June 30, 2012

Contract Number:
65A0328

Problem Statement and Historical Overview

The Berkeley Highway Lab (BHL) is one of two sites that form the integrated California Testbed. The testbed facilities provide transportation researchers throughout California with the necessary infrastructure to do work in a real traffic environment. Some of the users are: Caltrans Project Managers; Caltrans in-house Research Managers; Researchers of Transportation Research Institutes; Researchers of various California or other state universities; other transportation practitioners and private solution providers. Some of the applications supported by the California Testbed include traffic studies, micro-simulation calibration and validation, Field Operational Tests (FOTs), and equipment testing.

During fiscal years 2004-2006, the BHL and University of California, Irvine (UCI) testbeds were administratively integrated under the common title of The California Testbed. The integrated website is a gateway for researchers interested in using testbed capabilities of either physical testbeds. Both testbed facilities are funded by Caltrans and operate under the same project. CCIT is tasked to manage BHL in collaboration with UCI. The BHL budget covers functioning and maintenance cost, outreach, improved access to the research community under the integrated Testbed initiative, and specific projects aimed to develop the facility and increase the range of available applications.

During fiscal years 2006-2008, wireless sensors were tested at BHL and a WIMAX network as a data backhaul was planned and unit-tested. The BHL website was overhauled to provide seamless integration with the ATMS site to provide a better user experience. The video recording sub-system was also overhauled. BHL documentation was updated, a WIMAX base station was installed, a WIMAX CPE client was installed at the CCIT building, connectivity to the WIMAX stations was tested, the physical layout of the loop detectors of the BHL was validated and documented, and in addition, the structure and schema of the database supporting the BHL website was assessed and documented.



Work Plan

- The overall work plan is comprised of three main tasks:
1. BHL Management; operations and maintenance
 2. Testbed access and integration
 3. BHL development initiatives

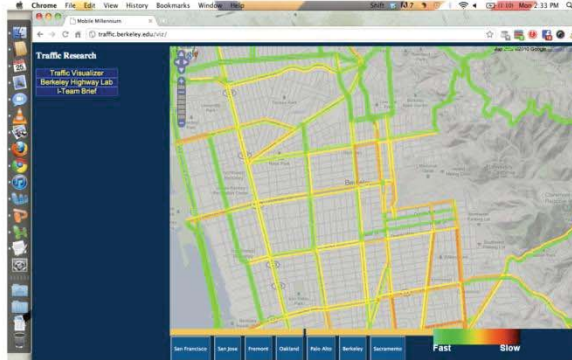
Figure 20: Fact Sheet on Tested Integration Maintenance of Berkeley Highway Laboratories

The final deliverable will be the ongoing operation of the lab combined with a project report.



Project Overview

During June 2009 to June 2012, CCIT will be responsible for managing the activities taking place at BHL, coordinate with the responsible authorities at Caltrans headquarters and District 4, ensure the proper operations of the equipment and the supporting software infrastructure, and support the sensor test branch and evaluation of emerging sensor technologies. In addition to the general management task, the ongoing operations of the BHL require frequent technical interventions to monitor and fix the different systems that make up BHL, and to provide service and assistance to BHL users. In order to maximize the user of the testbed, CCIT will continue to improve user access to testbed facilities and data, as well as maintain a dialog with the testbed user base to ensure that the Department's research needs are being addressed with respect to ongoing and future research projects that can make use of the BHL capabilities.



Progress to Date

In the past year the BHL has responded to customer requests for both video and detailed loop detector data. The lab has installed Infotek wizards along I80 in Pinole and researched new communication methods for wireless collection of traffic information. We have updated the video capture systems and are in the process of upgrading our I-80 to central server communications architecture. Our flexible project structure has permitted us to respond immediately to new Caltrans initiatives including the deployment of ICones for measuring traffic data in work zones and the generation of the Multimodal Transportation Systems Roadmap. We also cooperated with Berkeley Transportation Systems in a winning proposal to study detailed traffic flow on I-80. We are in discussion with IBM on utilization of their video processing technology.

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Corridor System Management Plan Microscopic Traffic Simulation Evaluation



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Project Budget:
\$ 318,382

Project Start Date:
June 30, 2009

Project End Date:
February 28, 2011

Contract Number:
74A0484

Problem Statement and Project Overview

Corridor system management and transportation planning are key components of managing transportation growth in urban areas. Conducting comprehensive, high quality studies is a complex and costly proposition. Government agencies at the federal, state and local levels recognize the need to refine and standardize a formal process to integrate both planning and operations into traditional corridor management. California has recently taken the lead to initiate comprehensive management planning at the corridor level, the first of its kind in the United States. This project builds on the success of the recent Caltrans sponsored Corridor System Management Plan (CSMP) demonstration, and CSMP studies that are occurring on approximately nineteen corridors throughout California to develop the framework necessary to understand and capitalize on this novel and upcoming approach to detailed corridor-wide operational analysis.

The intention of CSMP activities is to integrate detailed operational analysis into traditional corridor wide system management and planning so that more informed decisions can be made regarding capital and operational improvement investments. Microscopic traffic simulation has been widely used in current CSMP activities as a vital tool to evaluate and recommend a variety of improvement strategies. The development of corridor wide micro-simulation models, however, requires nontrivial resources and sometimes imposes challenges on data collection and demand estimation.

Under sponsorship from Caltrans, this project is building a systematic framework to evaluate the role of micro-simulation in the development of CSMPs. The framework consists of four major steps: (1) identifying the benefit and cost factors of using micro-simulation in the development of CSMP, (2) reviewing completed and ongoing CSMP micro-simulations, (3) interviewing CSMP modelers and Caltrans project managers (PMs), and (4) procedures for detailed benefit and cost analysis and recommendations.

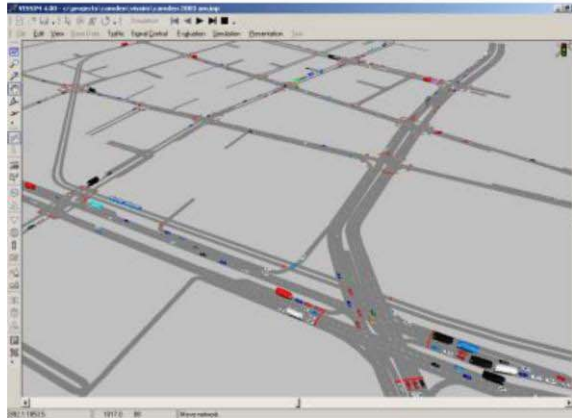


Figure 21: Fact Sheet on Corridor System Management Plan Microscopic Traffic Simulation Evaluation

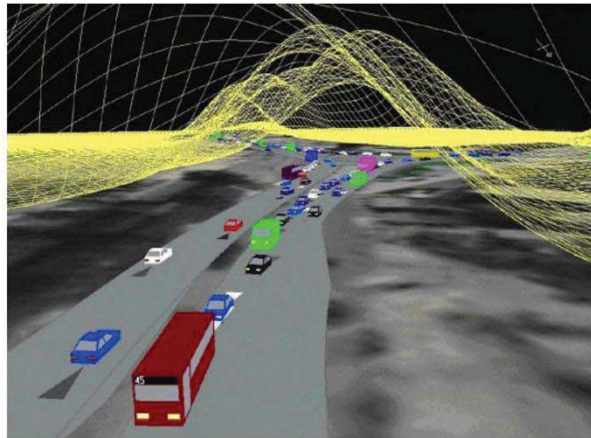
The development of CSMP is a process for effective decision-making that incorporates systematic study procedures to assess transportation deficiencies, identify options to address these deficiencies, and to evaluate the options in a comprehensive manner.

Project Objective

The ultimate purpose of this project is to create a decision document that underscores the benefits and costs of micro-simulation as it relates to the CSMP development. Results of this effort will provide critical information as input to an overall evaluation to determine the validity of CSMP's as a sustainable Caltrans business process. Furthermore, this study assists in investigating whether the use of CSMP's and the underlying microscopic traffic simulation models have resulted in the identification of the most effective traffic management strategies.

Project Goals

The goal of this effort is to understand if the use of microscopic traffic simulations adds value to corridor system management planning that exceeds actual and apparent costs. More than a simple benefit and cost analysis, this study establishes a framework to assess current and future CSMP efforts. This work also addresses factors other than cost that impact decisions to continue simulation studies, such as district and regional acceptance, and actual modifications to regional transportation plans as a result of this study.



Progress to Date

CCIT has formed a steering committee for the study. Formation of a technical advisory panel is under way. CCIT is also reviewing and summarizing literature on the use of CSMP at the state and federal levels, in order to draft survey questionnaire for modelers, project managers, and decision makers.

