Abstract

This article considers past and present European research into communications characteristics for transport telematics applications. The background for the work is derived from the European Commission's DRIVE/Transport Telematics programs and research projects, and recent CEN TC278 activities. The prospect that a single media cannot meet all the current applications requirements is supported by consideration of key services that have different communications requirements. However, media selection minimization and a migration path for homogeneous implementation of current research solutions are expostulated. The article concludes by questioning a defaulting media selection against our social consciences for matching media to requirements. The article is aimed at a readership with some technical knowledge and should be of interest to transport authorities and manufacturers intending to tackle the problems of implementing transport telematics systems.

Telecommunications Media for Transport Telematics

Paul A. Wingfield, WS Atkins

A substantial amount of effort has been invested in transport telematics research by a variety of organizations, particularly the European Commission's Directorate General XIII (DGXIII), during recent years. The EC's Dedicated Road Infrastructure for Vehicle Safety in Europe (DRIVE) program (with over 60 million European currency units, MECU, of work shared between 72 projects from 1990 to 1992 plus 140 MECU of work shared between 57 projects for transport telematics from 1992 to 1994) was extremely successful in producing much of the groundwork toward what is now most commonly known in the United States as intelligent transportation systems (ITS). This whole area of study has evolved from the inevitable development of telecommunications into applications from the fields of information technology (informatics) and transport — hence the generic term "transport telematics." However, with so much effort being applied in parallel on so many projects, the collective research has inevitably contained a degree of overlapping studies that have involved advanced transport telematics (ATT) applications.

We could adopt the popular view and simply criticize duplicated efforts on the basis of cost and lack of structured focus, but on second glance we would find that a small amount of parallel activity is a desirable feature of research programs.

The by-product of overlapping work, and especially that which is concurrently undertaken, is an increased likelihood of yielding optimal technical solutions for publicly identified user requirements. This is because a single consortium will derive solutions based on *their* own knowledge of equipment, suitable for requirements *they* have identified, which is unlikely to yield a 100 percent solution to anyone else's problems.

Attempts to implement telematics applications of similar natures, using different (or multiple) telecommunications technologies, have been inhibited due to some of the conflicts that occur, such as proprietary rights and the "not made here" syndrome. These conflicts are usually addressed by standards bodies and other, higher, authorities since they cannot be appropriately handled by the smaller research projects, often bound to confined objectives within tight specifications.

A pictorial representation of evolutionary aspects is shown in Fig. 1. In the graphical representation, the horizontal objectives can be considered mainstream subjects (urban or interurban studies, traffic management, environmental considerations, etc.), the vertical objectives specializations within the horizontal areas (such as the microwave, infrared, or GSM telecommunications aspects of traffic management). We can also see from experience that as time passes, projects focus on the more successful elements of their work (i.e., vertically narrower, more specialized aspects), so the horizontal axes may also represent an elapsed time scale from the center lines of the subjects.

The above generic research scenario identifies some of the aspects to be considered when choosing which projects to use to optimize results. While it is true that optimal solutions eventually will evolve from the parallel research approach, how can we help organizations trying to select the correct way forward as they would like to invest now in minimal-cost options but without loss of functionality — which transport telematics media is best?

In this article, known telematics applications are examined to investigate the need for an evolutionary path toward the integration of transport telematics services over multiple telecommunications media.

Applications

The selection of media for transport telematics is closely related to the applications required and the manner in which they can be supported. Common requirements for applications will become distorted according to the various enhancements or limitations of the media to be used, so we shall consider one such application by way of an example.

Location Coding — By way of an example, consider that a 16-bit radio data system (RDS) location code is provided for a specific junction's road element. The junction is later changed in terms of physical location due to the inclusion of an underpass and an extension to its slip road. The RDS code remains the same because it is still the same road element; but on a more dedicated addressing scheme such as a global positioning system (GPS), the data is altered because the actual location of the road element has moved. If a message describing an incident at this location is now promulgated, the decoding equipment might regard it as two incidents or, in a route guidance application, route drivers past their objectives.

