Literature Study on the State of the Art of Probe Data Systems in Europe

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Abstract. This work has been realised in the framework of the iMobility Support and FOT-Net Projects. Its purpose is to support the new founded iMobility Support Probe Data Working Group in scanning the relevant research findings, experiences and deployment results, obtained both by EU funded projects and national/regional initiatives, identifying the stakeholders, probe data applications, standardization status and the open issues and challenges.
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Acronyms

BSM  Basic Safety Message
CAM  Cooperative Awareness Message
CAN  Controller Area Network
CCTV Closed Circuit TV
DEN  Decentralized Environment Notification
DENM Decentralized Environment Notification Message
DSRC Dedicated Short Range Communications
ETSI The European Telecommunications Standards Institute
FCD  Floating Car Data
FOT  Field Operational Test
GPRS General Packet Radio Service
I2V  Infrastructure to Vehicle
ITS  Intelligent Transportation System
ITS-S Intelligent Transportation System-Station
ISO  International Standards Organization
OBU  On-Board Unit
PVD  Probe Vehicle Data
PDRM Probe Data Reporting Management
RSU  Road-Side Unit
SAE  Society of Automobile Engineers
TCC  Traffic Control Center
V2I  Vehicle-to-infrastructure
V2V  Vehicle-to-Vehicle
V2X  Vehicle-to-X
xFCD eXtended Floating Car Data
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Executive summary

The two major goals of Intelligent Transportation Systems are the reduction of the number of fatalities and injuries on the roads, and the reduction of traffic jam hours. The latter goal would also contribute to reducing the environmental impact of transport. Probe (vehicle) data (PVD) \(^1\) plays an increasing role for contributing to these top priorities of our society. In earlier works also called floating car data (FCD) this information stems mainly from sensors and contains at least position information, but may also include vehicle traction information, driver actions (steering, braking), weather and road surface conditions, etc. Based on published references, the present study investigates the state of the art in the PVD technology, the EU- and nationally funded projects, commercial products and systems, as well as available websites with realtime traffic information and tools. This work has been realised in the framework of the iMobility Support and FOT-Net Projects. Its purpose is to support the new founded iMobility Support Probe Data Working Group in scanning the relevant research findings, experiences and deployment results, report on the standardization status and the probe data applications, identifying the stakeholders and the open issues and challenges.

The massive development of mobile phone and applications in the last few years, which went hand in hand with the apparition of performant mobile navigation systems and with good cellular connectivity, caused that traffic information became ubiquitously available. The driver is much better informed on the realtime traffic, most cities and regions in Europe operate web sites and map applications showing realtime traffic on the roads, a part of it being obtained from Probe data.

A short analysis of the stakeholders shows that, besides large internet service providers, map and navigation tool providers, the road operators and OEM have an important role and responsibility to provide safety and level of service on the roads. They would use probe data to manage the traffic, to maintain the road (pavement) and to monitor and alert users in hot spots, where the danger of accidents accumulates. A number of system approaches to PVD are shortly discussed, and the main standardization works are reviewed in the report. Whereas internet companies enter into massive deployment of GPS-based probe data collection, which is today a mature technology, the road and service operators put their hopes in the deployment of cooperative-ITS services, with the probe vehicle data being one of them.

Technically, there are still some challenges we could identify through scanning the relevant publications: when all vehicles will be equipped with PVD collecting technology, a more flexible approach than "collect always and everywhere" might be desirable, to reduce the costs of transmitting, processing and storing non-relevant data. It would allow a fast sampling of the sensors for certain applications, where higher spatial accuracy is required. Another challenge is the privacy protection of probe data, since it might disclose the detailed user mobility pattern and driving behaviour. In particular mobile phone applications do not address sufficiently the privacy issues.

The probe data collection and aggregation of many vehicle traces into confident data enables the application and service providers to develop a large variety of functions for traffic information, management and control (e.g. alternate routing), for road maintenance in extreme weather cases, for monitoring

\(^1\) probing in ICT is a concept for monitoring networks and systems
the fuel consumption and emissions, for speed monitoring and speed limit setting, for identification of dangerous traffic spots, or for quick identification of incidents and traffic disruptions.

Since road operators and car makers plan to introduce the probe data service as soon as 2015, this report could be used by the Probe Data Working Group as a starting point to evaluate the adopted PVD solution for cooperative-ITS in Europe.
Chapter 1

Probe Vehicle Data Overview

The iMobility Forum has recently started a working group probe data to advance the European innovation, standardisation and deployment. One of its goals is also to support the tri-lateral EU-US-Japan collaboration on probe data.

The presented work has been commissioned by the iMobility Forum and the FOT-Net Project to investigate the state of the art of probe (vehicle) data in Europe. Its purpose is to support the iMobility Support Probe Data Working Group in scanning the relevant research findings, experiences and deployment results, obtained both by EU funded projects and national/regional initiatives, identifying the stakeholders, the probe data applications, the status of probe vehicle data standardization efforts and the open issues and challenges.