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Deployment Support of Efficient Deployment of Advanced Public Transportation Systems (EDAPTS)



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Project Budget:
\$ 175,000

Project Start Date:
May 2007

Project End Date:
September 2009

Contract Number:
2090DR



Problem Statement and Project Overview

CCIT completed Phase 1 of a 3-phase program aimed at turning the outcomes of the “Efficient Deployment of Advanced Public Transit Systems” (EDAPTS) research and development into a readily-available set of resources to help public transit agencies across California implement Advanced Public Transportation Systems (APTS). Consistent with Caltrans’ Division of Research and Innovation’s (DRI) terminology for research conduct, the program is referred to as “EDAPTS Stage 5 deployment.”



The EDAPTS Vision

EDAPTS has been defined as an approach available to transit agencies to implement APTS. This approach offers a set of tools aimed at easing and accelerating implementation of APTS systems that meet technical and economic standards.

Formally, EDAPTS is a set of hands-on and analytic tools, recommended procurement methodology, and information that facilitates implementation of APTS for small urban and rural transit providers. EDAPTS outlines procurement options, provides useful information on funding sources, and advocates open source designs and open interface protocols. The goals of EDAPTS are:

1. Assist small, urban and rural agencies in the identification of ITS solutions (i.e. APTS) that meet their specific needs
2. Promote the use and incorporation of non-proprietary subsystem interfaces that facilitate future expansion
3. Advocate system performance trade-offs that significantly reduce life-cycle costs but do not adversely impact the intended usefulness of the deployed system to the procuring agency

Figure 22: Fact Sheet on Deployment Support of Efficient Deployment of Advanced Public Transportation Systems (EDAPTS)

The expanding array of APTS technologies is constantly improving the efficiency and passenger services of public transportation systems around the nation. As the cost of technologies decreases, these solutions are no longer limited to large transit systems; they can be deployed at small urban and rural environments where the potential benefits of APTS are immense.



The tools offered by EDAPTS should include guiding documents, case studies and best practices, technical specifications, software, and possibly, dedicated state-funded consulting and engineering services and/or designated project funds. CCIT's Phase 1 recommendations include that, beyond the timeline of Stage 5 activities, Caltrans' Division of Mass transportation should coordinate the assistance offered to transit agencies as part of EDAPTS through their annual process of selecting transit agency proposals for funding.



Progress to Date

In the final report, the CCIT provided recommendations that are required to turn the EDAPTS vision into a tangible solution for small and rural transit agencies statewide:

- Familiar with APTS; small urban and rural transit agencies should find out ways APTS can benefit them by providing real-time arrival notifications and emergency alerts Rkgnr
- Identify stakeholders to involve in the investment and future success of APTS deployment
- For common understanding of the goals and APTS system changes, transit agencies must assess and prioritize needs
- Transit agencies must communicate the benefits of APTS to develop operational scenarios
 - This is a means of convincing external bodies such as city councils or regional planning boards to implement APTS
 - Operational scenarios demonstrate ways in which APTS functions and the benefits that are revived by each stakeholder

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Online Transit Trip Planning for Small Agencies with Google Transit



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Project Budget:
\$200,000

Project Start Date:
June 1, 2009

Project End Date:
February 28, 2011

Contract Number:
65A0324

Problem Statement and Project Overview

Two thirds of the US population is now online, a growing figure that is higher in California. Considering this statistic, disseminating public transport mobility options and schedule information over the internet is a winning proposition. As such, CCIT is working with small urban and rural transit agencies who typically have limited resources to implement Advanced Public Transportation Systems (APTS), such as web-based trip planners.

Google Transit (online transit trip planner) and Google Transit Feed Specification (GTFS) present such an opportunity for transit agencies. For small organizations, the opportunity is even greater, because it is unlikely that they possess the resources to develop and maintain a user-friendly web-based trip planner on their own.

There are a multitude of benefits to the transit agencies who engage in Google Transit Feed Specification (GTFS) implementation. As neighboring cities adopt Google Transit, the availability of routes expands; riders will no longer have to consult bus transit schedules from two or more different cities. The Google Transit system now allows for them to type in just origin and destination; it automatically chooses the best routes and displays all bus stops, routes, times, and distances. It is even available for planning days or weeks in advance.

The proposed work will select a handful of voluntary small urban or rural transit agencies, and provide them with the resources and technical assistance necessary to organize their schedule data and convert it to the Google Transit format. These agencies will be selected by choosing a corridor and working with transit agencies along this corridor. Potential corridors are expected to have one or more transit agencies in the proximity to the Google Transit network (e.g., I-80 corridor between the Bay Area and Sacramento).

In the process of assisting these agencies, CCIT will develop a set of guidelines and list available resources that can be applied by other agencies statewide. CCIT will also explore the need and feasibility of setting up statewide assistance for a limited time in order to help the smallest agencies with the adoption of the Google Transit trip planner.

Objectives

The CCIT research team, with guidance from Caltrans, will specifically engage in the following activities with the selected agencies:

- Develop a feed conforming to the GTFS
- Update and maintain GTFS implementation with limited resources
- Assess the opportunity for technical assistance resource or a grant program to further this effort statewide



Project Scope

CCIT and Caltrans will give limited initial maintenance assistance to the agencies in transitioning toward Google Transit. After full implementation, the agencies will be responsible for the GTFS feeds.

continued

Figure 23: Fact Sheet on Online Transit Trip Planning for Small Agencies with Google Transit

The Google Transit Trip planner is free to both agencies and users.

Many agencies already offering trip planners are switching to Google's Transit planner.

"Google's mission is to organize the world's information and make it universally accessible and useful." – Tom Sly, Google News Business Development



The following four maintenance models are being explored:

- Web-based upkeep, hosting by a third party vendor, with an annual cost of \$900
- Spreadsheet tools based upkeep by the transit agency staff for which the time commitment may vary from upwards of 40 hours a year based on the frequency and types of modifications to the system
- GTFS feed is hosted by an entity in your general area (e.g., Council of Governments or the Larger Regional Transit Agency) through an agreement
- GTFS feed is hosted at a central location by Caltrans and kept up using a centralized open source software by the transit agency through a web interface

The transit agency will own the final product, and will be able to provide access to Caltrans and others for planning purposes on request.

Progress to Date

In the San Luis Obispo region, Rideshare and RTA Routes 9, 10, 12A, and 12B have adopted Google Transit. Integration is under way for the North County Shuttle, Paso Express, and South County area transit. The Altamont Commuter Express trail has already established the Google Transit feed. For the Grapevine service in Lodi and the Yuba-Sutter Transit system, the feed is being currently established. It is also being implemented by the Cerritos on Wheels agency in the Los Angeles and Orange counties.



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Hybrid Data Traffic Collection Roadmap: Pilot Procurement of Third Party Traffic Data



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Project Budget:
\$ 1,101,276

Project Start Date:
July 19, 2010

Project End Date:
March 30, 2011

Contract Number:
51A0391-001



Problem Statement and Project Overview

Based on the Governor's Strategic Growth Plan, daily congestion throughout the State of California will grow up to 35% from 550,000 hours in 2005 to more than 750,000 hours in 2016. Effective congestion relief strategies are dependent on Caltrans' ability to obtain real-time, reliable traffic information. Accordingly, this proposed effort seeks to develop a roadmap to procure traffic data from a third party and demonstrate an efficient use of alternate traffic data sources to complement existing detection systems that are installed and operated by Caltrans.

As Caltrans strives to reduce congestion and to provide a world-class transportation experience that meets the need of the public and all of its stakeholders and transportation partners, it must look for innovative, cost effective ways to provide safe, uninterrupted traffic flow on the roadways of the State. Therefore, Caltrans desires to obtain data supplied by these new technologies to develop a more comprehensive reservoir of transportation system operations data from which it can draw to not only improve its understanding of the existing operations, but also to inform and improve future decisions leading to enhanced system operating performance.

The massive availability of accurate traffic data has important consequences for both the travelling public and roadway operators. Caltrans will use this richly detailed traffic data to improve system management, traffic flow, transportation safety, work zone safety, emergency services, and evacuation management as well as increasing the efficient movement of goods across California. The dissemination of traffic information enables a form of system "self management", in which individual commuters can make informed travel decisions. Not only will each user benefit personally, but the entire driving community will enjoy more balanced traffic across the road network.