Small demonstration projects can overcome these coding differences by simply reprogramming the offending data elements and effectively ignoring the nature of the problems. Larger projects and the working groups of standards bodies

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do not have such simple options; they, at least, must recognize that this is a more difficult task to resolve. It is their role to agree to a fundamental approach toward location coding in the definition of such an applications data structure. Therefore, we can see that these difficulties need to be arbitrated because, for specific applications, they posses different implementation criteria according to the media.

Emergency Call — Emergency calls, in general, refer to time-critical data that needs to be effectively passed on to relevant mobile and fixed locations. The main criteria for what constitutes an emergency call center on the telecommunications media used and how it can be best utilized, so their data are sent in a variety of formats.

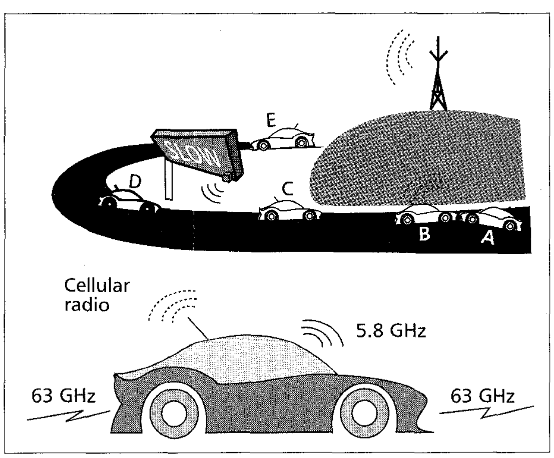
In the scenario depicted in Fig. 2, vehicle A has collided with vehicle B, which has reported the problem via the Global System for Mobile Telecommunications (GSM). Vehicle C is fortunate enough to have noticed the problem visually and is reporting to following vehicles, via 63 GHz microwave, that it is breaking hard. Vehicle D is receiving a message from the variable message sign (VMS) beacon to slow down and is also being warned by vehicle C that there is a problem ahead. If the problem affects vehicle D to the extent that it stops within range of the beacon, that information will be passed on to the traffic managers via the VMS beacon. Vehicle E is far enough away to be able to receive information from the GSM before it passes under the VMS beacon.

For a more detailed representation we need to consider the tasks from the perspectives of different media.

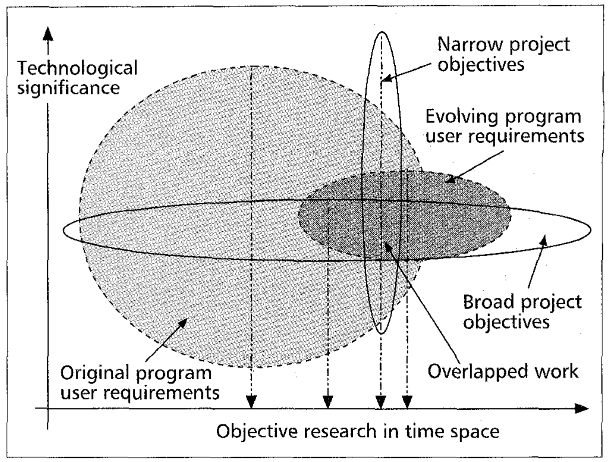
Cellular — Emergency calls from vehicles may occur if the driver falls asleep at the wheel and is involved in an accident. The system may send out a distress message based on information supplied manually (e.g., vehicle hijacked), automatically (e.g., vehicle stolen), or that can be determined automatically to indicate an accident has occurred (e.g., car upside down, fire, or deceleration shocks). The cellular medium offers continuous access to reliable data but is too slow to be used to pass time-critical information pertaining to an emergency situation, such as breaking hard, to vehicles approaching immediately from behind.

Millimeter 63 GHz — Emergency calls differ from the cellular radio type on this medium because of the directional nature of the service (i.e., transmission to roadside beacons is impossible if the vehicle is out of range or nose down in a ditch). However, 63 GHz is likely to offer much greater bandwidth and direct vehicle-vehicle communications; therefore, a rear-facing transmission may be used to indicate excessive deceleration, or even just the presence of the vehicle if it is travelling slowly or stationary. The millimetric band may yet prove to be of greatest value in adverse weather conditions such as fog.

