ATLIS JV LLC
Telesaurus VPC LLC
AMTS Consortium LLC
Telesaurus Holdings LLC
Skybridge Spectrum Foundation
Intelligent Transportation Wireless LLC

www.telesaurus.com
www.tetra-us.us

Advanced Transportation Location & Information Service • ATLIS • Berkeley CA

Ex parte presentations December 28, 2007

Marlene Dortch
FCC, Office of Secretary
445 12th Street, SW
Washington, DC 20054

Re: WT 06-49, LMS-M NPRM: Report of ex parte meetings.[1]

On December 13, 2007 Warren Havens of Telesaurus Holdings GB LLC ("Telesaurus") (and the other companies listed above) met with Julius Knapp and others with the Office of Engineering and Technology, and Fred Campbell and others with the Wireless Telecommunications Bureau.[2]

On December 17, Mr. Havens had meetings with Wayne Leighton of Commissioner Tate's office, Bruce Gottlieb of Commissioner Copps's office, Angela Giancarlo of Commissioner McDowell's office, and Renee Crittendon of Commissioner Adelstein's office.

In each of these meetings, Mr. Havens passed out and discussed the memo attached below including the letters from the California Center for Innovative Technologies (CCIT) at the University of California, Lyrtech, and ITS California. Mr. Havens also noted the expected presentation by Professor Raja Sengupta of the University of California, who is the Principal Investigator of the Telesaurus-CCIT research program, which was filed on ECFS in this docket on December 20, 2007.

Respectfully,
/s/
Warren Havens
President, Telesaurus Holdings GB LLC
and its affiliates listed above
2649 Benvenue Ave., #2-6
Berkeley, CA 94704
(510) 841 2220

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[1] Due to the year-end holiday-period travel, Telesaurus was not able to file this report until now. While it is not clear that this report is required, since it "presents data or arguments . . . already reflected in that person's written comments, memoranda or other filings in [the] . . . proceeding," reports of which are not required (see §1.1206 (b)(2)), this report is being filed since it adds additional details, emphases, and documentary support to Telesaurus's already filed data and arguments.

[2] Mr. Havens requested a meeting with Mr. Knapp and Mr. Campbell, which their offices arranged. They arranged for others to also attend the meeting.

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Ex Parte Meeting Presentations to FCC staff,
December 13 and 17, 2007

Herein, the above entities are together called "Telesaurus ATLIS."

Telesaurus ATLIS holds the most spectrum (MHz Pops), and most effective spectrum (900/200 MHz for urban/ rural) in the US for wide-area ITS wireless (including more than Progeny). This has taken numerous spectrum auctions, purchases and donations from 1999 to this end of 2007.

Main Points

1. LMS Multilateration location *clearly required* for US ITS. US experts (including the Telesaurus ATLIS - CCIT [University of California] project's Principal Investigator, Dr. Raja Sengupta)[3] explain need to augment GPS (even GPS at year 2005) with terrestrial multilateration for critical ITS nationwide. EU nations find likewise for Galileo GNSS. See Attachment 4 below; also Attachment 2.

2. Full ITS wireless architecture & plan: ATLIS. Telesaurus ATLIS plans ITS "Virtual Track Transport," and ITS "Vehicle-Grid-Vehicle" ("VGV"): (i) tracking all vehicles, all places, all times, with consistent high (sub-1-meter) accuracy, and related two-way and one-way ITS data, using LMS-M, LMS-N, DSRC and supporting 200 MHz.[4] Extends to VGV: integration of road transport & electric grid. See Telesaurus website, Attachments 5 and 6 below; also Attachment 2.

3. ATLIS tech & testbed being pursued. SDR-based: (i) wide-area pseudolites, (ii) TETRA 1 and 2, (iii) MIMO, etc. Vehicles are perfect platform for efficient, high-performance *software-based* mobile terminals. The TETRA legal block in US largely solved. See www.tetra.us-us, p. 2. Testbed 1 year after NPRM resolved. See also point 11 below, and Attachment 3 below.

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[3] Dr. Sengupta's background in ITS, vehicle location, DSRC and other relevant wireless to ATLIS is described at: http://www.ce.berkeley.edu/trans/Sengupta/. CCIT is described at: www.calccit.org. The CCIT letter, Attachment 2, below gives additional information.

[4] See attached Telesaurus ATLIS depiction & chart in Attachments 5 and 6, and the annotated Toyota study (one of the "Other" attachments).

4. ATLIS benefits & costs: major study. Telesaurus and CCIT (under the year 2008, 2nd year of their sponsored research contract: see Attachment 2 below), and ESRI,[5] (and possibly others) to conduct in-depth study of the major benefits to the US economy and quality of life and environment-- including reduction in accidents, congestion, pollution, fuel consumption, and loss of time-- of implementation of ATLIS (under Telesaurus' plan but independent also), along with Costs. For public release, target is mid 2008. *Scores of billions of dollars annually in savings are expected in direct economic benefits alone, but it must be carefully modeled.*

Land transportation is the largest man-made enterprise and infrastructure, and has the most impact the natural environment: it needs an integrated dedicated radio service. Wide-area LMS is central in this. Development and implementation should be a private-public-nonprofit endeavor. That is what Telesaurus ATLIS is pursuing, and has been for years, now with a growing group of experts in these fields and enabling technology and services as reflected herein.

5. Resolve NPRM by ancillary flexibility. Presented by Telesaurus in preceding FCC meeting. Simple § 90.353 (g) change: preserve ITS requirement, but ancillary flexibility. Presented again as Attachment 1 below.

6. US can lead in ITS wireless, based on LMS-M&N + DSRC-- *Credit FCC*. EU, US, Japan, others all have DSRC. Among leading nations in transportation, only US has a wide-area ITS band (LMS, - M and –N) and short-range DSRC. The FCC should be credited for that and fully maintain its commitment. (Telesaurus ATLIS also has 200 MHz nationwide, essential for rural areas.) In addition, the US is world leader in GIS, SDR, and IP technologies needed for integrated ITS wireless (which we call ATLIS). Together, these form the basis of US leadership in ITS wireless, which is the foundation for ITS. *Leadership in ITS will major benefits in international trade, public-interest leadership, and relations.* ITS is a major growing need internationally.[6]

7. Progeny & Part 15. The 1995 LMS Order establishing the service and current rules was *entirely well reasoned and visionary*, and current technologies and expanding ITS need and growth make it even better: one of the best Commission decisions.

Neither Progeny nor the (non-entity) Part 15 Coalition refute any of the Telesaurus arguments on the critical ITS needs that LMS-M can and should fulfill, just as the Commission wrote in the LMS Order.

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[5] Based on meetings to date, by: Skybridge Spectrum foundation, CCIT, ESRI Foundation, and others to be named in press release, early 2008. ITS wireless + dynamic ITS GIS are core enabling technologies.

[6] Telesaurus attended the 2007 ITS World Congress in Beijing and the 2006 WC in London, to learn first-hand of ITS developments worldwide, especially ITS wireless, and to present the Telesaurus (and Telesaurus-CCIT) plans.

The Progeny and Part 15 arguments are have no basis in current reality or advanced technology: each are trying to divert the needed ITS radio service and spectrum.

Unlike Telesaurus-ATLIS and current FCC rules, neither has presented any plan for use of, and each would waste, 99% of the LMS-M spectrum in the nation.

The public interest of ITS far exceeds that of yet another "flexible" wireless service, or of unlicensed device uses (which have hundreds of MHz available, and in any case, are mostly indoors, otherwise very local, and mostly nominal time of use. Millions of unlicensed radios still do not use much spectrum in time and space: see the Shared Spectrum Company published NSF spectrum occupancy study cited by Telesaurus in preceding filings.)

Updates and Other Points

8. Presentations to five Congress persons on the NPRM and ITS wireless. Arranged by ITS America. Staff of Senators Boxer and Feinstein, Representatives Lee, and others in the ITS Caucus.

9. LMS-M & 200 MHz assignments to SSF. These support planned core-ITS wireless for public safety and efficiency. Such services will be at no profit, and all *core multilateration and the broadcast services at no charge (like GPS and public radio)*: good citizen and best business.

Since last JV presentations, THL's disaggregation assignments to SSF of 2 MHz in all its LMS-M licenses was granted. Also, TVL and Warren Havens made and the FCC granted assignments of over one hundred fifty EA and EAG 220 MHz licenses to SSF. Further, ACL, TVL, and ITL plan to complete assignments of substantial portions of their AMTS licenses to SSF in the near future. Other spectrum assignments of the JV entities to SSF are intended.

10. Further authority, ITS-California, supports no rule changes. ITS California filed a letter opposing rule changes in the docket on October 12, 2007. California is most in need and most active of ITS, and is home to strongest collection of needed tech companies and nonprofit entities. The ITS-CA letter follows similar letters from ITS America and CCIT in this NPRM. Based in California, Telesaurus ATLIS is a member of ITS CA. Included here as Attachment 7.

11. ITS SDR best tech solution, underway. Spectrum Skybridge Foundation joined the SDR Forum this month, and agreed to work with the CEO and other members to set up a ITS interest group, work toward standards for ITS SDR, etc. See attachment to be filed with the report of this ex parte meeting for a description of the planned work.

See also Attachment 3: a letter from Lyrtech: a SDR company based in Quebec with current SDR development platforms for 200 to 928 MHz, which can accommodate the Telesaurus ATLIS spectrum and the protocol stacks needed for the planned ATLIS services,

including for pseudolites + GPS, TETRA Releases 1 and 2 for two-way and broadcast data, and DSRC.

In addition, the many reasons that SDR is the best, excellent solution for US wide-area ITS, as under the ATLIS plan, is described in the various reports on the nationwide "Finnish Software Radio Programme" ("FSRP").[7] An annotated copy will be attached to with the report of this ex parte meeting. This FSRP encompasses, as does ATLIS: multiple bands, multiple protocols, vehicle-installed radios, secure IP communications end to end, wide-area coverage from base stations, and terrestrial multilateration location to be used with, or independent of, GPS (GPS or Galileo or other GNSS).

Attachments

1. Proposed rule change, for ancillary flexibility. (Previously submitted.)

2. Letter from University of California CCIT, re Telesaurus-CCIT research contract: Principal Investigator, project to date, next phase tasks, etc.

3. Letter from SDR company Lyrtech (SDR 200 to 928 MHz platform, etc.).

4. DOT-RITA sponsored workshop report on need for terrestrial augmentation of GPS for critical US transportation (ITS) applications: with attached presentation by Dr. Raja Sengupta, Principal Investigator of CCIT-Telesaurus project.

   [Post meeting note: This item is attached in full to the letter filed in this docket on December 20, 2007, by Professor Raja Sengupta on behalf of Telesaurus and CCIT.]

5. ATLIS network architecture depiction and characteristics.

6. ATLIS spectrum bands: LMS sub-bands: uses, conditions, etc.

7. Letter from ITS California in this NPRM: in support of no rule changes.

Others: As noted above, to be provided with the report of this ex parte meeting.

[Post meeting note: Such "other" items will be filed in subsequent presentations.]

[7] Telesaurus and CCIT met with the Finland-based company currently implementing FSRP this past November to discuss possible assistance under contract to the ATLIS program. This is under mutual nondisclosure. Information may be made public later.

Attachment 1

(Same as filed with the Telesaurus report of Ex Parte meeting of 8.10.07.)

Proposed rule change. Section 90.353 (g):

Existing:

(g) Multilateration LMS systems whose primary operations involve the provision of vehicle location services, may provide non-vehicular location services.

Proposed change (underlining added; footnotes proposed as part of rule):

(g) Multilateration LMS systems whose primary operations involve the provision of vehicle location (or location and communication) service~~s~~, may provide non-vehicular ~~location~~ service~~s~~ on an ancillary basis as follows:

(1) ITS-Exclusive Ancillary Service. If the ancillary service is exclusively in support of Intelligent Transportation Systems or transportation infrastructure, then the licensee must submit on ULS a certification and showing, using Form 601, under the license or licenses involved. The application must describe all existing and planned primary services and the proposed ancillary service. The application must demonstrate that the proposed ancillary service will be exclusively in support of Intelligent Transportation Systems or transportation infrastructure. Said ancillary service may be provided prior to, as well as after, construction and commencement of operation of the primary service.

(2) Other Ancillary Service.

(A) General. If a licensee seeks to provide ancillary service other than for "ITS-Exclusive Ancillary Service" under subsection (g)(1) immediately above, then the licensee must submit on ULS an application, using Form 601, seeking amendment of the subject license or licenses. The application will be placed on public notice and subject to petitions to deny under 47 USC §309 (d). The application must describe all existing and planned primary services and the proposed ancillary service. The application must demonstrate that the proposed ancillary service will either substantially augment, or at minimum will not substantially diminish, the primary services by the time of and at all times after the second, ten-year construction deadline (and any extensions thereto) of the license(s) involved. Said ancillary service may be provided prior to, as well as after, construction and commencement of operation of the primary service.

(B) Flexible Ancillary Service. If the proposed ancillary service will not substantially augment the primary services, then either: (i) the application must further demonstrate that the proposed ancillary service will pose no more interference to existing systems of Part 15 devices than the proposed primary services in the same area, under the standards explained by the Commission in paragraph 69 of FCC 97-305,[8] or (ii) in lieu of the preceding demonstration regarding Part 15 devices, the

[8] In the Matter of Amendment of Part 90 of the Commission's Rules to Adopt Regulations for Automatic Vehicle Monitoring Systems, PR Docket No. 93-61, *Memorandum Opinion and Order*, released September 16, 1997.

applicant may, in the application, elect the following "safe harbor" technical limitations for the proposed ancillary service which shall be deemed to satisfy the purposes of said demonstration: [describe: see filing text above: [Telesaurus has no recommendation at this time, mostly since it does not seek the sort of flexible ancillary service under this paragraph. Telesaurus notes that the NPRM suggested technical limitations, as did at various points Progeny and the Part 15 Coalition.]