Mobile Millennium visualizer showing incidents and accidents around Treasure Island

Figure 24: Hybrid Data Traffic Collection Roadmap: Pilot Procurement of Third Party Traffic Data

"The ability of Caltrans to obtain traffic information has, in the past, been limited by the high cost of installing and maintaining equipment embedded in roadways. Today, new technologies are emerging that have the potential to assist Caltrans in obtaining system monitoring data by providing greater coverage at a fraction of the cost." –Caltrans

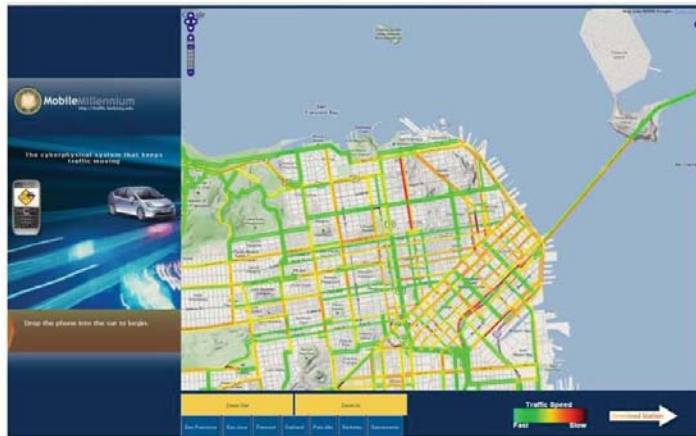


To avoid huge costs associated with installation and maintenance of new detection technologies, Caltrans is looking into procuring high-quality data from third-party vendors integration with existing Caltrans systems. This effort is investigating the feasibility and the business case for purchasing and fusing traffic data. The project is running a pilot demonstration to procure traffic data collected and processed by a third-party vendor. For acquirement of traffic data, this effort utilize highway modelling processes and techniques developed in a concurrent research project called Mobile Millennium. Led by UC Berkeley, Nokia Research Center, NAVTEQ, and CCIT, the project's aim is to demonstrate the capabilities of GPS-equipped cellular phones to operate as mobile traffic probes, and to instruct the design of an industrial-grade data collection system.

Project Objective

The primary goal of this task order is to provide Caltrans with a set of recommendations on how to procure and integrate data collected or purchased from a third-party vendor. The recommendations will be formed through a pilot procurement demonstration, potentially along the I-15 Caltrans District 8, in which CCIT, on behalf of Caltrans, will purchase traffic

1. Define data quality metrics and other procurement criteria
2. Purchase third-party traffic data
3. Integrate purchased and existing data using proposed fusion schemas
4. Validate the purchased and fused data
5. Assess various fusion models to enable Caltrans Management Systems to integrate different data sources



Mobile Millennium visualizer depicting traffic speeds around the Bay Bridge

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Hybrid Data Traffic Collection Roadmap: Objectives and Methods



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Project Budget:
 \$ 897,032

Project Start Date:
 September 2010

Project End Date:
 March 2011

Problem Statement and Project Overview

The Hybrid Traffic Data Collection Roadmap aims to leverage the recent expansion of potential sources and types of traffic data. Traffic data is now or will soon be available from multiple sources including cell phones, loop detectors, radars, toll tag readers, and Bluetooth readers. The potential areas of coverage provided by this data are unprecedented. However, as with all new technology, procuring and integrating this data into traffic metrics useful to traffic management entities or agencies require the development of quality standards, purchasing methods, integration methods and usage procedures.

The present effort focuses on core objectives and methods. In particular, the actual roadmap, in the form of a guiding document, is being developed as a deliverable of this task order. Probe data, its fusion with other forms of data, and analysis of this fusion's effects on placement strategies for fixed sensors are the primary areas of investigation in this project. The focus on probe data is critical, as the advent of cell phones and GPS devices has resulted in the possibility of nearly unlimited availability of this type of data.

Hybrid Traffic Data Roadmap: Work Plan

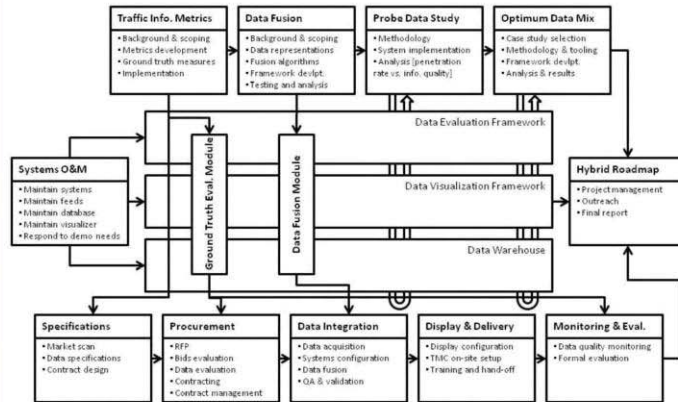


Figure 25: Fact Sheet on Hybrid Data Traffic Collection Roadmap: Objectives and Methods



Probe data will likely become ubiquitous in the near future. This, combined with its low cost of acquisition compared to fixed sensors, ensures its adoption as one of the primary methods of collecting real-time traffic data.

Project Objective

Provide quality metrics, usage methods, and planning recommendations for effective integration of traffic data from multiple sources. Make the case that traffic data procurement is a viable and cost-effective solution to collect more accurate and reliable data.

Project Goals

The overall goal of this effort is to understand the metrics associated with acquiring and using traffic data of multiple types acquired from multiple sources (vendors or public agencies). This requires examining publications, performing new research, and combining the results into new procedures and implementations. Traffic data is generally considered to be measures of occupancy, flow, instantaneous speed, average speed and travel time. Mathematical models are used to estimate values in areas where point measurements are not available. Current models often use only one type of data in making these estimates. With the advent of probe data, it is possible to fuse multiple types of data to provide traffic estimates of higher accuracy. Thus, future traffic information will result from running models on multiple types of data. Methods are needed for fusing this data and for measuring the quality of the data before and after fusion.



Mobile Millennium visualizer showing CHP incidents around Treasure Island

Progress to Date

As the project began in September 2010, CCIT is in the midst of the first stage, from which deliverables will be available in the coming months.

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Hybrid Data Traffic Collection Roadmap: Travel Time in District 3



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Project Budget:
\$ 170,000

Estimated Project Start Date:
November 2010

Project End Date:
March 2011

Contract Number:
51A0391-005



Problem Statement and Project Overview

This effort will extend the Caltrans District 3 traveler information coverage along I-80 and US-50 — stretches between Sacramento and Tahoe — and demonstrate an efficient use of traffic data sources to provide accurate and reliable travel time information to travelers.

Advanced Traveler Information System (ATIS) is a key component of managing transportation growth in California as well as providing valuable traffic information to travelers. One of the main pieces of ATIS content is undoubtedly travel time estimations. Estimated travel times between selected locations are found to be one of the most practical information drivers can use. Real-time traveler information on Changeable Message Signs (CMS) has gained popularity in urban areas. Caltrans provides a network of highway signs that is capable of disseminating a variety of information for different purposes.

Providing travel time is important in rural areas that host many travelers and tourists. These areas often times experience both recurrent and non-recurrent traffic congestions during weekends and holidays. The congestion intensifies specifically when the high volume of travelers confronts road construction, inclement weather conditions or incidents. US-50 and I-80 highways, connecting the Bay Area and Sacramento travelers to Reno or Tahoe Basin vacation resorts, face just such a challenge.

I-80 and US-50 corridors are heavily traveled all year round by people whose destinations are the resorts in the Sierra Nevada Mountains, the Lake Tahoe Basin and the casinos in the state of Nevada. The corridors experience congestion throughout the year, delaying travelers and freight transport. In addition, nine major roadway rehabilitation projects are on-going on I-80 stretching from Auburn to the Nevada State Line, continue through 2012, causing more delays. As a result, there is an urgent need to address the congestion problem by enhancing ATIS system and providing real-time traffic information to travelers.

CCIT has helped Caltrans District 4 successfully deploy an automated system, nicknamed MITTENS (Messaging Infrastructure for Travel Time Estimates to a Network of Signs), to display travel times on CMS in the Bay Area. This system uses link travel times generated by the local 511 system (hosted in MTC) to compute route travel times and display corresponding messages on CMS. The project aims to leverage this system to generate travel time messages along I-80 and US-50.

District 3 has already invested substantially to implement Fast-Trak toll tag readers as part of the 511 system along I-80 and US-50. For proper traffic management, transportation agencies require data collected by these readers to be converted to travel time; as such, District 3 has placed paramount value on ensuring that this data is properly converted to accurate time estimations. The current effort is a means of transferring and conveying this data into usable information for the public.

Figure 26: Fact Sheet on Hybrid Data Traffic Collection Roadmap: Travel Time in District 3

Real-time traffic information enables travelers to know what is ahead on their trip, and in some cases, to divert their route and reduce traffic. It also allows travelers to make informed decisions about delaying their travel plans based on accurate transportation information.