1.1 Introduction, vehicle probe data definition

For measuring the vehicle density and the average speed, road operators have invested in the past in expensive infrastructure, inductive loops in the pavement, microwave, ultrasound and infra-red sensors, gantries with video cameras, and recently, roadside units that, besides many other services, register the vehicles passing by (for an technology overview, see [26]).

Probe Vehicle Data (PVD), also called floating car data (FCD) (we will use both names alternatively) is data collected by the vehicles themselves. According to ISO 22837, probe data is defined as "vehicle sensor information, formatted as probe data elements and/or probe messages, that is processed, formatted, and transmitted to a land-based centre for processing to create a good understanding of the driving environment". Since the publication of the standard in 2008, the tracking possibilities using mobile and nomadic devices multiplicated, requiring a broader definition: a device in a vehicle that is able to determine at least the vehicle GPS position, and which communicates with some service application such as tolling, application servers in the internet, roadside unit, or UMTS base stations, can in fact deliver (intentionally or not) probe data.

Probe vehicle data collection shall however be distinguished from conventional methods that use detectors along the roadside such as: pneumatic road tubes, piesoelectric sensors, induction loops, infrared detectors, microwave radars, Closed Circuit TV (CCTV) video cameras, etc.

A PVD system has the advantages that it does not need expensive infrastructure at the place where data is collected, and it is able to collect data all the way along the route and not only transversally, as it is the case of fixed sensors. It is important to note that PVD data is formed to messages, which are sent to a processing server. They are not used for safety purposes, and need not to be exchanged between vehicles.

Using PVD collection, we can sense data that refers to the vehicle, to the environment (road, weather, traffic) and to the driver (driving style, etc.). Some authors consider the vehicles as forming a huge sensing network [27].

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Because of the large number of future sensors and applications of PVD, it is difficult to define a definitive set of data elements. A basic PVD message would typically contain the geo-location and timestamp of the measurement, followed by one or several type-value pairs, such as velocity, heading, etc. The message would concatenate several such raw measurement tuples.

An extension of the basic Floating Car Data (FCD) has been introduced by BMW in 2000 as eXtended Floating Car Data (xFCD)\[12]\[7], motivated by the availability to digitized sensor data from the Controller Area Network (CAN) bus. xFCD includes the state of windscreens, wipers or rain sensors, external thermometer and the air-conditioning system, the vehicles light system (brake and fog lights), the hazard warning flashers, the sensors for the systems controlling the vehicle dynamics, alerts from driver assistance systems. This information reflecting the environment and driving conditions is best mapped to events such as "start of poor visibility area" or "approaching a congested area", and is communicated as one, single notification.

1.1.1 Scope and structure of the study

This report has a strong focus on Europe: therefore some interesting uses of PVD in Japan (use of brake information) or US (tolling, pay as you drive, surveillance services, etc.) have not been discussed. Nor has the American only PVD protocol in SAE J2735 been analyzed in detail.

From the value chain, the details on transmission of data via different wireless networks have been neglected. The large amount of research work about the raw data processing (map matching and statistical filtering) has been only shortly discussed. The last step in the value chain—processing the aggregated data in order to realize the different applications, is definitely not in the scope of this report.

The rest of the document is organized as follows (see Figure 1.1): First, a short stakeholder analysis and their mapping to the value chain is given. In Chapter 3 we describe technical aspects such as

![Figure 1.1: Scope of the study](image-url)

the system architecture and the main approaches for collecting PVD. The status of standardization efforts of PVD in Chapter 4 concludes the technical part.

Chapter 5 of the study is devoted to PVD deployments that are divided into EU funded projects and FOTs, nationally funded projects and field trials, commercial deployments, and online available

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realtime traffic sites. Because of their large impact on the way in which PVD will evolve, we consider also the systems offered by large map and internet service providers. Section 5.6 lists the possible applications and functions of probe data, as mentioned in the scanned projects and trials above.

The challenges and concluding remarks (Chapter 6) begins with an evaluation of the techniques where we point out the trade-offs that have to be made: the data has to be quickly available at the processing server (e.g. road operator), it should be accurate both spatially and temporally, the collection process must scale up to all the vehicles, work for different types of data as required by the future applications. The system should be low cost, and widely accepted by the users (who are concerned about their privacy), and the probe data should be made available also to other stakeholders.

Finally, a number of remarks conclude the report.
PVD collection is an enabler for many services, but not an end-user service itself. However, a supply chain is only meaningful when the complete chain is depicted, including the applications based on FCD, as in [46].

Figure 2.1 is an example for the value chain with the responsible stakeholders. Depending on the system approach (cooperative ITS, mobile phone based, etc.) the responsible stakeholder may change accordingly.

