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Research Opportunities in Radio Frequency Identification Transportation Applications

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Washington, D.C.

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Editors

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Introduction

Gene Griffin
Upper Great Plains Transportation Institute

Radio frequency identification (RFID) is a technology that has potentially sweeping impacts in the transportation and travel industries. Its applications cover a broad range, including

- Supply chain management (tagging of containers, pallets and individual packages);
- Infrastructure (tagging of building equipment and components);
- Safety and security (vehicle collision avoidance, electronic preclearance of vehicles and individuals through security checkpoints, privacy issues); and
- System operations [electronic toll collection (ETC)].

Innovations and breakthroughs in the design, production and application of RFID are rapidly unfolding on a global scale. This conference focused on current and future research on RFID technologies in transportation applications. Participants included university RFID researchers, government transportation professionals interested in current or potential RFID applications, and industry representatives.

The conference was a unique opportunity to brainstorm, generate ideas, identify challenges, and begin creating a more focused research agenda for transportation applications of RFID technology. The conference objectives were to

- Inform government transportation agencies about current and potential RFID applications that have the potential to enhance the mobility of freight and people,
- Increase communication among researchers involved in RFID technology applications for transportation,
- Give government program managers a better understanding of University Transportation Centers (UTC) programs and link those program managers interested in RFID applications with university experts, and
- Identify RFID research opportunities.

I would like to extend a special thanks to the Office of Research, Development, and Technology of the Research and Innovative Technology Administration (RITA), U.S. Department of Transportation (DOT), and in particular to Tom Marchessault, for supporting this conference, as well as to the Transportation Research Board for organizing and hosting the conference.

Progress was made on all of these objectives, thanks to the open and frank discussion of participants. This circular attempts to capture what occurred at the conference so that it can be used as a resource in future discussions of RFID applications in transportation.

The conference participants developed a number of research problem statements based on the issues discussed. Those problem statements are included at the end of this report.

The nation's 60 UTCs (http://utc.dot.gov) are an incredible resource to the transportation industry; they conduct a broad range of research projects, and they are educating the next generation of transportation professionals. The planning team encourages the UTCs to review the research problem statements generated by this conference and to contact the UTC program staff about research problems that they would be interested in working on.

I also would like to thank the members of planning team, who did so much to shape the content of the conference.

Radio Frequency Identification

Public Policy Challenges of the Future

Byron L. Dorgan
U.S. Senator, North Dakota

Senator Dorgan is cochair, with Senator John Cornyn of Texas, of the RFID caucus in the U.S. Senate. The caucus was created to provide a forum to discuss the benefits, policy challenges, and innovative solutions of RFID.

Dorgan spoke about RFID development from a congressional/regulator perspective. He noted that the United States has always been a leader in research and innovation. "There's a lot of genius and inquisitiveness in this country that comes through in successful research."

He noted that where the federal government is concerned, the U.S. DOT and the U.S. Department of Defense (DOD) are leaders in the application of RFID technology.

Pointing out that RFID is a relatively new technology, Dorgan commented that Jeff Jacobson, Chief Executive Officer of Alien Technology, first approached him about 6 years ago to discuss fluidic self-assembly (FSA), a process to affix tiny microsensors to products. The company is now a pioneer in using that process to assemble large numbers of RFID devices. Alien Technologies, based in Morgan Hill, California, built and operates an advanced manufacturing facility in Fargo, North Dakota.

Dorgan related how he helped facilitate discussions among DOD, Alien Technologies, and North Dakota State University that explored how those sensors could be used in defense applications. "From that beginning I became very interested in what does this technology mean, and what does it mean for our future," he said.

Dorgan said he believes RFID technology is being driven by very large users who have a vision for the technology and who want to move in a particular direction with that technology. Examples include DOD, U.S. DOT, and Wal-Mart. "When Wal-Mart says to its suppliers, 'We have a new construct and we want to use RFID to track our inventory,' that changes everything in the private sector."

There are controversies surrounding RFID technology, Dorgan acknowledged. The Senate RFID caucus was created, in part, to address those controversies and the public policy issues surrounding the technology. He noted that controversy and public policy issues are common with most new technology.

First and foremost among those issues are issues of privacy, some serious and some not so serious. "On a public policy front it's very important for us to begin to address them," Dorgan said.

"Legislation may not be necessary at this point, but some may try to introduce legislation to retard, change, or slow down application of this technology," Dorgan said. "That's a reasonable thing to see happen whenever you have new technology. Privacy is a large issue, but we should not ignore it, we should confront it, address it, and move forward."

Dorgan predicted that RFID technology will have broad impacts in almost every facet of life. Currently it is playing an important role in inventory control and management at DOD. "Inventory control in the defense department is interesting because it's about what they have and how to move it, but also about national security," Dorgan said.

He noted that RFID technologies are being applied to collect transit payments and track movement of freight and hazardous materials on roads and on rails. He predicted that deployment of sensors and RFID technology could address border security issues, as well as issues of how to monitor people and freight passing over international borders. “These are all issues in which RFID will become a significant part of our future,” he said.

“There’s almost endless numbers of applications for this technology,” Dorgan said. “The question is; how do we move in that direction, developing common standards and common understandings of what is appropriate and what is inappropriate, while developing public policy initiatives where necessary on the subject of privacy?”

He emphasized that privacy is not an irrelevant concern. “Given the great concern about privacy as a result of the trail we’re leaving behind with the Internet and credit cards privacy is a very significant and challenging issue. We should not discard it in regard to RFID. We need to deal with it, confront it, answer questions about it, and move forward,” he said. “I want us to use the advantages and capabilities that come from this new technology, but we won’t be able to do that unless we are honest about the issues raised by others.”

RFID and the U.S. Department of Transportation

JOHN A. BOBO, JR.
Research and Innovative Technology Administration

RFID plays a key role across our nation's transportation system, from shippers and motor carriers to security specialists and policymakers. That is why it is vital that we stay ahead of the curve on the latest RFID technologies, applications, and challenges, and why we must be proactive in addressing issues such as privacy and safety.

At U.S. DOT we are looking to our UTCs for leadership and innovation on this important topic. This conference represents what I hope is the first of many opportunities for greater collaboration with our university partners on issues of importance to our nation's transportation system.

Many of you are already leading the way in RFID research, with at least 20 UTCs currently involved in RFID-related activities of one form or another.

At RITA, we are taking the lead in several activities to provide research, technical support, and coordination for U.S. DOT. RITA currently participates in an intragovernmental RFID council, a venue to coordinate with other government agencies. RITA has specifically appraised the council—chaired by the DOD—on the UTCs' RFID-related research activities, and the council has requested regular updates on what research is being performed and where.

As part of RITA's role as a leader in research and innovation, it is our hope to be able to identify the best of RFID technology and its applications to various modes of transportation.

As you know, the number of transportation applications for RFID is growing rapidly. RFID has become a critical component of port and border security, vehicle and vessel identification (ID), supply chain management, and inventory control.

RFID is a key component of electronic tolling systems like EZ-Pass. We are working with state and local highway departments that are expanding their use of toll tag systems by placing readers at strategic locations to compute traffic speed and volume for real-time traffic information and transportation planning.

Public transit agencies are also using RFID technology, enabling buses to "communicate" with traffic signals in order to extend the green time at intersections and keep passengers on schedule.

Tire manufacturers are also exploring the installation of sensors in tires, coupled with RFID tags, to communicate the status of tire pressure and tread life to the driver. This could be a vital step in preventing accidents and saving lives on America's roads.

There are many other areas where RFID technology is being used in our nation's transportation system, which is why we are excited that you have taken time to join us here in Washington for an open dialogue about this important topic.

RFID technology couldn't be emerging at a better time. Our new secretary of transportation, Mary Peters, is focused on tackling the tough transportation challenges…from saving lives to improving performance to finding 21st century solutions to 21st century problems. As we move from a culture of civil engineering to system performance, technologies like RFID promise to play a key role in solving problems.

To accomplish this, we would like to collaborate with you in the following areas:

- Identifying what type of RFID research is needed and how to fund it;
- Evaluating new applications for RFID and the impact of those applications on transportation systems;
- Identifying required coordination with other governmental or international organizations;
- Identifying and addressing privacy issues;
- Identifying and addressing security issues; and
- Performing operational tests and, where appropriate, participating in the development of standards.

We recognize that not all of the answers originate here in Washington. So we are counting on you and others throughout the UTC community to be a source for innovative ideas and solutions. With exciting opportunities often come difficult challenges, and your expertise and insights will be vital for advancing technologies like RFID as well as for identifying and crossing hurdles when they arise.

Thank you again for joining us today. I look forward to the innovative ideas that will come out of this conference, and for the long-term solutions that will be achieved as we continue to strengthen the collaborative partnership between U.S. DOT and the UTC community.

The Future of RFID Technology

ALAN ESTEVEZ
U.S. Department of Defense

The DOD is responsible for managing the global supply chain that supports the nation's troops throughout the world. RFID technology is a tool that helps to ensure that equipment and material are delivered efficiently and that they can be readily found when needed amid large supply warehouses. RFID provides the data DOD needs to do business, allowing knowledge-enabled, precision-guided logistics.

Logistics is big business at DOD. It is a complex enterprise, and delivering cost-effective operational availability is a central challenge. DOD deals with 51,000 vendors, using more than 2,000 legacy logistics systems. It processes more than 45,000 requisitions per day, and it carries an inventory worth $80 billion. More than $700 billion in assets must also be tracked by DOD, including 300 ships, 15,000 aircraft, 30,000 combat vehicles, 900 strategic missiles, and 330,000 ground vehicles.

DOD spending on RFID technologies is expected to double from $115 million today to $230 million by 2010. Total federal RFID spending (including DOD) is expected to reach $560 million by 2010.

DOD is fully committed to the use of RFID as a key tool for the nation's armed forces. According to the *2006 Quadrennial Defense Review Report*, active and passive RFID technologies will play a key role in achieving the department's vision for implementing knowledge-enabled logistics support to the war fighter through automated asset visibility and management.

RFID is designed to enable the sharing, integration, and synchronization of data from the strategic to the tactical level, informing every node in the supply chain network. This information should provide greater insight into the cause-and-effect relationship between resources and readiness.

Active RFID technologies are used on freight containers, air pallets, and large engine containers. These technologies consist of 433-MHz readers and tags. The tags, which are battery powered, use DOD's data formats and are applied primarily by DOD and the services. Because these tags cost about $80 each, the tags are reused. In 2004, active RFID became the standard way of doing business at DOD.

Passive RFID technologies, which do not contain batteries and which require readers to "wake up" the tags, are applied at the case and pallet level. DOD has adopted the EPCglobal standard for passive RFID, which is the same standard used by the commercial sector (Wal-Mart, HP, Johnson & Johnson, Sony, etc.). During the migration to EPCglobal's Class 1 Generation 2 technology, EPC Generation 1 Class 0 and Class 1 tags were accepted by DOD until February 28, 2007. The passive RFID tags use EPC tag data formats, and suppliers are contractually obligated to tag their items before delivering them to DOD. By embracing this common standard, DOD will benefit from economies of scale.

Experience to date with passive RFID technology has been very good. For example, the Norfolk Ocean Terminal has experienced a 3 percent improvement in accuracy (i.e., 3% fewer misrouted shipments), and a 39% improvement in time savings. In an ongoing project with the Advanced Traceability and Control System, passive RFID is used to track high-value items through the logistics system; the automated receipts generated by RFID provide proof of delivery for 355 shipments, worth $12.6 million, where no proof-of-delivery information had previously been recorded. The information provided by these receipts prevents duplicate orders from being filled, precludes weapons from sitting idle, and enables the use of fewer aircraft, among other benefits.

DOD's premier application of RFID is its Alaska project, in which RFID technology is used throughout the different branches of the armed forces to track goods as they move from California to Alaska on commercial ships, military aircraft, and commercial trucks. Reengineered business processes were automated with passive RFID technology, and the workforce was trained to execute the RFID-enabled processes. This system will eventually be expanded to additional nodes and to include additional levels of tagging.

The DOD supply chain has been called "a strategic weapon" (Kenneth J. Krieg, Under Secretary of Defense for Acquisition, Technology and Logistics, speaking to the House Committee on Armed Services, April 5, 2006). RFID has greatly increased the military's confidence in the supply chain. It has allowed DOD to reduce the value of inventory in Iraq from $127 million to $70 million, reduced the wait time for items from 28 to 16 days, increased the fill rate from 77% to 89%, and reduced the retail backlog from 92,000 to 11,000 orders.

The Evolution of RFID Technologies

Richard Doering
TransCore

RFID has provided the means to automate significant aspects of transportation in the past two decades. Every day, RFID allows transportation movements for millions of people to be simplified, allowing greater speed and efficiency, enhancing the capacity of our transportation network, and reducing wasted time and pollution. This paper surveys some of the key RFID technologies that have contributed to, and will continue to drive, this transportation revolution.

GOALS, REQUIREMENTS, AND BENEFITS

The practical goals for the majority of RFID transponders (tags) and readers have included the following:

- No battery, or a long battery life measured in years, for simple aftermarket devices installed by the vehicle driver/owner.
- Secure ID number storage and readout, with some systems having factory programming and locking to prevent changing, while others use authentication of the tag or reader to ensure higher levels of security.
- Additional memory in the transponder for scratchpad read-write memory as the transponder passes by readers. (In many cases, read-only systems are quite viable.)
- Communications occurring in a small zone (at normal speed, without having to slow down), so as to facilitate tag data receipt to a specific item or vehicle. The absence of communication for a vehicle at that point in space/time means that the item is untagged, or that the tag is not functioning.
- Devices that are approved for sale by regulatory agencies such as the Federal Communications Commission (FCC). (For *Code of Federal Regulations* references, see 47 CFR 90.351 and elsewhere.)

Because vehicles carrying RFID tags need to be identified at high travel speeds, and with some systems involving millions of tags and millions of transactions (and millions of dollars) per day across the country, very high performance levels are expected:

- Fewer than five misses in 10,000 vehicles (99.95% success rate).
- No more than one incorrect number in 10 million transactions.
- No missed transactions due to traffic density.
- Minimized instances of duplicate transactions or out-of-sequence RFID numbers.
- Tags that can be read on vehicles on open roads (i.e., no constraints upon vehicle movement on an open highway). In many systems, vehicles are expected to maintain highway speed, with no stopping; this improves safety and minimizes pollution from vehicle acceleration.