Objectives and Approach

This project's goal is the operational deployment of a system that collects traffic data from different sources and generates standard format driving time messages for any user-defined destinations along US-50 and I-80 corridors. The generated messages will feed the existing ITS elements along the two corridors, i.e. Changeable Message Signs, and Highway Advisory Radio. In this project the objectives are to:

- Validate the quality of the existing data (collected from toll tag readers)
- Enable MITTENS (travel time message generation system) to fuse various data types to fill in gaps and enhance travel time accuracy and reliability in the District. This feature will help the district integrate other types of data (i.e. probe data) for future coverage expansion plans.
- Generate real-time travel time messages and integrate them into the existing dissemination tools.



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Limited Deployment Pilot Project: Monitoring Truck Traffic Patterns in Caltrans District 7



PROJECT FACTS

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Project Budget:
\$ 250,000

Project Start Date:
January 15, 2009

Project End Date:
June 30, 2010

Contract Number:
65A0313



Problem Statement and Project Overview

There is a large number of trucks travelling to and from the Los Angeles area ports, which makes a significant contribution to LA area traffic congestion. Truck transportation impacts every aspect of traffic and infrastructure in the Los Angeles area. That impact is growing as the truck traffic continues to grow and needs to be addressed and managed effectively.

This effort was designed to deploy, as a pilot test, technology to classify long trucks at 26 single-loop sites along CA-60 and I-710 between the Ports of Los Angeles and Long Beach. This effort has facilitated the collecting of truck data in order to evaluate the ability to automatically classify long vehicles on a large scale. This effort has continued research of truck traffic by deploying 26 TMS-100 systems to:

1. Gather truck traffic data on a larger scale over a longer period of time
2. Compare data accuracy from the system with data collected from Automatic Vehicle Commission (AVC) and Weigh in Motion (WIM) installations along a test corridor to evaluate the system
3. Demonstrate the value of data collected and evaluate the TMS-100 system for managing traffic and highway maintenance



Projections

Based on observed barriers to collection of detailed truck data, the hypotheses for this research project were that:

1. Taking advantage of existing single-loop infrastructure would provide enough data sites to create better traffic management decisions, providing tangible benefits to stakeholders.
2. Information collected at the increased number of sites could provide the basis for analysis to improve highway maintenance schedules.
3. The TMS-100 equipped with the automated vehicle classification software module has web-browser based remote diagnostic and repair capabilities that would allow diagnosis of faulty loop sensors and remote reset of the detector rack, resulting in a reduced number of field trips.

Figure 27: Fact Sheet on Limited Deployment Pilot Project: Monitoring Truck Traffic Patterns in Caltrans District 7

Having good census data on truck traffic, and establishing a good assessment of real-time truck traffic through the deployment of new technologies, will help Caltrans to efficiently tackle the traffic congestion problem in and around our crowded port areas.



Project Goals

The result of this project includes a functioning truck traffic information system on the heavily traveled Long Beach and Los Angeles port routes, as well as a replicable, scalable program ready for implementation at other District 7 locations and in other Caltrans districts. CCIT has provided deployment support, which enables Caltrans to procure vendors for installing 26 TMS-100 systems. It also provided documentation of installation processes, system evaluation, and census group data analysis methodologies documentation.



Progress to Date

The project was completed in June 2010. 26 TMS-100 systems were deployed along US-60 and I-710. CCIT has completed the evaluation task and is finalizing the report.

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Implementation and Evaluation of Automated Vehicle Occupancy Verification



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Project Budget:
\$ 249,994

Project Start Date:
July 1, 2008

Project End Date:
June 30, 2011

Contract Number:
65A0291

Problem Statement and Project Overview

This collaborative effort will enable HOV facility managers in California to ensure effective operations of High-Occupancy Vehicle (HOV) and High-Occupancy Toll (HOT) facilities using automated vehicle-occupancy verification (AVOV) and enforcement systems.

Efficiently operated High Occupancy Vehicle (HOV) or High Occupancy Toll (HOT) lanes increase travel speed, reliability, and the vehicle and person-carrying capacity of roadways in urban areas. The success of these HOV/HOT facilities as a viable transportation strategy is dependent upon the enforcement of occupancy regulations. On-site monitoring and enforcement of these regulations is difficult, expensive, and potentially hazardous for enforcement officers.

As more managed lanes (i.e., lanes with limited access and/or pricing) emerge that employ a widening array of users and an increasing mix of managed lane strategies in combination with HOV/HOT, enforcement has become more complicated, especially with regard to identifying high occupancy vehicles that receive special access or pricing for travel within a varied traffic stream. For priced lanes, persistent violation problems can result in a significant amount of lost revenues.

This project is being undertaken as a collaborative effort with the San Diego Association of Governments (SANDAG) and will identify, test, and evaluate promising concepts and methods for automated vehicle-occupancy verification (AVOV) and enforcement that can be adopted for permanent field implementation.

An existing SANDAG-sponsored project performed by the HNTB Corporation will identify the most promising technologies for roadside occupancy detection. The project includes the demonstration of a limited-duration pilot test to determine how well the detection systems meet requirements.



Project Methodology

The most promising candidates or combination of candidates will be selected for pilot testing and evaluation at one or more HOV facilities. In addition to the planned pilot on a portion of existing managed lanes on Interstate 15 in San Diego County, more test locations may be identified as further research is conducted. The research panel consists of the sponsoring agencies, the CCIT research team, and the respective HOV facility operator and enforcement agency.

PATH and CCIT will conduct the monitoring and evaluation of the AVOV and enforcement systems to be deployed as part of this effort. CCIT will lead the effort in assessing the user acceptance of the AVOV and enforcement systems as well as develop a deployment package that will serve as a guideline for future use of proven AVOV and enforcement systems in California and elsewhere.

Figure 28: Fact Sheet on Implementation and Evaluation of Automated Vehicle Occupancy Verification

Vehicle occupancy verification is a principal impediment to more efficient HOV/HOT lane enforcement. Electronic toll collection, license plate recognition and a myriad of other technologies have been developed... However, the target of these technologies has usually been the vehicle, not the occupants.



Further, the research proposed will also explore how automated vehicle-occupancy technologies can be integrated with other applications, such as automated toll violation operations; managed lane enforcement operations; vehicle occupancy data collection; and HOV/HOT lane performance monitoring, reporting, and evaluation.

The technical proof of concept will be complemented by an assessment of the legal and institutional barriers to implementation of automated managed lane enforcement. Deliverables will document and synthesize the results of the literature review, expert interviews, and focus groups and make recommendations for future applications, implementation, and research.



Progress to Date

Through a competitive bid process that occurred in April 2009, Delcan was selected to test their infrared camera for automated enforcement of HOT lanes. A field operational test was conducted in August 2010 testing the cameras. The next step is to analyze and evaluate the data.

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CONCLUSION

CCIT's development of three categories of outreach and promotion emphasizing the particular audience to be served – internal, external, and both internal and external –and utilizing the guidance of NCHRP Report 610 presents a model for accelerating deployment of DRI sponsored research.

Had outreach and promotion not been an integral element in the evolution of the projects presented in here, they might well have remained as merely interesting research summarized in technical reports. By actively engaging the media, transportation practitioners, and Caltrans management throughout the research process significant attention was brought to bear on the technological and societal impacts of this groundbreaking work.

Equally important was the fact that outreach and promotion of these projects (and others like them) enabled Caltrans to leverage available resources and to draw the attention of industry to create public-private partnerships. The formation of these partnerships spurred the transfer of the technology directly into product development saving years of the traditional process of technology transfer.

In effect, outreach and promotion via project fact sheets, the CCIT services brochure, website (<http://www.calccit.org>), and biennial report (<http://www.calccit.org/?page=resources>) accelerated deployment of the Mobile Century and Mobile Millennium research into real-world products now in daily use by the traveling public.

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Project Millennium

The potential of cell phones to operate as traffic data collection devices has been considered by the Intelligent Transportation Systems (ITS) community for several years. Government agencies currently deploy networks of infrastructure-based traffic sensors that are expensive to install and maintain. Leveraging the existing infrastructure of commercial cellular networks could drastically cut the ongoing costs of traffic monitoring and expand coverage to thousands of miles of highways and urban arterials for which sensors are not currently a viable option.



On February 8, 2008, Nokia and the University of California, Berkeley demonstrated the reconstruction of traffic on highways using cell phones by running an experiment, nicknamed *Mobile Century* for its 100 cars traveling in 10-mile loops on Hwy 880 in the San Francisco East Bay for 8 hours, which amounted to 2% of traffic. During the experiment, GPS-equipped Nokia N95 phones sent traffic information in a privacy protecting system capable of broadcasting traffic information in real time on the internet. The successful experiment, funded by the California Department of Transportation (Caltrans), led to the development of a pilot system, *Mobile Millennium*, to make this technology available to the public.