(3) Classes of Ancillary Services. The proposed ancillary services under subsections (g)(1) or (g)(2) above may include the following classes of service: common carrier or non common carrier services; private or commercial mobile radio services; land, maritime, or aeronautical services; as well as fixed wireless services. The application must provide a sufficient description of each the proposed ancillary service to demonstrate each such classification.

Attachment 2

December 12th, 2007

Subject: Status of Telesaurus-sponsored research at the California Center for Innovative Transportation

To Whom It May Concern:

It is my pleasure to write this letter and present the current status of engineering and economic studies conducted by the California Center for Innovative Transportation (CCIT) in the area of wide-area wireless services for Intelligent Transportation Systems (ITS), under sponsorship from Telesaurus, LLC. CCIT was founded jointly by the University of California, Berkeley and the California Department of Transportation. Its mission is to accelerate the implementation of research results and the deployment of technical innovations by transportation practitioners.

CCIT has been under contract with Telesaurus since April, 2007. Academic guidance is provided by UC Berkeley's Civil and Environmental Engineering Professor Raja Sengupta, whose research focus in on control theory and systems engineering applied to large-scale information technology architectures. As CCIT's Associate Director, I oversee CCIT's technical activities and supervise its engineering team, including on our Telesaurus-sponsored projects.

Our investigations to date have covered the following topics:

- A taxonomy of network services and applications that could be offered by a wide-area wireless network for ITS;
- An overview of existing and planned wireless services that provide vehicular applications;
- A technical review of design options for the provision of three core services: broadcast, two-way communications, and Position, Navigation, Timing (PNT) signals.

An overview of those investigations was presented at the 14th World Congress on Intelligent Transportation Systems in Beijing last October. CCIT and Telesaurus are currently finalizing the details of a second set of investigations that will focus on the potential economic benefits of wide-area wireless services for ITS and establish deployment priorities.

Pr. Sengupta is a recognized expert in the areas of transportation systems, wireless networking and vehicle navigation. He has led multi-million dollar research efforts for state and federal agencies, and is participating in the national Vehicle-Infrastructure Integration research program. Pr. Sengupta has also received funding from General Motors to investigate vehicle-to-vehicle connectivity concepts.

In Pr. Sengupta's opinion, the prospect of providing PNT services from terrestrial pseudolites to supplement GPS carries considerable interest. The availability of reliable, high-precision location capabilities can enable a host of applications, in the transportation industry as well as in other sectors of the economy. In the next few months, Pr. Sengupta intends to set a research agenda to

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explore this concept further. Pr. Kannan Ramchandran, a Professor in the Department of Electric Engineering at UC Berkeley and a faculty member of the Berkeley Wireless Group, has also expressed his desire to be associated to that effort.

Lastly, Telesaurus and CCIT have jointly approached several companies that may have a role to play in either the design or the implementation of a wide-area wireless network for ITS. Those include ESRI, a leading company in the Geographical Information Systems sector who has shown significant interest, as well as Lyrtech and Elektrobit, both wireless components design firms.

I hope that the information provided above is an adequate description of the nature of the work conducted by CCIT with sponsorship from Telesaurus, and that, in turn, this sets a clear picture of what that sponsor is trying to accomplish. I cordially invite you to contact me with any questions you may have about it.

Sincerely,

J.D. Margulici, Associate Director

University of California Berkeley
2105 Bancroft Way, Suite 300
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Phone: (510) 642-4522
Fax: (510) 642-0910
http://www.calccit.org

Attachment 3

November 29th, 2007

To whom it may concern,

Commencing this year, I and others at Lytech have discussed with Warren Havens, with Telesaurus LLCs and Skybridge Spectrum Foundation ("Telesaurus/Skybridge"), the matters indicated in this letter including certain plans of Telesaurus/ Skybridge, some of which are generally public. As described on the Telesaurus public website (www.telesaurus.com), I understand that Telesaurus/Skybridge is pursuing development of certain nationwide wide-area location and communication networks for vehicles, to provide Intelligent Transportation System applications, based on the FCC licenses they hold in the lower 200 MHz and lower 900 MHz ranges, including "Location and Monitoring Service - Multilateration" licenses.

Lyrtech is a leader in the worldwide digital signal processing (DSP) market with more than 20 years of experience in the delivery of advanced technology solutions in Asia, Europe and the Americas. Lyrtech is a one-stop provider place for electronic design, prototyping, manufacturing and delivery of a full range of value-added products and services, which range from off-the-shelf DSP/FPGA development platforms to turnkey project solutions and electronic manufacturing services (EMS). The company works in partnership with industry leaders such as Texas Instruments, The MathWorks, and Xilinx. Lyrtech delivers unsurpassed quality and support to its large OEMs customer base, which includes many prestigious names such as Nokia, Nortel, Fujitsu, Sony, GM, Honeywell, Toyota, Honda, BAE Systems and EADS.

Lyrtech launched, in collaboration with Xilinx and Texas Instruments, the Small Form Factor (SFF) Software Defined Radio (SDR) Development Platform at the 2006 edition of the SDR Forum Technical Conference, an event that provides an international perspective on the current state of development of software-defined radio. Lyrtech is member of the Software Defined Radio Forum and a gold sponsor of the SDR Forum's Smart Radio Challenge, a competition where universities and research centers from all over the world will work to solve critical SDR problems.

Lyrtech Small Form Factor (SFF) Software Defined Radio (SDR) Development Platform

Lyrtech SFF SDR Development Platform is capable of supporting two-way wireless operations from 200 MHz to 928 MHz range, and can accommodate software for TETRA (release 1, and release 2 once that is commercially available), as described in the product literature available on the following web site :
http://www.lyrtech.com/DSP-development/dsp_fpga/sffsdrdevelopmentplatform.php

Lyrtech implemented Software Communication Architecture (SCA) on the SFF SDR Development Platform. The SCA implementation integrates technologies from Lyrtech, Communications Research Centre Canada (CRC), Objective Interface Systems (OIS), and Green Hills Software into a seamless package. Lyrtech has commenced review with Etherstack with regard to use of Etherstack's TETRA software protocol stack on the SFF SDR Development Platform and SFF SCA Development Platform.

Lyrtech has also provided SDR-based products for wireless location-based testing and applications. Lyrtech board was used by Los Alamos National Laboratory to detect any nuclear tests that may occur based on several sensing methods and Angle Detection of Arrival algorithms. Lyrtech boards have also been used for an Angle Detection of Arrival project as part of Japan's 4G Wireless HAPS (High Atmosphere Platform System) in wich prime Japan research labs (NICT, NASA, TAO, Matshushita, and SkyTower) were involved.

Japan's 4G Wireless HAPS Project

Vehicle-installed radio terminals that Telesaurus-Skybridge need for their ITS wireless applications can take advantage of the major advantages of SDR, more so than handheld terminals, since vehicle-installed radios do not have the serious limitations as to power, size, and weight that handheld radios have. SDR is an excellent and cost effective solution using current technology and manufacturing processes. In a growing number of cases, as in the Telesaurus-Skybridge case, the terminals (1) are vehicle installed, (2) use multiple distinct frequency bands, (3) employ multiple protocols, (4) will be upgraded during the life of the terminals (such as upgrades to TETRA Release 2 functions that Telesaurus plans), (5) will involve dynamic allocation/ re-allocation of spectrum during the day, and

other periods of time, between base stations in a wide-area wireless network, (6) allow for over-the-air programming/ re-programming, including for user authorization, blocking, special security functions, preemption in emergency by public safety entities, and various other advanced, flexible features.

Thanks to its significant utility for the military and commercial providers, both of which must serve a wide variety of changing radio protocols in real time, Lyrtech expect SDR to become the dominant technology in radio communications. We are already involved in SDR-based product design for partner companies, and are confident that technologies now reached a stage where commercial viability is possible for SDR-based products such as Telesaurus-Skybridge ITS systems.

Etienne Fiset

Etienne Fiset, MBA, Eng.
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Telesaurus marked.
Attached is one presentation at this event.

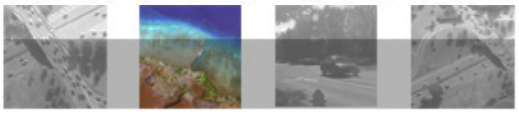
Attachment 4

Integration of PNT, remote sensing and transportation workshop

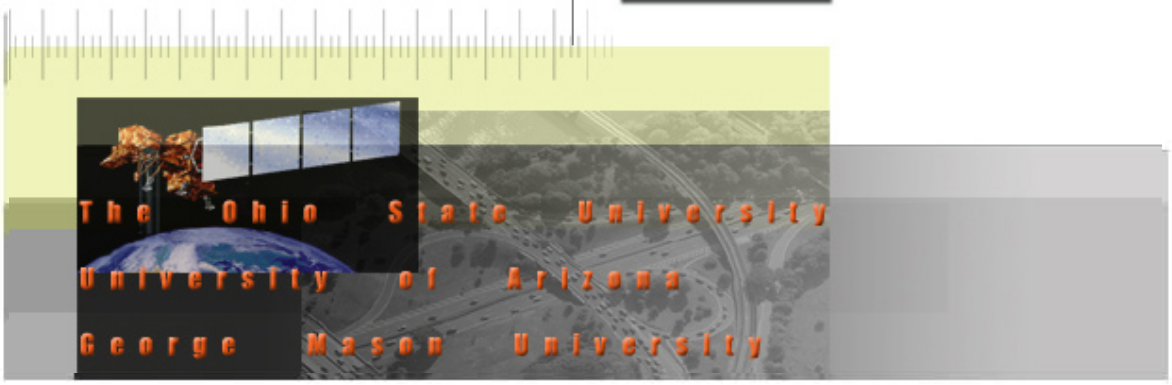
mark mccord, carolyn merry and prem goel

march 2006.

NCRST-F Workshop Report



NCRST-F
National Consortium on Remote Sensing in Transportation
Flows



Notations herein, including highlighting and underlining, are by the Telesaurus LLCs and Skybridge Spectrum Foundation. - W. Havens

Integration of PNT, RS, and Transportation Workshop
Hosted by the U.S. DOT's
National Consortium on Remote Sensing in Transportation – Flows (NCRST-F)
Blackwell Hotel, 2110 Tuttle Park Place
The Ohio State University, Columbus, Ohio
November 30, 2005 – December 1, 2005

Workshop Summary Report Prepared for:
Research and Innovative Technologies Administration (RITA)
U.S. Department of Transportation
Washington, DC

Introduction

Real-time operations and off-line planning in both the private and public transportation communities have already greatly benefited from the ability to locate vehicles and equipment with GPS (Global Positioning System) and other satellite-based systems. The value of these systems has also been increased by ground-based augmentation technologies that increase positional accuracy and extend the coverage to areas inaccessible to the satellite systems. Similarly, air- and space-based remote sensing has shown the potential to improve quality and safety and decrease costs in the transportation sector by assessing the status of infrastructure, traffic, and multiple environmental variables and hazardous conditions that impact the planning, construction, and operation of the multi-modal transportation system (see http://www.ncrst.org).

The U.S. GPS and parallel international space-based PNT (Positioning, Navigation, and Timing) systems are being modernized (see http://www.pnt.gov/), and more satellite-based radio-navigation systems are planned for the next 20 years. These systems include the European Galileo (see http://www.aatl.net/publications/galileo.htm; http://www.esa.int/esaNA/GGGMX650NDC_index_0.html) and Japanese Quasi-Zenith Satellite System, QZSS (see http://staff.aist.go.jp/f.tappero/research/research/ressox.html). It would appear that transportation applications could be developed or improved in the future by integrating space-based PNT systems, ground-based augmentation systems, and air- and space-based remote sensing systems.

Because of the potential benefits to transportation applications, the National Consortium for Remote Sensing in Transportation-Flows (NCRST-F) at The Ohio State University was asked by the Research and Innovative Technologies Administration (RITA) of the U.S. Department of Transportation to organize a focused workshop of invited academic and industry leaders in transportation systems and in GPS-PNT technologies. This was to

be the first in a series of three workshops seeking to develop a Year 2025 Vision for the applications of space-based technologies for improved Safety and Security, Mobility, Environmental Stewardship, and Global Connectivity of multimodal transportation systems in the U.S. and around the world.

This first workshop was to focus on improving and creating transportation applications through the integration of remote sensing (RS), space-based PNT technologies, and ground-based augmentation systems that could improve positional accuracy and extend coverage to areas that would otherwise be hindered by line-of-sight considerations. A second workshop, hosted by the National Consortium for Remote Sensing in Transportation – Infrastructure (NCRST-I) is expected to be held in Santa Barbara, CA, in May 2006. This second workshop is to be devoted to the integration of Geographic Information Systems, Remote Sensing, and Transportation. A third workshop will follow in Washington, D.C., for federal administrators.

The Integration of PNT, RS, and Transportation Workshop was held on 30 November-1 December 2005, on the campus of The Ohio State University, in Columbus, Ohio. The workshop concluded with a set of transportation applications that would benefit from aggressive augmentations to anticipated satellite-based PNT systems. This document serves as the summary report after 1-1/2 days of workshop discussions and suggestions for areas of focus in the future workshops.

Modernization and Augmentation of Global Navigation Satellite Systems (GNSS)

The plans to modernize and augment satellite-based PNT systems are briefly discussed before presenting the format, findings, and conclusions of the workshop.

Many civilian applications have already benefited from the ability of GPS and other Global Navigation Satellite Systems (GNSS) to provide accurate locations on the Earth. A description of the basics of GPS can be found in a standard text, such as Bossler (2002) or Wolf and Ghilani (2005). The first group of (11) GPS satellites formed the Block I constellation; these experimental satellites were launched between 1978 and 1985. The second group of GPS satellites formed the Block II and Block IIA constellation; these operational satellites were launched from 1989 to 1997 to produce a total of 24 Block II/IIA satellites. There are also 18 Block IIR replenishment satellites; the first was launched in July 1997, with the last Block IIR satellite launched in 2005. Twelve of these satellites – Block IIR-M – are being redesigned as part of the GPS Modernization Program. The first launch of the Block IIR-M satellite took place in September 2005.