<table>
<thead>
<tr>
<th>Description</th>
<th>Stakeholder</th>
</tr>
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<tbody>
<tr>
<td>Define sensor data type, parameters, time interval and road segment</td>
<td>Road operator, application provider,</td>
</tr>
<tr>
<td>Sample the sensor, with location and time stamp according to configuration</td>
<td>Vehicle, OBU or nomadic device</td>
</tr>
<tr>
<td>Buffer the samples, filter according to threshold, sampling rate, prepare the PVD message, anonymize</td>
<td>vehicle</td>
</tr>
<tr>
<td>Transmit the message via WLAN, cellular, wimax</td>
<td>Road operator, and/or network operator</td>
</tr>
<tr>
<td>Aggregate probe data, map matching, storage</td>
<td>Road operator, service provider</td>
</tr>
<tr>
<td>Service applications: calculate travel time, speed, visualization, prediction, etc., inform driver</td>
<td>All (Road operator, driver)</td>
</tr>
</tbody>
</table>

Figure 2.1: Example of PVD value chain
Traditionally, a stakeholder analysis is defined as a process of identifying the parties (stakeholders) which are affected by a project or event, and analyzing the aspirations of the stakeholders regarding the incoming changes (COMeSafety Architecture Task Force, 2010).

2.1 The Road Operator

The overall goals of the road operator are: a) optimal use of the existing road network resources by the road users, b) optimum safety level for the road users, c) minimum negative environmental impact and d) high cost-efficiency of the service.

The activities of the road operator (see [43] for a detailed analysis of road operators as stakeholder of cooperative services performed in the project EasyWay) are:

- Management of traffic data: to collect, administer, validate, simulate, forecast traffic data etc.
- Control and inducement of traffic: to harmonize traffic flow, optimize the distribution of traffic in the road net; to adjust the road capacity dynamically to the traffic situation; to provide information to the road users regarding traffic situation, local hazards etc.

The EC member states differ in their organisational structure of highway road operation and the existing type of road operator on an institutional level. In some member states several types of road operators exist:

- The road operator is a public authority. Most of the activities of road operation are conducted by the public road operator himself. A few activities are contracted out to private service providers. Examples: Germany, The Netherlands.
- The road operator is a public authority. The public road operator predominantly acts as a supervisor of a considerable number of private contractors which take over specific activities in the process chain of road operation. Examples: Finland, Sweden.
- The road operator is a private service provider responsible to a public road authority. The road operator competes with other providers. Examples: Austria, France, Italy.

Specifically for the PVD generation, the road operators see themselves entitled to collect the raw data in order to achieve the goals above. PVD is also perceived as one of the DAY ONE services after the rollout of the ITS roadside infrastructure for C-ITS (as proposed by the Amsterdam Group, see [5]).

The ideal PVD collection, that covers the whole road network and that has low latency, cannot be achieved by a road operator, because of the very large number of roadside units required. Nevertheless, a smart architecture with possibility to control where and when to collect could mitigate the drawbacks above.

As mentioned before, the PVD collection is the enabler; the applications that use this data are the ones that bring the value, for which users would pay. An example of a "value web" related to PVD is given in the Figure 2.2 presented by the Project Drive C2X [31].

2.2 The User (Vehicle Driver)

Users are in general the vehicle drivers. Their acceptance to PVD collection is higher, when they drive a company car than when they drive their private cars [34].

The users are sensitive to the additional costs for services in general, and to PVD in particular, since they do not have information about the final benefit created through better traffic control, notifications etc. Therefore, business models developed by road and service operators have to offer a package of services, including PVD collection and the communication services. In case of the cellular communications, communication costs are usually part of the service subscription costs.

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According to the Amsterdam Group (see Section 3.3.1), users are interested to obtain traffic, environment, hot spot information also in normal situations, not only when there is a hazard (which is covered by Decentralized Environment Notification Messages (DENMs) created by the affected vehicles and transmitted in Vehicle-to-Vehicle (V2V) mode). The normal state can be obtained via PVD collection.

Several user studies have been conducted in order to learn the arguments for and against data collection. In one study performed in Austria [34] more than 800 respondents showed a mixed picture: whereas part of them support PVD (45% private car owners) mainly for traffic optimization, alternative route suggestion, etc., 91% see the danger that anonymization of PVD could fail, that personal data would be kept into surveillance, or might be published on the internet. Concerning the confidence in the potential operators of the FCD service, the largest part of the responders (71%) consider that the road operators should take this role, only 40% would trust a private service provider, or a car manufacturer (24%).

2.3 Car manufacturers

Car manufacturers want to be the ones that add more value in their cars either with navigation systems, assistants and now with OBU capable to run standardized services. On the one side, car manufacturers have the key for the integration of OBUs with data collection from the various sensors in the car, on the other side they have to calculate carefully the prices for these extras, as the pressure from nomad devices such as mobile phones that offer innovative services at lower, app prices (Google, Waze, TomTom, etc.), grows significantly. Currently, car manufacturers and road operators collaborate to standardize services and interfaces and agree to the roll-out priorities.