The project is a partnership between Nokia, NAVTEQ, and UC Berkeley, based at the California Center for Innovative Transportation (CCIT) and supported by the U.S. and California Departments of Transportation.

Researchers have constructed an unprecedented traffic monitoring system capable of fusing GPS data from cell phones with data from existing traffic sensors. The research and development phase of this project was dubbed *Mobile Millennium* for the potential thousands of Early Adopters who participated in the pilot deployment, launching November 10, 2008 and still running at the time of this publication.

Left: A Nokia smartphone shows Mobile Millennium traffic pilot software displaying real-time freeway traffic in Berkeley, CA



Collecting Traffic Data from Mobile Phones

Mobile Millennium will cover not only highways, but also the arterial network, where there is currently almost no sensing infrastructure. The software will work on Nokia and non-Nokia phones, and the public will be able to download it free of charge.

It will gather data in a privacy-preserving environment, relying on Virtual Trip Lines technology, a data-sampling paradigm that anonymizes the GPS-based position information and aggregates it into a single data stream.

The aggregated data is then encrypted and sent to a computer system, which blends it with other sources of traffic data and broadcasts this real-time, data-rich information back to the phones and to the internet through a user-friendly interface.

This Special IQ Section contains the following articles on the Mobile Millennium:

Part 1. Using GPS Mobile Phones as Traffic Sensors: A Field ExperimentPage 34

Part 2. Impacts of the Mobile Internet on Transportation Cyber Physical Systems: Traffic Monitoring using SmartphonesPage 38

Part 3. Automotive Cyber Physical Systems in the Context of Human MobilityPage 43

The convergence of sensing, communication and multi-media platforms has enabled a key capability: mobility tracking using GPS.

Using GPS Mobile Phones as Traffic Sensors: A Field Experiment

This article presents the Mobile Century field experiment, performed on February 8, 2008, to demonstrate the feasibility of a prototype location-based service: real-time traffic estimation using GPS data from cellular phones only. Mobile Century consisted of 100 vehicles carrying a GPS-equipped Nokia N95 cell phone driving loops on a 10-mile stretch of I-880 between Hayward and Fremont, California.

The data obtained in the experiment was processed in real-time and broadcasted on the internet for 8 hours. Travel time and velocity contour estimates were shown in real-time using a privacy-preserving architecture developed to provide this new service in an environment acceptable to users and participants.

The quality of the data proves to be accurate against data obtained independently from the experiment. The experiment also shows that it is not necessary to have a high proportion of equipped vehicles to obtain accurate results, confirming that GPS-enabled cell phones can realistically be used as traffic sensors, while preserving individuals' privacy.

Background The convergence of sensing, communication and multi-media platforms has enabled a key capability: mobility tracking using GPS. Major cellular phone manufacturers plan to embed GPS receivers in most of their phones in the near future. This trend has major implications for the traffic engineering community.

Currently, traffic monitoring is most commonly based on fixed detectors, which provide vehicle counts, roadway occupancy, and often speed. Unfortunately, their high installation and maintenance costs prohibit more widespread deployments, particularly in developing countries. Moreover, the reliability and accuracy of this type of detectors vary. GPS-equipped mobile phones can provide speed and position measurements to the transportation engineering community by leveraging infrastructure deployed by phone manufacturing companies and network providers. Because this technology is market driven, it will penetrate transportation networks at a very rapid pace, soon covering rural areas with a significant impact in developing countries where there is a lack of public traffic monitoring infrastructure. The present study describes a field experiment to assess the feasibility of this new traffic monitoring system based on GPS equipped phones.

System Architecture A prototype system architecture was created to gather probe vehicle data in a privacy preserving environment. The architecture uses the concept of virtual trip lines (VTLs). Virtual trip lines are geographical markers stored in the client (i.e. the mobile handset), which trigger a position and speed update whenever a probe vehicle crosses them. Sampling in space through VTLs, rather than in time leads to increased privacy by facilitating a distributed monitoring architecture that processes only anonymous location updates (i.e. no single infrastructure entity possesses identity and accurate location information [1]). A privacy-aware placement algorithm that generates the VTL database was designed and used for this study.

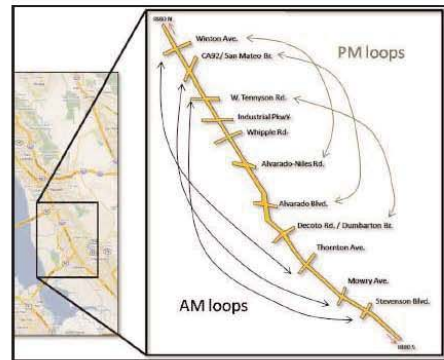


Figure 1. Deployment section on Highway I-880, California, for the Mobile Century experiment

We demonstrated the validity of the implementation of the virtual trip line concept through a preliminary 20-vehicle experiment on a highway segment on November 2, 2007.

The system architecture comprises four entities: the probes (i.e. GPS-equipped cell phones traveling onboard vehicles), a cellular network operator, an ID proxy server, and a traffic monitoring and reconstruction system. Standard encryption techniques secure the data transmissions.

To further address the privacy concern, the VTL concept can be associated with a cloaking technique whereby several speed updates are aggregated based on trip line identifiers, without collecting the geographic locations of individual trip lines.

Thus, VTLs facilitate the design of a distributed architecture, where no single entity has complete knowledge of probe identity and fine-grained location information. The data collected is used to estimate the state of the system (in this case, velocity and travel time on the highway). It is sent to a server, which runs traffic flow reconstruction algorithms using this data. The algorithms rely on nonlinear flow models, which describe evolution of the traffic velocity, and can accurately reproduce shock-waves created from accidents or bottlenecks on the highway. These flow models are embedded into an inverse modeling estimation algorithm. This algorithm employs Ensemble Kalman filtering, which enables the use of the discretized nonlinear flow models. The estimates produced by the algorithm are sent back to a visualization server, which broadcasts traffic state through the internet (see interface in Figure 2).

Mobile Century: A Field Experiment

The Mobile Century experiment took place on February 8th, 2008. It consisted in deploying 100 GPS-equipped Nokia N95 cell phones on a freeway during 8 hours. The experiment was conducted on Highway I-880, near Union City, CA, between Winton Ave. to the North and Stevenson Blvd. to the South (Figure 1). This 10-mile long section was selected for its traffic properties (in particular the known existence of a recurrent bottleneck between Tennyson Rd. and CA92 in the northbound (NB) direction), and a high loop detector density useful for validation purposes. 165 UC Berkeley students drove loops on the section of interest between 10am and 6pm. This period encompasses free flow and congested conditions, and the transition between the two of them. The loop structure was implemented in order to achieve a desirable penetration rate of 3%-5% of the total flow. Different ramps were used by different vehicles and at different times of the day (AM and PM loops in Figure 1) for experimental reasons. The data was collected in two ways during the experiment. First, the privacy preserving architecture described earlier collected data from the 45 VTLs deployed in the section of interest (each VTL covers both travel directions). This data was used to produce real-time travel time and speed estimates on the section of interest. In addition, each cell phone was storing its position and velocity every 3 seconds. This data (trajectory data) becomes available only once the experiment is finished, and is used a posteriori to evaluate the quality and accuracy of traffic data. This data is only generated for experimental purposes, and would never be collected in an operational system.

VTL data. The data obtained in the experiment was processed in real-time, and used to produce real-time travel time and velocity estimates, which were broadcasted for 8 hours. Figure 2 illustrates the interface used to broadcast travel time and speed during the day. The figure shows traffic at a time after an accident occurred in the NB direction between Tennyson Rd. and CA92. The figure also shows the 511.org traffic display at the same time.



A Google Earth rendering of collected GPS data. Virtual trip lines measuring speed upon crossing of the vehicles are shown in red.

The quality and accuracy of the VTL data depends on the proportion of equipped vehicles that cross them. To evaluate this, VTLs were placed on existing loop detector locations to compare the speed measurement provided by each one of them. A loop detector can be thought of as a VTL that collects data not from a subset, but from all vehicles. Figure 3 shows this comparison for two locations. The first location (part a) of the figure, is between Whipple Rd. and Industrial Pkwy. in the NB direction and has an average penetration rate of 3%-4%, while the second location is between CA92 and Winton Ave. in the NB direction and penetration rate rarely exceeds the 2% of the total flow. As expected, accuracy of the measurements increases with the proportion of equipped vehicles crossing the VTL. Notably, high penetration rates are not needed to provide reasonable speed measurements.