This automation of access control or toll revenue collection involves lane controllers that validate each tag number, capturing images and license plate numbers for any necessary follow-up enforcement and fee collection. At the back office, user accounts are debited, and billing settlements or account replenishments are performed.

Switching to ETC has increased lane capacity from 400 to 600 vehicles per hour (vph) to 1,500 to 2,200 vph. By eliminating the staffed booth or high-maintenance automatic coin machines, toll plazas can blend into the road infrastructure, and the bottlenecks, high real estate costs, and collision risks associated with large approach and departure fan-out areas are eliminated.

HISTORY OF RFID

The history of RFID has been chronicled in *Shrouds of Time* by Jeremy Landt, Amtech founder (Amtech is now part of TransCore): www.transcore.com/enabling-technologies-overview/rfid/rfid-history.html.

Some highlights of the history of RFID include the following:

- The Identify Friend or Foe radar systems, initiated in 1939.
- Radar backscatter techniques for communication (described in a paper by Harry Stockman, Communication by Means of Reflected Power, published in the *Proceedings of the IRE*, October 1948).
- Retail theft reduction in article surveillance (1 bit) systems, which were developed in the 1960s.
- Laboratory and commercial interest took off in the 1970s at Los Alamos and elsewhere.
- Animal ID applications (particularly with dairy cows) in the 1970s.
- Pioneering automatic vehicle identification (AVI) systems (deployment of RFID toll transponders at 420 kHz on the Golden Gate Bridge in 1972 and at the Lincoln Tunnel in 1973).
- RFID tests by Long Island Railroad and the Association of American Railroads in the 1980s.
- Trucking weigh stations in Arizona and the heavy vehicle electronic license plate program in the late 1980s.
- First ETC system to go live, 1988.
- Open road toll systems, which first appeared in 1997.

The technologies used in the above-listed applications have followed these developments in electronics:

- More highly integrated circuits (IC) with fewer components;
- Lower levels of battery consumption;
- Elimination of batteries using backscatter modulation, a technique that requires a switching transistor operating at the data modulation frequency, not the radio frequency (RF) carrier frequency, since the antenna is only switched on and off to reflect back the ID number; and
- Integration to a single integrated circuit mounted on an antenna structure.

As the tags have become simpler and with fewer components, the complexity and performance of the readers have increased to handle both multiple communication protocols and higher speed vehicles. Many readers are now similar to high-speed “modems,” conveying the raw information to controllers that system integrators use to process and qualify the data for end-application validation and use.

The technologies or protocols used for RFID communication have followed developments in other areas of communication with a progression of techniques:

- Radar-modulated backscatter (using a continuous wave carrier);
- Amplitude modulation (AM);
- Frequency shift keying;
- Orthogonal frequency division multiplexing (OFDM);
- Biphase shift keying;
- Quadrature phase shift keying; and
- Quadrature AM.

While some systems use unsynchronized tag responses (all tags in the field respond at their own data framing times), other systems use triggered wake-up and response. Systems such as the commercial vehicle information systems and networks (CVISN) use time division multiple access techniques to allow dozens of transponders to communicate in a fraction of a second. Some systems, especially low-frequency systems, use a frequency doubling technique, where the response is twice the interrogation/wake-up frequency. Other systems use a swept RF signal to stimulate a surface acoustic wave device to obtain the ID number from the phase-shifted and reflected responses. Taking advantage of the FCC rules for spread spectrum devices, some systems also frequency hop around the band in order to be able to utilize higher power emissions in an unlicensed environment. The ultra wideband pulses now permitted between 5.8 and 7.2 GHz are also discussed as a means for RFID.

RFID tags and readers have been designed for many frequency bands:

- Low frequency: 66/132 kHz;
- High frequency: 13.56 MHz;
- Very high frequency: 49 MHz;
- Ultra-high frequency: 315, 433, 902 to 904, 909.75 to 921.75 MHz, or 2.45 GHz; and
- Microwave frequency: 5.8 GHz (Europe—backscatter), 5.9 GHz (US-OFDM).

Frequency selections are made by designers based on regulatory limits for products, available components, data bandwidth, latency, and the number of readers/speed performance at the site.

Horizontal polarization has been most common, although some communication systems use vertical polarization, or even circular polarization, to allow relaxed tag positioning, with a power/selectivity penalty.

Various sleep or wake-up cycles, plus solar-powered assistance, help extend battery life of some independently powered transponders. As mentioned previously, some backscatter systems have eliminated the battery, while still providing highway speed performance.

There is also an effort among the U.S. DOT, the RFID manufacturer’s consortium, and the automakers to utilize the newly assigned 5.9-GHz band not only for RFID, but also for dedicated short-range communication (DSRC) exchange of information between vehicle and roadside. Known as wireless access in vehicular environment (WAVE), this 802.11a–like OFDM system has been tailored to minimize multipath interference common in highway and large building infrastructure by doubling the signaling time for each bit being transmitted with the side benefit that the occupied bandwidth is halved to 10 MHz. The seven resulting channels are being organized into application uses from safety to information exchange channels. Most important, this system has been designed to minimize latency, allowing the hundreds or thousands of vehicles in range of a roadside reader to exchange vital information. Standardization is being coordinated through the IEEE 802.11p working group, with the pioneering physical layer standard ASTM E-2213 mandated by the FCC rules for the 5.9-GHz band in 47 CFR 90, subparts L and M.

Additional exciting developments in mesh networks are addressing the "hidden transmitter" problem, where relaying of information automatically is also incorporated into the system design.

Successful implementation of RFID overcomes the challenges of applying RF techniques, some of which are not obvious to persons who are only familiar with ID using their eyes:

- Antenna coverage volume;
- Polarization and orientation of tag;
- Metallic or conductive material shielding or antenna degradation;
- Poor antenna matching or tag mounting, causing failed writes or reads;
- Minimal time in antenna pattern;
- Achieving useful data rates in noisy RF conditions;
- RF interference from other users of the same or adjacent bands;
- Null zones or long-range reflections;
- RF power levels—sufficient but not too high to properly locate tag and match it to sensed vehicle; and
- Tag power consumption—battery life.

The RFID applications and associated DSRC uses are quite extensive when considering the various areas of transportation:

- Access control to facilities;
- Toll or revenue collection;
- Regulation enforcement, such as vehicle dwell time at airports;
- Traffic travel time monitoring;
- Vehicle location and detection of schedule adherence and bus bunching;
- Weigh station automation and bypassing;
- Border access control by people, vehicles, containers, and goods;
- Safety communication;
- Container ID and status of door and temperature alarm;
- Equipment ID, such as with a railcar; and
- Odometer data transmission.

As an example of how some RFID devices can be applied to solve transportation challenges, onboard vehicle parameters such as odometer readings can be transmitted to a facility reader for vehicle maintenance tracking. Such odometer tags can also be applied to automate collection of road use taxes in this age of hybrid or alternative fuel vehicles. Gone are the days when taxes that were based on fuel usage were a fair means of charging for road use. A network of readers on roadways and at fueling stations may someday be the basis for highway taxes.

Time-of-day or congestion charging has also been implemented on certain facilities, especially some high-occupancy vehicle lanes used for tolling (known as high-occupancy toll lanes). The transponder and its associated account provide the pricing mechanism to help deal with congestion using market forces.

TYPICAL TAG AND READER CAPABILITIES

For examples of classes of transponder and reader capabilities, consider rail tags (which form the basis of some toll systems) and typical read-write toll tags:

- Read-Only Rail Tags—Association of American Railroads Standard S-918: 120-bit, 13-msec read, 20/40 kHz subbit encoding for an effective data rate of 9600 baud; and
- Read–Write Toll Tags: 128 to 256 bits, triggered read 500 kbaud.

Some applications include tags for a wide variety of punishing environmental conditions:

- Waterproof external tags used on license plates or in pavements;
- High-temperature tags for coal railcar mounting, placed in a coal thaw shed for some 20 min of gas-fired burner flames to melt the ice holding the coal in the hopper car;
- Bulletproof tags using a slot antenna;
- Tire ID tags;
- Tamper-resistant tags—triggering an alarm if removed from initial authorized location; and
- Display tags.

Readers in the 902 to 928 MHz band are licensed under rules of the FCC with a maximum of 30 watts effective radiated power, inclusive of the high-gain antennas often used for defined read zone coverage. RFID antennas are commonly mounted 15 to 18 ft overhead, so that they look down at the windshield of the vehicle for superior read zone performance (excluding vehicles in adjacent lanes). Therefore, following RF level adjustments with internal or external attenuation, feed-line losses, and accounting for antenna directivity, less than 1 watt is typically radiated at the horizon.

TRENDS

RFID technologies being developed today for vehicle ID applications include the following:

- Read–write sticker tags that operate at highway speed while having no battery;

- Multimodal readers to allow upgrade to new technology while still using old tags;
- Mutual authentication of tag and reader for certain applications;
- Electronic vehicle registration stickers and license plates that include RFID;
- Vehicle mileage sensing using odometer and Global Positioning System (GPS) inputs;
- Multiple communication methods from transponders; and
- DSRC WAVE transponders for enhanced safety and data transfer applications, using IEEE 802.11p.

These technologies and the needs of the marketplace provide a fertile environment for research and development for RFID in transportation.

Making Sense of Data

DAVID BROCK
Massachusetts Institute of Technology

RFID technologies will flood organizations with huge amounts of data and information. The real issue is, what will we do with all that data? How will we interpret it and use it to make management decisions?

Each year, the amount of data collected grows in the range of 40% to 60%, and there are now more than 500 industry standards for data interchange.

The Data Center at Massachusetts Institute of Technology is seeking a method for data fusion—for integrating silos of information, or databases. Using the schema neutral “M” language under development at the center, disparate data can be integrated and converted into useful information. For example, weather forecasts can be combined with data on roadway conditions and traffic operations to provide real-time travel advisories.

The Data Center is currently preparing a proposal for the oil industry, which would allow data to be pulled apart and then fused together so as to create valuable information—without the need for changing standards.

In an earlier project, the center used wireless sensors and RFID technologies to track temperatures throughout the supply chain. The shelf life of individual “Meal, Ready-to-Eat” (MRE) containers was adjusted in real time based on temperature history and food composition.

Supply Chain–Related RFID Research and Applications

JOHN KALISKI
Cambridge Systematics, Inc., Facilitator

DAVID BROCK
Massachusetts Institute of Technology, Recorder

RFID has the potential to improve the productivity and security of the supply chain by enabling tracking of items as they move from initial supplier to ultimate consumer. RFID can provide a common framework for sharing information that can link cargo and assets ranging from vehicles to containers to pallets to individual parts. Current RFID applications in supply chain management include inventory control, electronic payment and automated transactions, access control, theft prevention, counterfeit detection, recycling and disposal management, recall management, and asset and chain of possession tracking. When integrated with roadside sensing and transportation systems, RFID also can assist with load and route optimization, regulatory screening, and security monitoring activities.

This session addressed the benefits of RFID for supply chain management, opportunities to integrate RFID with other technologies to enable real-time monitoring of product condition and security, and issues and challenges facing the users of these systems.

The session also identified future research areas related to RFID and supply chain management. Key topics for discussion included interoperability across supply chain partners, institutional and business model issues, privacy and data use, costs and benefits of deployment, and technical constraints on the use of RFID in different supply chain environments.

PRESENTATIONS

RFID technology is already being applied in specific industries. Participants in this breakout session heard several examples of those applications and then looked at a broader perspective on how to use RFID to secure the nation's freight system and improve its efficiency.

David Brock of the Massachusetts Institute of Technology presented Building a Next-Generation Information Infrastructure for Logistics. He outlined the move toward "The Internet of Things," in which nearly everything is fitted with sensors and networked. The result is that we're already seeing a 40% to 60% increase in the amount of data collected. He outlined some potential strategies and described how various data and systems could be integrated. A key issue in that integration is standards for data, data collection, and data exchange.

Ronald Char, of Johns Hopkins University Applied Physics Laboratory, presented Improving Transportation Safety and Security Using RFID. In his presentation, he suggested that RFID technologies, when deployed in conjunction with information sharing and process improvements, offer great potential to improve safety, security, and efficiency of the intermodal transport system. Without clear direction and coordination of efforts, however, there is the risk of the technologies heading in different directions, missing opportunities, duplicating efforts, and deploying incompatible solutions. He outlined how RFID is being deployed to leverage limited inspection resources to expedite the handling of legal cargo and identify potential risks, and he highlighted some of the advantages and challenges of the approach.

Ergin Erdem of North Dakota State University presented Application of RFID Technology for Quality Management in Production and Distribution of Frozen Food Products. He described applications for RFID technology coupled with sensors to monitor food quality characteristics and provide that data to management systems. He described the development of microsensors used in these applications and outlined the needs of the frozen food industry. Benefits include improved quality control (QC), tighter process control, and an early warning system for temperature fluctuations. He described main issues and challenges, as well as implementation issues.

Burkhard Englert of California State University–Long Beach presented Evaluating and Improving the Security of RFID Tags in Shipping Containers. His presentation focused on a project by the METRANS Transportation Center, a university transportation center, in collaboration with the U.S. DOT to examine the use of RFID to secure shipping containers. He described how the research fit with the Customs-Trade Partnership Against Terrorism program. Only 4,000 of 50,000 U.S. importers have applied to join the program to date. If investment in the program can also contribute to improved supply chain efficiency, the program will grow. He outlined potential approaches, as well as concerns and challenges.

Duncan Wright of Horizon Lines presented Container Tracking System for the State of Alaska. He described his company's RFID-based system for tracking containers in the Alaska trade lane. The system boosts efficiency and customer service. He described equipment and deployment challenges and outlined potential obstacles to wider deployment and use. A key concern is return on investment (ROI) for users.

Hai Zeng of the RFID Application Center at North Dakota State University presented Application of RFID Technology to Loss Management in Pharmaceutical Distribution. His presentation focused on the use of RFID technology to limit counterfeiting, theft, and diversion in this high-value industry. Potential strategies were described, including implementation at the item level. Challenges and performance characteristics were described.

DISCUSSION POINTS

During the breakout session a number of challenges were identified to RFID deployment in the supply chain. Many participants felt that a primary challenge is the lack of information on ROI in both the public and private sector. It was noted that it will be important to build a strong business case for RFID investment if the technologies are to be developed and deployed. The cost of tag and systems must also include costs for cryptography, data, algorithms, and deployment.