2.4 Network Operators

Network operators are involved in gathering mobility and PVD from two sides: they provide the cellular connections for the GPS tracking in navigation applications etc., and they collect floating phone data which they sell, also for traffic measurement and management purposes.
At the time of writing, it is not clear whether the ITS-G5 short range communication or the cellular technology (UMTS, LTE) will dominate the vehicular communication for PVD.

2.5 Service providers and integrators

PVD processing and storage is only a small part of the traffic system and IT development that is performed by these companies for delivering turn-key solutions for road operators, traffic management centers in cities. In particular map and navigation service providers benefit from the use of probe vehicle data.

2.6 Fleets and professional transport services

The present study does not cover in detail traffic applications for the logistics sector and for fleets in general. However, the requirements for positioning and tracking are well known and used by the major packet services such as DHL, DPD, etc. Also smaller companies offer logistic applications that include GPS vehicle tracking, such as XLOC\(^1\), Geoloc\(^2\), Safefleet\(^3\), and many others. The GPS on-board units use in general proprietary messages to communicate with the central service application.

\(^1\)http://www.xloc.at/
\(^2\)http://www.geoloc-systems.com
\(^3\)http://safefleet.eu/
A typical architecture of a PVD collection system is shown in Figure 3.1. In the vehicle, an on-board data collection system is an integrated or a nomad device that has access to car sensors, primarily a GPS receiver. The sensors are periodically sampled and the data is formatted to PVD messages that are sent over a wireless data connection to a server of the service provider. There, messages from several vehicles are processed (aggregated, map-matched, etc.) and stored into a database for further use. Applications (which can belong to a third party) use the PVD for traffic information and control, for environment information, etc. Some of this enriched information is disseminated back to the drivers (dotted line), another part is used by road operators and the other stakeholders.

Figure 3.1: High Level Probe Vehicle Data System architecture

3.1 Fleet based systems

PVD is today a mature source to collect mainly traffic relevant data from moving vehicles. The early systems required a fleet such as taxis [30],[19] equipped with wireless (cellular) data communication devices, and a server that processes the incoming data streams. In early studies [12], [7], it has been shown that a percentage between 1% and 5% of collecting cars driving in the area of interest is needed to provide useful information on the urban traffic.

Taxis or road based public transport are still used due to the extended periods of time they spend on the urban road network. Although taxis and buses provide a major source of inner-city traffic information, because of the time they spend moving, they have limitations. Problems arise if the taxi drivers, through detailed knowledge of the local road network, take steps to avoid congested areas,
which, as a consequence are not reported [29]. A big advantage of fleets such as taxis is that no user privacy concerns arise, when these vehicles are tracked.

The sampling rate of the GPS position of vehicles in the fleet is in general low because of airtime transmission costs. At the server, the samples have to be map-matched, a process which is challenging if the samples are sparse, in particular in urban environments. [35] shows a method to improve the usage of such sparse traces, applied to taxis in Stockholm. The sparse sampling approach has however other drawbacks; in order to reduce the amount of data collected steadily by the vehicle fleet, the sampling interval is relatively large, e.g. 30 seconds, leading to a low accuracy (in 30 seconds a car may advance more than 1 km without collecting any data). Certain FCD based applications need a high accuracy of a few meters between the samples. Another problem is that, at low densities and low penetration rate, one has to wait for minutes to collect enough samples. Since the data collection cannot be targeted to a region, although the operator knows from everyday operations, where more information is required, a large amount of data is collected in regions and at times of day which are not relevant; their transmission, processing and storage is a waste of resources.

The same Daimler group reports in [37],[23] about the use of Kerners Three-Phase traffic theory to detect the global states of traffic (free flow, synchronized flow, and wide traffic jam) using PVD. The probes are processed in a fusion process that results in the display of the states in a spatial-temporal diagram. The method uses real probes collected by TomTom navigation systems representing 1-1.5% vehicle penetration and shows typical movement of traffic jam upstream, see Figure 3.2.

![Figure 3.2: Reconstruction based on TomTom’s PVD on 10th December, 2009 on the A5-South in Hessen, Germany](image)

In the Ph.D. Thesis of Martin Linauer[28], the author calculates the density of cars needed in order to observe a change (in the speed) coming from three FCD collecting vehicles within 1, 2 or 3 minutes. The results are probabilistic, Poisson arrival distribution is assumed. So, for example to decide within 1 minute about the change with a probability of 0.9 we need a flow of 320 FCD enabled vehicles/hour.

### 3.2 Massive Deployments

In contrast to the taxi fleets equipped with a GPS tracking on-board unit, that could offer a quite poor statistics of the dynamic traffic situation, the high penetration of mobile phones have completely
changed the situation in the last few years. Large map application providers such as Nokia, Google, TomTom, Apple with their huge user base, added GPS tracking to leverage their maps, navigation and traffic services software. The technology is well understood, the scale is huge: smart phones (nomadic devices) or specialized GPS navigation clients (TomTom) send periodically GPS position fixes via the cellular network to a server, where map matching and the further processing and aggregation are performed. The latter, also called Data Fusion takes data from multiple probe and sensor sources; the processing starts with spatial filtering and outlier detection, traffic state calculation; it continues with temporal filtering and alignment, confidence measurement; and ends with a high accuracy, low latency traffic flow information. The integration, between the apps running on the smart phone/navi and the central system that aggregates the information from hundreds of probes, is seamless for the user, except an initial click, where the user agrees to share her position. The interfaces between the mobile device and the application server are mostly proprietary.