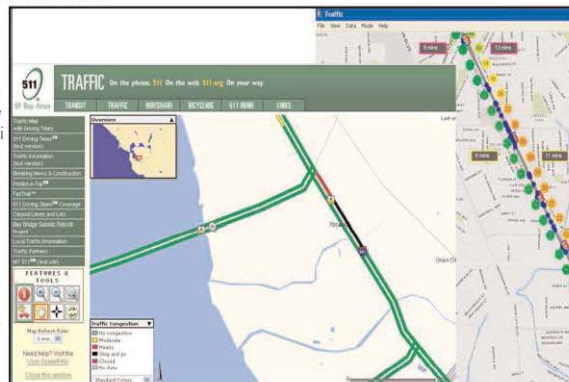


Figure 2. Traffic report provided by 511.org and our system at 10:52am on February 8, 2008, after an accident on the NB direction of I880 occurred.

Trajectory Data Data stored by every cell phone was processed after the experiment, in order to conduct more detailed analysis on the quality of the data. Trajectory of every vehicle can be reconstructed using this data. Figure 4 shows 50% of the collected trajectories in the NB direction. The transition from the AM loops to the PM loops occurs at 1:30pm and can be clearly seen in the figure, as well as the fact that different vehicles were using different ramps to get in and out of the highway. The propagation of the shockwave generated by the accident is clearly identified in this plot as well. Using these trajectories, a velocity map can be constructed and compared with the one provided by PeMS (Figure 5). The velocity map computed from the trajectories uses Edie's speed definition [2]. The section chosen for this plot is between Decoto Rd. and Winton Ave. in the NB direction, from 10am to 6pm. This 6.5-mile section of highway is covered by 17 loop detector stations, providing a very good estimate of the actual speed contour. Blank spots in part a) of the figure mean no equipped vehicle was at that time at that location. The agreement between the two plots in Figure 5 is evident, considering that less than 5% of the trajectories are known. The discrepancies at the ends of this section can be explained by the low penetration rate at these locations (especially at the north end, where the penetration rate is less than 2% as shown previously in Figure 3).

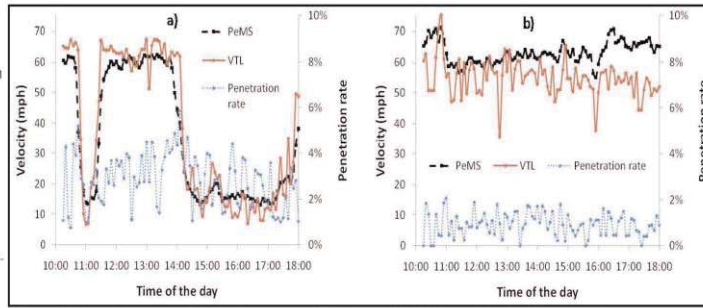


Figure 3. Loop detector velocity data versus VTL data with different levels of penetration rates.

The Mobile Millennium project in its early phase will span some of the major highways in California, and provide similar levels of service as demonstrated during the experiment.

Final Comments The Mobile Century experiment has demonstrated that GPS-enabled cell phones can be used as sensors for traffic monitoring purposes, while preserving individuals' privacy when collecting data. The experiment shows the possibility of reconstructing traffic using a penetration rate of equipped vehicles less than 5%. The results show the accuracy of the reconstructed speeds and their correlation with the loop detector data available throughout the experiment. This prototype system is in the process of being scaled up so it can handle up to 10,000 vehicles for a pilot deployment of six months, in a project called the Mobile Millennium.

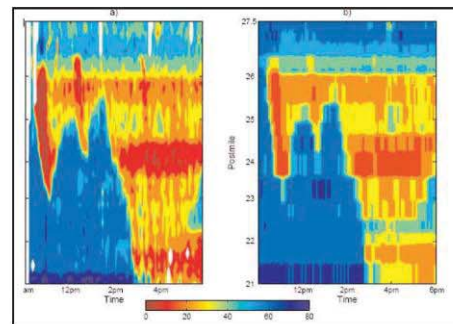


Figure 5. Velocity contour map (in mph) using a) vehicle trajectories and Edie's speed definition, b) 17 loop detector stations.

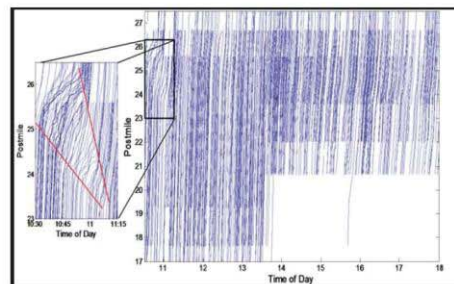


Figure 4. Vehicle trajectories in NB direction extracted from the data stored by 50% of the cell phones. The shockwave propagation can be seen during the accident in the morning.

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- ² L. Edie. Discussion on traffic stream measurements and definitions. In Proc. of the Second Int. Symp. on the Theory of Traffic Flow, pages 139-154, Paris, France, 1965.

Impacts of the
Mobile Internet on
Transportation
Cyberphysical Systems

Traffic Monitoring using Smartphones

By Daniel B. Work and Alexandre M. Bayen

The mobile internet is changing the face of the transportation cyberphysical system at a rapid pace. In the last five years, cellular phone technology has leapfrogged several attempts to construct dedicated infrastructure systems to monitor traffic. Today, GPS equipped smartphones are progressively morphing into an ubiquitous traffic monitoring system, with the potential to provide traffic information in real time for the entire transportation network. Traffic information systems are one of the first instantiations of the potential of participatory sensing for large scale cyberphysical infrastructure systems. While mobile device technology is very promising, fundamental challenges remain to be solved, in particular in the fields of modelling and data assimilation.

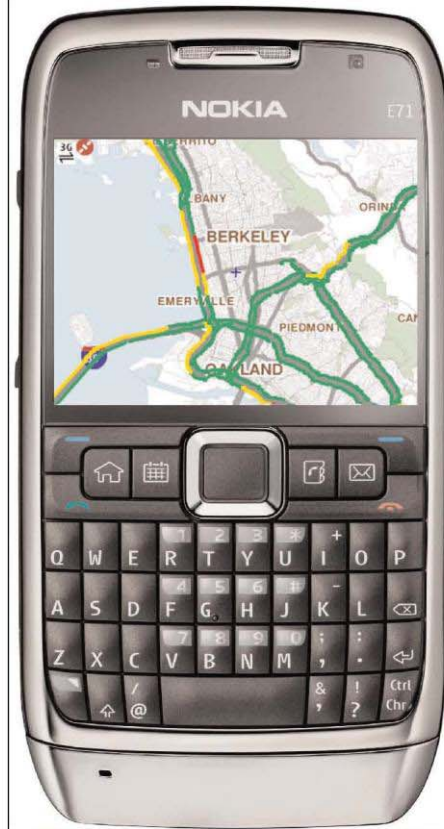
Traffic Monitoring at the Era of Mobile internet Devices

Smartphones as sensors of the built environment.

The convergence of communication and sensing on multimedia platforms such as smartphones provides the engineering community with unprecedented monitoring capabilities.

Smartphones such as the Nokia N96 now include a video camera, numerous sensors (accelerometers, light sensors, GPS, microphone), wireless communication outlets (GSM, GPRS, WiFi, Bluetooth, infrared), computational power and memory. This phone can be used to listen to the radio, to watch digital TV, to browse the internet, to do video conferencing, to scan barcodes, to read pdfs, etc. The rapid penetration of GPS in smartphones is enabling device geolocation and context awareness, which in turn is causing an explosion of Location Based Services (heavily relying on mapping) on the devices. For example, Nokia Maps display theaters and museums near the phone, Google Mobile provides driving directions from the phone location, and the iPhone Travelocity shows hotels near the phone.

Due to their portability, computation, and communication capabilities, smartphones are becoming useful for numerous applications in which they act as sensors moving with humans embedded in the built infrastructure. Large scale applications include everything from population migration tracking and traffic flow estimation to physical activity monitoring for assisted living.



A Nokia Smartphone shows Mobile Millennium traffic Pilot software displaying real-time freeway traffic in Berkeley, California.

The competition for probe traffic data collection as a proxy for the larger war to conquer the mobile internet.

In recent months, there have been increased levels of competition between cell phone manufacturers, network providers, internet service providers, computer and software manufacturers, and mapping companies. Following the transition from desktops to laptops to smaller and more portable devices, top companies in these industries are redefining themselves to remain relevant as the internet goes mobile. In the context of traffic monitoring, the examples below are eloquent and show the importance of information technology for transportation systems. In late 2007, Google made a move towards the phone industry with the launch of the Open Handset Alliance and the Linux-based Android platform (leading to the T-Mobile G1 Google phone). In part because of the pressure to use open platforms enhanced by the Google OS, Nokia, who manufactures 40% of the cell phones in the world, purchased Symbian, which licenses the operating system running on more than half of the smartphones in the world.