Most RFID applications are currently small in scale or prototypes. Information is needed to move these systems to large-scale, production-level systems at price points that will work for industry and that will work in a real-world environment. Many current systems operate in a closed-loop environment within a single company. There is not much interoperability between systems, and there is only limited public-sector infrastructure to track shipments once they leave terminals. A lack of interoperability across supply chain partners is an issue—technical and institutional hindrances will need to be overcome. A key question will be how existing public- and private-sector systems can be leveraged to incorporate RFID for tracking freight.

Privacy and customer acceptance is a growing concern, especially as industries move toward item-level tagging. Security of tags, including protecting data from attack, counterfeiting, and theft, is an issue.

POTENTIAL RESEARCH

Participants discussed how ROI could be determined. How could ROI be extrapolated from current prototype applications? How can we determine and measure all of the benefits from implementing RFID systems?

The next generation of RFID technology is under development. What capabilities should be integrated into these products? At the same time, how can RFID technologies be produced at low cost while being tamperproof, weatherproof, rugged, and long-lasting? What is the trade-off between quality, capability, and cost?

How can RFID be linked to existing infrastructure? Can the existing investment in weigh stations, road and weather stations, and other features be leveraged by integrating RFID technology? How can RFID deployment in the supply chain be optimized by linking to other sources of data?

Considerable time was spent discussing the feasibility of developing an RFID architecture in the supply chain. Can standards be developed? In what areas? Is it possible to get supply chain partners to work together in this area? What has been learned from the national intelligent transportation system (ITS) architecture effort that could be applied in the supply chain?

The shift toward item-level tagging poses additional technical issues, as well as concerns over privacy and disposal.

BREAKOUT SESSION

Construction Transportation–Related RFID Research and Applications

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CARL HAAS
University of Kentucky, Facilitator

PAUL GOODRUM
University of Kentucky, Recorder

The objective of the breakout session was to talk about RFID applications in construction. The session included an overview (goals and objectives), presentations, dialogue, and development of a research problem statement. The goal was not only to inform, but also to develop a dialogue and increase communication among researchers and identify research areas.

PRESENTATIONS

The first presentation, RFID and GPS Applications for Asphalt Construction, was delivered by Amr Oloufa, University of Central Florida.

- Asphalt quality can be measured by density. In practice, the quality is measured by the number of passes by a compactor. If there are too many passes, the aggregate can be crushed, reducing the quality of the asphalt cement concrete. Too few passes is another obvious problem.
- Traditional density measuring using nuclear density gauges represents more of a point measurement—is it really reflective of the true quality?
- How can you ensure the correct number of density tests has been done?
- Research is being conducted in which asphalt compactors are augmented with sensors and GPS devices so as to be able to record the location of the tests.
- The compaction tracking system used an interface using different colors to represent the number of passes experienced by different sections of the asphalt pavement.
- RFID is being proposed to be able to track the batching and placement of specific truck loads of asphalt concrete. This information could then be integrated into the compaction tracking system to record the number of passes that were applied to each section of asphalt pavement.
- Issues:
  - A question was asked about the use of inertial navigation systems to replace the use of GPS, but the costs of inertial navigation systems are still significant.
  - The systems have a goal of accuracy within 2 cm. It was discussed whether that level of accuracy was necessary, and what level of accuracy is required for successful

industry implementation. This is an issue that researchers have struggled with for some time.

A brief was provided by Charles Schwartz, University of Maryland, regarding marrying pavement performance data with location data and material property data.

- In the past, one would find a problem with a material property data after it had been installed, but he or she would have no idea on where the material had actually been installed. An example was given describing the batching, testing, and installation of asphalt materials.
- Researchers at the University of Maryland are investigating whether RFID technology could be used to record data regarding the material property and then whether that data could be embedded on a tag in the asphalt so that it can be successfully read and located.
- Issues:
  - How thick of a pavement can a tag be read through?
  - Research has been done at the University of Texas (UT) at Austin on embedding RFID tags in concrete structures. Sharon Wood in UT–Civil Engineering is a contact for that research.

Automated Tracking of and Capturing Information Related to Engineering-to-Order Products Using RFID and GPS was presented by Burcu Akinci, Carnegie Mellon University.

- The objective of the research is to understand how RFID and GPS technologies can be used to track the production history of engineered-to-order components.
- Barcode and manual material tracking is ineffective and inefficient.
- Can the technology be able to provide Level 1 Intelligence, which includes unique ID (UID) and capability of communicating its status and the ability to store data about itself?
- The research targeted manufacturing, construction, and operation and maintenance of the components.
- Field tests were conducted at a concrete double-tee storage yard. The storage yard was already equipped with a wireless network and barcode network; the yard would typically scan the component and then scan the grid to store the data on storage location.
- The field trials investigated passive and active UHF systems.
- For the passive case, antennae (base station readers) were placed on the cabin of the crane operator and the boom. Read ranges were experienced from 3 to 20 ft. In 90% of the cases, the tags could be read within 5 ft, and the reliability range would decrease at distances farther out.
- For the active tags, the reliable read range increased to 20 to 25 ft. If the tags were on the opposite side of concrete component, the read range decreased by 20%.
- In another field trial, the tags were stored on firewalls to examine their use for storing maintenance data. The time reads were successful on the first attempt 95% of the time. The read range was still less than advertised. While the signal strength is unreliable, there does appear to be some possibility of using it for tracking direction and distance to the tag.
- Issues:
  - How do you know which reader is reading which tag? How do you have positive ID?

- Battery-life is a significant issue regarding the tagging of components that you are going to track for many years. How long will the batteries really last?

RFID Reliability Test for Tool Tracking on Construction Sites was presented by Julian Kang, who had worked on a prototype to help identify the location of tools.

- Foremen tend to hoard tools to avoid running short of tools, even though this is not the most efficient practice from a project management aspect.
- Traditional tool management practices utilize tool rooms where tools are issued to the crews and records are based on barcodes.
  - The problem with bar codes is that they require line of sight. RFID tags do not require line of sight.
  - Barcodes must be attached to the surface of the marked item and aligned. RFID tags can be placed inside the tool casing.
  - Bar codes carry limited amount of data (usually measured in bytes), whereas RFID tags can carry kilobytes worth of data.
  - It is difficult to identify how frequently tools are utilized after they are checked out, but RFID can potentially be used to identify underutilized tools.
  - How far down the chain of tools do you worry about tagging? For example, you may want to tag hammer drills and reciprocating saws that cost hundreds of dollars, but the economics probably do not justify tagging handheld screwdrivers and hammers.
- The research proposed two automation options:
  - A portal system. Tagged tools with RFID devices are detected automatically when the crews carry the tools through the portal.
  - A gang box with a reader to identify which tagged tools are inside the box. The test was more successful when the lid of the gang box was closed versus open. When the lid was closed, all of the reads were successful (210 successes out of 210 attempts). With the lid open, 206 out of 210 attempts were successful.
- General conclusion: Reliability of RFID technology is high when the tools are stationary and the effect of metal on radio waves is negligible.
- Further investigation is needed to understand the sensitivity of the results.

Tool Tracking was presented by Paul Goodrum, University of Kentucky. The research examined the use of active RFID for tracking tools at construction job sites.

- Reliable read ranges of 3.5 to 10 m were observed on tags embedded inside hand tools that were used by construction crews over 4 months.
- The performance of the tags was not affected by the heat or the electromagnetic waves produced by the power tools’ motors.
- The read ranges of the tags were degraded by prolonged exposure to cold temperature. The research observed this on construction job sites and confirmed it in laboratory conditions.
- One current limitation to the technology is the lack of direction and distance data from the reader to the tags.

Models for Locating RFID Nodes was presented by Carl Haas, University of Waterloo. The research examined how to go the next step with using RFID by identifying a tag's three-dimensional location on a job site. He discussed a set of classifications for RFID location models.

- Manual searching and mapping: Drop and map the location, and return to the last known location.
- Triangulation based on transmission space: Computes the position of an object by inferring its distance from multiple reference points with known locations, depending on whether ranges or angles relative to reference points are being inferred.
- Proximity models for localizing RFID nodes, to determine whether an object is near one or more known locations:
  - The location process uses the method of constraints.
  - The research did find that there was a correlation between strength of signal and approximation of the location space.
  - The research successfully used the Dempster-Shafer method for locating the tags. An alternative approach would have used fuzzy logic.

ISSUES FOR DISCUSSION

Following completion of the presentations, the breakout focused on the following discussion issues:

- What do you see as key RFID applications having the greatest potential for improving construction processes?
- What research is necessary?

The following applications were identified:

- Tracking and recording information about a project throughout a life cycle:
  - QC, quantities, location, material properties, received or shipped status.
  - Getting information about the asphalt application.
  - Recording the components installed on a site (e.g., bridge).
  - Cradle-to-grave information.
- Embedding RFID tags in materials:
  - To be able to supply information for future inspection. The embedded tag should also be used to record certification of material
  - To be able to monitor the integrity of reinforcement steel that is installed in place. This information should be able to be used in forensics studies after failure of an area.
  - To store the origin, material, and delivery information for bulk commodities.
- Being able to record the production of construction equipment:
  - Can we use RFID to verify that all the equipment is being used? To provide information on heavy equipment utilization and location? To be able to verify that equipment is actually on a job site as claimed by the contractor?
  - Can it be used to estimate productivity?

- Use RFID to stage the order of the commodities:
  - How can RFID be used to change the mindset of the organization of a storage yard?
  - Track bulk commodities by removing the use of paper tickets onsite within the project limits.
- Merging RFID location with design information and plans:
  - For control,
  - For inspection, and
  - For quantity tracking.
- Supply chain tracking for critical components, such as long-distance material tracking.
- Understanding the accuracy and precision of RFID:
  - Technical performance issues.
  - What accuracy is needed to make the technology feasible?
  - Understanding the risk and reliability of power sources for active RFID.
- A synthesis to identify RFID technologies that might be useful:
  - What are the gaps in construction?
  - What are the existing commercial applications and existing and previous research efforts?

Several cross-cutting issues were discussed, including

- Merging RFID location with design information and plans for control, inspecting, quality tracking.
- What to do with all the data? How do you make the data elements useful information?
- How do we specify and design a RFID system for different applications?
- How do we develop performance specifications for RFID systems?
- How can we use RFID technology and other technology sensors to detect and identify out-of-bound parameters?

RESEARCH OPPORTUNITIES

From these discussions, three suggestions for research problem statements emerged.

1. A synthesis of RFID technologies that might be useful. This project will explore the existing commercial applications and existing and previous research efforts and identify gaps in the technology.
2. An investigation of how RFID can be used to track project information throughout its life-cycle (providing cradle-to-grave information using RFID).
   - QC, quantities, material properties, location.
   - Embedding RFID tags in materials to assist with future inspections. Embedded tags should be able to store information about the material's origin, properties, and certification. Includes supply chain tracking for critical components.
   - Includes the concept of merging RFID location and design information with the plans for more efficient project control, inspection and quantity tracking.

- Issues such as understanding the accuracy and precision requirements for each activity will need to be considered (technical performance issues, what accuracy is needed to make the technology feasible, understanding the risk and reliability of power sources for active tags).
- How does one specify and design an RFID system for different applications?

3. An investigation of how RFID can be used to improve productivity of equipment during construction. Can we use RFID to verify that all of the equipment is being used? Can we provide equipment utilization and location information in order to be able to verify that equipment is actually on a job site as claimed by the contractor?

RFID Applications in Transportation Operations, Safety, and Security

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RFID is currently used for transportation operations such as electronic toll and traffic management, AVI and location in rail and public transit, and commercial vehicle mainline clearance. More recent applications include using RFID as a component of tracking, monitoring, and reporting systems to secure the shipping of hazardous materials, secure ports, and aid in customs and border crossings. Research is also ongoing in safety applications such as using RFID for tire recall, automotive collision avoidance, and traveler information systems.

This session addressed innovative research and challenges for RFID use in transportation operations, safety, and security applications. In addition, issues in implementing information security, such as authentication, data privacy, and data integrity to properly secure these applications against any potential threats that may disrupt their use, were addressed.

SESSION GOALS

The goals of this breakout session were to

1. Inform government agencies about current and potential RFID research and applications in transportation operations, safety, and security;
2. Give government program managers a better understanding of UTC programs and link those interested in RFID applications with university experts;
3. Discuss potential benefits of new RFID applications for improving transportation operations, safety, and security;
4. Identify key issues and challenges impacting the future of RFID use in transportation; and
5. Identify research opportunities and formulate research problem statements.

PRESENTATIONS

To accomplish the goals, the breakout session was centered on four presentations that served as points of departure for discussion. We wanted to identify new applications in operations, safety, and security; engender a discussion of technical challenges or barriers to overcome before either existing or new applications can be implemented; and brainstorm on research opportunities.

Richard Begley of the Rahall Transportation Institute at Marshall University presented The Development of Autonomous Railcar Tracking Technology Using Railroad Industry Radio Frequencies. An overview of the newly funded project for automatic railcar tracking was described. In that project, rail cars' locations are continuously available using GPS and a proprietary power source that uses the motion of the railcar to charge a battery. The aim is that economic gains may be realized through better asset utilization.

The first comment was directed at data fusion with existing trackside readers that read information about a railcar as it passes fixed points. Begley pointed out that there are data quality issues associated with that data. Also, the data from existing systems are only accurate at the moment they are read. After that, car locations and loads shift frequently, and data usefulness can degrade rapidly. The railroad industry is aware of the shortcomings of the existing system and can see a definite ROI in a car-specific database. In addition, this new system could be adapted to other modes. Finally, it was observed that such an application could not be a trackside system; the devices must be onboard the railcars.

An observation of the proposed system was that unless every car is equipped with the new system, the advantage of the new system over the existing automatic vehicle location systems is limited. Begley assured the audience that the desire is for every car to be equipped. In this manner a business case can be made to eliminate 2200 jobs that currently relate to tracking data and resolving interchange fees.

The issue of involvement of RFID in this application arose. Was security an issue? Begley stated that security was an issue and was being addressed. A major crossover point for this application will be using the railroad industry RF, which is currently under redesign by the railroad industry. Regarding security, industry shipment data would be minimal, and the risk associated with some data falling into the wrong hands would be minimal when compared with the improvements in shipment visibility, data collection, and accuracy.

The next presentation was by Kelvin Wang of the University of Arkansas, who made a presentation on Potential Application of RFID in Road Asset Management. In this study, Wang described a road sign asset management system, in which a roadside sign's location, type, size, height, and condition are noted and encoded onto passive RFID tags placed on the sign. Readers would be located in official vehicles to query the signs and to encode sign condition. Issues to be dealt with include higher speed reading of tags, tag energy source, tag integration and miniaturization, and securing suitable off-the-shelf components.