On the one side there is more potential in a smartphone for data collection in the future, as it has a large number of sensors besides GPS: compass that can determine the heading, accelerometer, microphone, camera, etc.

On the other side, nomadic devices do not offer the same level of integration as an embedded on-board unit connected to the CAN bus. Therefore, specialized FCD applications are still difficult to realize with mobile phones and have more chances in a cooperative ITS environment with open and standardized interfaces. In Chapter 5 will will shortly describe the commercial players in this important market: Nokia, Google, TomTom, etc.

3.2.1 Floating Phone Data

Besides GPS tracking, an earlier technique to obtain traffic probes from mobile phones is called floating phone data [26]. The mobile phone positioning is regularly transmitted to the network by means of triangulation or by other techniques (e.g. handover) and then travel times and further data can be estimated over a series of road segments, before being converted into useful information by traffic centres.

There are however some differences to GPS based PVD collection: the data collector is always one of the mobile network operators, the localisation has lower accuracy than that of GPS, and is possible only at those road segments that represent also a border line between two neighbouring cell areas. Sophisticated algorithms are needed for processing the large number of traces. With the massive introduction of much more accurate GPS tracking, it is expected that floating cellular data will loose significance.

3.3 Cooperative ITS Approaches

Cooperative Intelligent Transportation System (ITS) services derive their name from the coupling between on-board driver assistants and the road infrastructure services in order to improve the traffic control and safety of the vehicles, and learn from the vehicle sensors the traffic and environment situation. The two-ways interaction Vehicle-to-infrastructure (V2I)/Infrastructure to Vehicle (I2V)) uses typically short range low latency communications in Europe in the 5.9 GHz band according to IEEE 802.11p (ITS-G5), and in US 5.8 GHz, Dedicated Short Range Communications (DSRC) protocol.

The system architecture in a cooperative ITS is based on the "ITS station", described in the ETSI standard "EN 302 665, ITS Communications Architecture" document. The most important messages exchanged between ITS stations defined sofar, are the Cooperative Awareness Message (CAM, a "Hello" message), and the Decentralized Environment Notification Message (DENM). A probing vehicle data message is not yet defined by ETSI.

3.3.1 The Vehicle Probe Collection of the Amsterdam Group

The Amsterdam Group, a strategic alliance of road operators and industry on a European level, is coordinating the efforts towards deploying cooperative ITS. Involved are CEDR as an organisation of public road operators, ASECAP as an umbrella association of the toll road operators, POLIS
as an umbrella association of cities and the Car2Car-Communication Consortium representing the automotive manufacturers and associated industries.

The stakeholders seen by the Group are the users (drivers) and the road operators. The motivation of PVD is the need to know traffic and environment information also in case where NO hazards or other events occur (which are anyway disseminated by Decentralized Environment Notification (DEN) messages).

The Probe Vehicle Data Service has been selected among the cooperative services planned for deployment starting 2015 (Day One Services). (The mentioned services are: V2V services: a) Hazardous location warning b) Slow vehicle warning, c) Traffic jam ahead warning d) Stationary vehicle warning e) Emergency vehicle warning f) Emergency Brake light g) Motorcycle approach warning. V2I services: a) Roadworks warning, b) In-vehicle signage c) Decentralised Floating Car Data d) Signal Phase and time [5])

In its first version (May 2013), the proposal of the Amsterdam Group was based on buffering the cooperative awareness messages (CAM) between two successive Road-Side Units (RSUs). This approach reduces of course the generality and variety of sensors that can be sampled. In addition, the generic control of the data collection area via Probe Data Reporting Management (PDRM) messages (described in ISO25114) is not used, as the collection starts at a RSU and ends at the next RSU, in any case and for all vehicles. According to the proposal, the delivery of the PVD message by the vehicle can however be cancelled, when the destination RSU first broadcasts a kind of PDRM message to the vehicles saying ”don’t send me PVD data”: as a result the vehicle discards the collected data and starts collecting again on the following road segment.

The proposal above is not the final one. One concern raised in this forum is the privacy one: the very fact that a vehicle releases a GPS trace between two distant points is already a privacy threat (see the section on privacy by design).

The Amsterdam group is working on a road map towards implementation of the Day 1 services. Individual stakeholders are setting up agreements on deployment strategy, infrastructural requirements, and technical requirements. These applications will be deployed starting 2015.

### 3.3.2 The Controlled Probing Approach (CP)

Developed at FTW (Telecommunications Research Center Vienna), controlled probing [33] allows a central application, run by a road operator, to collect data from arbitrarily selected areas of interest (road segments), at a certain time for a certain time duration, at a certain data sampling rate and for a certain type of data (supported by the system).