DSRC (5.78 GHz Microwave and Infrared) — Emergency calls over dedicated short-range communication (DSRC) will be capable of issuing a limited number of messages due to the confined data rate and restricted bandwidth,[1] which in turn limit the number of communication modes (e.g., bursts of vehicle-infrastructure communications within beacon ranges only, not vehicle-vehicle communications).



■ **Figure 2.** *The emergency call.*



■ **Figure 1.** *Research overlaps and evolving requirements.*

Media Selection Criteria

Both examples provided were retrospective assessments of potential hazards to avoid when dealing with different media. However, these assessments do not help road authorities understand which media covers their requirements best and for the least cost. This is a perfectly reasonable $64 million (of public money) question, but the answer is inevitably clouded by the fact that the media on offer have different implementation and running costs depending on the requirements of environments and applications.

Environments

Since the environments form an important part of the selection process, we can specify their nature to reflect the requirements criteria as follows.

Urban — Heavily populated areas that are well supported in terms of road and telecommunications infrastructure. The road classes will vary from narrow, restricted access streets up to dual all-purpose roads and restricted access motorways. Vehicle speeds can vary with traffic density in a tidal manner according to the normal working hours and locations of dwellings and commercial properties.

Interurban — Areas of varied populations between major towns or cities. The environments are serviced mainly by motorways, dual all-purpose roads, and some minor roads. While a good level of roadside telecommunications infrastructure is normal, some areas

[1] *For the purpose of the given example, DSRC characteristics such as multipath distortion and ambient daylight interference between microwave and infrared are not considered here.*

Applications	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Hazard warning	b	c	b	a	z	b
Weather	b	b	b	b	b	b
Traffic data/incidents	b	b	b	a	c	c
Traffic information	b	c	b	a	c	c
Park'N'Ride	a	b	a	z	z	a
Vehicle control AICC	b/c	c	b	z	a	b
Infrastructure information	z	z	a	b	c	a
Route guidance	a	b	a	a	z	c
Info. for specific vehicles	b	b	a	b	a	b
Ferries, trains, ports, airports	b	a	a	b	z	a
Fleet operators, HGV, PSV	b	a	a	a	a	a
Fleet operators, emergency		a	a		a	
Hazardous goods	b	c	a	b	b	a
Petrol stations	z	z	a	z	c	a
Yellow pages	z	z	a	z	z	a
Hotels	z	z	a	z	z/c	a
Tourist information	z	z	a	z	z/c	a
Journey times	a	a	c	c	c	z
Automatic fee collection	z	z	z	z	c	z
	a b	High priority Medium priority		c z	Low priority Not required	

Table 1. *RTA proposed applications.*

will not be covered, and cellular radio can be unreliable at present.

Rural — Spatial areas with small pockets of populated villages. The villages are normally connected by a mixture of all-purpose roads and minor roads. Cellular radio coverage is adequate in populated areas; roadside telecommunications infrastructure coverage is varied.

Remote — Spatial regions that are generally uninhabited. These areas have minor roads or tracks and some all-purpose roads that are infrequently used. Cellular radio cover is possible in some areas, but roadside telecommunications support is sparse in extremely remote areas.

Users

The users of transport telematics networks need to be identified before their requirements can be assessed; we can consider them to be in the following categories:

- Road authorities — normally national administrations, but can be private road owners
- Third-party transport telematics service providers — automobile clubs and associations
- Emergency services — fire, police, and ambulances
- Fleet vehicles — taxi, bus, coach, and lorry companies
- Car drivers — company or privately owned
- Vehicle passengers — all vehicles
- Pedestrians — at shopping centers, bus stops, or even at home

The users all need to perceive a benefit in using transport telematics services or they will not buy the systems. The road authorities themselves are key users that will inevitably invest large amounts of effort (if not money) in the networks, but they have different motivations than the others in that they are responsible for the collection and promulgation of appropriate data. It is therefore convenient to partition the above users according to their objectives and needs. This leaves two main user groups that will ultimately need consideration:

- Road authorities (traffic managers)
- Road users (end users)

Traffic Managers — The road authorities primarily require services that facilitate traffic management or enable more efficient and safer use of existing road infrastructures, such as dynamic road data and automatic rerouting of traffic. Road authorities can currently use traffic lights, variable message signs, oral radio broadcast messages (indirectly), and RDS-TMC (traffic message channel) broadcast messages as multimedia approaches to routing traffic in the event of dynamic disturbances to their network. The use of more modern transport telematics media would immediately improve this capability by the collection of extra real-time road data and by providing data to a significant number of equipped vehicles on a composite telematics network in the longer term.