Wang, in response to a question of why data were put on the tag rather than held in a remote database, said that this option was being evaluated as a function of the passive tag. He further agreed that the metal backing of the sign could pose a problem with tag antenna design. During the discussion, it was stated that in this case the reader is moving rapidly past the tag, as opposed to current systems in which the reader is more or less stationary relative to the tags. It was also postulated by another in the audience that active tags are more accurate than passive, which is why passive tags are not used for tolls. This was quickly refuted by another discussant who pointed out that Texas collects tolls using passive tags.

Other issues that were discussed included whether sign obstruction due to foliage or ID of signs that were knocked down could be addressed with this. Wang stated that this might be possible, but was beyond the scope of the study. Also, the potential for use of RFID for management of other roadside assets, such as control box inventory, was also thought to be good, but beyond the scope of the present study. However, he did plan on looking at tag power sources in cases where the tag may have to last for about 10 years.

Finally, there was a lively discussion about the potential of this system to be used in an in-vehicle signing system. The need for data standards was put forward, as was the need for data authentication. The use of tags in the traveled lane or in the lane markings was seen as providing minute control information to the vehicle, allowing system knowledge of vehicle location in the lane, both latitudinal and longitudinal. Moreover, such information would be key in vehicle lane departure warning, vehicle collision avoidance, and parking management systems, to name a few.

The third presentation was by Amr Oloufa of the Center for Advanced Transportation at the University of Central Florida. His presentation was titled “CVROCS Research.” The abbreviation in the title stands for commercial vehicle remotely operated compliance stations and describes a system that utilizes an array of different sensors for weigh in motion, oversize/weight monitoring, hazardous materials compliance, brake adjustment, and many other aspects involved in monitoring commercial vehicle compliance with regulations. Such systems could be used as precursors to requiring a commercial vehicle to stop at or bypass a staffed weigh station and as a means for monitoring weigh station bypass routes. RFID devices were identified as having the potential for identifying specific commercial vehicles, commercial vehicle companies, security at restricted areas, and origin-destinations of runs. Other potential applications lie in developing RFID sensors that can provide more data on safety and regulatory features of commercial vehicles, such as is currently done by tire pressure monitoring devices. Such applications could include brake and tire temperature, load securement and shifting, axle load bearing, and many others. Much of this depends on research into RFID and sensor integration.

The fourth and final presentation was made by Robert Harrison of the Center for Transportation Research at the University of Texas at Austin and Gary Becker of the U.S. Department of Homeland Security (DHS). Their presentation, RFID at the Southern Border: Operations, Safety and Security, focused on the use of RFID technology at point of entry locations along the Mexico–United States border.

The demands of the North American Free Trade Agreement are being pitted against a border crossing system that does not function very well. Existing attempts to monitor visitors to the United States and their return to Mexico are not working well enough. Systems must be shown to provide benefits to the users; however, the users may not be those directly involved in tags and readers. In one application, credentialing vehicles and containers could have a huge impact on safety and security. In another pilot test application, visitors to the United States applied for and received electronic ID tags that provided them access to the United States and monitored their return to Mexico. In this pilot test, it was shown that using the ID tag system did not increase the time it took to process an individual seeking entrance to the United States, but it did offer the potential (not measured in this study) to provide better security by giving DHS the knowledge of who had entered the United States and whether they had departed yet.

At issue also in this pilot study were data standards, data authentication, multiple users having confidence in the data, ROI and revenue stream, and standards for compliance testing and certification. The ensuing discussion also revealed two other major issues highlighted by this presentation: application of RFID technology may mean reengineering of entire facilities and processes; and RFID technology has the potential for providing system performance measures, such as in freight movement.

SUMMARY

Incorporating RFID can result in reengineering of facilities and processes. This would have implications for staff training needs for the new processes. However, the realization of value in RFID systems lies in system integration and data sharing. It was noted that this would necessitate multiple agreements for database sharing, as well as standards to instill confidence in data that are required across agencies. Finally, and very important, it must be remembered that RFID is not an end in itself, but is an enabler of decision making, performance measurement, and system evaluation within the context of a much larger system that is often integrated with other technologies, such as sensors, data fusion, communications, and geographical information systems.

Typical impacts of RFID technology on mobility of freight and people were evidenced in the presentations. For example, the U.S. Visit program, as described in the fourth presentation, includes the potential for increasing national security, while the RFID technology allows this to be done with no significant delays at the border. The third presentation, involving in-line weigh-in-motion stations, proposed that RFID can improve regulatory compliance and provide origin-destination information and other system performance metrics.

It seems that the key issue affecting the use of RFID technology is cost. Many participants noted that the area of demonstrating ROI in a public-sector application continues to be a burden. In addition, new application designs involving the lifetime of the item being tagged, the material being tagged, and the environment in which it will operate also dominate discussions. Other issues are data standards, data verification, component interoperability certification, data validation, location precision, and data authentication. Finally, future implementations will have to look at deployment and transition strategies: start small and expand, geographical phasing, all at once, etc. Again, cost may well be the key determining factor.

The key research issues highlighted in the breakout session were as follows:

- How to power tags on items with long lifetimes;
- Determining the system design and installation techniques required for reading and maintaining tags in installations such as road signs and in pavement;
- Determining likely performance characteristics in harsh environments;
- Evaluation and certification of product sets now and in the future so that capabilities and limits are known for new applications; and
- Using RFID for object location determination within an acceptable precision for the application (e.g., vehicle location within a lane, stop sign location at an intersection).

Policy and Institutional Issues for RFID Deployment

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Policy and institutional issues hold an important place in the RFID domain. Institutional issues in RFID deployment generally fall into at least three broad categories: jurisdictional, organizational, and behavioral.

Jurisdictional issues are those that require collaboration across governmental or corporate boundaries. In the domain of RFID, jurisdictional issues include intergovernmental and public-private cooperation about matters of data ownership, technical standards, and financial accountability and clearance of funds.

Organizational issues relate to the capacity of the entities involved in the RFID system, such as adequate personnel, financial resources, and procurement capabilities. Behavioral issues are those relating to the behavior of system users and, in the case of RFID, include data privacy, public acceptance, and security from tampering or sabotage.

Policy and institutional issues play an important role in RFID deployment, because the success of any technology's widespread use cannot be separate from the sufficient and appropriate policy and institutional support.

Two presentations provided an introduction to policy and institutional issues. Tom Marchessault of RITA presented Policy and Institutional Issues for U.S. DOT on Using RFID Technologies in Transportation. Oscar Franzese of the Oak Ridge National Laboratory presented RFID Interoperability: Barriers and Solutions.

Four aspects of policy and institutional issues were discussed in the breakout session: standards, privacy, the role of U.S. DOT, and data ownership.

STANDARDS

Several group members, especially those directly involved with the RFID industry, strongly supported the introduction of standards—at least minimum-level standards, which are necessary to create a level playing field. While many participants acknowledged that standardization without a prior adequate analysis may raise problems for the introduction of new technologies or dissemination of existing technologies, many also felt that a minimum level of harmonization and regulatory direction is better than no standards at all. RFID standards can help promote business opportunities and competition.

In this vein, the following questions have been asked and several research directions have been recommended:

- What is the required level or minimum level necessary to create a level playing field? At what point might it affect creativity and competitiveness?
- Is there a need for international harmonization?
- What is the life cycle of standards (initial development, maintenance, retirement)?
- What are the costs of bad standards?

Possible research includes the following.

- Conduct an analytical review of RFID applications and standards being used in a transportation context.
- Current players' status: U.S. DOT's role [FAA, Joint Program Office (JPO), FRA] in RFID-related activities.
- U.S. DOT programs on RFID. The use of RFID technology is application-specific. Is there a need for an office to develop relevant standards? FAA has three or four RFID applications they support. National Highway Traffic Safety Administration, FRA, and Federal Motor Carrier Safety Administration each support separate RFID standards. What standards exist in a transportation environment by mode? Who is doing what and where? What could be the benefits and costs of standards use?
- Harmonize standards internationally. Review the extent of harmonization and dissonance, as well as their consequences.
- Conduct case studies on the tradeoffs of standard implementation; consider the timing and flow of benefits, as well as the cost of premature standards.
- Standards can promote business cooperation and competition. Nevertheless, the industry usually needs many years to set up and develop the proper standards. If technology deployment is held until standards are systematically set up, a lot of benefits are irretrievably lost. Such foregone cost could be huge.
- Consider models and lessons from other industries (mobile phone technologies, weather data, crash data, etc.).
- Weather data often include some issues on data collection by government, data ownership, and the permission to distribute the data. Aviation application has one set of arrangements, while nonaviation application has another one.

PRIVACY ISSUES

Privacy issues are an important institutional concern related to RFID use. The group identified three categories of attitudes towards privacy: privacy "hawks," privacy "pragmatists," and those who are indifferent. It is important to analyze which is the central tendency of people's attitude toward RFID privacy issues before acting to regulate. Commentators pointed out that transparency in collecting information is vital for ensuring privacy. Some sort of protocol, if not standards, may be needed with respect to privacy issues/anonymity in data collection, ownership, and dissemination.

The following research activities were suggested.

- Review best practices on RFID privacy, both domestically and internationally, including ITS America's Privacy Principles.
- Assess the potential benefits from RFID use vs. privacy concerns.

- Conduct a well-designed, broad coverage, representative survey of attitudes about privacy and perceptions of RFID benefits and risks; develop an adequate statistical analysis of survey data and interpretation of results with policy recommendations.
- Determine the appropriate educational role for the government in RFID-related privacy issues.
- Establish procedures for access and ownership of RFID information.

WHICH INSTITUTION IS THE MOST APPROPRIATE TO PROMOTE AND COORDINATE RFID-RELATED ISSUES?

Some members of the group suggested that U.S. DOT could be an effective champion for RFID issues. Multiple RFID activities within U.S. DOT are currently ongoing in an uncoordinated manner (FRA, FAA, FHWA–JPO).

The group discussed the conditions under which U.S. DOT could play such a role. Capability issues, such as personnel availability and qualifications within U.S. DOT and across government, have been mentioned in this respect. Again, standard practices were invoked: some privacy and security issues can be solved by standardizing or coordinating business practices. Many in the group felt there is also a strong need for an independent validation and verification (IV&V) of RFID-related risks and benefits and that universities can play an important role in this direction.

Several research questions and topics have been suggested as follows:

- What is the potential impact of improved RFID use on the mobility of people and freight? What impact do RFID technologies have on congestion?
- How can RFID technologies be harnessed to further DOT priorities? What are the implications for DOT not taking a leadership role in RFID for transportation?
- What standard practices could U.S. DOT promote to improve RFID benefits?
- U.S. DOT could support professional capacity development, for both training and education components, on the use of RFID in transportation.
- Develop a procedure for independent verification and validation.

DATA ACCESS AND OWNERSHIP

Data ownership has become an issue in several ITS and RFID-related projects. An important question is, who owns the data collected from RFID systems? Negotiating data ownership after-the-fact is very difficult. Organizing a partnership at the very beginning of an RFID effort is much better than any remedy after the fact.

The following research topics have been recommended:

- Conduct a survey of data access and ownership issues in RFID, legal standards, and standard procedures. Establish law enforcement requirements for access, as well as Freedom of Information Act requirements.
- Determine what the legal requirements are for archiving data.
- Evaluate the impact of public-private partnerships on data ownership.
- Conduct case studies of data ownership in other industries.

PANEL DISCUSSION

Future Directions in RFID Applications and Research in Transportation

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RICK KESSLER
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Federal Highway Administration

RON CHAR
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The panel addressed several issues that had been raised during the conference breakout sessions:

IMPLEMENTATION ISSUES

- How do you move from limited to wide-scale deployment of RFID?
- How do we develop a business case for RFID development?
- What are the prices and capabilities of RFID systems in the future?
- How do you convert to an RFID system?

STANDARDS

- To what degree are RFID standards required to achieve RFID interoperability and global deployment?
- How should standards compliance and interoperability certification be performed, and who should administer the process? Who should take the lead on the development of IV&V?

PRIVACY

- How do you address RFID privacy concerns?

- Who should own RFID data? How does data ownership limit or expand the potential benefits of RFID transportation?

ROLE OF GOVERNMENT

- What is the role of the federal government in the future of RFID?
- How can RFID be used to promote U.S. DOT's goal of congestion reduction?
- How do we increase RFID professional capacity in transportation?
- Does the onset of the vehicle infrastructure integration (VII) program limit the potential role of RFID in transportation?

IMPLEMENTATION

Kessler said that the deployment of RFID technologies at Horizon Lines was driven by the company's business need to "get data quicker," so that they could react to it. For example, finding the location of an empty container can be a challenge. A container might be emptied of its contents at 8 a.m., but the tracking system might not be updated until 3 p.m.—which would mean that the container would sit empty and unused the better part of the day. With RFID, the company knows when a container enters the gate and thus can easily locate an empty container. You get a lot of data with RFID, but you have to have a framework and the business processes in place to handle it.

At Horizon, the business case is determined by the expected ROI. For example, there are huge returns to be gained by eliminating empty moves and gaining visibility in the supply chain. Horizon's customers are also making a business case for RFID, as better real-time information will allow them to reduce their inventory. Moving from limited to wide-scale deployment is done in "baby steps," said Kessler.

Shippers spend billions of dollars on order management systems and internal inventory tracking, but those systems are ineffective without reliable data on container status. Customers of shipping companies are also making a business case for real-time data so that they can reduce their inventory levels.

As part of Horizon's Seattle-Alaska RFID project, RFID readers have been installed on the Alaskan Highway, allowing containers to be tracked in real time. The challenge now, said Kessler, is to figure out how to implement the technology on roads in the Lower 48, to complement what is being done in Alaska.

RFID's capabilities, said Kessler, are "way ahead" of what industry is ready for it to do. Tags currently contain only an ID number; eventually, businesses will want to include manifest and other information on the tag. Early adopters will willingly pay more for the technology, but as more companies adopt the technology, the prices should come down.

Order said that, in some respects, U.S. DOT is also a user of RFID, if DSRC are considered RFID. For example, DSRC is used in U.S. DOT's CVISN program, which is designed to help facilitate the regulatory process for truck safety, as well as in the VII program, which involves installing devices that allow vehicles to communicate with each other to avoid crashes at intersections.