Nokia then established the Symbian Foundation, with the intention of unifying the platform and making it open-source (Apple also partially opened its iPhone OS to software developers with the release of a software development kit). To strengthen its own mapping capabilities, Nokia bought Navteq, which is the largest mapping company in the world, following personal navigation device manufacturer TomTom's purchase of Tele Atlas, Navteq's chief competitor. Navteq in turn owns Traffic.com, one of the leading traffic data collection and broadcast companies. Its competitors include Inrix, which provides traffic data to Microsoft's web, desktop, and mobile applications.

New sources of traffic data for the transportation network.

Highways have traditionally been monitored using static sensors, which include loop detectors built in the pavement, radars and cameras along the road, and more recently toll tag readers (such as FasTrak or EZ-pass), which can serve as probes wherever such infrastructure exists. While this infrastructure has proved to be efficient for highways, the costs of deployment, communication, and maintenance for such an infrastructure in the arterial network make it prohibitive for public agencies or companies to deploy on a global scale.

To alleviate possible communication bottlenecks, on October 21, 1999, the Federal Communications Commission allocated 75MHz of spectrum as part of the US Department of Transportation's (DOT) Intelligent Transportation Systems (ITS) US-wide program, with mostly traveler safety, fuel efficiency and pollution in mind. The first industry-government supported standard followed on August 24, 2001, when ASTM's E17.51 Standards Committee voted 20-2 to base Dedicated Short Range Communication (DSRC) on a modification of the IEEE 802.11a specification now named IEEE 802.11p.¹ At the same time, the US DOT launched a plan which included the deployment of around 250,000 road side DSRC radios, but only led to around 100 radios deployed for the entire US to this day.

This example highlights the difficulty of creating a dedicated system for the transportation network. At the same time, the need of monitoring traffic remains unsolved: if traffic information was available at a global scale including the arterial network, several problems could potentially be solved: (1) real-time congestion estimation of the arterial network; (2) re-routing of the highway traffic into arterial networks where beneficial; (3) optimized travel time, fuel efficient or emission optimal routes for commuters.

Impact of the Mobile internet on the Transportation CPS

Smartphones: a transformation from dedicated infrastructure to market-driven technology.

The scale at which cell phones are produced, and the rate at which they integrate new technology is dramatic. The total number of cell phones worldwide exceeds three billion, with some European countries with a penetration of more than 150% (150 cell phones for 100 people). Nokia alone produces more than 17 phones a second, which means with the increasing penetration of GPS in the cellular phone fleet, cell phones will soon constitute one of the major traffic information sources available to the public. In North America and Europe, the overwhelming majority of commuters have a cell phone, potentially populating the entire arterial network with probe traffic sensors. Obviously, the use of cellular devices as traffic sensors has numerous benefits. (1) It is possible to leverage the market driven communication infrastructure already in place. (2) The spatio-temporal penetration of cell phones in the transportation network is increasing at an extremely fast pace. (3) The use of cell phones as traffic probes is device and carrier agnostic, leading to faster penetrations. (4) Major car manufacturing companies already have cradles and interfaces with cell phones (for example BMW and the iPhone) in their new cars so the sensing information gathered by modern cars can also be sent to such monitoring system.

Lagrangian vs. Eulerian Information.

While cellular phones provide an ideal bridge between the physical world (vehicle flows and dynamics on the road) and the information world (software systems monitoring the network), there is one major difference between the data collected by cell phones and traditional data, commonly used to estimate traffic in real time: the data collected by phones in cars is Lagrangian, i.e. gathered along cars trajectories, and not Eulerian, i.e. control volume based. This poses major challenges in building an information system for a cyberphysical infrastructure such as the transportation network. While a static loop detector or a camera (both Eulerian) can easily capture all vehicles going through the space monitored by the sensor, and therefore infer from it exhaustive quantities (flows, counts, local speed), a Lagrangian sensor can only monitor quantities following the vehicle, which does not give direct access to flows, counts, etc. In addition, measurements are only available where participating vehicles / phones are located. These are not predictable, and the local penetration of devices in the network might vary. These problems open many research avenues with direct impact on technology development for traffic monitoring.

Modeling and computational challenges for monitoring the transportation CPS.

As indicated in the name cyberphysical, the two key components of cyberphysical systems are "information" (cyber) and "constitutive laws" (modeling the physics of the system). Monitoring cyberphysical systems such as the transportation network poses two major challenges:

- Distributed models for the transportation network. Because GPS enabled phones sense velocity, or travel time between two consecutive GPS readings, constitutive models used to describe the evolution of the system need to incorporate these reading and bypass quantities which cannot be measured (density, flows, counts). The development of such flow models, for highways and arterials is still at its infancy. Techniques used for this include partial differential equations, queuing systems, and hybrid systems models of flow equations.
- Machine learning models to circumvent lack of geographical information. Mapping the entire US with an automated traffic monitoring system prevents the use of accurate knowledge of signage and traffic light presence, let alone cycle information. The presence of stops, lights, and their effect on traffic is not available from databases on a US-wide scale. Furthermore, they change too often to be incorporated in flow models. This difficulty has to be circumvented by machine learning algorithms capable of learning the flow features without knowledge of the detailed infrastructure, using for example, clustering analysis.

Spatially aware sampling and privacy.

At the heart of such a system, privacy by design sampling techniques must be used to prevent privacy invasion. In addition to proper anonymous data collection and encryption, sampling the vehicles at locations which are privacy safe is key to ensuring ongoing participation of the public which is needed for such a system. One possible architecture for preserving privacy is to collect data using a concept known as Virtual Trip Lines (VTLs), which are virtual geographic line segments deployed across roadways in the transportation network, triggering phones to collect and transmit data to the system. Defining optimal sampling strategies, which are privacy preserving is still a relatively unexplored field.



Mobile Millennium traffic client. Traffic is displayed directly on the phone screen, with traffic information such as construction, accidents, etc., and audio traffic reports. For drivers who want to opt in, the phone can also send information to the system (Lagrangian measurements).

Real-time, online and robust availability.

Unlike the more permanent Eulerian detectors, to which data quality, reliability and performance indices can be easily attributed, the penetration of cell phones at a given location and time is highly variable. Furthermore, in the coming few years before this type of monitoring becomes the standard, the participation of the public will be spatially and temporally varying. This means that the algorithms used for estimating the traffic must be robust to variability in penetration.

Inverse modeling and data assimilation.

At the age of massive data collection, one of the most fundamental theoretical challenges associated with the reconstruction of traffic using mobile data will be the proper use of techniques to incorporate data into flow models or statistical models. The development of these techniques in fields such as oceanography or meteorology is relatively mature. For cyberphysical systems, in particular large scale infrastructure systems, the state of modeling, model inversion and computation is still at its infancy and promises significant breakthroughs in the near future.

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Limitations of the current automotive Cyberphysical System. Its vehical-centric view only provides partial information about the surrounding environment,

Automotive Cyberphysical Systems in the Context of Human Mobility

By Daniel B. Work , Alexandre M. Bayen and Quinn Jacobson

For the past century, the primary function of the automobile has been to move people efficiently. The main challenge has been to build vehicles which are safe and dependable, and meet the intrinsic societal need for mobility. The automobile has enjoyed dominance in meeting this need, which has been characterized at a fundamental level as getting people and goods where they need to be. As the demands for mobility have increased in complexity, from simply enabling people to reach destinations that were previously impractical, to getting people to their destination safely and reliably, technology developed in the automobile sector has also increased in complexity. The vehicle has developed from a purely physical system based on the laws of mechanics and chemistry, to a more sophisticated Cyber Physical System (CPS) which embeds electronic components and control systems to improve performance and safety.

The demand for mobility over this time has continued to increase, creating a new set of challenges which cannot be addressed by simply improving the technology of a single vehicle. In California alone, there are 280 billion vehicle miles traveled each year, and the need for human mobility is now a lifeline of the economy. But California commuters spend more than 500,000 hours delayed in traffic each day, with an annual estimated cost of \$21 billion per year, and the problem is not isolated to this state. These problems suggest a new Human Mobility CPS (HM-CPS) will be required to answer the problems which are faced by all commuters independent of the vehicle. This HM-CPS will emphasize the coupling of the physical movements of people both at an individual and aggregate scale with the cyber communication, computation, and sensing needed to monitor and efficiently enable mobility in the surrounding physical environment.

Fundamental Limitations of the Existing Automotive CPS

A. Limited Information

Automobiles are well suited to collect information about the local physical world, but they lack the capability to collect global information about the environment in which they evolve.