Each GPS satellite transmits two navigational L-band frequency signals (L1 at 1575.42 MHz and L2 at 1227.60 MHz). The current plan to modernize GPS is focused on improving the quality of civilian uses of GPS, primarily through the implementation of a new L2C code on the L2 frequency and a new civilian signal on the L5 frequency of 1176.45 MHz (Spilker and Van Direndonck, 2001). In addition, under the GPS modernization program, a new encrypted M-code will be implemented exclusively for

military use, ensuring that military and civilian users will have entirely separate signals and codes. Consequently, the anti-spoofing (AS) policy will be abandoned. (Selective availability – SA – has already been turned off.) The new dual-frequency civilian tracking capability is available on the Block IIR-M GPS satellites.

The GPS Block IIF satellites represent the next generation GPS system. These satellites are presently in the design phase, with the first launch planned for 2007. The Block IIF satellites will meet both military and civil customer requirements. Among other features, the GPS Block IIF spacecraft will feature an extended design life of up to 15 years, a modular design, 3-m spherical error probable (CEP), options for the L5 civilian signals, increased autonomy from the ground segment, and rapid on-orbit re-programmability (see http://www.deagel.com/pandora/?p=pm00371004). Hardware miniaturization, further development of software receivers, improvements in reliability, faster sampling rates, lower noise and more multipath resistance, more real-time operations and a ubiquitous dual-frequency measurement capability are also expected (Rizos, 2002).

Other GNSS that are complementary to GPS are the Russian GLONASS system (see http://www.spaceandtech.com/spacedata/constellations/glonass_consum.shtml), originally developed for the Russian military, the European Galileo system (civilian), which is expected to become fully operational in 2008 (see http://europa.eu.int/comm/dgs/energy_transport/galileo/index_en.htm), and the upcoming Japanese Quasi-Zenith Satellite System, QZSS (see http://staff.aist.go.jp/f.tappero/research/research/ressox.html). GLONASS became operational with a full 24-satellite constellation in 1996. However, as of 26 January 2006, there were only 12 operational satellites. The most recent satellite launch was 26 December 2005, when three new GLONASS satellites were placed in orbit, but the GLONASS system long-term stability is questionable. Nevertheless, GPS/GLONASS receivers, which take advantage of the extended constellation created by the additional satellites in view, have been developed. More information on GLONASS, Galileo and QZSS can be found in *GPS World* and *Galileo's World* (see http://www.gpsworld.com/gpsworld/).

In addition to determining positions directly from GNSS, there has been a great deal of work devoted to augmenting these GNSS to further extend their operational capabilities to environments where satellite-based-navigation is difficult or impossible. The augmentations can be considered to fall into two main categories – space-based and ground-based augmentation. Each augmentation type includes reference ground-based stations. The "space-based augmentation" term means that the communication of differential corrections to the user is done via geostationary telecommunication satellites, whereas, the "ground-based augmentation" uses Internet, radio beacon or a cellular phone connection to communicate differential corrections to the user.

In what is considered space-based augmentation, differential correction signals are provided from additional satellites to improve the accuracy of a position on the earth. The U.S. government provides for two space-based GPS augmentation systems. The Coast Guard operates the Differential GPS (DGPS) for surface users; technically, this service

broadcasts correction signals on marine radio beacon frequencies, so it is ground-based augmentation. The Federal Aviation Administration (FAA) operates the Wide Area Augmentation System (WAAS) for many users, although the primary users are from the aviation sector. As part of WAAS, there are several geostationary satellites in the satellite-based component that transmit GPS differential corrections to users and the provision for a ranging capability to improve the availability, reliability and integrity over the U.S. (see http://gps.faa.gov/Programs/WAAS/waas.htm). On the ground, 25 reference stations, 2 Wide-Area Master Stations, and 3 Ground Earth Stations (GES) uplink the GPS differential corrections and timing information to two geostationary satellites (see http://spacecom.grc.nasa.gov/icnsconf/docs/2005/05-A3-Navigation_System_DO/A3-04-Beering.pdf). The specified accuracy of WAAS is 7.6 m 95% of the time, with the actual accuracy better than this. The reliability of WAAS is close to 100% and the integrity of the system, which is important for navigation purposes, is very high. The maritime DGPS service provides 10 m (2D RMS) navigation accuracy, integrity alarms for GPS and DGPS out-of-tolerance conditions within 10 seconds of detection, and coastal coverage to the continental United States, the Great Lakes, Puerto Rico/US Virgin Islands, and selected portions of Alaska and Hawaii (see http://www.navcen.uscg.gov/dgps/default.htm).

Examples of foreign space-based augmentation systems, which are similar to the US WAAS, include the European Geostationary Navigation Overlay Service (EGNOS) (http://www.esa.int/esaNA/GGG63950NDC_index_0.html), the Japanese Multi-Function Satellite-Based Augmentation System (MSAS) (http://dret.net/glossary/msas; http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=61200&&pageID=4), and the Indian GPS Aided Geo Augmented Navigation, GAGAN (http://gps.faa.gov/Library/Data/SatNav/SATNAV6.PDF; http://www.avweb.com/news/avionics/185185-1.html).

Precise point positioning (PPP) is a promising technique in GPS surveying, although not widely used yet. PPP is an absolute GPS positioning technique based on the carrier phase observables (in contrast to code range, used in DGPS) with all major error sources carefully modeled. For example, the errors in GPS broadcast ephemeris and clock corrections can be successfully reduced using the precise orbits and clocks provided by the International GNSS Service (IGS, see http://igscb.jpl.nasa.gov/). Accuracies of the final IGS orbits and clocks are better than 5 cm and 0.1 ns, respectively. Ionospheric corrections can also be obtained from the IGS or from local or regional CORS networks (discussed below).

The ground-based augmentation category consists of systems that are locally-based ground systems, rather than satellite systems. The National Geodetic Survey coordinates two networks of ground-based reference stations, called CORS (Continuously Operating Reference Stations) – the national network and the cooperative network (see www.ngs.noaa.gov/CORS/). The reference stations continuously log positional information at precisely known locations. The data from these CORS sites can serve as either a single reference for DGPS processing or can be considered as a reference network for the virtual reference station (VRS) approach. Access to CORS data online is

free. Access to VRS is inexpensive, but not free. For example, the Ohio Department of Transportation (ODOT) charges a low annual fee. VRS software/hardware is sold commercially, and agencies that install VRS, say state-wide, normally charge for the service. Ohio maintains a cooperative network that has a very dense network of CORS, ensuring a 45-km spacing between CORS stations. Ideally, users can perform very high precision positioning with a single GPS receiver using CORS data. With CORS the GPS carrier phase and code range measurements can provide positional accuracies that approach a few cm relative to the National Spatial Reference System.

Network-based real-time kinematic (RTK) GPS is a relatively new approach to accurate GPS positioning that is gaining popularity in a number of countries (see, for example, Vollath et al., 2000; Wanninger, 2002; Kashani et al., 2005; Grejner-Brzezinska et al., 2005). With network-based RTK, a network of permanent tracking stations – such as CORS – use GPS data to estimate ionospheric and tropospheric corrections in real time and broadcast the corrections to users via the Internet, beacons, or mobile phones. Users can obtain solutions in the field with centimeter- to decimeter-level accuracies.

An example approach to network-based RTK is the VRS system (which is commercially available) that uses observations from multiple reference stations to estimate the systematic errors in the data and creates a unique virtual reference station for each user's location. A synthetic data set (at the VRS location) is sent to the user located in the vicinity of VRS and is then used for a relative positioning solution. The systematic errors modeled include ionosphere, troposphere, satellite orbit, and multipath errors. Data are delivered to a stationary or a kinematic user in RTCM/CMR+ format.

Wide Area Differential GPS (WADGPS), also referred to as International Global Differential GPS (IGDG), is an example of Internet-based ground-based augmentation system provided by NASA JPL. This system is based on the NASA Global GPS Network (GGN) consisting of approximately 60 sites (see http://gipsy.jpl.nasa.gov/igdg/). IGDG is designed for dual-frequency users, and offers 10 cm horizontal and 20 cm vertical real-time positioning accuracy.

The use of pseudolites represents another approach to ground-based augmentation (see, for example, Bryant and Van Dierendonck, 1996; LeMaster and Rock, 1999; Stone and Powell, 1999; Dai et al., 2001a, b; Grejner-Brzezinska and Yi, 2003; Barnes et al., 2003a, b). Pseudolites are ground-based stations that transmit signals either similar to those transmitted by GPS satellites or on different frequencies (such as the license-free 2.4 GHz Industry Scientific and Medical (ISM) band) and increase the ability of satellite-based systems to operate in areas that would typically be "out-of-sight" of the satellites. Both pseudo-range and carrier phase measurements can be made on the pseudolite signals, making it possible to achieve the full range of GPS-like accuracy capability, but with extended coverage. Presently, troublesome areas include locations in downtown urban areas ("urban canyons"), where tall buildings obstruct the line of sight from the satellite to the receiver, and locations under dense foliage, in tunnels, and inside buildings, where the line-of-sight is similarly obstructed. GPS RTK, augmented by pseudolites, will be the trend for future applications that require PNT in real time.

The Local Area Augmentation System (LAAS), currently still under development, represents a supplement to WAAS that is aimed at improving aircraft safety during airport approaches and landings. LAAS is comprised of ground equipment and avionics. The ground equipment includes 4 reference receivers, a LAAS ground facility, and a VHF data broadcast transmitter. This ground equipment is complemented by LAAS avionics installed on the aircraft. LAAS will offer very precise guidance to aircraft, eventually providing guidance all the way to the runway surface, even when visibility is near zero (see http://gps.faa.gov/gpsbasics/index.htm).

A more extended discussion on modern trends in GNSS techniques and its augmentation and modernization can be found in Grejner-Brzezinska (in press) and Rizos (2005).

Workshop Format

As mentioned above, the intent of the workshop was to bring together a small group of individuals with expertise in PNT or transportation to discuss future transportation needs for advanced PNT technologies. The NCRST-F planning committee (Appendix A) had multiple contacts in both the PNT and transportation communities. The U.S. DOT sponsor provided additional names of experts, including U.S. DOT modal representatives. Individuals were personally called or e-mailed and invited to the workshop. Schedule conflicts precluded many of those contacted from attending the workshop. Individuals contacted and those attending the workshop are listed in Appendix B. Those who expressed a willingness to attend after initial contact were sent a formal letter of invitation by e-mail. An example letter appears in Appendix C.

A tentative program for the workshop was developed by the NCRST-F planning committee in consultation with the RITA sponsor. The workshop program was not finalized until the day before the workshop, after receiving final confirmation of invited speakers' attendance. A copy of the program, which was distributed to the participants upon arrival in Columbus or e-mailed to local participants not traveling the day before the workshop, appears in Appendix D.

The program of Appendix D was followed, except that the planned breakout and plenary sessions of the second morning were merged into one plenary discussion session, as described below, and time limits were not strictly followed. (For example, the breakout sessions on the first day continued until after 6 pm, effectively eliminating the planned "free time" slot.)

The workshop began with a discussion of the plans and logistics of the workshop by Professor Carolyn Merry, Director, NCRST-F. This was followed by a local welcome by Professor Doug Kniss, Senior Associate Vice-President for Research at The Ohio State University. Dr. K. Thirumalai, U.S. DOT-RITA, then presented a national welcome and set the stage for the workshop. He discussed the series of three anticipated workshops and

mentioned that this first workshop was to focus on integrating PNT, Remote Sensing, and Transportation.

Dr. Thirumalai then provided a vision for integrating PNT and transportation systems to achieve the following objectives**:**
http://www.cfm.ohio-state.edu/information/download/ThirumalaiTalk.pdf

> (1) Safety: Significantly reduce or eliminate fatalities and injuries in transportation systems, prevent potential incidents and minimize losses after an incident
>
> (2) Mobility: Develop landmark user services for significantly improving the mobility of transporting people and freight on land, sea, or in the air
>
> (3) Global Connectivity: Develop advanced technology capabilities to facilitate more efficient transportation flow, monitoring and management systems that can be managed from around the globe
>
> (4) Environmental Stewardship: Implement advanced technology based solutions to reduce the impact of transportation systems on the environment
>
> (5) Transportation Security: Provide technology tools and systems for cost effective monitoring and management of security without impairing mobility, and develop coordinated preparedness and intelligent and automated response to critical security issues

Mr. Steve Bayless, of U.S. DOT, then presented an overview of the future of PNT, covering planned extensions to GPS and other international efforts related to satellite-based PNT. His presentation is available at:
http://www.cfm.ohio-state.edu/information/download/GPS-PNTworkshop/BaylessTalk.pdf .

To plant the seed for the breakout sessions, several transportation experts followed with presentations of ongoing work in which they are using present PNT capabilities and speculated on what advanced PNT capabilities could contribute to their work. These presentations are available at:

http://www.cfm.ohio-state.edu/information/download/GPS-PNTworkshop/CoifmanTalk.pdf
http://www.cfm.ohio-state.edu/information/download/GPS-PNTworkshop/KuhneTalk.pdf
http://www.cfm.ohio-state.edu/information/download/GPS-PNTworkshop/MirchandaniTalk.pdf
http://www.cfm.ohio-state.edu/information/download/GPS-PNTworkshop/OzgunerTalk.pdf

http://www.cfm.ohio-state.edu/information/download/GPS-PNTworkshop/SenguptaTalk.pdf Attached at end.