To move to wider scale deployment, Onder said there is need for an architecture that will tell you what data are available and what data are needed.

Onder said that truckers do not necessarily see a return on any investment in RFID. There is need for a strong business case that will clearly show how investments in RFID technologies will generate savings in time and costs for trucking companies.

He cautioned that one impediment to widespread deployment might be that there are already sufficient tools for tracking goods and assets. He cited the example of United Brands, in Columbus, Ohio, which manufactures goods in China and ships those goods through Hong Kong to Columbus. United Brands has good, solid data that provides visibility of their goods throughout the supply chain, without the need for wireless communications.

Char said that widespread deployment of RFID will ultimately be up to the private sector, but companies will need help developing a business case that they can take to management. Companies understand how to move goods and containers very efficiently, but they need help deciphering the various sales pitches they hear from vendors offering RFID technologies. One of the difficulties to building a business case is that the benefits do not always accrue to those bearing the costs. Char said that it can be hard to quantify specific time savings and other benefits from RFID, despite the studies that have shown large benefits from deployment of RFID.

Donath pointed out that DSRC, which is another medium for wireless communications, is not an RFID technology. He said that the architecture and protocols that U.S. DOT is developing for DSRC (802.11p) are based on GPS. GPS cannot, however, provide lane-level positioning in urban areas. Only RFID can enable that kind of real-time, lane-level positioning.

Donath said that research should focus first on developing a better definition of RFID. The next focus should be on developing a science and taxonomy of RFID systems that is in the public domain.

RFID applications to date have been dominated by supply chain logistics and asset and inventory management, and thus have rightly focused on efficiency, which has been the interest of the private sector, said Donath. But now we need to focus on the public sector—how to improve safety and improve congestion on our roadway. That’s where Donath believes U.S. DOT should be focusing its attention.

Kessler added that the Horizon Group is moving forward with RFID deployment not because the DOD and Wal-Mart say so, but because the company can see the benefits of the technology and thus are committed to becoming early adopters of it.

In distinguishing between DSRC and RFID, Onder said it appears that DSRC primarily applies to vehicle-to-roadside communications, while RFID is increasingly being used to track packages.

Char said that before getting to a mandate situation, you need to be certain that the system works. Stating that RFID is still in the infancy stage, he stressed the need to start with an incentive. Once there is a proven record of success and a critical mass of users, a mandate might then be appropriate.

Donath called for well-designed, field operational tests that demonstrate the utility and effectiveness of the systems. He said that is where we will learn if they work and if they are cost effective. If the technology can be proven effective in improving safety and congestion mitigation, then people will opt in voluntarily, as they did with EZ-Pass.

STANDARDS

Standards are dictated by what the market will accept, said Kessler. First, early adopters will accept some of the RFID tags and readers that are out there, and sooner or later the masses will accept them, at which point they will become the standard. If Horizon had waited for the "right" standard, Kessler said the company would not have moved ahead with RFID. If Horizon's tags no longer work in 2 or 3 years or they are no longer the best thing out there, Kessler said "it's just a tag—we'll just put a new tag on." What is important is how the company uses the information gleaned from the RFID system—that information is the value that the tags add to the overall process and to the business. Kessler said he expects the mechanism used for moving the data back and forth to change in the next 3 to 4 years.

Onder said that standards help keep the price of a product or device low and stimulate business. But patents can be an obstacle, causing costs to rise. He questioned what the role of government should be in standards development. He believes industry should develop the standard, as industry is making the product, selling it, and so forth. Should the government be a facilitator for standards development? For the most part, standards are important for interoperability, especially in transportation, not only in the United States, but in North America.

Char said that standards are needed. As with any technology, a large number of vendors have developed their systems using proprietary technologies, which helps them carve out market share. Because these technologies are not interoperable, they will not be sustainable. The system will eventually consolidate, but to what, he questioned. A single standard? Multiple standards? A formal ISO standard? A de facto standard?

Donath said that performance standards are needed, not standards that get into the details of how to build tags or readers. Such standards would spell out the performance or quality of service, so that users would know what to expect when they buy the devices.

PRIVACY

Donath said data security should be considered along with privacy. There are some simple ways of handling privacy that don't involve sophisticated encryption. The privacy guidelines for using RFID should be no different than guidelines for other types of applications, such as for the GPS. The application should drive how much privacy you build into it. As an example, he cited the concern that an RFID tag in a passport would be able to be read by anyone passing by. There clearly needs to be a mechanism for preventing inadvertent or intentional data capture by other readers. He cited several concerns from "The Limits of Privacy," by Amitai Etzioni, including the need for accountability, identifying the purpose at the time of data collection, informed consent; limited retention of data, accurate and complete data, security, and individual access to data.

Donath questioned whether the data would be admissible as evidence in court. There are lots of institutional and legal issues related to the use of the data. Will the data be released in some sort of anonymous form? Are the data accessible to police investigators? To insurance companies? What about the transparency of the process—do we all know what is going on? Who owns the data? Can we trust the government? Is government going to be the protector of privacy? Or do we need an outside agency to be responsible for this?

Char said that often when we hear about problems with privacy issues, it is really because people are surprised. For example, drivers who rent cars and take them into Mexico, in conflict with the terms of the rental agreement, are often surprised to find that the rental company is aware, through GPS technology, that they have driven the car across the border. Char said that we need to think about the level of privacy required *now*—before RFID tags are commonplace. He also cautioned that we need to recognize that the data will be readily available to anyone with an RFID reader.

Onder said that ETC systems, which record where you've been, and when, were one of the first uses of RFID. Data collected by ETC systems have already been shared with law enforcement agencies. He suggested this may be an area for research and for policy development. Some uses may be negotiable at the time the system is being developed.

Kessler said privacy is a big concern to trucking companies, who worry about competitors acquiring information from their company's RFID tags. He pointed out that the data will be of no use to competitors, as it is limited to the container ID number. His company uses the tag data from its containers to drive business practices and change business behaviors. For example, by tracking the progress of a container, a company can monitor the speed of a truck. The tag thus improves in-transit visibility.

ROLE OF GOVERNMENT

Donath called for all 50-plus DOTs to become involved and to work together on RFID implementation. All the federal government can do is develop the standards and use the carrot or the stick to get the DOTs to deploy the technology and improve safety. He said that the basic role of government is to ensure that things really work and that the public is protected from "snake oil" salespeople. Someone needs to develop the standards and tell us what we need and don't need. We expect government to support the research and to support improvements in safety.

Char said that U.S. DOT has a key role in RFID research and in providing the resources for research and for pilot projects. U.S. DOT can also provide a neutral ground for discussions about privacy and other issues. He stressed the need to recognize this not a U.S.-only technology; it is global, with all kinds of international implications. The federal government is the appropriate entity to negotiate with the European Union and others in setting standards and policies.

Onder agreed that research is needed to better understand what the devices are capable of doing. There are at least four administrations within U.S. DOT that have projects involving RFID and wireless data capture devices. For example, FRA is involved in RFID, as RFID tags are affixed to all the rolling stock in the United States. U.S. DOT is thus a stakeholder in some respects, he pointed out, and should play a role in standardization coordination.

Onder said that there is an interagency RFID council under the auspices of DOD. The growing trend for federal agencies to work together on RFID is a good thing, as it gets agencies to look beyond their area of responsibility and to become aware of what other agencies and organizations are doing. Onder suggested an interagency council would be helpful in finding ways to reduce the impact on those organizations that have to be compliant with standards and regulations.

Kessler said funding of research is an import role for government, as is the enforcement of standards. Government should guide industry so as to avoid reinventing the wheel. Trying to set standards across all states is a challenge, and whatever the government can do in that aspect would be good, he said.

In response to a question posed about how RFID might be used to accurately count the number of people in a vehicle, Onder suggested that this could be the basis for a research problem statement.

A Wireless Local Positioning System for Road Safety

SEYED (REZA) ZEKAVAT
Michigan Technological University

In 1998 U.S. DOT announced the intelligent vehicle initiative. Eight areas were identified where intelligent systems could improve or impact safety, including four kinds of collision avoidance (rear end, lane change and merge, road departure, and intersection), two kinds of enhancements (vision and vehicle stability), and two kinds of monitoring systems (driver condition and driver distraction). Wireless systems capable of positioning vehicles remotely in complex mobile environments have promising applications in traffic safety, such as vehicle-to-vehicle (V2V) and vehicle-to-pedestrian collision avoidance systems.

This paper introduces a novel wireless local positioning system (WLPS) recently patented at Michigan Technological University. The research is being supported by the National Science Foundation's Information Technology Research for National Priorities. The proposed WLPS is categorized as an RFID system with two main components: a base station deployed in a mobile unit (e.g., vehicle), which serves as a dynamic base station (DBS); and a transponder (TRX) installed in wireless mobile handheld units and vehicles that act as *active targets*. UID codes are assigned to each TRX. DBS transmits periodic ID request signals in its coverage area. Transponders reply to ID request signals as soon as they detect them. Such a framework offers several attractive features: high probability-of-detection performance via active, as opposed to passive, targets; low-cost TRX made of simple transceivers; and infrastructure-less operation via dynamic, as opposed to static, base stations.

This poster sketches a futuristic view of mobile ad hoc network-based transportation infrastructure and WLPS potential applications in road safety and the automotive industry. Theoretical and practical research is ongoing (*1–5*). A system prototype is under development at the Wireless Positioning Lab at Michigan Tech (http://www.ece.mtu.edu/pages/research_labs/wlps/index.html).

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POSTER SESSION

RFID and GPS Applications for Asphalt Compaction

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H. MAHGOUB
South Dakota State University

OBJECTIVE

Monitoring and documenting the interface between production and the laying and compacting operations of hot-mix asphalt concrete.

BRIEF DESCRIPTION

In the Florida Quality Control (QC) Specification, the contractor is required to perform QC testing, and Florida Department of Transportation (DOT) is responsible for quality assurance. Loss of quantitative information between paving operations and the asphalt mixing plant, coupled with delivery location errors, led to the need for an automated system that can accomplish the following:

- Collect all mix information from the plant QC system.
- Transfer the information automatically to a tag mounted on the truck headed for the paving site, along with the batch of material.
- Transfer this information once on site to the paver information system.
- Locate and date the information along the road at the particular place where the corresponding material has been laid.

Agency Involved: Florida DOT

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Key Element of Success: Long-term evaluation of asphalt longevity.

POSTER SESSION

Evaluating and Improving the Security of RFID Tags in Shipping Containers

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The METRANS Transportation Center is a U.S. DOT UTC. Established in 1998 through the Transportation Equity Act for the 21st Century, METRANS is a joint partnership of the University of Southern California and California State University, Long Beach.

DESCRIPTION AND OBJECTIVES OF PROJECT

Recently there has been considerable media attention concerning the vulnerability of U.S. ports in general, and the Los Angeles and Long Beach ports in particular. These concerns are being addressed in a number of programs, including the Smart and Secure Trade Lanes (SST) initiative. The SST initiative uses RFID tags to provide efficient, instant notification of container security breaches. RFID container seals provide automatic notification of tampering by going "silent." To be truly effective, this approach requires systems that can constantly log and monitor all container seals in a given geographical area so that any that suddenly stop responding can be flagged for action.

In this project, we study the security of RFID tags as they are used at the Los Angeles and Long Beach ports. It is our goal to determine the following:

- The ease with which it an attacker can eavesdrop on an RFID tag signal.
- Whether it is possible for an attacker to "impersonate" an RFID tag signal. Can an attacker tamper with a shipping container, causing the RFID tag to go silent, and then subsequently emulate the original signal of the RFID tag to avoid detection?
- Are there any cryptographic algorithms that could be used to authenticate an RFID signal? Such algorithms would have to be simple enough to be executable by an RFID tag situated in a container.
- Are there other feasible technologies to authenticate RFID tags in shipping containers that do not involve cryptography and might therefore be less expensive? In particular, we will study the feasibility of silent tree walking and the use of pseudonyms.

KEY ELEMENTS OF SUCCESS

We are currently working on lab experiments to determine how easy it is for an attacker to impersonate an RFID signal. We also surveyed terminal operators, asking them if they are currently using RFID technologies, and if so, which technologies. We are currently waiting for responses to our questions.

POSTER SESSION

Vehicle Positioning System

A New Concept for Sensing Lane-Level Vehicle Position

EDDIE ARPIN
MAT BEVILACQUA
MAX DONATH
CRAIG SHANKWITZ
University of Minnesota

OBJECTIVE

Development of a sensor that provides real-time vehicle position with lane level accuracy (lateral error < ± 0.5 lane width) for transportation applications in locations where sufficiently accurate position cannot be determined using the GPS.

DESCRIPTION

A vehicle positioning system (VPS) is designed to provide real-time, lane-level position in areas where GPS signal availability is poor or where multipath is excessive. VPS uses an RFID reader located on the front bumper of the vehicle to read a set of data (the road ID, the lane number, the longitudinal position from a reference, the direction of travel, and other parameters) from RFID tags located in or on the road. The RFID reader can be packaged and deployed together with the license plate, facilitating deployment across an entire vehicle fleet in a short period of time. VPS does not require a digital map or precise tag installation, allowing for quick and universal deployment. VPS, together with wireless V2V, vehicle-to-infrastructure, and infrastructure-to-vehicle communication, enables many applications that require positioning with lane-level accuracy, such as emergency electronic brake lights, lane change and merge assistance, traffic signal priority, and violation warning. Using RFID technology, it is possible to overcome some of the challenges associated with other technologies, such as GPS, computer vision, and magnetic sensing.

Agencies and Organizations Involved: The ITS Institute, a UTC funded by RITA of U.S. DOT.

Contact: Max Donath, Director, ITS Institute, University of Minnesota, 612-625-2304; e-mail: donath@me.umn.edu

OTHER KEY APPLICATIONS

A system integrating wireless communications (i.e., based on VII) and VPS facilitates detection of approaching vehicles (assistance with entering intersections), rear-end collision avoidance, corridor and incident management, congestion pricing–based lane-by-lane electronic tolling, load balancing across lanes, adaptive cruise control, platooning of buses, monitoring traffic on arterials, replacing current loop detectors, and route guidance in the absence of GPS.

POSTER SESSION

Models for Locating RFID Nodes

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Location sensing in a wireless sensor network with a random topology is a significant and fundamental problem in emerging applications in transportation, such as vehicle tracking in ITS. This research introduces some methods to be used as the basis for localizing RFID nodes in a wireless sensor network and qualitatively compares these methods based on the key performance characteristics such as cost, flexibility, scalability, computational complexity, ability to manage uncertainty and imprecision, and ability to handle dynamic sensor arrays. Additional quantitative comparisons are in progress.