Most automobile sensors are specifically designed to monitor infrastructure within the vehicle itself, such as the engine temperature or the fatigue of some components. Localized sensing is effective at managing issues such as vehicle reliability, but it can only provide limited solutions for larger scale aspects of the CPS such as safety, route planning, and context aware location based services.

As an example of the limitation of the current automotive CPS framework, most safety critical sensing is aimed at minimizing the severity of accidents. While this has undoubtedly saved the lives of several commuters, it does not provide sufficient monitoring to prevent accidents from occurring. Although sensors can be added to the outside of the vehicle to determine where neighboring vehicles are located, better information can be provided if vehicles or surrounding infrastructure share information in cyberspace.

While near misses or car crashes on a very short timescale are hard to avoid using automation, new soft safety concepts such as warning of upcoming slowdowns are achievable with today's wireless technology (in particular mobile phones). More advanced safety applications will evolve only when the existing sensing and communication limitations are removed. Another challenge in collecting information is the timeliness in which it must arrive to be useful to the embedded human. Information about the level of use of the immediate surrounding infrastructure can be obtained locally by the vehicle, but this information must be collected before the vehicle arrives for important navigation decisions to be made. Even if a vehicle has a navigation device on-board, it must get traffic information from a global aggregator. Due to the expense of installation of sensing equipment such as inductive loop detectors (ILDs) or radio frequency identification (RFID) transponders, this information is limited at best. Interestingly, although no single vehicle has complete information about the current state of the transportation network, it can easily be inferred from the data that each vehicle is collecting locally, such as speed and acceleration. The problem of limited information in this case is manifested as a problem of communication.

B. Inadequacy to Address Human-Centric Needs

Another category of limitations arises from the local/global interaction because the current automotive CPS largely ignores a defining feature of the HM-CPS: embedded humans. Embedded humans in the CPS are important because they are the primary consumer for traditional transportation infrastructure information, such as travel times and route navigation. They will also trigger the development of a new breed of mobility services which have previously been outside the domain of the automotive CPS.

Following a trend similar to that found in the mobile phone, context aware location-based services will play an increasingly important role in the HM-CPS. The information which ultimately creates the demand for trips will need to be more closely integrated with the vehicle to address the human-centric mobility needs. Ultimately, embedded humans perform three tasks: (i) they can sense, (ii) decide, and (iii) assess. A poorly designed CPS will require the human to actively participate in information acquisition instead of allowing the system to automatically integrate sensed information into the infrastructure. Instead of requiring the user to integrate driving directions and historic traffic patterns collected from experience, a human-centric system should leverage infrastructure to gather information, leaving the embedded human free to make higher level decisions such as preference for the fastest route or the shortest route.

The most important aspect of the impact of human-centric needs with respect to the automotive CPS is that embedded humans make the overall assessment of how well the system performs. This creates new challenges because humans are exposed to a wide variety of human-centric systems with which the automotive CPS must compete. As new human-centric features appear in other CPSs ranging from mass transit to mobile devices such as cell phones, the utility of the automotive CPS will depend on its ability to adapt and integrate similar features.

C. Pace of Adaptation

As the automobile CPS is forced to interact with other cyber infrastructure systems for data collection and to address human-centric needs, the rate at which it integrates new technology will become critical to its utility. This poses a significant problem because the automotive CPS inherently moves at three timescales.

Changes in the transportation infrastructure may take decades to become fully implemented. Vehicle scale changes may take years. The virtual infrastructure, led by high tech innovation, evolves on Internet timescales of a few months. The automotive CPS simply moves too slow to evolve with cutting edge products and services in an integrated way. The rapid changes of the virtual infrastructure makes it very difficult for the physical components of vehicles to even integrate themselves at a fundamental level. As communication protocols and ports change, in-vehicle infrastructure runs the risk of almost immediate obsolescence. This problem cannot be ignored: the embedded human which generates the need for mobility is also driving the need for integration with the virtual infrastructure.

Research Challenges

A. Openness

The constraints of the existing automotive CPS suggest that it must be opened to access the surrounding environment, both physical and virtual (cyber). The availability of new data sources will enable the automobile to better navigate the surrounding environment, as well as provide a higher quality commuter experience. When the system is opened, it will force it to directly confront the need to remain dynamic and relevant in the human mobility CPS.

Designing a platform with an open architecture for automobiles will not be easy. The design must be sufficiently flexible to meet the demands both today and decades from now. The key will be to create a platform with which hardware and software are upgradable and replaceable. Interfaces can be built to collect and interact with the vehicle's infrastructure, while leaving core CPS components to be developed through aftermarket devices.

Determining how to verify the safety of applications developed on an open platform presents additional barriers beyond the simple transition to an open platform. In the phone industry, Apple has attempted to walk this delicate line by providing a publicly available software development kit for the i-Phone, but all applications must be approved by Apple before they can be widely distributed. Others, such as the Nokia Maemo platform and the Google Android platform provide less centralized control, because such a structure provides more freedom for the open source communities to create innovative products. The ongoing move to open devices in the mobile phone industry should be viewed as an early indicator of how an open platform increases the functionality of the product, and a similar leap could be expected for the automotive CPS.

B. Data Processing and Analysis

One advantage the automobile has over other technologies such as the phone is that it can be used to enable a powerful and energy demanding sensing platform that physically moves one through the infrastructure. Although automobile location based applications and services have not yet become mainstream, the vast amount of useful data which could be collected from the vehicle is encouraging for their development. This data becomes even more rich when it is put in context with other geo-referenced databases obtained online or from other infrastructure systems. Even vehicle specific data may begin to serve expanded functions when integrated with other services on computers and mobile devices. It would not be difficult to imagine a future mapping service which recognizes your vehicle has insufficient fuel to arrive at your destination to automatically route you to the cheapest gas station. Other potential applications might range from new forms social networking to environmental quality sensing. The challenge of such cyber-information systems is the transmission, processing, and analysis of the data. The quality and volume of the potential data sources is phenomenal. Because of the mobile aspect of the vehicle, most communications with the vehicle and the virtual environment will need to be made wirelessly.



Fig. 1. The Nokia N95 mobile device is used to collect and transmit anonymous speed and position data when on-board vehicles. The height of the columns correspond to the speed of a vehicle equipped with an N95 on I-80 near Berkeley, CA.

The Federal Communications Commission (FCC) has dedicated a portion of the wireless spectrum for this communication, but there has not been sufficient momentum to develop standards which are meaningful outside the immediate context of the vehicle. The Dedicated Short Range Communication (DSRC) standard is problematic because the lack of usage of this technology outside the domain of the vehicle limits connectivity with the vast majority of devices in the virtual infrastructure. One of the biggest research opportunities in this field will be to create large scale distributed CPS models to assimilate the data into useful information. Human mobility modeling is at its infancy, and fundamental questions still exist such as (i) the correct characterization of human mobility at local and global scales; (ii) multi-modal trip modeling; and (iii) transportation in urban networks. The current state of our knowledge still leaves open the debate over the correct model to understand automobile traffic on highways, which is an area which has received a significant amount of attention in the transportation modeling community. Clearly, a new class of models and abstractions will be necessary to interpret the vast amount of data generated by an open automotive CPS correctly and efficiently in the context of human mobility.

C. Privacy

The openness of a networked automotive CPS, and large volumes of data coupled with an embedded human create opportunities for abuse. Specifically, geo-referenced data contains information which is particularly sensitive. Attacks on this data range from direct privacy intrusions such as being able to identify a speeding vehicle, to more sophisticated attacks such as inferences gained from trips taken. A non-direct trip from work to home may reveal personal affairs the driver wishes to remain private. Recent research has shown that simply anonymizing data is insufficient to prevent privacy intrusion.

Worse yet, economic incentives exist for companies (insurance, for example) who can successfully infer information from the data streams collected. The data collected from a HM-CPS could potentially be as sensitive as personal health records, since many health related exposure risks may be determined from location based information. Determining how to structure data collection and communication in a privacy preserving environment is an area of research that must be developed quickly to enable a functioning human-centric CPS. Ultimately, the success of the HM-CPS system depends on it, since the human-in-the-loop will otherwise make choices to avoid these types of services all together.

Promising Innovations

On February 8, 2008, we successfully demonstrated a new technology for highway monitoring: GPS equipped mobile phones (Fig 1.) The Mobile Century experiment, (covered in the previous two articles), is still in the early stages of research, but this project highlights the value of location based information in a privacy-by-design architecture, while emphasizing the impact of advanced mobility modeling. As the CPS continues to advance and leverage technologies from other industries, the potential for new promising innovations is great.

Daniel Work and Alexandre Bayen's Biographies are listed in the previous article.

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