Breakout sessions were held at the end of the first day. Prof. Prem Goel presented a charge to the breakout groups. The first day breakout sessions were intended to motivate the groups to think about transportation applications that could be achieved with advanced PNT. Specifically, the participants were asked to discuss transportation applications that are not possible with present capabilities, but which could be implemented with perfect knowledge of location in three-dimensional space along with time (*i.e.*, the (x,y,z,t) coordinates) of vehicles, passengers, or cargo. These discussions were to set the stage for the second day's discussions. Previously, the planning committee assigned the workshop attendees to one of two breakout groups. The assignments were made so that each group contained an approximately equal number of experts in PNT and in transportation. Based on knowledge of the attendees' specific expertise, the planning committee also tried to place individuals with similar areas of interest and expertise in different groups. A list of the breakout groups appears in Appendix E. Professors McCord and Mishalani led the breakout groups. (Professor Hickman was originally scheduled to lead one of the groups but could not attend the workshop because of flight complications.)

It was expected that the participants would briefly meet as a group in the morning of the second day to hear the charge for the planned breakout group discussions and to determine a common set of assumptions for the discussions. The charge, presented by Professors Mark McCord and Rabi Mishalani, was to identify transportation applications that only could be achieved with anticipated PNT capabilities consisting of GPS III, other satellite-based systems planned internationally, and a widespread ground-based PNT augmentation system(s). While trying to agree on the assumptions, it became clear that more progress could be made by identifying and discussing these applications in one plenary group, rather than in two breakout groups. The results of this session are presented in the following section.

Following the discussion that identified the applications, Professor Goel outlined the next step – namely, that the planning committee would write a report on the workshop and submit it to the RITA sponsor for input to the subsequent workshops. He also requested all participants to send in any comments within the following few days. Appreciation was extended to the participants for making the 1-1/2 days a successful workshop.

Transportation Applications

On the morning of the second day, the plenary group attempted to identify transportation applications that would appear feasible only if a widespread augmentation system was in place to complement the expected performance of GPS III and other international satellite-based positioning systems likely available by the year 2025. Professors McCord and Mishalani jointly moderated this plenary session. The workshop participants agreed on common assumptions to be made when identifying the applications in this "with-augmentation vs. without-augmentation" analysis.

For this exercise, it was decided that the year 2025 satellite-based PNT system would provide horizontal accuracy of 1.8 m and vertical accuracy of 3.2 m (with 95% probability) without augmentation and that the system would not be able to operate reliably in urban canyons, in tunnels, under foliage, or under overpasses. With augmentation systems, it was assumed that the accuracy would be 1 m everywhere, except in tunnels, which were still expected to pose problems for reliability, but that the accuracy could be increased to 1 cm where needed.

Several participants pointed out that many of the applications would only be feasible if sufficient advances in communications technologies and algorithms would occur. The participants were optimistic that such advances would be made, but applications that were determined to require such advances were noted.

Market penetration of location technologies was determined to be an important characteristic. The assumption was made that all commercial vehicles and public fleets (*e.g.*, transit vehicles, police and EMS vehicles, snow plows) would be equipped with advanced technologies that would allow their positions to be determined and available with the assumed accuracies. A "very high" proportion of private autos, but a "very low" proportion of individual travelers, was assumed to be equipped with such technologies and willing to share the location information.

It was decided to ignore institutional barriers, such as public willingness to have their vehicles tracked or liability issues. The goal was to determine technically feasible applications that appeared to have important transportation benefits.

The moderators suggested applications from the lists obtained in the previous day's breakout sessions, and the workshop participants either agreed or disagreed with each suggestion and, in some cases, revised them further. Other applications were suggested from the participants and discussed to determine if they appeared feasible with augmentation, but infeasible without augmentation. The applications were made without reference to transportation categories, but the workshop planning team later mapped the applications into the five objectives – Safety, Mobility, Global Connectivity, Environmental Stewardship, and Security – presented by Dr. Thirumalai during his presentation on the morning of the first day.

The resulting applications are listed in a summary table (Table 1) and briefly discussed below. The table indicates whether the workshop participants believed that increased accuracy or coverage would be required from the augmentation system and whether they believed that communications breakthroughs would be required for the application to be feasible. The table also indicates the transportation objectives the planning committee determined to be addressed by the application.

Cooperative Active Safety: This designation could be considered for all modes, but the participants considered its usual sense of automotive vehicles on roadways automatically communicating with each other to reduce the potential for accidents. This is an active area of research and development.
http://www.its.dot.gov/itsweb/press/cicaspresentation_files/frame.htm#slide0001.htm
http://www.calccit.org/itsdecision/serv_and_tech/Collision_avoidance/intersection.html

Work Zone Safety: Although this application could be considered a subset of the cooperative active safety application, the special needs of automatically communicating speed and lane keeping information to vehicles traveling through temporary obstructions and around workers motivated the participants to propose this as a separate application.

Reversible Lanes: Like work zone safety, this application might be considered a component of cooperative active safety. However, the major objective to keep vehicles traveling in the correct direction in reversible lanes motivated the participants to propose this separately. Although some reversible lanes could be located in downtown areas, where line of sight to the satellites is obstructed by tall buildings, the majority of the reversible lane applications would be expected to occur in more open areas. Therefore, augmented coverage was generally considered of less importance than the augmented accuracy required to correctly identify the lane in which a vehicle is traveling. Providing additional directional capacity in this way would also be valuable in decreasing delays and tailpipe emissions caused by recurring congestion and in improving the efficiency of non-recurring evacuations necessitated by natural or man-made disasters.

Traffic Control and Management: Knowing the positions and distances between successive vehicles as they approach intersections would allow more efficient operations of traffic signals, without the need for cameras or loop detectors on all approaches. Similarly, knowing the locations of vehicles entering a freeway, as well as the locations of vehicles on the freeway, would allow more efficient ramp metering, while reducing the need for local detector technologies. In addition, present detector technologies identify vehicles in only limited regions, whereas advanced vehicle location technologies would greatly expand the range in which the vehicles could be identified and increase the accuracy of their locations through time. It was believed that the 1.8 m accuracy considered to be available without augmentation would be sufficient, but augmentation would be needed to expand the areas in which vehicle locations would be used for traffic management. If vehicle monitoring is moved on-board the vehicle, tools that augment controls – *e.g.*, in-cab signals or simply telling drivers that a slower speed will put them at the intersection right at the start of the green – would be a likely future extension. More

efficient control of traffic signals and ramp meters would be beneficial in assisting in typical traffic management and in management required for emergency evacuations.

Traveler Information Systems: Knowing the locations and velocities of vehicles on multiple links of the roadway network would also be useful in determining the state of traffic conditions, which is a critical input to traveler information systems. Present surveillance systems suffer from limited spatial coverage of conditions. Again, these information systems would be valuable for both routine and emergency conditions.

Real-time Passenger Vehicle Dispatching: Demand-responsive public transit was mentioned in the context of transit applications. Taxi dispatching could similarly be improved by knowing where vehicles are located in real-time as passengers request service. Again, 1.8 m accuracy would appear sufficient, but augmentation would be required for increased coverage.

Automatic Transit Bus Location: Several applications related to automatic tracking of fixed route transit buses were mentioned: using present locations of buses to provide real time updates to passengers of when buses are expected to arrive at bus stops; determining for planning purposes whether buses are stopping at, before, or after the physical bus stop; determining for real-time operations and off-line planning purposes whether buses are arriving on time, early, or late at bus stops; and tracking passenger trips to allow the use of automatic fare cards that charge the passenger on the basis of distance traveled. The 1.8 m accuracy expected without augmentation would appear sufficient for these applications, but the ability to locate vehicles everywhere in the system would be important.

Facility Pricing: The ability to price facilities as a function of usage is seen as a possible means of improving system performance when faced with limited capacity. Presently, users must opt in to receive the benefits of special facilities, such as electronic toll collection. Under the assumption that a very large proportion of the private vehicle fleet will be able to be tracked almost everywhere, facility pricing could be extended so that it is the norm, rather than the exception, for the private fleet, while greatly decreasing the need for local infrastructure. Lane-level pricing, where one would pay more to use less congested lanes, was thought to need better than 1.8 m accuracy.

At-grade Railroad Crossing Warnings: Protected highway-railway crossings are expensive to build and maintain. Active warning systems that alert drivers in their vehicles to the presence of an oncoming train are seen as a way to both increase safety and decrease the costs associated with on-site infrastructure. The 1.8 m accuracy of GPS III would likely be sufficient to warn vehicles in danger of colliding with an oncoming train; but once again, the improved accuracy would increase the likelihood of the acceptance of such a system. It would be important to be able to tell when any part of the train will occupy the crossing, not just the cars in the vicinity of the GPS receiver, which would likely be located on the locomotive.

Railroad Siding Operations: The infrastructure required to maintain safety for opposing or overtaking train operations at railroad sidings is expensive to maintain, especially in remote and difficult to reach areas. Transferring warning systems from the track and into the trains would allow substantial savings in these infrastructure costs and increase the efficiency of train operations while maintaining the safety of the present system. The workshop participants mentioned that the 1.8 m accuracy of GPS III without augmentation would likely be sufficient for this application, but that the industry would likely want to ensure better accuracy before accepting such a system. Coverage problems could arise in steep terrain or forested areas. The difficulty of ensuring that the last car in the train has cleared the switch, and not just the locomotive or the potentially few cars equipped with tracking equipment, was explicitly mentioned as a concern.

Air Traffic Collision Avoidance: Increased accuracy from an augmentation system would allow the decentralized management of air traffic in a manner similar to the roadway-based cooperative active safety application. Since in-air collisions are presently extremely rare, this application is not seen as improving safety substantially. However, it should allow the air transport system to maintain, or possibly marginally improve, the safety of in-air operations with greatly reduced ground-based infrastructure, even with increasing traffic volumes. Because of the lower volume of traffic compared to that of roadway cooperative safety, the participants did not perceive a need for important communications breakthroughs to enable this application. The accuracy achieved from GPS III would probably be sufficient to allow operations, since much greater clearances between aircraft would be required. However, in safety applications such as this, it was thought that the improved accuracy would increase the likelihood of the acceptance of such a system, especially given the high speeds involved

GPS not good at height determination, also: improved by terrestrial pseudolite augmentation.

Automated Aircraft Landing: The ability to land aircraft autonomously in emergency situations, such as loss of pilot capability, was seen as a safety consideration.

Assisted Aircraft Landing: Presently, only major airports are equipped with the infrastructure that allows aircraft to land under the most rigorous conditions. Widespread augmentation would increase the capacity during bad weather at airports that do not have the resources to upgrade their landing systems. This increased capacity would decrease delays presently encountered at major airports and that are expected to increase in the future.

Risk-based Insurance: The ability to track driving behavior would also offer the opportunity to adjust insurance rates based on the documented behavior. Charging premiums for risky driving would be expected to decrease such driving and increase safety.

Driving Law Enforcement: Enforcing adherence to motor vehicle laws could be done remotely with an augmented PNT system. Weaving and wrong-way driving were two violations specifically mentioned.

Accident Reconstruction: Digital imagery is increasingly being used to document accident scenes. Such rapid documentation increases safety at the scene of the accident and allows the vehicles involved to be removed more rapidly, thereby reducing delays and tailpipe emissions. It was mentioned that better than 1.8 m accuracy would likely not be necessary with present methods, since the important information can be determined from relative, rather than absolute positioning. However, it was thought that automated image processing of airborne imagery would be useful and that such processing would be aided by accurate georeferencing of the image to absolute locations. Such precise automatic georeferencing would require the accuracy of the augmented PNT system.

Off-line Accident Analysis: Like a "black box" recorder on commercial aircraft, recording vehicle movements just before an accident occurred is expected to assist in determining the cause of the accident. Better understanding of accident causes from such after-the-fact analysis could then be used to determine strategies to reduce the frequency or severity of accidents.

Traffic and Trip Data for Off-line Planning: In addition to managing traffic in real time, the ability to locate and track vehicles would be useful for planning purposes. Presently, many agencies commit vast resources to collecting traffic volume data (how many vehicles use highway segments), origin-destination data (where trips begin and end), and parking studies (utilization of parking facilities as a function of time and where individuals are parking). The ability to track and manage the locations of vehicles would allow these tasks to be conducted more comprehensively and at lower cost.

Equipment Tracking: The ability to locate freight containers and equipment when inside buildings was mentioned as having potential benefits to the freight sector.

Automated Vehicle Operations at Terminals: Many vehicle fleets (*e.g.*, buses) are often stored in common locations when not in use. These vehicles must be parked in tight spaces and sometimes moved – for example, to be washed on a regular basis (*e.g.*, nightly). It was mentioned that, in addition to being labor intensive, these terminal operations can often cause damage to the vehicles. Although these accidents rarely cause personal injury, they are expensive to the agency. With increased positioning accuracy, these terminal operations could be automated. Automating the operations would decrease labor costs and damage from accidents.

Inside needs terrestrial pseudolite augmentation.

Port Operations: Assisting the docking and maneuvering of ships in harbors was mentioned as having value to overall port operations. This application would have safety implications, but it would also increase the efficiency of international ports. Also, more accurate location of containers and gantries would allow automated movement and handling of containers.

If tall ships and buildings nearby, needs terrestrial pseudolite augmentation.

Railway and Roadway Condition Assessment: Increased accuracy in locations would allow sensors carried on vehicles to assess railway and roadway positions more accurately, both for offline-planning and, in the case of rail geometry and bridge failures,

for real-time safety warnings. The ability to sense dynamic responses of the infrastructure was specifically mentioned.

Construction Quality Control: Accurately determining the (x,y,z) locations of components (*e.g.*, blades) of earthmoving equipment so as to provide precise earthwork was noted as a success story of local augmentation. This application was said to be a "compelling argument for a widespread augmentation network."

Airborne Transportation Imagery: Airborne remote sensing has widespread application for facilities and right-of-way mapping and for conducting the environmental studies required for infrastructure implementation. Digital imagery and LiDAR data have also been shown to be useful for traffic flow measurement and estimation. Better accuracy of the sensor location and sensing angle would lead to better accuracy of objects imaged on the ground. These better locations would allow better automatic image processing and, therefore, more accurate results at lower costs.

Conclusions

Most of the preceding applications need terrestrial pseudolite augmentation, even with GPS improvement out to year 2025; if that improvement fully materializes.