End Users — Most road users abide by the mandatory information presented via traffic lights and so forth; and, with varying degrees of satisfaction, they recognize broadcast traffic and travel information to be helpful. The perceived potential benefits of transport telematics systems include minimizing journey times and reducing stress. Conversely, early route guidance trials[2] have indicated that road users do not adhere to route advice given for some time after they have received travel information which is recognizably manipulative. It is therefore possible that they would have more confidence in autonomous in-vehicle systems, optionally fed with dynamic travel information, depending on equipment and subscription costs.

Applications Requirements

Transport telematics applications requirements comprise the specific database elements of the user's requirements. As such, they are living entities that need continuous assessment and updating as users (or rather "potential" users) become more familiar with what is actually on offer in the foreseeable future. Very few of us drivers at present are prepared to actually let go of the steering wheel and be chauffeured around by a robot on the open highway, but the potential for this application exists in theory; however, we shall not consider it in depth here since it is not a practical option using today's media.

User Requirements

In Europe the Comité Européan de Normalisation (CEN) Technical Committee 278 (TC278) is in the process of approving certain user requirements documentation for the DSRC

[2] *LISB Route Guidance trials in Berlin, summary report presented in Brussels by Siemens in 1990.*

medium (i.e., 5.8 GHz microwave and infrared). This documentation was prepared by working groups of professionals from around the world who were involved in the research and development of the transport telematics industry and specialized in the DSRC domain. A number of these TC278 participants were involved in a proposal known as the Road and Traffic Advisor (RTA) for the EC's 4th Framework Program, which was originally planned to demonstrate harmonized use of DSRC on six different European test sites, and it has since developed into separate national projects, notably in the United Kingdom and France.

Dynamic Information is remotely provided information that is likely to change frequently and elements of it may be provided automatically, e.g. traffic congestion information, speed limit changes on controlled motorways.

The RTA group's preliminary investigations revealed 19 DSRC applications that were of interest to their respective road administrations with measures of initial interest as detailed on Table 1. The significance of these applications is that they are now also being considered by the European project Validation of Dedicated Short-Range Communications (VASCO, EC DGXIII project TR1062), which specializes in the demonstration of the emergent TC278 standards.

The applications shown in Table 1 are identified at the highest level only and do not highlight the media-dependent data elements that form them; this significance was demonstrated earlier using the "emergency call" application. It is therefore assumed to be reasonable to consider the listed applications for media other than DSRC and to start with the classification of data needs at the applications layer for inclusion into databases as elements.

MESSAGE CLASSIFICATIONS

Transport telematics services cannot just pop up in an ad hoc manner without affecting the traffic management task of road authorities; they need to fit in with existing information systems and offer enhanced features, particularly for the benefit of control offices. This approach will prevail in the United Kingdom, where the road authorities are already using an extensive motorway control system known as the National Motorway Control System, version 2 (NMCS2). New projects are planned to adapt the database structures to account for data in the following four notional message classifications that are broadly in line with their network positioning:

- Fixed information
- Semi-static information
- Dynamic information
- Traffic management information

These classifications are suitable for currently envisaged telecommunications media; here it is shown from the perspective of the DSRC medium, where a combination of these classifications will utilize data elements that correspond to the imminent CEN TC278 Working Group (WG) 4.2 specifications for medium-range pre-information (MRPI).

Fixed Information — Fixed information can effectively be read-only memory (ROM) stored at the roadside equipment. It comprises data that will not need updating and is unlikely to change. This includes all fixed sign information such as distances to towns, motorway services, dangerous bends, junction layouts, and other locations. Permanent hazards such as weight-restricted bridges, height-restricted tunnels, or even the permanent threat of falling rocks due to roads passing close to cliffs can be considered to be in this category.