The models introduced for locating RFID tags include those based on fine-grained node localization using detailed information, such as triangulation; coarse-grained node localization using minimal information, such as different proximity methods; and manual searching and mapping. We also introduce the ontology of portals and probes to explain locating models.

In recent research, there is substantial evidence that shows RFID technology provides an appropriate platform for locating and tracking assets and estimating the system state. Over a broad range of applications, significant potential impacts include improved real-time project and facility management, improved control via effortless productivity and asset tracking, time and cost saving, and a potential extension to safety and security applications.

POSTER SESSION

RFID Coming to National Geospatial Information Agency

GREGORY HANSON
Oak Ridge National Laboratory

A pilot RFID system is being installed at the National Geospatial-Intelligence Agency at the Washington Navy Yard (NGA/WNY). The effort will demonstrate the use of RFID technology in a secure facility for automated property management and real-time emergency evacuation accountability. RFID is a generic term used to describe a system that transmits the identity of an RFID tag (in the form of a unique serial number) and associates the tag with an object or person.

The pilot project is an active RFID system that utilizes battery-powered tags capable of bidirectional communications. To address security concerns, the physical characteristics and mode of operation of the RFID system were carefully researched and selected. Choke points are being created (by installing activators) at all building exits and at key points on each floor. Activators utilize low-frequency, short-range magnetic fields to tell tags to "wake-up" and transmit. Tags remain asleep (no transmissions) until awakened. Once a tag is activated, it transmit its ID and the activator ID, and then goes back to sleep. An RFID reader receives the tag message and forwards the data to a central server. The RFID tags contain only an ID; no asset or personnel data are stored on them. By viewing the sequence of messages from a tag, the route and direction that the tag travels can be determined.

The property management subsystem will use RFID to ensure appropriate control, redistribution, and disposition of all accountable government property at NGA/WNY. RFID tags will be affixed to approximately 14,000 pieces of property. The RFID system will then track the movement and location of each item, from entry into the building until disposal. The emergency evacuation accountability subsystem will utilize activators located at all building entry and exit points (including emergency exits, loading docks and roll-up doors) and at all perimeter fence gates. During the pilot project, approximately 800 NGA/WNY employees will be assigned an RFID tag that will be attached to their personnel badge. During routine operation, the tags will be read as employees enter and leave the building, or as they pass through interior choke points. In the event of an emergency evacuation, employees with RFID tags will be accounted for immediately.

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RFID Interoperability
Barriers and Solutions

OSCAR FRANZESE
Oak Ridge National Laboratory

The purpose of this project was to conduct a technology survey of RFID systems in use by the transportation industry and to assess incompatibility and interoperability issues across different functions, such as road tolls, weigh stations, ports, and border crossings.

The project's main focus was on the ID of barriers to interoperability of RFID applications in transportation, including container tracking, vehicle tracking, toll collection, port-of-entry controls, and electronic weigh station bypass. To accomplish this, a technology scan of various RFID systems in use by the transportation sector was conducted.

As a result of this survey, two main barriers for RFID interoperability were identified: technological barriers and institutional or business barriers. The most important technological barriers included the existence of two major (and somewhat conflicting) organizations that are developing standards for RFID technology and systems, and the unavailability of overlapping frequency ranges among different production/consumption centers (United States, Europe, Asia). Institutional barriers chiefly involved long-standing legacy issues and proprietary concerns, such as data sharing protocols and business models.

The project also investigated solutions that are being applied to the different interoperability problems identified. Those solutions included the development of convergent standards; technological advances; open protocol deployment; active business communications; cooperation and coordination; and partnerships and consortia that share common goals. Several transportation examples in which RFID interoperability problems have been successfully solved were summarized and presented in the final report.

Parts of this project were sponsored by the Federal Motor Carrier Safety Administration, the Defense Logistic Agency, and the Engineering Science and Technology Division at the Oak Ridge National Laboratory.

The project found that the biggest barrier to interoperability of RFID systems is not technological, but rather institutional and business inertia. Cooperation and coordination, together with the creation of partnerships, were identified as critical since even when all the technological and standardization issues are solved, different systems need to be integrated so that information can be accessible across all these systems.

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POSTER SESSION

Application of RFID Technology for Quality Management in Production and Distribution of Frozen Food Products

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ABSTRACT

The overall aim of this research is a comprehensive approach for improving product quality and safety from production floor through the distribution chain for the frozen food industry. RFID technology leads to many opportunities for increasing quality and safety of frozen foods. We first present a framework for a representative RFID system on the production floor. The main challenge is to construct the network of readers, tags, sensors, and data processing units. Then we look at the implications of the proposed RFID system in the distribution chain. By using the proposed framework, critical parameters can be monitored by RFID tags and sensors, and with the help of the collected data, an optimal set of process and environmental parameters can be determined. Using this methodology, reliability throughout the food production and distribution network can be enhanced. Additionally, the data can be used to create reliable pedigree information, which greatly contributes to enforcement and policing of food standards.

OVERVIEW

Frozen food products are susceptible to adverse conditions that may be experienced through the distribution chain, and even a modest fluctuation of a couple of degrees may put the safety of frozen products in jeopardy. For that reason, the weak points in the distribution chain where temperature fluctuations may occur should be identified, and necessary precautions should be taken. RFID technology coupled with sensing technology is a valuable tool for ensuring the safety of frozen food products. Through use of sensor-equipped active RFID tags, it is technically possible and feasible to create a very accurate time-temperature profile of the frozen product. This information may be used for increasing the efficiency of the distribution chain and for guarding the safety of the frozen food products by reducing the risks posed by growth of microorganisms.

RISK IDENTIFICATION AND MANAGEMENT

Recent terrorist attacks and threats bring the security of food products into question and necessitate a solid system for ensuring food security. Failure to safeguard the production and distribution of food products could have disastrous effects.

RFID tags that are placed on food products may be used for generating reliable pedigree information and for identifying the parties involved in production and distribution. Atempts at spoiling or diverting food products might be identified and disclosed by using a solid RFID system. The information obtained during shipment can be used during the sale of the product. To cite an instance, products that are exposed to marginally unfavorable conditions may be served ahead of products that have not been exposed to those conditions. Also, different pricing schemes for marginal food products could be developed, if reliable data were available. This leads to a more informed policy, which can change the normal practice in which the frozen food product that arrives first to the sale location is placed on the shelf first. Implementing will help to increase the efficiency of the cold chain and to increase the uniformity of quality and safety in frozen food products.

PROSPECTIVE APPLICATIONS

The distribution chain for frozen food products is an integral entity. It extends from suppliers that provide raw materials to food manufacturers to distributors to the customers at food sale locations. For this reason, absolute traceability should begin at the processing stage. In the proposed system, the RFID tags utilized throughout the distribution chain are attached to the frozen food products at the end of processing. The tags that are attached to frozen food products continue to exchange information throughout the distribution chain with strategically placed readers. The attachment of these tags cannot violate existing food standards and procedures, and the tags should not detach as the food products are handled throughout the distribution chain.

RFID tags expressly designed for frozen food products must be suited for operating at low temperatures. The RFID tags deployed through the distribution chain must be able to reliably receive and transmit information at those temperatures. Two different RFID systems can be employed in this context. The first group of RFID tags may be attached to the frozen food products, and they may be coupled with microsensors. These microsensors may transmit the information about the temperature of the product, and an RFID module of the system can provide ID information related to the frozen food product. The second system can be used for measuring the ambient air temperature surrounding the frozen food products. These products may be evaluated regarding pathogen-borne risk using the time-temperature profile that is generated by the attached sensor–RFID tag pair. Models are available that use time-temperature profiles to assess the threats to food safety that are posed by these microorganisms. These models may be developed further based on the information obtained by RFID systems that are deployed in the distribution chain.

POSTER SESSION

Application of RFID Technology to Loss Management in Pharmaceutical Distribution

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ABSTRACT

It is estimated that about 10% of drugs offered for sale throughout the world are counterfeit. An efficient and secure distribution system is demanded by all pharmaceutical stakeholders. We analyze and discuss the relevant issues, including vulnerable points in the pharmaceutical distribution system; different anti-counterfeiting technologies; implementation of RFID in the pharmaceutical distribution chain, from both hardware and software perspectives; and building and managing an e-pedigree system. In order to counter counterfeiting in drug distribution, major research is needed in tag placement, safety features, tag data encryption, and security in wireless communication.

PHARMACEUTICAL DISTRIBUTION CHAIN

The pharmaceutical industry is gigantic, with a sales volume of $602 billion in 2005, and it is projected to increase by 7% every year. The pharmaceutical distribution chain is one of the most complicated distribution systems in the world. Within the system, many parties are involved, and they are often connected with each other in both traditional and nontraditional ways. It is supposedly a closed distribution chain. But drugs from foreign sources can slip into the closed loop and threaten the integrity of the system. What further complicates the supply chain is that all pharmaceutical parties are able to connect with each other, but such connections are not on a regular basis and are thus difficult to identify and monitor.

ANTICOUNTERFEITING TECHNOLOGIES

Anticounterfeiting technologies can be grouped into four categories: overt, covert, forensic, and tracking and tracing technologies. A comparison of those technologies finds that each has its strengths, but that only one technology—RFID—combines the security feature and the tracking capability. With its unique operational mechanism, RFID finds itself in a strong position for anti-counterfeiting purposes in pharmaceutical distribution.

IMPLEMENTATION OF RFID IN PHARMACEUTICAL DISTRIBUTION CHAIN

Pharmaceuticals have several packaging forms, including bottles, vials, syringes, tubes, and blister packs. Accordingly, when we choose the tags for pharmaceutical products at the item level, we want to pick the ones that fit these different packaging forms. In pharmaceutical item-level tagging, tags can typically be placed inside or outside of the pill bottle. The tags can be also embedded in the pill bottle during the plastic molding process. The tag placement and label design need to be further investigated by considering the requirement of tamper-proofing. To date, pharmaceutical item-level tracking is still in its pilot period. There are only a small number of pharmaceutical companies that have tried a few drugs at the highest risk of counterfeiting. Use of RFID tags in the pharmaceutical market remains limited.

Existing commercial pharmaceutical passive RFID tags, as well as their specifications, have been surveyed, leading to a comparison and discussion on the read-range and other features of those tags. The available tags are typically low-cost passive tags, which are relatively inexpensive and that are based on cost-oriented product strategies, rather than on a security orientation. Security features are very limited, and research on tag data encryption is urgently needed. In addition, for the issues such as selection of ultra high frequency and/or high-frequency regimes for tagging pharmaceutical products, no clear winners or solutions have been found, and case-by-case analysis is still the predominant approach.

BUILDING E-PEDIGREE SYSTEM

RFID technology offers a unique functionality for managing the e-pedigree of drugs and for creating high visibility at all stages of the distribution chain. To combat pharmaceuticals losses, a full e-pedigree verification system should be launched. Before building an e-pedigree, however, one ought to understand how data are stored and shared between different pharmaceutical shareholders. This involves the concept of the electronic product code (EPC) network architecture. It is vital to understand the local EPC information services (EPCIS) and central EPC discovery services (EPCDS) and data retrieving mechanism in the architecture. At the same time, a comprehensive e-pedigree building process chart is offered. This process involves data filtering, aggregating, smoothing and EPC duplication checking from the savant. Data querying from central EPCDS to locate the local EPCIS through the object name service is also to be tracked. After verifying the prior parties' finished and digitally signed pedigree, new data will be added to the current party's own EPCIS, who then inserts its digital signature and registers all the information in the EPCDS each time the custody of the drugs changes, finally accomplishing the e-pedigree building process.

CONCLUSION

At present, more and more pharmaceutical companies are piloting trial applications of RFID for loss management. Due to the importance of RFID technology for the pharmaceutical supply chain, we believe that RFID will be everywhere in the chain and that more companies will achieve their target ROI from this technology. We argue, however, that the biggest winner will be the patients, as they will be more confident about the safety of the drugs they are taking.

POSTER SESSION

Improvements in RFID Tag Geometry and Manufacture

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ABSTRACT

For the past 5 years, teams of researchers at North Dakota State University have been active in various aspects of design and manufacture of wireless sensors. The work takes as a foundation the basic RFID tag—an integrated circuit chip and an antenna mounted on a flexible substrate. The research then addresses several issues in the manufacture of more complex, advanced generation tags, with emphasis on improvement of performance and lowering of manufacturing costs. Four discrete, but related, research topics are featured here: (1) assembly of advanced generation RFID tags; (2) process engineering for printing of silver-ink antennas for wireless sensors; (3) process engineering for printing of microbatteries; and (4) robust encasing of RFID tags.

THE RESEARCH LANDSCAPE

Deployment strategies for RFID technology will undoubtedly change and expand. As the potential for gathering information and tracking product is explored and experienced, creative users will perceive and demand more and more complex information. Extension of the capabilities of RFID tagging to smarter tags will necessarily result in increased complexity. Many prospective applications, especially in item-level tagging, will call for one or more sensors and an active memory integrated with query capability. Thus, an advanced generation RFID tag will be much more complex than the simple Gen 1 and Gen 2 tags of today. Future generation tags will likely contain multiple ICs (including signal processing and an active memory), one or more transducers, an antenna, and an onboard power source (perhaps a microbattery).

ASSEMBLY OF ADVANCED RFID TAGS

Gen 1 and Gen 2 RFID tags are simple devices, containing a single integrated circuit and an antenna. Advanced generation tags will be composed of four separate types of components: integrated circuit chips, transducers, antennas, and microbatteries. Microassembly processes must be adapted or newly created in order to position all components deterministically. Assembly onto a tag will very likely require different methods for at least some of the components. Integrated circuit chips and at least some types of transducers can probably be assembled by similar methods. In our research, the preferred method has been FSA, a patented process of Alien Technology Corporation. The strength of FSA lies in its ability for high throughput assembly. The weakness is the randomness of the process. For antennas and microbatteries, the focus has been on printing methods. Work on interconnects has featured other printing methods (not included in the presentation).