The long list of seemingly valuable transportation applications that would be feasible only with widespread augmentation reflects the high level of activity and productivity exhibited by the workshop participants. However, the list of applications was elicited without specific reference to the general transportation objectives presented during the morning of the first day. The list of applications appears to emphasize the safety and mobility objectives. A few of the applications had connections to transportation security, primarily in the ability to improve evacuation and traffic management under emergency conditions. The relative newness of the transportation security area as a focus for research and development might explain the lack of applications that target this objective as their primary focus. Special attention to this high priority and highly visible objective would be warranted at future workshops.

The transportation applications were also elicited without emphasis on modal representation. The list has a preponderance of roadway-based applications. The possible overrepresentation of the highway mode could be a result of the backgrounds of the transportation experts in attendance. The participants did recognize other modes, but there were only a few applications specifically targeting efficiencies in freight and intermodal shipments. Many of the application devoted to increased highway mobility would benefit freight shipments made entirely or partially by truck. However, because of the increasing recognition of their importance to the national and global economies, coordinated freight tracking and monitoring of the international supply chain, as well as other freight and intermodal applications, would also deserve special attention at future workshops.

To ensure that transportation needs are included in future PNT development and deployment policies, it is important to develop both incremental strategies and a clear and coherent vision of a transportation system that exploits widespread integration of

anticipated PNT technologies in routine transportation operations. Incremental strategies to continually demonstrate the value of more systematic and smarter use of augmentation capabilities available at the time would raise awareness of the future potential of the next generation of GPS among federal policy makers and provide valuable lessons on the path toward the future. Focused discussions at the upcoming RITA workshops by academic, industry, and government experts on a long-term vision and a set of strategies that could incrementally, but systematically lead to the realization of the vision would be useful input to U.S. DOT, who will ultimately be responsible for articulating the vision and implementing the strategies in a series of demonstration projects. The transportation applications developed in this workshop can serve as a framework for these upcoming discussions.

Telesaurus Note: Most of the below deal with terrestrial pseudolite networks. C. Rizos & associates have done much of the work in this area. In mid 2007, C. Rizos prepared for Telesaurus a paper on use of wide-area pseudolite networks for ITS applications that, in sum, indicates needs and solutions similar to those indicated herein.

References

Barnes, J., Rizos, C., Wang, J., Small, D., Voigt, G., and Gambale, N. (2003a): Locata: A new positioning technology for high precision indoor and outdoor positioning, *16th Int. Tech. Meeting of the Sat Div of the U.S. Inst. of Navigation*, Portland, Oregon, 9-12 September.

Barnes, J., Rizos, C., Wang, J., Small, D., Voigt, G., and Gambale, N. (2003b): High precision indoor and outdoor positioning using LocataNet, *2003 Int. Symp. on GPS/GNSS*, Tokyo, Japan, 15-18 November, 9-18.

Bossler, J.B. [ed.] (2002): Manual of Geospatial Science and Technology, Taylor and Francis: New York.

Bryant, D.E., and Van Dierendonck, A.J., (1996): Pseudolites, in: Global Positioning System: Theory and Applications (Vol. I), B.W. Parkinson and J.J. SpilkerJr. (eds.), 51-78.

Dai L., J. Wang, T. Tsujii and C. Rizos (2001a): Pseudolite applications in positioning and navigation: Modeling and geometric analysis, Proceedings KIS, 2001, Banff, Canada, June 5-8, CD-ROM.

Dai, L., Rizos, C., and Wang, J. (2001b): The role of pseudo-satellite signals in precise GPS-based positioning, *Journal of Geospatial Eng., HK Inst. of Engineering Surveyors*, 3(1), 33-44.

Grejner-Brzezinska, D. (in press): D. A., Integration of Global Positioning Systems (GPS) to Agricultural Geophysics, chapter 8 in Handbook of Agricultural Geophysics, B. Allred, J. Daniels, and R. Ehsani (editors), CRC Press.

Grejner-Brzezinska, D.A., Kashani, I., and Wielgosz, P., (in press): On Accuracy and Reliability of Instantaneous Network RTK as a Function of Network Geometry, Station Separation, and Data Processing Strategy, *GPS Solutions*.

Grejner-Brzezinska, D. A. and Yi, Y. (2003): Experimental GPS/INS/Pseudolite System for Kinematic Positioning, *Survey Review*, Vol. 37, No. 288, pp. 113-126.

Kashani, I., Grejner-Brzezinska, D.A., and Wielgosz, P., (2005): Towards Instantaneous Network-Based RTK GPS over 100 km Distance, submitted to *Navigation* (accepted).

LeMaster, E., and S. Rock (1999): Mars exploration using self-calibrating pseudolite arrays. Proceedings, ION GPS, 1999: 1549-1558. Nashville, Tennessee, September 14-17.

Rizos, C. (2005): Pseudolite Augmentation of GPS, presented at workshop on Geolocation and Navigation technology to support environmental geophysical mapping

applications, organized by Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) Annapolis, June 30-July 1.

Rizos, C. (2002): Where do we go from here?, in Manual of Geospatial Science and Technology, J. Bossler, J. Jensen, R. McMaster and C. Rizos (editors), Taylor and Francis, London and New York, 623 pages.

Spilker, J. J. and Van Direndonck, A. J. (2001): Proposed new L5 civil GPS codes, Navigation, Vol. 48, No. 3, pp. 135-143.

Stone, J.M., and J.D. Powell (1999): Precise positioning using GPS satellites and pseudolites emphasizing open pit mining applications, *4th Australasian Symp. on Satellite Navigation Technology & Applications*, Brisbane, Australia, 20-23 July, 8pp

Vollath, U., Buecherl, A., Landau, H., Pagels, C., and Wagner, B. (2000): Multi-Base RTK Positioning Using Virtual Reference Stations, ION GPS, 19–22 September 2000, Salt Lake City, UT, pp. 123–131.

Wanninger, L. (2002): Virtual Reference Stations for Centimeter-Level Kinematic Positioning. ION GPS 2002, September 24–27, Portland, Oregon, pp. 1400–1407.

Wolf, P.R. and C.D. Ghilani (2005): Elementary Surveying: An Introduction to Geomatics, 10th edition, Prentice-Hall, Inc.: Old Tappan, NJ.

Table 1. Transportation Applications Identified as Needing Widespread Augmentation, in Addition to Advanced PNT, with Characteristics

	Augmentation Performance Required		Communi-cations	Transportation Objectives Addressed				
	Improved accuracy	Coverage in difficult locations	Develop-ments required	Safety	Mobility	Global Connec-tivity	Environ-mental Steward-ship	Transpor-tation Security
Cooperative Active Safety	X	X	X	X				
Work Zone Safety	X	X	X	X				
Reversible Lanes	X		X	X	X		X	X
Traffic Control and Management		X	X		X		X	X
Traveler Information Systems		X	X		X		X	X
Passenger Vehicle Dispatching		X			X		X	
Automatic Transit Bus Location		X			X		X	
Facility Pricing	X	X	X		X		X	
At-grade Railroad Crossings	X		X	X				
Railroad Siding Operations	X	X		X	X			
Air Traffic Collision Avoidance	X			X				
Automated Aircraft Landing	X			X	X	X		
Assisted Aircraft Landing	X				X			
Risk-based Insurance	X	X		X				
Driving Law Enforcement	X	X	X	X				
Accident Reconstruction	X			X	X		X	
Off-line Accident Analysis	X	X		X				
Traffic/Trip Data for Off-line		X	X		X		X	

Planning								
Equipment Tracking		X			X	X		
Automated Vehicles at Terminals	X	X		X				
Port Operations	X			X	X	X		
Rail/Roadway Condition Assessment	X	X		X	X			
Construction Quality Control	X				X			
Airborne Transportation Imagery	X				X		X	

Appendix A. Workshop Planning Committee

Dr. Benjamin Coifman, The Ohio State University
Dr. Prem Goel, The Ohio State University
Dr. Dorota Grejner-Brzezinska, The Ohio State University
Dr. Mark Hickman, University of Arizona
Dr. Mark McCord, The Ohio State University
Dr. Carolyn Merry, The Ohio State University
Dr. Pitu Mirchandani, University of Arizona
Dr. Rabi Mishalani, The Ohio State University
Dr. Umit Ozguner, The Ohio State University
Dr. Charles Toth, The Ohio State University

Appendix B. Individuals Contacted and Workshop Attendees

Individuals contacted – agreed to attend workshop:
GPS-PNT experts:

Dorota Brzezinska	The Ohio State University dbrzezinska@osu.edu
Phil Bruner	Northrop Grumman-Navigation Systems Division phil.bruner@ngc.com
Stewart Cobb	Integrinautics Stewart.Cobb@integrinautics.com
Ron Hatch	Navcomtech rhatch@navcomtech.com
Christopher Hegarty	The MITRE Corporation chegarty@mitre.org
Alfred Leick	University of Maine leick@spatial.maine.edu
Pujara Neeraj	Wright-Patterson Air Force Base Neeraj.Pujara@wpafb.af.mil
Prof. John Raquet	Air Force Institute of Technology John.Raquet@afit.edu

Transportation experts:

Benn Coifman	The Ohio State University coifman.1@osu.edu
Prem Goel	The Ohio State University goel.1@osu.edu
Larry Head	University of Arizona larry@sie.arizona.edu
Prof. Reinhart Kühne	Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) sandra.zache@dlr.de
John D. Leonard II, Ph.D.	Georgia Institute of Technology john.leonard@ce.gatech.edu

George List	North Carolina State University GList@aol.com
Mark McCord	The Ohio State University mccord.2@osu.edu
Carolyn Merry	The Ohio State University merry.1@osu.edu
Pitu Mirchandani	University of Arizona pitu@sie.arizona.edu
Rabi Mishalani	The Ohio State University mishalani.1@osu.edu
Alan Murray	The Ohio State University murray.308@osu.edu
Stan Morain	University of New Mexico – NCRST-H smorain@edac.unm.edu
Val Norohna	University of California - Santa Barbara – NCRST-I noronha@geog.ucsb.edu
Morton O'Kelly	The Ohio State University okelly.1@osu.edu
Umit Ozguner	The Ohio State University ozguner.1@osu.edu
Srinivas Peeta	Purdue University peeta@purdue.edu
Scott Samon	Mississippi State University – NCRST-E scotts@ext.msstate.edu
George W. Saylor	Ohio Department of Transportation George.Saylor@dot.state.oh.us
Raja Sengupta	University of California, Berkeley raja@PATH.Berkeley.EDU
John Ray	Ohio Department of Transportation John.Ray@dot.state.oh.us

Keith Redmill	The Ohio State University redmill@ee.eng.ohio-state.edu
Tom York	The Ohio State University york.2@osu.edu

Federal representatives:

Steve Bayless	Office of the Secretary - US Department of Transportation Steven.Bayless@dot.gov
K.T. Thirmulai	U.S.DOT Research & Innovative Technology Admin Kuppusamy.Thirumalai@dot.gov >

Individuals contacted – could not attend workshop:
GPS-PNT experts:

Charles Toth	The Ohio State University

Transportation experts:

A. Emin Aktan	Drexel University
Dan Dailey	University of Washington
Pablo Durango	Northwestern University
Randolph Hall	University of Southern California
Haris Koutsopoulos	Northeastern University
David Levinson	University of Minnesota
Karen Smilowitz	Northwestern University
Brian Smith	University of Virginia
Fred Turner	University of Wyoming

Federal representatives:

James Arnold	FHWA/TFRC
Richard John	VOLPE
Michael Freitas	FHWA
Harry B. Kane	Federal Aviation Administration
Tom Naegle	Federal Aviation Administration
Jerry Pittenger	Battelle Institute
Hank Skolski	Federal Aviation Administration
Mark Yachmetz	DOT/FRA
Daniel Salvano	Federal Aviation Administration
Michael Shaw	NOAA
Kevin M. Tokarski	Maritime Administration/DOT
Jim Zok	DOT

Appendix C. Letter of invitation

THE OHIO STATE UNIVERSITY

Center for Mapping

1216 Kinnear Road
Columbus, OH 43212

Phone (614) 292-1600
Fax (614) 292-8062

15 November 2005

name
address

Dear xxx:

The Research and Innovative Technologies Administration (RITA) of the U.S. Department of Transportation is initiating a series of workshops to outline and develop a Year 2025 Vision for the applications of space-based technologies for improved Safety and Security, Mobility, Environmental Stewardship and Connectivity of multimodal transportation systems in the U.S. and around the world.

The National Consortium for the Remote Sensing of Transportation – Flows (NCRST-F) is hosting the first of these workshops with a specific focus on possible uses of 2025 era space-based positioning-navigation-timing (PNT) technologies (http://pnt.gov/). We would like to bring together two small groups of visionary experts – one specializing in transportation and the other specializing in PNT – to assist RITA in this task. This workshop will be held at The Ohio State University in Columbus, Ohio, starting at 8:30 A.M., November 30, and ending at 3:00 P.M., December 1, 2005.

The workshop planning committee believes that you would be a valuable participant in this workshop and would be most grateful if you would attend this workshop. NCRST-F will reimburse you for your travel and lodging expenses, according to Federal guidelines. The meetings will be held at the Blackwell Hotel (866-247-4003 or 614-247-4000; http://www.theblackwell.com; 2110 Tuttle Park Place) on the OSU campus. We have already reserved a hotel room for you at the Blackwell. There is a complimentary, pre-arranged airport transportation shuttle (based on availability) to and from the Port Columbus International Airport. They ask that you contact the Concierge or Guest Services Representative (614-247-4050 or 866-247-4003) to schedule your airport transportation (24 hours prior notification). Please make your own airline flight arrangements and purchase your ticket. Also, please save any meal receipts to be reimbursed. We need to have your home address and social security number – send this to Diane Rano (614-292-3396, rano@cfm.ohio-state.edu, fax: 614-292-8062) as soon as possible, so that she may process your travel request.

We request you to kindly confirm your anticipated participation to Prof. Mark McCord (mccord.2@osu.edu) or Prof. Prem Goel (goel.1@osu.edu) at your earliest convenience.