Semi-Static information — Semi-static information is that which can be remotely altered from the control offices but is considered to be relatively permanent in use, for example, recommended maximum speeds that are below the normal speed limits due to road topography, local places of interest, and planned long-term road works. Maximum normal speed limits might be considered to be part of this group to facilitate the simple modification of speeds in the event of roads having their speed limits altered,[3] but this data requires a high level of data security, and due to the infrequency of the need to change the information, it may be considered to be of the fixed data classification.

Dynamic Information — Dynamic information is remotely provided information that is likely to change frequently, and elements of it may be provided automatically (e.g., traffic congestion information, speed limit changes on controlled motorways). This classification includes weather-related hazards, road friction coefficients, or road closures due to short-term roadworks.

Traffic Management Information — Traffic management information is information collected for the provision of traffic management. It can be collected from various types of roadside equipment, including traffic loops and other sources such as RDS or even other beacon networks as well as the local beacons themselves. However, this information is all uplink information from the beacon's perspective and, in some cases, can be automatically processed, then fed directly to relevant local beacons. External network access to filtered data can be achieved through the TIC database at the discretion of the road authorities. Typical beacon-collected data would be journey times, road speeds, road friction, and relevant weather information deduced from wipers, lights, or road temperature sensors in accordance with the findings of projects such as the Road Safety Enhancement System (ROSES).

Medium-Range Pre-Information — Currently CEN TC278 WG4.2 is developing documentation (prENV278) that includes the specifically relevant concept of medium-range pre-information (MRPI). MRPI data is likely to affect travellers who are typically en route and need fixed, semi-static, or dynamic travel information. Much of the background to this research was undertaken in the PROMETHEUS ADAMS project where RDS format data was fed to microwave-receiver-equipped vehicles from gantry-mounted beacons. Fixed MRPI relating to wildlife hazards and junctions and semi-static MRPI relating to motorway services were demonstrated as part of the ADAMS project in France.

SUMMARIZED CRITERIA

The details presented in this article have been included to highlight the range of transport telematics possibilities that we face. The cost criteria will change rapidly with technological developments such as cheaper millimeter-wave hardware

[3] *In 1973 the speed limits on U.K. motorways were reduced to help conserve fuel during the oil crisis.*

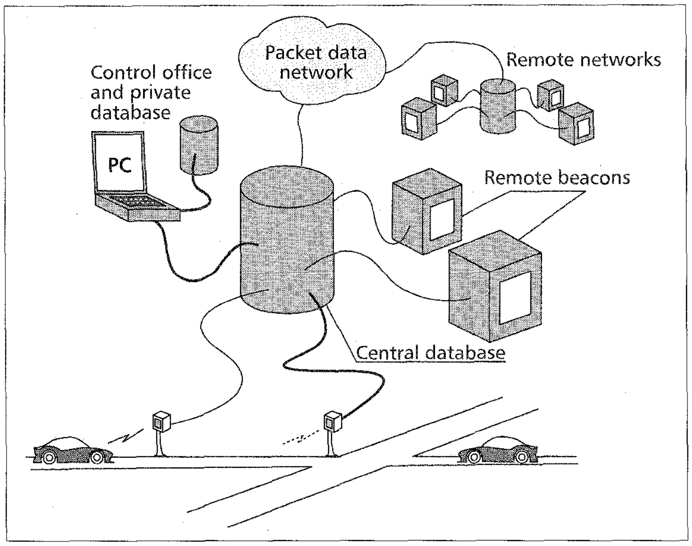


Figure 3. *Basic structure of a 5.8 GHz beacon network.*

substrates and economies of scale for all widely introduced networks. Therefore, the strategic elements of consideration are not only those of initial costs, but also the longer-term implications and technical issues.

Urban environments with well-equipped highways in terms of supporting telecommunications infrastructures can support 5.8 GHz beacon networks (Fig. 3) relatively cheaply because the beacons can be connected to their longitudinal cables and powered by mains supplies readily at traffic signals and street lighting posts. Also, cellular networks already cover most urban environments, and the GSM's general packet radio service (GPRS) in particular looks like the most promising prospect for mobile offices, but the data exchange costs will need to be considered as a significantly negative factor for the users of transport telematics. The RDS-TMC, being well specified, is still worthy of consideration as a potentially cost-free medium but is haunted by a painfully slow data rate (33 b/s), the location coding limitation (64,000 maximum individual addresses per broadcast area), and the problem of who will take legal responsibility for the data.