To describe the operation of Controlled Probing, we consider the road sketched in Figure 3.3. Central to the approach is the existence of a RSU infrastructure, but not necessarily in the area of interest. A "collection job" is defined and managed at the central Traffic Control Center (TCC) (1). It refers to an area of interest (4) on which each, passing vehicle must produces probes. The RSUs, which are relevant to this job can be categorized into two sets: upstream RSUs\(^1\) (3) which a vehicle meets before entering the area of interest and downstream RSUs\(^2\). The area of interest within the road infrastructure is identified by the longitude and latitude coordinates of the start and end points. The main idea, as shown in Figure 3.3, is that the vehicles are able to receive Probing Commands at upstream RSUs and deliver the collected PVD at downstream RSUs. The Probing Command has similar functionality to a PDRM message in ISO TS-25114 [15]. The upstream RSUs periodically broadcast the Probing Command to all passing cars. This set of RSUs is calculated by searching the road graph. After traversing the area of interest, a vehicle can deliver the collected probes at any subsequent downstream RSU. All the probes that refer to a certain job are routed to a certain RSU where the data aggregation is performed. Jobs are created, activated and deactivated by a central FCD application in the traffic control centre.

---

\(^1\)RSUs on any road leading to the area of interest.

\(^2\)RSUs on any road leading away from the area of interest
3.3.3 Vehicular Sensor Networks

The work of [47] uses sensor network techniques to gather PVD; in a Cooperative-ITS system based on dedicated short range communication, the road side unit initiates the probing process by sending a message to the cars passing by; each vehicle has three tasks: a) to collect PVD from its own sensors (speed, light, etc.), b) to collect the information from the vehicle in front of it and c) to forward the aggregated data to the vehicle behind it. In this way the PVD is relayed to the RSU. The authors simulate the reception probability of messages which decreases with the distance between vehicles, and the delay between measurements and delivery which is in the range of a few seconds. The open questions with this approach are the created data traffic, and especially the overlapping functionality with the newly defined ETSI V2V messages (Cooperative Awareness Message (CAM) and DENM).

3.4 User Privacy Protection

User and data privacy in the context to PVD is a fundamental and difficult problem to solve: on the one side it means to disclose a user mobility trace which is processed by a untrusted third party in order to provide travel time, traffic situation, dangerous hot spots, etc. On the other side it has to make this trace un-distinguishable from other "near" traces (near in time and place). PVD privacy draws attention in the standardisation bodies, see Section 4.5.

A first approach followed in the research is to anonymize the traces by removing all the identifiers of the individual measurements, or hiding the relationship between a trip identifier and the individual measurement [36]: apart from the need for a (untrusted) third party to use this relationship in order to calculate travel time, this approach is not sufficient as discussed in [11], because the drivers can be re-identified by the high spatio-temporal correlation between successive points and by correlation of anonymous location traces with data from other sources. The metric analysed here is the "time to confusion", e.g. the tracking duration of a certain user. The solution proposed in the work of Nokia Research is called "virtual trip lines" [11] which corresponds to limitation of the collection of data to certain virtual points on the route, where, as a result of aggregation sufficient anonymity for data traffic monitoring can be guaranteed.

Privacy by design is a similar concept and consists of methods to insure that the data, once released by a vehicle cannot be used to re-identify the user.

A sound work on privacy mechanisms with application to floating car data has been performed in the EU Project Preciosa [21], lead by the University of Twente, NL.
Chapter 4

STANDARDS FOR PROBE VEHICLE DATA

In this chapter we investigate the existing PVD standardisation efforts from International Standards Organization (ISO), Society of Automobile Engineers (SAE) and The European Telecommunications Standards Institute (ETSI). Generally, PVD comes in two categories; the first is a collection of one or more raw sensor samples, named snapshots in SAE documents, which are usually generated either periodically or after driving a particular distance. The second category is purely event based, meaning that messages are only generated when sensor thresholds are exceeded, and contain position, time stamp, and the event type. This distinction is reflected in the following standardisation documents.

4.1 ISO 22837 Vehicle Probe Data for Wide Area Communications

The document ISO 22837 [14] from 2008 describes in an object diagram the main elements of a probe system, from probe element generation, over message generation, collection, processing and until the probe application (see Fig. 4.1). The document has the character of a data dictionary: it mentions first the probe core data elements: Timestamp, Latitude, Longitude, Altitude.