We hope that you will be able to assist the US DOT in this important task.

Sincerely,

Carolyn J. Merry
Professor and Interim Director

Appendix D. Planned Workshop Program Distributed to Attendees

Center for Mapping
1216 Kinnear Road
Columbus, OH 43212

Phone (614) 292-1600
Fax (614) 292-8062

Integration of PNT, RS, and Transportation Workshop
Hosted by the U.S. DOT's
National Consortium on Remote Sensing in Transportation – Flows (NCRST-F)
Blackwell Hotel, 2110 Tuttle Park Place
The Ohio State University, Columbus, Ohio
November 30, 2005 – December 1, 2005

Wednesday November 30, 2005

7:30-8:30 Sign-in and Continental Breakfast

8:30-8:45 Workshop Logistics: Carolyn Merry, Professor and Chair, Dept. of Civil and Env. Engineering and Geodetic Sciences; Interim Director, Center for Mapping, The Ohio State University; Director, NCRST-F

8:45-9:00 Local Welcome: Doug Kniss, Professor; Senior Associate Vice-President for Research, Office of Research, The Ohio State University

9:00-9:30 National Welcome and Motivation for the Workshop: Dr. K. Thirumalai, Chief Engineer – Office of RD&T, U.S.DOT Research and Innovative Technology Administration

9:30-10:00 Future of PNT: Steven Bayless, Presidential Management Fellow, Office of the Secretary – US Department of Transportation

10:00-10:15 Discussion

10:15-10:35 Break

10:35-11:05 PNT and ITS Research: Pitu Mirchandani, Professor, University of Arizona; Leadership Team, NCRST-F

11:05-11:20 Discussion

11:20-11:50 PNT and Vehicular Safety Research: Raja Sengupta, Assistant Professor, Professor, University of California, Berkeley

11:50-12:05 Discussion

12:15-1:15 Lunch

1:25-1:55 Traffic Surveillance from an Uninhabited Aerial Vehicle (UAVs): Benjamin Benjamin Coifman, Associate Professor, The Ohio State University

1:55-2:05 Discussion

2:05-2:35 Communications and Control – Ground Vehicles and UAVs: Umit Ozguner, Professor and TRC Inc. Chair on ITS, The Ohio State University

2:35-2:45 Discussion

2:45-3:05 European Perspective: Reinhart Kühne, Professor; Director, Institute of Transportation Research, German Aerospace Center

3:05-3:10 Charge to Breakout Sessions: Mark McCord, Prem Goel, The Ohio State University; Leadership Team, NCRST-F

3.10-3:30 Break

3:30-5:00 Breakout Sessions: Transportation Needs and Expectations from Next Generation PNT
(Part I); moderated by Mark Hickman and Mark McCord, Leadership Team, NCRST-F

5:00 - 6:30 Free time

6:30-7:30 Dinner

Thursday December 1, 2005

7:30-8:30 Continental Breakfast

8:30-10:00 Breakout Sessions: Transportation Needs and Expectations from Next Generation PNT
(Part II, continuation from day before); moderated by Mark Hickman and Mark McCord, Leadership Team, NCRST-F

10:00-10:30 *Break and Preparations for Plenary Summary Session*

10:30-11:00 Plenary Summary Session: Presented by Breakout Facilitators

11:00-11:30 Discussion and Reaction

11:30-12:00 Next Steps

12:00-1:00 Lunch and Adjourn

Appendix E. Breakout Group Assignments

Center for Mapping
1216 Kinnear Road
Columbus, OH 43212

Phone (614) 292-1600
Fax (614) 292-8062

Integration of PNT, RS, and Transportation Workshop
National Consortium on Remote Sensing in Transportation – Flows (NCRST-F)
November 30, 2005 – December 1, 2005

Breakout Session Assignments

Breakout Group I	*Breakout Group II*
Phil Bruner	Steven Bayless
Dorota Brzezinska	Stewart Cobb
Prem Goel	Benn Coifman
Larry Head	Ron Hatch
Christopher Hegarty	Mark McCord
Mark Hickman	Carolyn Merry
Reinhart Kühne	Pitu Mirchandani
Alfred Leick	Stan Morain
John Leonard	Alan Murray
George List	Srinivas Peeta
Rabi Mishalani	John Raquet
Pujara Neeraj	Keith Redmill
Val Norohna	Scott Samson
Morton O'Kelly	Raja Sengupta
John Ray	George Saylor
K. Thirumalai	Tom York

Telesaurus note:
Mr. Sengupta is the Principal Investigator of the Telesaurus-sponsored research at University of California's CCIT: California Center for Innovative Transportation which began after the below paper (which thus did not consider LMS spectrum in the multilateration location discussed below).

PNT and Vehicle Safety Research

PNT, RS, and Transportation Workshop

Raja Sengupta
Assistant Professor, Systems
CEE, UC Berkeley

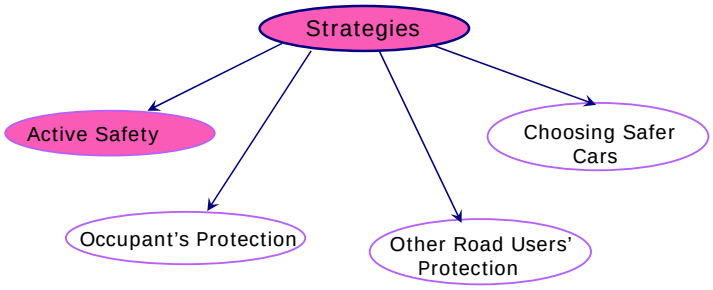
1

Joint work with….

- **Duke Lee**
- **Jim Misener**
- **Hariharan Krishnan**
- **Shahram Rezaei**
- **Steven Shladover**
- **Pravin Varaiya**

2

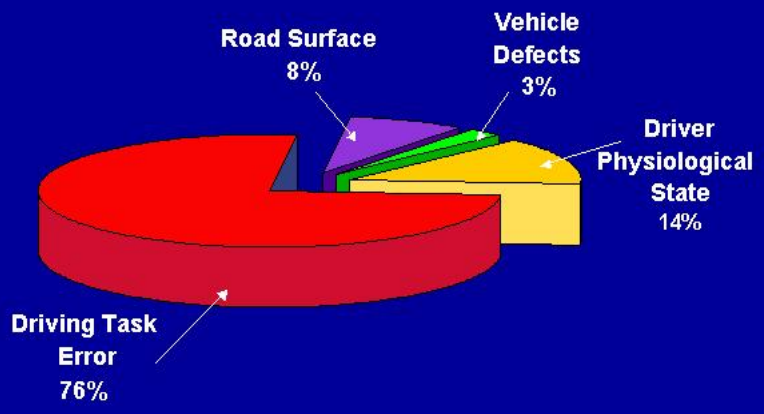
Focus on Active Safety



The Safety Problem

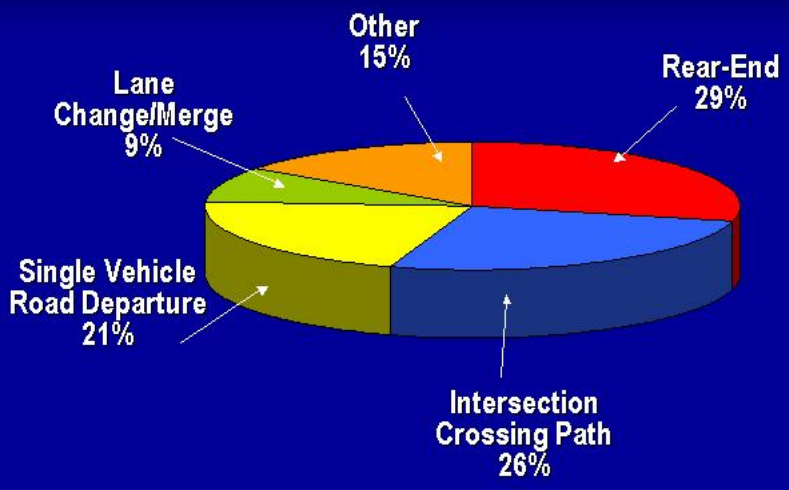
NHTSA People Saving People

Causal Factor Distribution

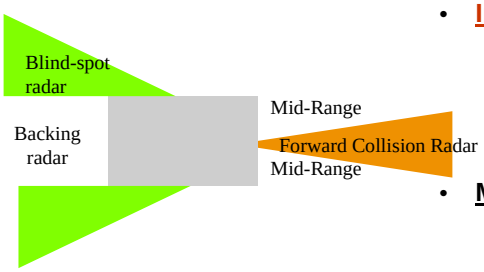


Analysis of the Safety Problem

NHTSA
People Saving People

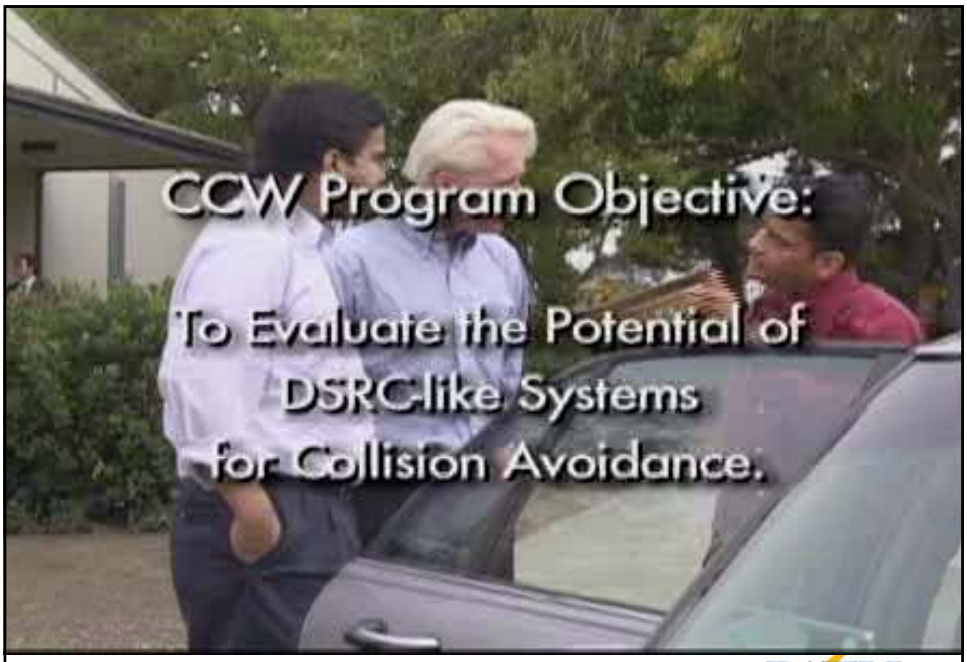


Led to Research on Active Safety Systems targeting the Different Crash Types



- **Initial Approach:**
  - **Sensor based**
    - **Multiple sensors for 360° coverage**
  - **Cost remains significant**
- **More Recently:**
  - **Cooperative Active Safety**
  - **Wireless equipped vehicles communication GPS coordinates**
  - **Cheap**

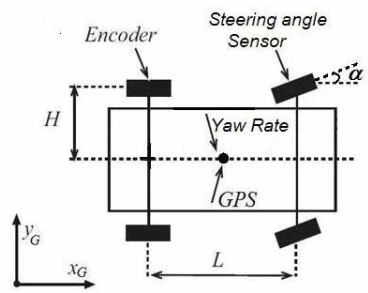
CALIFORNIA PATH



Papers

- T. K. Mak, K. P. Laberteaux R. Sengupta. A Multi-Channel VANET Providing Concurrent Safety and Commercial Services. In Proceedings of the 2nd ACM Workshop on Vehicular Ad-hoc Networks, Koln, Germany, September 2005.
- M. Zennaro, R. Sengupta. Distributing Synchronous Programs Using Bounded Queues. To appear in the Proceedings of EMSOFT 2005, Jersey City, USA.
- Rezaei S., Sengupta R. Kalman Filter Based Integration of DGPS and Vehicle Sensors for Localization. Proc. of International Conference on Mechatronics and Automation, Niagara Falls, Canada, August 2005.
- Xu, Q., Mak, T., Ko J., Sengupta R. Vehicle-Vehicle Safety Messaging in DSRC. In Proc. of the 1st ACM Workshop on Vehicular Ad-hoc Networks, October 2004, Philadelphia, USA.
- Qing X., Sengupta R., Jiang D., "Design and Analysis of Highway Safety Communication protocol in 5.9 GHz Dedicated Short Range Communication Spectrum", Proc. of the IEEE Conference of Vehicular Technology, Korea, Spring 2003.
- Ergen M., Lee, D., Sengupta R., Varaiya P. Comparison of Wireless Token Ring Protocol with IEEE 802.11. In proceedings of IEEE Symposium on Computers and Communications, Antalya Turkey, July 2003. Received Best Student Paper Award.
- Qing X., Hedrick K., Sengupta R., Vanderwerf J. Effects of Vehicle-Vehicle Roadside-Vehicle Communication on Adaptive Cruise Controlled Highways. Proc. of the IEEE Conference of Vehicular Technology, September 2002.
- Journal – In review
  - Medium Access Control Protocol Design for Vehicle-Vehicle Safety Messaging. Submitted to the IEEE Transactions on Vehicular Technology
  - Kalman Filter Based Integration of DGPS and Vehicle Sensors for Localization. Submitted to the IEEE Transactions on Control Systems Technology

Use an Extended Kalman Filter
2nd Order Bicycle Model



GPS/Vehicle Sensor Integration

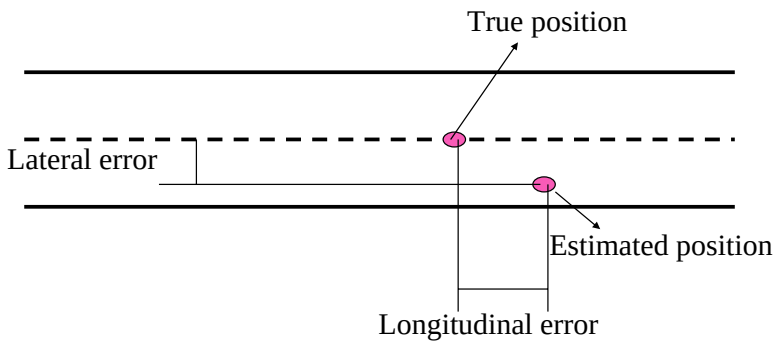
- **Wheel Speed Encoder**
- **GPS (Position, Heading, and Speed)**
- **Steering angle sensor**
- **Yaw rate sensor (Fog)**

Driving Cooperative Active Safety: Government, Industry, Academia

- **ACM created Vehicular Ad-hoc Networks Workshop and IEEE V2VCOM**
- **Federal Communications Commission created DSRC**
  - ***The record in this proceeding overwhelmingly supports the allocation of spectrum for DSRC based ITS applications to increase traveler safety, reduce fuel consumption and pollution, and continue to advance the nations economy.***
    - **FCC Report and Order, October 22, 1999, FCC 99-305**
    - **Amendment with licensing rules in December 2003**
- **DSRC Standards**
  - **ASTM E17.51, IEEE 802.11p**
  - **http://grouper.ieee.org/groups/scc32/dsrc/**
- **Automotive companies created Vehicle Safety Communications Consortium (VSCC)**
  - **Final Report Submitted January 2005**
- **USDOT/CAMP have created Cooperative Intersection Collision Avoidance (CICAS) Consortium**
  - **http://www.its.dot.gov/cicas/cicas_workshop.htm**

FCC first created LMS, for longer-range applications (location-determination-centric:especially LMS-M), then the FCC created DSCR for short-range applications. These are the two "ITS Radio Services." No other nation yet has both the long-range and DRSC ITS spectrum allocations: only the US.