To choose a single medium for the support of transport telematics services would be a utopian solution, providing all the traffic management information for road authorities to neatly share, even across national borders, but it must be borne in mind that no single network is ideal for all regions, either technically or politically. The systems really depend on our comminution of requirements to determine where the networks will operate from, what infrastructure exists now, and how the networks will be controlled.

As yet unknown applications are certain to evolve around any telecommunications infrastructures available to incorporate new ideas as the services become economically viable and perceived demand for them increases. At the moment, such market forces might support the implementation of 5.8 GHz networks as the cheapest way of communicating with traffic on motorways and in the most populated areas, but how will the cellular network owners respond in terms of competition? We should also consider that society may require 100 percent coverage of remote regions, which will affect the network implementation and maintenance costs.

In short, one telecommunications medium will not be enough. We need to implement technically versatile network options that are comprehensive (in terms of regional coverage) and competitive (in terms of cost), and encourage the development of low-cost future applications.

Background and Projects of Relevance

The CEC identified the main requirements for transport telematics in Europe through the projects sponsored by the DGXIII/F DRIVE program between 1989 and 1992. Since then the work has continued under the EC DGXIII/C4 Transport Telematics program and more recently through the EC DGVII.

European Commission Directorate Generale XIII (DGXIII) Projects under DRIVE

DACAR — Data Acquisition and Communication Techniques and their Assessment for Road Transport — An objective of this project was to determine the best communications medium for transport telematics from radio, infrared, microwave, and control cables laid beneath the road surface. The outcome confirmed that selection would be difficult and that no single medium suited all applications.

SMILER — Short Range Microwave Link — The SMILER project briefly looked into the bandwidth requirements of the short-range communications links (vehicles to infrastructure), including consideration of both microwave (< 10 MHz) and infrared networks. Their recommendations corresponded to the 5.78 GHz band allocation by WARC92.

VIC — Vehicle Inter-Communication — Looked into technical aspects of vehicle-vehicle communications. Its main focus was aimed at 60 GHz microwave and cooperative driving systems.

CIDER — DRIVE Integrated Telecommunications — This project studied a variety of telecommunications media and concluded an interface between layers 3c and 4 of the open systems interconnection (OSI) model would be a good way forward to standardize the interconnection of the different media. The interface concept was known as the DNT and was debated by a number of projects and members of the European Telecommunications Standards Institute (ETSI), but it did not actually evolve, partly due to the beacon communications members who generally considered that a layer 7 interface would be more appropriate via CEN TC278.

PAMELA — Pricing and Monitoring Electronically of Automobiles — The project developed, and successfully demonstrated, a two-way microwave link (vehicle-infrastructure) for automatic debiting systems using 2.45 GHz microwave. Their user requirements formed part of the thinking behind the EC's recommendations for 5.8 GHz to WARC92. Members of the project later continued to investigate aspects of using PAMELA techniques for road congestion pricing.

SOCRATES — System of Cellular Radio for Traffic Efficiency and Safety — The largest of the DRIVE projects, it focused on the use of cellular radio as the main carrier of traffic and travel information. SOCRATES' functionality was demonstrated at their Gothenburg test site with particular attention to using duplex communications (via Mobitex) for dual-mode dynamic route guidance.

Under Transport Telematics

SOCRATES2 — This project continued the work started under DRIVE and strived to achieve a separate data channel

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allocation on GSM networks. Their work inspired the ETSI TC Special Mobile Group (SMG), and a separate data service evolved that eventually became the GPRS.

COMIS — Communication Using Millimeter-Wave Systems — Working together with projects from other EC programs, COMIS investigated the use of monolithic integrated transceiver circuits operating at 63 GHz. User requirements were briefly considered for vehicle-vehicle communications as well as vehicle-infrastructure, and the front-end of the transceiver hardware system was designed by this project team.