PRINTED ANTENNAS

The most critical component that limits reduction in size of RFID tags is the antenna. It is also one of the most costly components. Processes for cost reduction are thus prime targets for research. Our work has focused on adaptation of established processes of stencil and screen printing. Experience has been gained with both thermally-cured inks and zero-volatile, ultraviolet (UV) cured inks. Substrates used include flexible polyimide films and rigid FR-4 boards. By using commercial thermally cured inks, stencil printed patterns of 500-micron lines on 250-micron spaces were successfully printed on 125-micron polyimide substrates. The screen printing trials used custom formulated, as well as commercial, UV-curable inks and were printed on FR-4. The most effective inks were those using a mix of solid particles in the filler—150-nanometer spheres mixed with 15-micron flakes.

PRINTED MICROBATTERIES

The most costly component in an advanced generation tag will be the battery (or other micropower source). Likewise, along with antennas, the power supply is a limiting factor for tag size reduction, which will be a distinct challenge. One approach for both size and cost reduction is the manufacture of a complete microbattery by means of printing processes. Examination of candidate electrochemical systems indicates that the most challenging feature in printing a complete battery is the current collector layer. The hypothesis constructed for this research is that if a representative current collector can be printed, the other layers of a battery can also be printed. Initial effort was therefore concentrated on this battery element. Stencil printing was selected as the first evaluative process. Experimental results indicate that printing of complete microbatteries is feasible.

ROBUST RFID TAG PACKAGING

In applying RFID tags to goods, current practice is an adhesive attachment, as in conventional labeling. However, applications where RFID tags will be reused often include environments where robust packaging is a necessity. This research investigation sought to establish the feasibility of encasing a standard RFID tag in a robust protective enclosure. Sample Class 1/Gen 1 RFID tags were encased in several prospective flexible thermoplastic materials, and the results were evaluated for effective signal strength retention. In first trials of molding low-temperature flexible thermoplastics around an RFID tag, yields of up to 50% were achieved. Tags encased in walls of about 500 microns of flexible polymer retained usable readability, suffering attenuation in read distance of less than 40%.

Battery-Assisted RFID Devices for Sensor Applications

AARON REINHOLZ
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RFID technologies span a range of cost and performance parameters, from very low cost passive tags to active RFID devices that use RF transceivers. A technology falling between these two capabilities is the battery-assisted passive RFID tag. These devices offer additional capabilities beyond passive tags, including the ability to sample and store sensor readings and the ability to communicate at longer ranges. They require significantly less battery power to operate compared with transceivers found in an active RFID tag.

Researchers at North Dakota State University (NDSU) have been focused on development of battery-assisted passive devices for microsensor applications. The research is sponsored by the Defense Microelectronics Activity organization within the DOD. The tags utilize application-specific ICs developed to provide backscatter communication capability, as well as provide processing and data storage. These devices have been developed for implementation in flexible substrates with very small form factors. The research has been focused on both the design aspects of such devices and the advanced manufacturing techniques that would allow the devices to be produced at very low cost in large volumes. Key accomplishments to date include the following:

- Development of a microcontroller application specific integrated circuit (ASIC) to host application firmware for microsensor devices.
- Implementation of RFID protocol on the ASIC to provide data communication with an RFID reader.
- Development and integration of a chemical sensor that is designed for implementation on flexible substrates.
- Development of advanced techniques to utilize FSA methods licensed from Alien Technology Corp. for assembling sensors on flexible substrates with thin film metallization interconnects.

Further research and development on battery-assisted passive RFID sensors at NDSU will focus on extending the read ranges of the reader–tag system, further reductions in power consumption, and integration with other types of transducers to expand the range of sensor applications.

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POSTER SESSION

Locating Transportation Infrastructure Components and Accessing Histories for Bridge Inspection with Radio Frequency Technology

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BRIEF DESCRIPTION OF THE PROJECT

Bridge inspectors currently use paper-based reports to access historical information of bridge components during inspection and to visually locate specific bridge components that are of interest. These approaches can be cumbersome and time-consuming because bridge components often look similar to each other, thus making it difficult to locate the right component, and because inspectors sometimes need to carry prior inspection reports with them to the field so that they can search for related information during the inspection.

RFID technology provides an opportunity to make historical information readily available with the bridge components in a distributed fashion, to update the information stored with the component when work is performed, and to locate bridge components effectively. This would enable the bridge components to be "intelligent." This research study presents a vision of intelligent bridge components within which components know their histories, communicate their historical information to inspectors, and guide the inspectors who want to locate them. We have been testing the technological feasibility of such vision by evaluating the performance of active RFID on precast components and developing an approach to guide the inspectors to the right location based on the component of interest. Some results of these tests will be presented.

AGENCIES AND ORGANIZATIONS INVOLVED

- The Pennsylvania Infrastructure Technology Alliance is a collaboration among the Commonwealth of Pennsylvania, the Institute for Complex Engineered Systems at Carnegie Mellon University, and the Center for Advanced Technology for Large Structural Systems at Lehigh University.
- The Precast–Prestressed Concrete Institute (PCI), headquartered in Chicago, is dedicated to fostering greater understanding of precast and prestressed concrete.
- High Concrete Structure Inc. (HCSI) is a precast concrete manufacturing company serving Pennsylvania, Ohio, and Illinois.

KEY ELEMENTS OF SUCCESS

- Evaluation of active and passive RFID technologies for locating components and accessing history information (accomplished).

- Formalization of information flow patterns within precast concrete supply chain (accomplished).
- Probabilistic approach to RFID-assisted guidance system to locate components of interest within a facility (in progress).
- Design of active RFID network to assist in locating components of interest within a facility (in progress).

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RFID Reliability Test for Tool Tracking on Construction Sites

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Among many things field construction managers need to take care of is making sure that appropriate types and quantities of tools are available when needed by crafts workers. RFID technology opens the possibility of automating the entire tool management process. Tools tagged with RFID devices should be detected automatically by the RFID reader when, for example, a worker carries tools through the portal system. However, RF signals are known to bounce off metal or to be absorbed by water at ultra high frequencies. One may wonder if RFID tags attached on metal tools would work reliably.

Two tests were conducted to determine (1) the reliability of identifying active RFID tags when work crews are carrying tools through the RFID portal system (portal test), and (2) the reliability of identifying active RFID tags when tools are sitting in a metal storage box (gangbox test). These tests were carried out at a Zachry Construction tool center and Texas A&M University in conjunction with the FIATECH Smart Chips project. RFID tags were provided by HOUNDware systems.

For the portal test, a 2-ft-long prototype RFID portal system was fabricated. The reliability of RFID tags was tested under variables such as the speed of carrying tools through the portal and the number of tools carried through the portal at the same time. The results of the experiment showed two clear trends. First, when the number of tools passing the portal was increased, after a certain limit the RFID sensors were unable to successfully detect the tools. The accuracy of the detection fell from 100% to 90.1%, even when the speed of the trolley was 0.1 m/s. Second, the accuracy in detection diminished as the velocity of the trolley was increased from 0.1 m/s through 1.5 m/s. The percentage of the successful detections decreased from 97% at 0.1 m/s to 45% at 1.5 m/s, on average. These values determine that the reliability of the RFID technology depends greatly on the velocity and the number of tools passing the portal.

The gangbox test was similar to a hide-and-seek game. Three experiment participants were instructed to pile seven tools with RFID tags attached in a storage box that contained other tools. After the tools were piled into the storage box, the RFID reader installed in the gangbox ran for 2 min, and the number of tags identified was determined. Out of 30 trials, the RFID reader successfully identified all seven tags 26 times within 2 min. Overall, the RFID reader missed only 4 tools out of 210 tools tested. This test was implemented with the storage box lid opened. When the same test was conducted with the lid closed, all seven tools were identified successfully within 2 min.

There is a speculation among the authors regarding generalization of the results of the experiment as the tests were conducted using just one RFID tag system designed for tool management in the construction industry. Further investigation is required to understand the sensitivity of the results while generalizing to all RFID systems used in the construction industry.

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POSTER SESSION

Microscopic Traffic Simulation Integrating Variable Message Signs and DSRC Vehicle-to-Vehicle and Wayside-to-Vehicle Messages

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OBJECTIVES

- Provide a microscopic traffic simulation tool to evaluate the effectiveness of variable message signs (VMS) and dedicated short-range communications (DSRC) V2V and wayside-to-vehicle messages.
- Integrate VMS and DSRC V2V and wayside-to-vehicle messages into an existing microscopic traffic simulation model.
- Issue the source code under the GNU General Public License as published by the Free Software Foundation.

PROJECT DESCRIPTION

FHWA Research Project No. DTFH61-03-C-00138, Enhancement of the TEXAS Model for Simulating Intersection Collisions, Driver Interaction with Messaging, and ITS Sensors, contained tasks to integrate VMS and DSRC V2V and wayside-to-vehicle messages into the TEXAS (traffic experimental and analysis simulation) model for intersection traffic. This project started 10/1/2003 and ended 9/30/2005.

PROJECT SPONSOR AND PRINCIPAL INVESTIGATOR

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ACCOMPLISHMENTS

- Modifications to the TEXAS model for intersection traffic have been completed and tested.
- Source code issued under the GNU General Public License as published by the Free Software Foundation and executable programs for Windows on Intel and Linux on Intel available.
- Source code, documentation, and executables available at ftp://ftp.ce.utexas.edu/texas_model and ftp://ftp.ce.utexas.edu/texas_model_documentation (research report available when approved).

POSTER SESSION

Development of Autonomous Railcar Tracking Technology Using Railroad Industry Radio Frequencies

RICHARD BEGLEY
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OBJECTIVE

The objective is to develop and test technologies that will enable the railcar to be independent of the locomotive for transmitting in-transit or stationary locations using radio frequencies currently in use by the railroad industry.

BRIEF DESCRIPTION

The motion of the railcar is utilized to generate electricity to minimize the discharge of rechargeable batteries used to operate off-the-shelf tracking devices in a modular system currently under development. The system includes standard RF communication devices for transmitting the location information and should improve location transmission reliability and require less maintenance than systems that rely on rechargeable batteries only.

AGENCIES AND ORGANIZATIONS INVOLVED

- Federal Railroad Administration,
- CSX Corporation, and
- Rahall Transportation Institute (a U.S. DOT UTC at Marshall University).

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KEY ELEMENTS OF SUCCESS

Reliable transmissions of railcar locations need adequately charged batteries requiring frequent battery replacement limiting the deployment throughout the industry. Capturing the energy from railcar vibration has the potential to provide the means to keep the batteries from discharging, enabling the potential deployment to more railcars offering many potential advantages for improving railcar inventory control and management in the industry.

APPENDIX A

Abbreviations and Acronyms

AM	amplitude modulation
ASIC	application specific integrated circuit
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
CVISN	commercial vehicle information systems and network
CVROCS	commercial vehicle remotely operated compliance stations
DBS	dynamic base station
DHS	Department of Homeland Security
DOD	Department of Defense
DSRC	dedicated short-range communications
EPC	electronic product code
EPCIS	EPC information services
EPCDS	EPC discovery service
ETC	electronic toll collection
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FCC	Federal Communications Commission
FSA	fluidic self-assembly
GPS	Global Positioning System
IC	integrated circuits
ID	identification
ISO	International Organization for Standardization
ITS	intelligent transportation system
IV&V	independent validation and verification
JPO	ITS Joint Program Office, U.S. DOT
OFDM	orthogonal frequency division multiplexing
RF	radio frequency
RFID	radio frequency identification
RITA	Research and Innovative Technology Administration
ROI	return on investment
SST	smart and secure trade lanes
TRX	transponder
UID	unique ID
U.S. DOT	U.S. Department of Transportation
UTC	University Transportation Centers
UV	ultraviolet
VII	vehicle infrastructure integration
VMS	variable message sign
vph	vehicles per hour
VPS	vehicle positioning system

V2V	vehicle to vehicle
WAVE	wireless access in vehicular environment
WLPS	wireless local positioning system

APPENDIX B

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Analysis of Potential Impacts of RFID Tags on the Environment and Recycling Infrastructure

PROBLEM

RFID technology applications have great potential for enhancing commerce, personal and business security, and government and business processes. Market estimates for RFID applications range from $1 billion in 2004 to almost $5 billion by 2008, with about 30% of all capital goods expected to be carrying RFID tags by 2008. This has important implications for businesses and consumers.

Introduction of RFID technology into the marketplace requires an explanation of the benefits of the technology and discussions about actual and perceived challenges to implementation. Issues involving technical standards, spectrum, international operability, implementation costs, data privacy, and security are part of the current discourse on RFID. With the exception of a few groups in the paperboard industry, however, there has been little consideration of the potential environmental impact of the constituents of the RFID tags on material recyclers or manufacturers using recycled materials.

OBJECTIVE

The purpose of this project would be to have an independent research organization analyze the potential impact of RFID tags on selected material waste streams including paper, plastic, aluminum, steel, industrial packaging, and glass. Performance/technical standards for RFID are currently being developed, making it is essential that the environmental aspects of the constituents be analyzed and included in the debate as soon as possible. The research should include analysis of the following issues:

- Material flows from application of RFID tags into recycling and disposal processes.
  - Provide composition data for passive tags (i.e., material IDs and mass per tag).
  - The physical–chemical makeup of the passive tags (including self-adhesive label, disk- or pill-shaped tag, and smart card):
    - Substrate: polyethylene terephthalate;
    - Antenna: copper, aluminum; ink antennae;
    - Integrated chip: silicon, flip chips;
    - Face material: polypropylene (label surface) and paper (label); and
    - Adhesives: acrylate, polyurethane.
- The impact of the constituents of the tag on the recycling stream, by material type (i.e., paper, aluminum, steel, glass, plastic, drum reconditioners).
- Disposal—at end of their life, packages and products are recycled, dumped in a landfill, or incinerated. What is the impact of tag disposal, by material type (e.g., paper, aluminum, glass, PET)?
  - What is the impact on recycling manufacturing?

    - What is the tag load, by material recycling type, that is acceptable without reducing the quality or cost of fiber reprocessing?
    - Can constituents be destroyed without presenting a hazard?
    - What is the impact on recycling manufacturing process?
    - What is the impact if a tag is incinerated; what is the threshold for triggering environmental problems?
- The ability to recycle the tags or reuse the tags attached to reusable containers/boxes.
- The impact of the tags on the cleaning process.
- The impact of the tags on the recovery process.
- The threshold level at which the contaminants could pose a health or environmental risk.
- Market analysis: what is the estimated amount or quantity of passive RFID tags that will be available in 2005, 2010, and 2015, in the United States, as well as globally?
- Will disposal of RFID tags exceed the regulatory level for silver under the Resource Conservation and Recovery Act's toxicity characteristics (i.e., 5 mg/L)?
- Are there design alternatives that would make the tag compatible with current recycling infrastructure (e.g., adhesives, metal)?
- Are there industries for recycling the tags to prevent or eliminate the potential for these tags to be discarded as electronic waste?