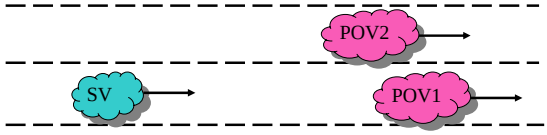
Lateral Positioning Accuracy Requirements



- **Lateral Error < 90 cm for correct lane assignment**
  - **Based on 3.6 m lane width and 1.8 m car width**

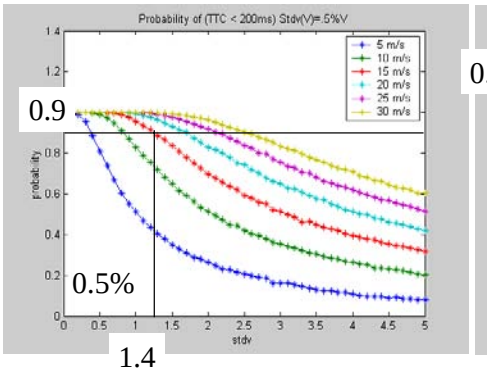
Positioning Accuracy for Forward Collision Warning

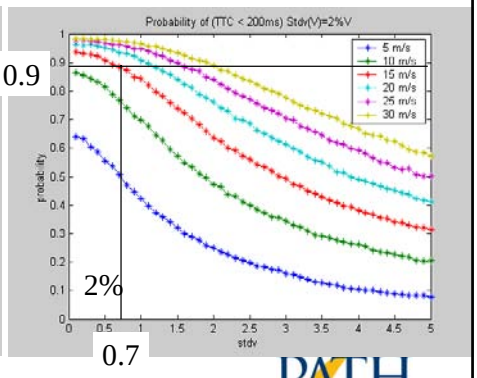
- **Warning is assumed to be based on time to collision**
  - **TTC = (y2 – y1)/(ý1 – ý2)**
- **Calculate Prob(|WarningTTC – TrueTTC| < 200 msec)**
- **Accuracy of the TTC estimate depends on the combined effects of all these errors.**



Positioning Accuracy for Forward Collision Warning

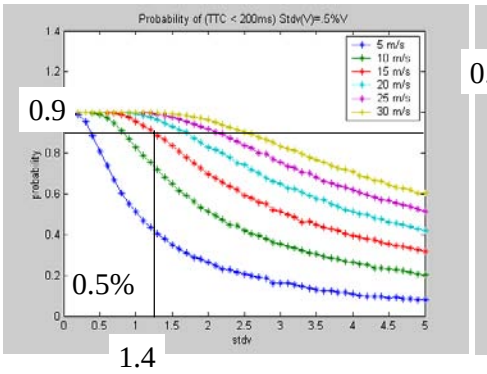
- **Colors are for different SV speeds**
- **True TTC = 3 sec**
- **X-axis: Standard Deviation of Position Error**

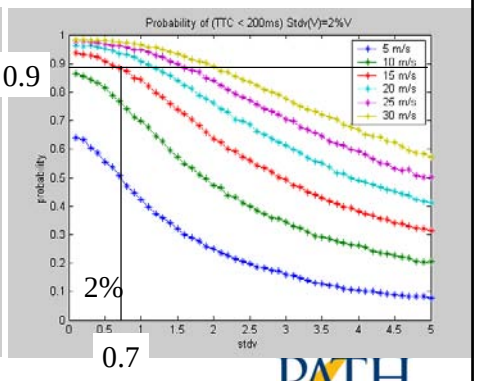




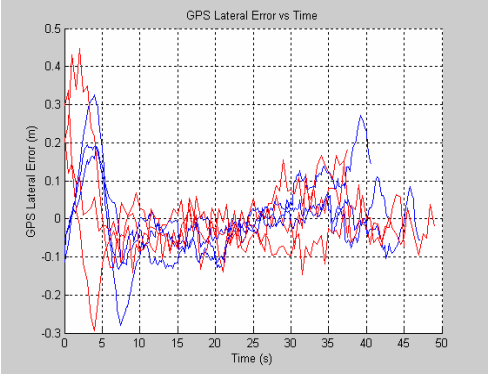
Positioning Accuracy for Forward Collision Warning

- **Standard deviation of error in longitudinal position should stay under 1 meter**





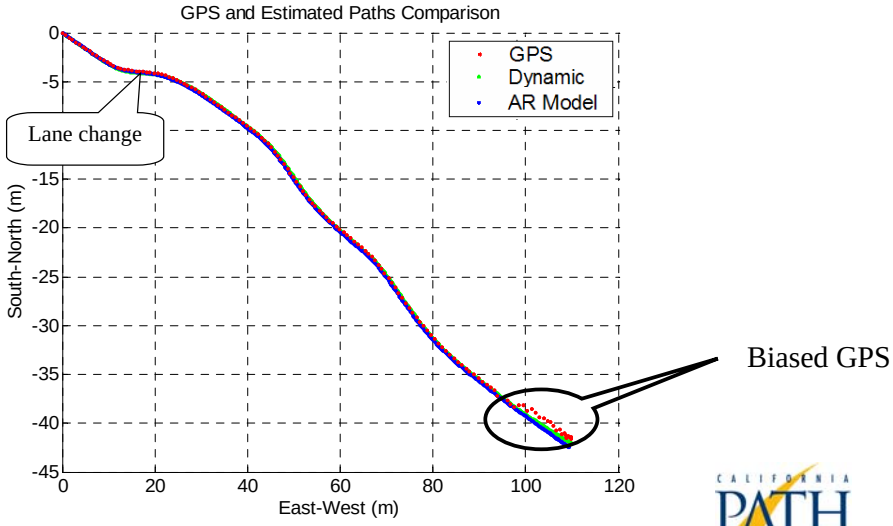
Ashtech DG12 Receiver with Differential Correction



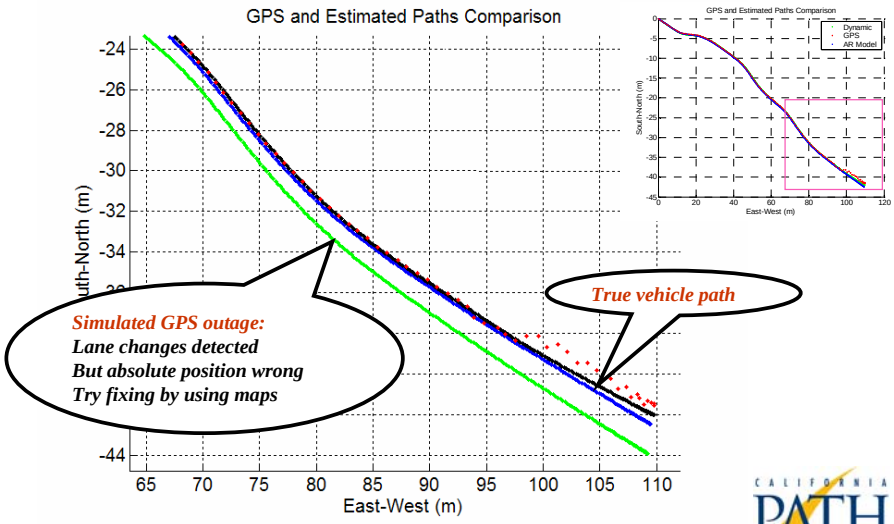
GPS Lateral Error on low speed tests

- **With good satellite conditions (7 or more) Ashtech DG 12 GPS is good**
  - **Errors under 30 cm**
- **Similar analyses for**
  - **Yaw rate**
  - **Steering angle**
  - **Wheel speed**

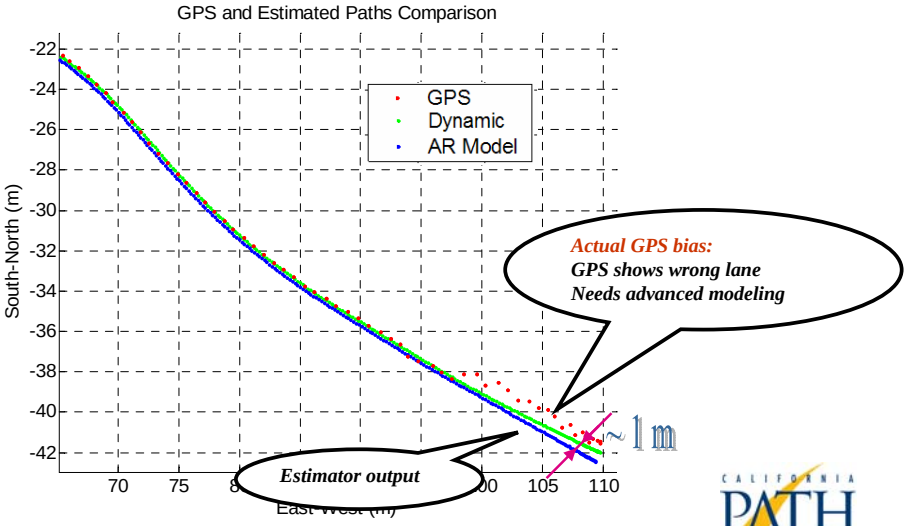
Research Challenge: GPS outage and bias



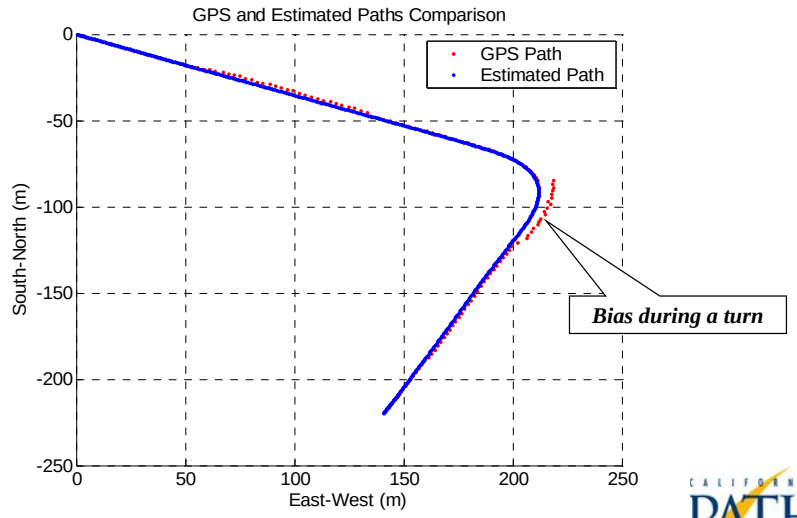
Research Challenge: GPS outage



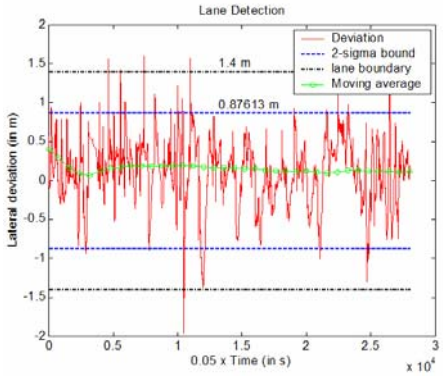
Research Challenge: GPS bias

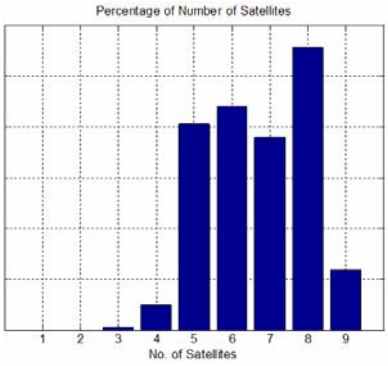


Research Challenge: GPS bias Right turn at intersection



Lane Positioning Error Rate near the PATH Headquarters

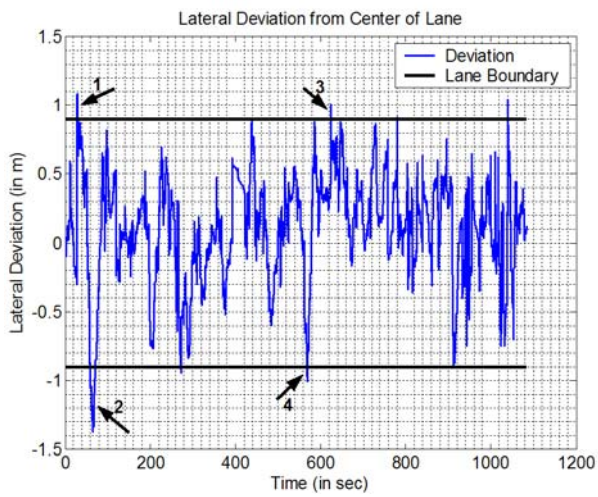




Total distance ~20 mile

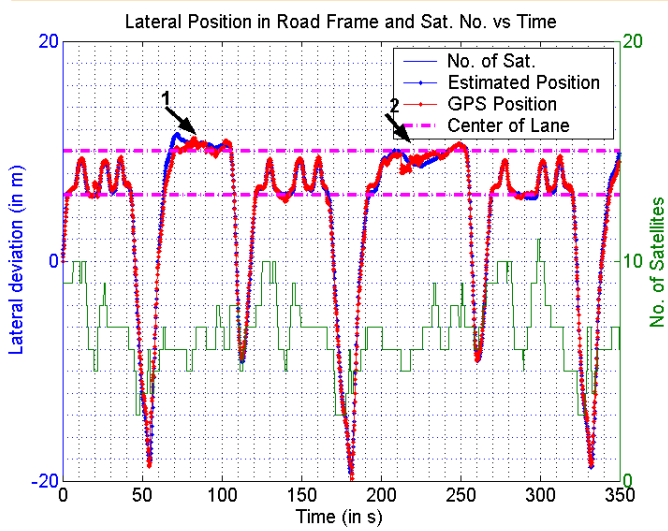
Average number of satellites is 6.