![Figure 4.1: ISO22837 reference probe architecture](image)

In addition to the "core", there are probe data elements derived from on-board sensors and related to traffic, weather, road conditions, safety and navigation. They are grouped in a vehicle package, a surrounding package and a road network package.
<table>
<thead>
<tr>
<th>ISO 22837</th>
<th>CAM</th>
<th>SAE J2735</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature (with confidence)</td>
<td>AmbientAirTemperature</td>
<td></td>
</tr>
<tr>
<td>Rain wipers status (on/off, intermittent, slow, fast)</td>
<td>WiperStatus + WiperRate</td>
<td></td>
</tr>
<tr>
<td>Rainfall intensity (from rain sensor)</td>
<td>RainSensor</td>
<td></td>
</tr>
<tr>
<td>Exterior light status</td>
<td>ExteriorLights</td>
<td>ExteriorLights</td>
</tr>
<tr>
<td>Outside light condition (from light level sensor)</td>
<td>SunSensor</td>
<td></td>
</tr>
<tr>
<td>Vehicle velocity with confidence (which is accuracy in m/s)</td>
<td>Speed + SpeedConfidence</td>
<td>Speed</td>
</tr>
<tr>
<td>Obstacle detected (boolean)</td>
<td>ObstacleDistance</td>
<td></td>
</tr>
<tr>
<td>Obstacle distance</td>
<td>ObstacleDistance</td>
<td></td>
</tr>
<tr>
<td>Obstacle direction as seen from detecting vehicle</td>
<td>ObstacleDirection</td>
<td></td>
</tr>
<tr>
<td>ABS activation (boolean)</td>
<td>AntiLockBrakeStatus</td>
<td></td>
</tr>
<tr>
<td>Traction control activation (boolean)</td>
<td>TractionControlStatus</td>
<td></td>
</tr>
<tr>
<td>Stability control activation</td>
<td>StabilityControlStatus</td>
<td></td>
</tr>
<tr>
<td>Gforce (vertical acceleration exceeded)</td>
<td>VerticalAcceleration</td>
<td></td>
</tr>
<tr>
<td>Acceleration with confidence</td>
<td>AccelerationControl</td>
<td>AccelerationSet4Way</td>
</tr>
<tr>
<td>Brake force activated (boolean), brake Boost activation</td>
<td>BrakeBoostPressure + BrakeBoostApplied</td>
<td></td>
</tr>
<tr>
<td>Yaw rate</td>
<td>YawRate</td>
<td>AccelerationSet4Way.yaw</td>
</tr>
<tr>
<td>Current and average fuel consumption</td>
<td>LateralAcceleration</td>
<td>LateralAcceleration</td>
</tr>
<tr>
<td>Vehicle direction/heading, slope</td>
<td>Heading</td>
<td>Heading</td>
</tr>
<tr>
<td>Vehicle type, usage</td>
<td>StationType</td>
<td>VehicleType</td>
</tr>
<tr>
<td>Seatbelt status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doors status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking brake</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steering manoeuvre</td>
<td>AccelerationSet4Way</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1: Data elements in ISO 22837 and how they are covered in other standards used for PVD. Not supported elements are denoted with X.

Since the document is rather general and will be updated by more concrete proposals, we will not elaborate on the definition of the probe data, but compare this maximum set with elements defined in the awareness message (CAM) and the American SAE J2735 probe data message in Table 4.1. SAE J2735 is the American standard for cooperative ITS and is the only one that defines a concrete PVD message. This is the reason to present it shortly in the next section.

### 4.1.1 Probe Data According to SAE J2735

SAE J2735 [40] is the collection of all messages, data frames and data elements which an Intelligent Transportation System-Station (ITS-S) must be able to generate and receive. Besides defining the Basic Safety Message (BSM), the default hello message, the standard specifies both the PVD message and the collection mechanism. PVD is sent with best-effort quality, i.e. there is no acknowledgement of reception by the RSU and if the message is not received by the RSU, due to channel interference, the message is lost. In the context of SAE J2735, PVD consists of one or more snapshots. Each snapshot contains the time and location of the snapshot, accompanied by one or more key-value pairs of sensor readouts. The generation of a snapshot can be triggered by either a timer, the travelled distance since last snapshot, by particular events such as Anti-Lock brake status or periodically, as a function of speed. The latter is based on the assumption that high speeds occur only on motorways, where the density of RSUs is sparse and given the minimum requirements of 30 snapshots, the individual snapshots must be more distributed.

*iMobility Support & FOT-Net Project*
CHAPTER 4. STANDARDS FOR PROBE VEHICLE DATA

<table>
<thead>
<tr>
<th>ISO 29284:2011</th>
<th>DENM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion</td>
<td>Traffic Condition</td>
</tr>
<tr>
<td>Flowing Traffic</td>
<td>Traffic Condition</td>
</tr>
<tr>
<td>Slippery Road</td>
<td>Hazardous location - Surface condition</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Adverse weather condition - Precipitation</td>
</tr>
<tr>
<td>Low Visibility</td>
<td>Adverse weather condition - Visibility</td>
</tr>
<tr>
<td>Crash</td>
<td>Accident</td>
</tr>
<tr>
<td>Breakdown</td>
<td>Vehicle breakdown</td>
</tr>
<tr>
<td>Emergency Brake</td>
<td>Dangerous situation</td>
</tr>
<tr>
<td>DirtRoad</td>
<td>—</td>
</tr>
</tbody>
</table>

Table 4.2: Events types defined by ISO 29284:2011 and how they map to DENM elements. The table shows only the main event categories, e.g., "entering congestion" and "existing congestion" are reduced to one entry. Note that DEN contains more events which are not related to probe data.