DURATION

Due to the speed at which standards are being developed internationally, the research should be done within a 6- to 9-month timeframe.

COST

Approximately $200,000.

DELIVERABLES

Paper outlining the impact of RFID components on the environment and on the recycling stream, together with recommendations for action (such as performance certifications).

APPENDIX C: RESEARCH PROBLEM STATEMENTS

Supply Chain–Related RFID Research and Applications

The following are potential topics for future research.

1. ROI from RFID technologies. Study the ROI in RFID and help develop the business case for private and public investments in RFID systems. How does RFID compare with other solutions?
   - Identify private-sector costs for deployment; document initial results from deployment and associated business process reengineering in specific industry sectors to date; and extrapolate these benefits to large-scale deployments. What role could or should incentives play?
   - Identify potential public benefits in terms of reduced congestion at freight chokepoints, lower logistics costs, and enhanced economic competitiveness.
   - Address safety and security benefits of RFID (this could be a separate research project).
2. Next generation tags—Define aspects of the next generation of tags, which could include the following capabilities:
   - Integration with sensors to detect temperature, intrusion, other aspects of shipment condition;
   - Tamper-proof and secure;
   - Robustness under weather conditions and other harsh environments; and
   - Ability to be powered by alternative energy sources.

   What types of capabilities are possible at a practical level, rather than at the research level only? Can these capabilities be deployed in a cost-effective manner?
3. Potential for leveraging existing infrastructure with RFID to provide inland visibility of intermodal shipments. Although most ports and terminals already have RFID infrastructure in place, beyond the terminal or port gates there often is a large gap in readers and other infrastructure. RFID might be able to piggyback on other infrastructure (for example, linkages to CVISN systems at weigh stations and fixed inspection sites, metropolitan ITS, and GPS). Identify implications of potential nationwide deployment of the VII initiative. Identify concepts of operations and potential benefits. Evaluate how RFID will work with GPS, etc., to provide visibility throughout the supply chain.
4. Optimization of the supply chain across a broader set of data; integration of RFID-based data on asset ID, location, and condition with data on freight system operation, including traffic, weather, and work zone information.
   - Compiling local data to regional/corridor/national/global level to match the scale at which freight moves.
   - Integration of models and algorithms that can make use of data.
5. Is it feasible to have an architecture for RFID in the supply chain? Do we first need a common definition of RFID? Today RFID is a bottom-up process, with each user developing its own approach; there is no top-down guidance. How do you persuade businesses that that have spent 30 years developing their own technologies to drop their processes and standards and move

to new information technology structures? What architectures and standards need to be reconciled to facilitate widespread deployment of RFID applications in the supply chain? Potential changes to legacy systems, institutions, and processes should be identified, as should lessons learned from related efforts, such as EPC-Global (including DOD participation), national ITS architecture, and Automated Commercial Environment–International Trade Data System (ACE–ITDS).

6. What are the opportunities, benefits, and costs of transitioning to item-level tagging? Where will item-level tagging make sense?
   - Privacy and customer acceptance issues—Is there a private-sector solution that can solve these privacy issues before legislative actions are created that may limit the uses of RFID technology?
   - Disposal issues.
7. What are the institutional barriers to RFID application in the supply chain? Prepare case studies on how these were resolved in prior deployments.
8. Other potential topics:
   - Deployable systems for detecting intrusion into containers.
   - Creating reliable pedigree data.
   - Environmental impact of RFID tag disposal, which is likely to grow as item-level tagging becomes more common. Is it possible that tags could self-identify hazardous components and components that could be recycled?
   - Potential to create an active RFID tag that could be used in an air cargo environment without interfering with aircraft communications.

APPENDIX C: RESEARCH PROBLEM STATEMENTS

Using Radio Frequency to Improve Productivity of Equipment During Construction

PROBLEM

The construction industry faces many challenges, including the lowest productivity increase rate among other industries. Traditional methods may not be the most effective ways for delivering transportation projects. Construction companies and workers must keep an eye out for new technologies in the market. The cost of some of these new technologies might become justifiable as they provide better alternatives to current methods. One such promising technology is RFID. A key area of interest is how this technology might be used to estimate construction equipment productivity and to verify equipment is actually on a job site, as claimed by the contractor.

OBJECTIVE

RFID is a technology that first appeared in the 1980s for tracking animals and access applications. A wireless RFID system works for noncontact reading and consequently is effective in manufacturing processes and in other harsh environments where barcode labels could not survive. It is also capable of tracking moving objects. The technology has become vital for automated data collection, ID, and analysis systems in many applications all over the world.

RFID refers to a branch of automatic ID technologies in which RFs are used to capture and transmit data. Unlike barcodes, which use striped labels with fixed ID codes, RFID technology involves the use of tags or transponders that can collect data and manage it in a portable, changeable database within the tag; that can communicate routing instructions and other control requirements to equipment; and that can withstand harsh environments. RFID is effective in applications where vision is blocked, where surfaces become dirty, and where the ability to store data on an object is important. Several RFID applications have been developed in the areas of automated tolling, supply chain management, asset location and tracking, animal tagging, personnel ID, and facility access.

The objective of this study would be to investigate how RFID technology can be used to better track the location and productivity of equipment during the construction phase of a transportation project. RFID may need to be coupled with GPS in order to optimize its usefulness.

RELATED WORK

Much of the related RFID work in construction has been in research and development. Jaselskis performed a study for the Construction Industry Institute to investigate the use of passive RFID to more efficiently receive materials on industrial projects (*1*). Song et al. investigated the use of active RFID tags to dynamically track engineering material items (pipe spools) as they arrived on a construction site and established the benefits of using RFID (*2*). Akinci performed research on the use of active RFID tags to track precast concrete bridge elements in a precast yard; he also developed an integrated framework for using RFID throughout the project life cycle (*3*). Kang worked on a prototype for identifying the location of tools at a construction site, with the aim of improving the efficiency (*4*). Goodrum used RFID to assess the impact of improved tool tracking processes using active tags (*5*). Researchers in Taiwan have used RFID to keep track of the material properties of concrete poured into cylinders for improving material QC on a job site.

There has not been any research on developing an RFID system for tracking the productivity of construction equipment on jobsites.

URGENCY AND PRIORITY

Improving equipment productivity on job sites can lead to more efficient use of project funds. There is also the potential for significant cost savings from the ability to better track equipment on construction sites. This project should have a high priority.

COST

The cost to perform this work is estimated at $300,000 for a literature and product review, development and implementation of a productivity tracking application, and an evaluation of its effectiveness.

USER COMMUNITY

The users who will most benefit from this study include state DOT and heavy equipment construction contractors (earthmovers, asphalt and concrete pavers, and bridge builders).

IMPLEMENTATION

Implementation of such a tracking system will involve user training. It will also require a more educated and technology-savvy workforce, including both the engineers and the craftworkers who will directly or indirectly use this technology.

EFFECTIVENESS

If such a system were to be developed, it would improve a DOT’s ability to verify claims by contractors that equipment was indeed being used on a job site. It would also provide contractors with important information about how effectively their projects are being run.

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APPENDIX C: RESEARCH PROBLEM STATEMENTS

Real-Time Project Status Tracking and Control Using RFID, GPS, 3-D Scanning, Wireless Networks, and Integrated Project Control Systems

PROBLEM

Getting better project information and getting it faster can help us make better decisions in a more timely fashion. It has always been a challenge to get timely information about progress, productivity, location of prefabricated elements in the supply chain, quality, and other factors relative to construction projects; yet this is precisely the information we need to manage a project effectively and to achieve schedule, cost, quality, and safety objectives.

OBJECTIVE

New technologies such as RFID tags, GPS units, 3-D modeling systems based on laser radar scanners, and wireless communications are facilitating a breakthrough opportunity to radically improve project performance by providing faster, better project information. Integrated with project process control systems, these technologies will allow us to continually track the location and status of materials, prefabricated components, equipment, and key people on a project, and it will enable information to be distributed in real time using project control systems that support better and faster decision making.

These technologies are already rapidly being commercialized and soon they will be widely deployed. They ultimately will have a greater impact on construction than does the Internet, because they represent deployment of digital communications from the office to the site, and they will also have a greater impact on construction practices than the cell phone because they will expand the information bandwidth from simple voice communications to drawings, pictures, specifications, and myriad other forms.

The challenge for state DOTs is to anticipate the impact of these technologies, ease their adoption, exploit their potential, and prepare for the unpredictable consequences of their deployment. Specifically, DOTs need to:

- Define the potential applications and estimate the costs and benefits associated with each application, such as fleet management and batch tracking of asphalt concrete pavement and other materials.
- Identify the impact on current project specifications and contract clauses for scheduling, reporting, expediting, etc.
- Identify technical requirements specific to DOT applications in terms of battery life, robust packaging, resistance to environmental impacts, data exchange standards for QC and inspection, etc.
- Report on and share lessons learned from pioneering deployments of these new technologies.

RELATED WORK

Jaselskis performed a study for the Construction Industry Institute (CII) to investigate the use of passive RFID to more efficiently receive materials on industrial projects (*1*). Haas, Goodrum, and Caldas will soon complete a current study for CII on the impact of technology on productivity, which focuses on the impact of the technologies described above on the industrial sector of the construction industry. That study includes full-scale field trials of RFID and GPS technology for materials and tool tracking to improve project performance.

Song, Caldas, Ergen, Haas, and Akinci investigated the use of active RFID tags to dynamically track engineering material items (pipe spools) as they arrived on a construction site and established the benefits of using RFID (*2*). Akinci has performed research on the use of active RFID tags to track concrete bridge elements in a precast yard and has also developed an integrated framework for using RFID throughout the project life cycle (*3*), with the objective of learning how RFID and GPS technologies can be used to track production history of engineered-to-order components. Kang worked on a prototype to help identify the location of tools on a construction site to improve the use efficiency of each tool (*4*).

Goodrum used RFID to assess its impact in improving the construction tool tracking process using active tags (*5*). Researchers in Taiwan have used RFID to keep track of the material properties of concrete poured into cylinders for improving material QC on a jobsite.

URGENCY AND PRIORITY

Improving project cost and schedule performance is critical. This project should have the highest priority.

COST

The cost to perform this work is estimated at $300,000 and would include a literature and product review, site visits, a survey to collect data on recent experiences, and development of a body of suggested specifications and contract clauses.

USER COMMUNITY

The users who will most benefit from this study include state DOTs and the traveling public. It is expected that the most significant impact will be to expedite project schedules.

IMPLEMENTATION

Implementation will occur by learning about the costs, benefits and implications of these technologies via the project products, as well as adoption of the suggested contract specifications and clauses.

EFFECTIVENESS

Given the potential benefits of accelerating the deployment of these technologies via this suggested project, the effectiveness of the project could be extremely high.

REFERENCES

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APPENDIX C: RESEARCH PROBLEM STATEMENTS

A Synthesis Study on the Use of RFID Applications for Constructing Transportation Projects

PROBLEM

ID, tracking, locating, and updating the status of the installation of construction equipment and bulk materials on highway construction projects are time consuming and labor intensive. A manual approach has traditionally been used to track and record the installation of bulk commodities and track the operation of construction machinery. This process consumes time and is prone to errors. Furthermore, when materials are actually installed, additional time is incurred by both the contractor and the owner to verify its installation and update the project's status reports.

A number of research efforts have examined how RFID tags can be used to achieve a number of functions described herein. While some of the research has been targeted to the use of RFID technology on highway construction projects, a number of previous efforts have focused on the use of the technology in commercial and industrial construction settings. The findings, however, are applicable to the highway construction industry sector.

Meanwhile, commercial development of RFID tags has rapidly increased their functionality and dramatically lowered their costs. For example, state transportation agencies have used RFID technology as temperature data logging components in concrete maturity systems. Outside of construction, much of the commercial development of the RFID technology has targeted the technology's application in other industries where supply chain management is a critical component to the production process. Obviously, many of the commercial applications could be transferred to construction.

While RFID offers incredible potential during the construction phase, research has identified limitations of the technology. For example, while active RFID tags offer significant read ranges, their performance is dependent on battery power, which can be a concern for applications in extreme environmental conditions or where the tag is expected to be used over a long period of time. Passive tags do not rely on battery power, but they have significantly smaller read ranges. Understanding these and other limitations will help researchers understand the role that RFID technology can play on future construction projects.

OBJECTIVES

The purpose of the synthesis study is to explore the existing commercial applications and previous research involving RFID technology with a focus towards the use of RFID in the construction of highway systems. The synthesis will include, but not be limited to, the following:

- Searching the literature, including online sources;
- Identifying the performance parameters and economics of using the current state of RFID technology;
- Identifying problem areas that are creating gaps between research and practice;

- Interviewing end users of RFID technology in both construction and other industries to identify lessons learned in implementation;
- Interviewing manufacturers of RFID technology to help forecast future costs of the technology and anticipated applications; and
- Identifying the barriers that prevent widespread implementation of the technology in the highway construction industry.

RELATED WORK

Multiple information sources already exist about RFID applications in construction. A sample of relevant publications and papers includes:

1. Song, J., C. Haas, and C. Caldas. Tracking the Location of Materials on Construction Job Sites. *Journal of Construction Engineering and Management*, ASCE, Vol. 132, No. 9, 2006, pp. 911–918.
2. Papers presented at Research Opportunities in Radio Frequency Identification Transportation Applications Conference. Transportation Research Board of the National Academies, Washington, D.C., October 17–18, 2006.

URGENCY AND PRIORITY

There is a high urgency for this research. The use of the technology is accelerating, which highlights the current technology's limitations. Identifying the nature of the gap between the technology's current capability and desired performance will assist the technology's stakeholders to address such gaps.

COST AND DURATION

The estimated cost and duration for this study is $90,000 and 12 months.

USER COMMUNITY

This synthesis would be valuable to researchers, practitioners, and technology suppliers of RFID technology.

IMPLEMENTATION

Identifying the nature of the gap between the technology's current capability and desired performance will assist the technology's stakeholders to address such gaps in future research and implementation efforts.

EFFECTIVENESS

There have been a number of research efforts that have examined the use of RFID technology on construction projects and other environments that closely resemble construction (e.g., mining), but that information is fragmented. As such, current and future implementation efforts may not fully realize currently known limitations of the technology before rediscovering the implementations themselves.

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