Example Data Set: Lateral Error Analysis



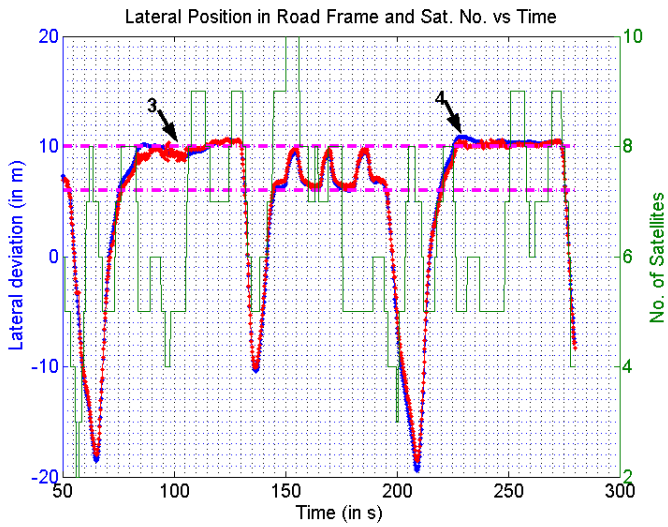
- **20 miles of driving**
- **6 satellites on average**
- **1,2,3,4 are lane recognition errors**

Typical Lane Recognition Error 1



Problem at 1 & 2:
During turns, if GPS goes bad, it may cause error in heading estimation. This will result in divergence of the estimated path from the true path.

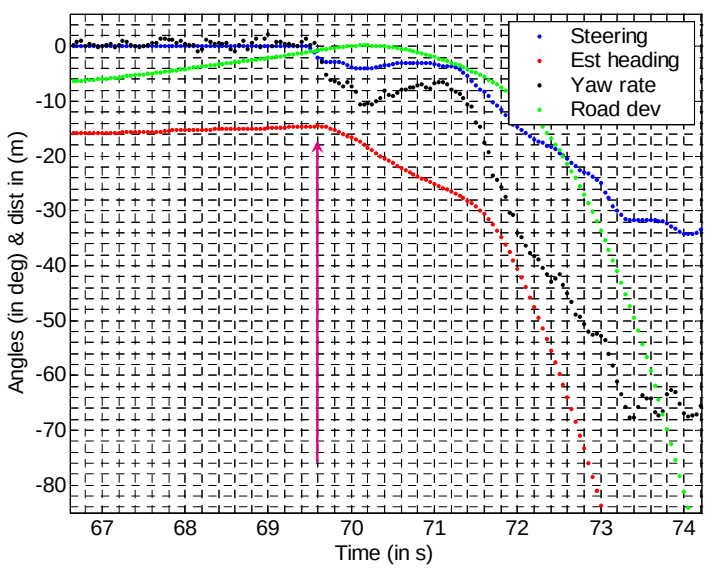
Typical Lane Recognition Error 2



Problem at 3 & 4:
Also, while going straight, if GPS stays bad for long time (~20 sec), error will grow up.

Will be targeted by enhanced CVS design

Fast Response to Vehicle Sensors: Turn Detection

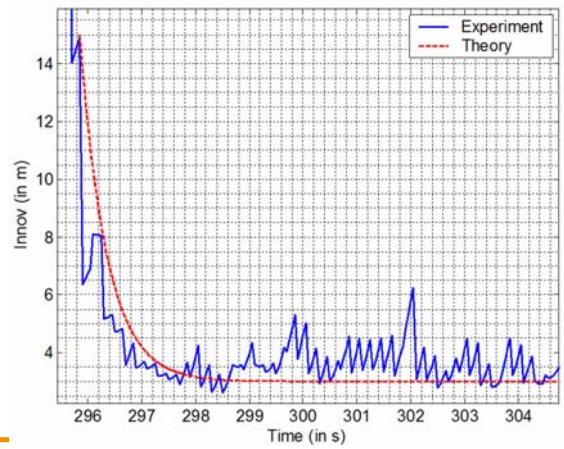


The delay between the time turn happens and time estimator shows that in less than 100 ms (2 timestamps).

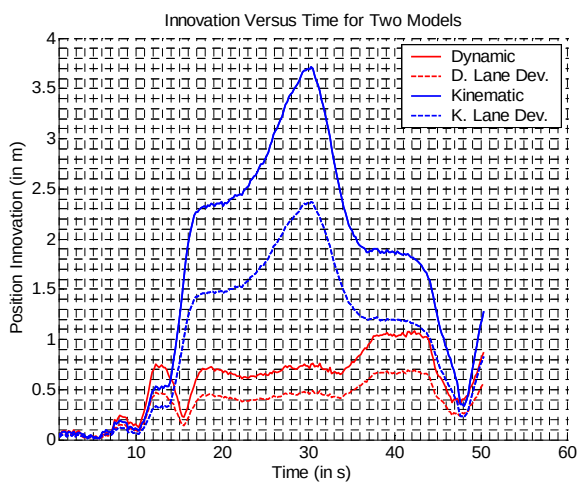
In the plot, all angles are scaled by 5, heading has an offset of 20 before scaling. Road deviation is scaled by 20.

Fast Response to GPS as well

The estimator is driven by the GPS readings. Response to a step input is similar to response of a first order system with time constant less than 500 msec. (i.e. two consecutive GPS readings).



The literature uses kinematic models. We use a dynamic model.



GPS outage is simulated in this run. **After time 10 sec, the system is run open loop until end of run.** Dynamic (bicycle) has better performance compared to kinematic model.

Summary: Position Estimation

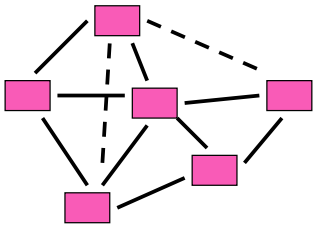
- The current filter structure has been optimally tuned
  - Bicycle model based extended Kalman filter
- Fails when
  - GPS goes bad during turns leading to incorrect lane assignment after turn
  - GPS goes bad for long durations (15 sec or more)
    - Long: Depends on speed
- Bad GPS during turns or prolonged outages remain a problem
  - Urban Intersections
  - Urban Canyons
- Bad
  - No Satellites: Outage
  - Satellites on one side: Bias
- Can this be fixed in urban areas?

An Improvement Idea

- Can DSRC function as a complementary terrestrial positioning infrastructure?
- Augment GPS position with DSRC radio ranging
  - Vehicle-vehicle ranging
  - Vehicle-roadside ranging
  - Accurate roadside access point position
- Advantage: Cheap
- Challenge: Correlation between RSSI/TOA and distance very noisy
- May work in large sample

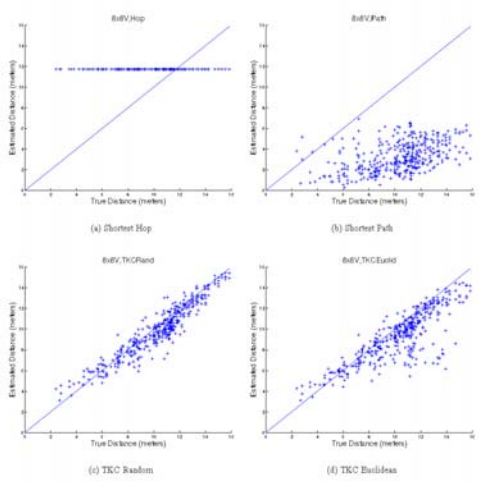
The GPS-complementary terrestrial posititioning infrastructure can be provided by LMS-M, and supplemented by LMS-N: exactly as the FCC (in mid 1990's) contemplated, and and Telesaurus and Spectrum Skybridge Foundation plan.

Localization Based on Multi-dimensional Scaling



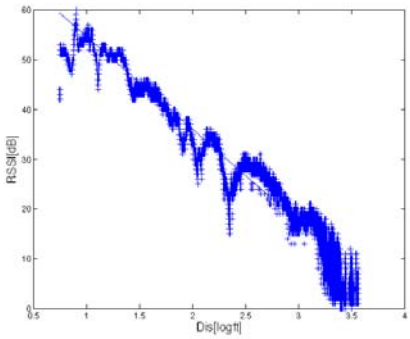
- **Every vehicle receives many distance estimates**
- **It fuses the multiple measurements using an algorithm**
  - **Relies on Distributed Multi-lateration**

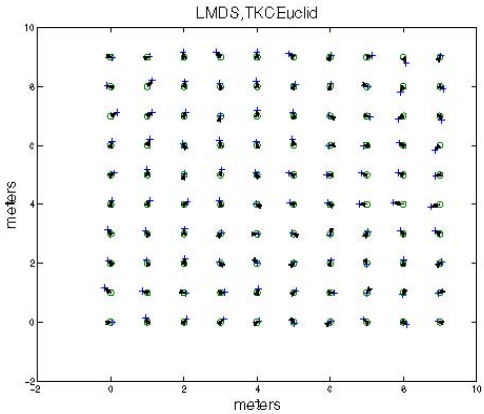
Comparison of Distributed Multilateration Methods



Tried in Sensor Networks with some success

- **Approach**
  - **Localization by Multi-dimensional scaling**
- **Performance in sensor networks with acoustic and radio signals**





Lee, Varaiya, Sengupta, IEEE Transactions on Mobile Computing, 2004

End

Intelligent Transportation
Society of California
(ITS-CA)

Attachment 7

Intelligent Transportation
Society of California
(ITS-CA)

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street. S.W.
Washington, DC 20554

12 October 2007

Re: WT Docket 06-49. Notice of Proposed Rulemaking Regarding Location and Monitoring Service wide-area Multilateration (LMS-M) Licenses under FCC Rules, Part 90, Subpart M: Intelligent Transportation System Radio Services.

Dear Ms. Dortch:

At the direction of our Board of Directors and with the support of our membership, ITS California hereby requests that the Commission maintain the current rules regarding LMS-M licenses in the above-referenced docket.

Intelligent Transportation Systems (ITS) applications, products and markets are experiencing explosive growth in the United States and internationally. Much of this growth is due to the wide proliferation of location-based applications and services such as in-vehicle navigation (both imbedded and portable devices), automatic vehicle location and tracking (private and public vehicles including transit), emergency roadside assistance, emergency response, and many others. As these wireless applications and services evolve, they require ever-increasing geographic coverages, data capacity, positional accuracies, and reliability, particularly for safety-of-life applications.

Considerable investment is now being made by both the public and private sectors (including a number of ITS California members) in next generation applications that will rely on wide-area coverage, sub-meter positional accuracies and extremely-high-reliability data communications. One example of such an application is the Vehicle Infrastructure Integration (VII) program currently being pursued by the US Department of Transportation, the California Department of Transportation (Caltrans), automotive manufacturers, and many other companies, laboratories, and state and local agencies throughout the Nation (including a number if public-sector and private-sector members of ITS California). By enabling real-time data communications among road vehicles, and between vehicles and the roadside, the VII program promises to dramatically reduce the human suffering and tremendous financial costs levied by the fatalities, injuries and property damage resulting from accidents on our Nation's roadways. In addition, VII can provide an important tool to help mitigate roadway congestion through improved traffic monitoring and management.

While VII Dedicated Short Range Communication (DSRC) can partly be accomplished using the 5.9 GHz band, the longer-range capability and reduced obstacle-obscuration vulnerability of the 900 MHz LMS-M band make it an important companion to DSRC for attaining the required VII reliability and positional accuracy, which can best be attained through system redundancy and through diversity in multiple dimensions including frequency, space, time, and capacity. In addition, the longer range and the lower obstacle susceptibility of LMS-M can significantly reduce the cost and greatly accelerate the rate of deployment of VII and other ITS Location Based Services, as well as reduce the cost of operating and maintaining such services.

Accordingly, ITS California requests that the Commission maintain the current LMS-M rules, including the currently authorized power levels and unrestricted time-of-use needed for various wide-area location and communications services to vehicles, to allow LMS-M licensees to develop and provide ITS wide-area radio services in the nation. There are many other commercial and private radio services in which other, non-ITS-specific wireless can be provided. However, as the Commission is aware, there is no other radio service established for such wide-area ITS-specific wireless.

Respectfully,

Lawrence E. Sweeney, Jr., Ph.D.
Chair, Board of Directors
ITS California

P.O. Box 2947, San Anselmo, CA 94979