PROMISE — Prometheus CED 10 Mobile and Portable Information Systems in Europe — PROMISE aimed to provide a multimodal traveller information system. Their objective was to connect users to information centers via cellular networks, by means of (specially developed and equipped) palmtop computer terminals; the results were demonstrated at the Swedish test site at Gothenburg.

ICAR — Integrated Confined Area RTI Communication System — This project investigated the use of leaky feeders and waveguides for use as GSM interfaces in confined areas such as viaducts and tunnels. Their new cables and techniques for the handling of 900 MHz and 1800 MHz signals were demonstrated at an unused road tunnel in Belgium.

UNDER EC'S 4TH FRAMEWORK PROGRAM AND NATIONAL SPONSORSHIP

VASCO — Validation of Dedicated Short Range Communications — The use of short-range systems($\leq$ 300 m) in Europe for automatic fee collection is now well underway, but a common protocol has not been adopted. The CEN TC278 WG9 is currently defining standards for this application and for the more general information applications on both infrared and microwave (5.8 GHz) systems. The members of VASCO are nearly all contributors to the CEN standards, and their aim is to demonstrate the functionality of the prestandards and standards, where possible, at various European test sites.

RTA(UK) — Road Traffic Advisor (UK) — The RTA(UK) project was originally part of a larger proposal to demonstrate standardized use of the 5.8 GHz microwave medium for information systems, throughout Europe, by merging the work of six nations' test sites with that of the CEN TC278. The large European project objectives were not favored by EC DGXIII, so the scale was reduced and the project continued in the United Kingdom on a 350-mi-long test site, as RTA(UK), under sponsorship of the government. The French part of the original project is also continuing, but separately, as part of a new EC DGVII project to be known as MARTA. The main goals of RTA, proving the use of simple MRPI applications, are maintained in principle for both of the surviving projects. The key participants are automobile manufacturers, road operators, and equipment suppliers.

MOVE-IT — The MOVE-IT project addresses issues related to the use of automatic fee collection systems across Europe. It was originally expected to complement the work of RTA in a number of countries by addressing legislative, institutional, and international cooperation issues. The main participants are national motorway operators and authorities.

ADEPT II — Automatic Debiting and Electronic Payment for Transport — This project continues with the objectives of an earlier project that developed smart card payment systems for automatic fee collection. The method of payment may also be suitable for congestion pricing systems.

PROMISE-PTA — PROMISE-Personal Traveller Assistant — This project builds on the experience of PROMISE to develop dynamic travel information services for individual multimedia access terminals. Cellular radio is used to communicate with the portable terminals.

FURTHER INFORMATION

Historical project and contact information can be found in publicly available EC publications such as "DRIVE 1990" to "DRIVE 1993."

Contemporary information is most easily tracked down by means of the Internet. There are now a number of World Wide Web sites of interest in the transport telematics field that provide access to useful, related information. In the United States the development of the National Transportation Communications for ITS Protocol (NTCIP) is also of interest.

The following sites are of particular interest:

- VASCO http://www.comnets.rwth-aachen.de/~vasco/
- EC DGXIII http://guagua.echo.lu/home.html
- NTCIP http://fhwatml.com/ntcip/

BIOGRAPHY

PAUL A. WINGFIELD has over 20 years of electronic systems engineering experience and has specialized in telecommunications applied to transport since 1989. He is currently WS Atkins' project manager of dedicated short-range communications projects for the European Commission's fourth framework program, and contributes towards international standards via the CEN TC278 as a task force member. He acquired over three years' experience as a project officer for several of the largest DRIVE1 and DRIVE2 projects while seconded to the European Commission in Brussels, and his key roles have included project management of automatic data collection for Kent motorways using digital cellular radio, and lead engineering for the telecommunications works on the Conwy crossing of the A55 North Wales Coast Road. Prior to joining WS Atkins in 1989, and following six years of service with the data and telecommunications group of the Greater London Council, he designed the 64 kb/s digital data service used by Mercury Communications. Paul received an award as the "Best Analogue Hardware Designer" from the ERA for his telecommunications work while studying as a mature student for his B.Sc. degree in electronics systems engineering at Kingston Surrey in the United Kingdom, and his telematics papers have been published at international conferences by both the European Commission and the IEE.