Privacy is achieved by stripping all snapshots from any identifying data. Additional privacy enforcing parameters define that an On-Board Unit (OBU) must not generate any snapshots while it is switched off as well as for the first 500 meters (default) of the trip.

4.2 ISO 29284 for Event Probe Data

Events are in fact a part of probe data, such in ISO TS 29284 (Event based probe vehicle data 2011) [16], where a new Area package is introduced and contains: detected Congestion, Low Visibility and Precipitation Events as additional probe data types. In Europe, events are defined in the ETSI Decentralized Environmental Notification (DEN) message [10]. They have however a safety related purpose and should reach primarily the neighboring vehicles using V2V communication, and later the infrastructure. Additionally, ISO 29284 extends the original definition of a raw sensor data to include the precision confidence of the location as well. In Table 4.2 we identify which events defined in ISO TS 29284 are handled by DENM, J2745.

4.3 ISO TS 25114 Probe Data Reporting Management

This document [15] is motivated by the fact that massive collection of probes has to be efficient in order to limit the use of scarce air time resources. The general idea is to send instructions to vehicles that collect probe data, specifying when, where how often to collect and deliver data. The document is in a preliminary phase, but the concepts described are very important for a scalable probing solution as we will see in the subsequent sections.

In Figure 4.2 the generic object architecture for probe data reporting management is shown: the PDRM contains instructions to (a) selectively enable or disable various levels of probe data reporting, (b) selectively enable or disable reporting of particular types of probe data, (c) adjust the criteria for probe data reporting for specific probe data elements, e.g. by specifying the threshold values, or (d) adjust the criteria for probe data reporting for specific data elements based on the delta value (for example do not report a smaller than plus/minus 3 degree difference in air temperature). The PDRM messages are created by a probing processing center, are distributed to infrastructure nodes (e.g RSUs) and broadcasted to the vehicles, where they have an impact on the data reporting process.

The message contains common data elements, the most important ones are:

- PDRStartTime and PDRStopTime which define when to start/stop the reporting
- PDRM InstructionType: three reporting modes: dataCapture, Threshold based or Delta-based
• Region: regionType (type of boundary such as rectangular, road class, or circular) AND region data i.e. location definition matching the defined location type, such as coordinates.

• heading (of vehicle or road) defines GPS directions for which the PDRM reporting is valid.

• data elements as defined in ISO 22837 specify which sensor types should be considered for reporting

• the vehicle types for which the reporting is valid

• frequency in seconds with which a reporting message is sent.

The instructions distinguish correctly between data value sampling or more advanced processing methods that reduce the data amount, such as delta or threshold reporting. For example, speed dropping below a certain threshold or temperature below certain limit should only be reported, otherwise not. For the threshold mode, a direction is specified (greater than, less than, or both). For the delta model, both the direction and a TimeDiff period in seconds, considered to calculate this interval are defined.

The components of this reference architecture are specified as follows:

5.1 Referenced data repository
Referenced data repository holds data for reference by the probe message generator.

5.2 On-Board data Source
The onboard data source provides original data that will become a probe data element. Original data may be raw sensor data or data from other onboard applications. Onboard data sources may be (various types of) sensors or onboard systems.

Figure 4.2: ISO 25114 reference architecture for PDRM

4.4 Extracting Probe Data From a Cooperative Awareness Message

The probe data report [46] compares the data elements of SAE J2735 BSM Part1 and Part2 used in probe data in the US, with the data elements used by the Japanese service ITS-Spot. Since in Europe the mandatory CAM data elements would be anyway available in the ITS station and local dynamic map database, they could be used to build the probe vehicle data message. According to [39] a significant effort has been invested into harmonizing the European standard with the American one. As a result, the messages are not completely identical, but contain more or less the same information. The comparison in Table 4.3 illustrates this fact.

4.5 Personal Data Protection, Privacy in Probe Vehicle Information Services

The international standard ISO 24100 [3] defines personal data as "data which pertains to an individual and can identify a particular individual, and are handled by probe vehicle systems defined in ISO 22837 when collecting probe data via a telecommunication network". Personal data includes data that can be referenced to other databases and thereby used to identify a particular individual. Privacy enhancing mechanisms should avoid the possibility of linking content of the probe message such as locations, time stamps, driving manoeuvres, with user or vehicle identifiers such as IP addresses, address books, in the probe header. The probe message block consists of the probe header, the authentication data and the probe message. The document ISO 24100 uses the 1980 defined eight OECD principles for data privacy, applied to the probe data collection to derive general guidelines: 1) collection limitation
### Data Elements

<table>
<thead>
<tr>
<th>Data Elements</th>
<th>US J2735 BSM Part 1</th>
<th>US J2735 Probe Data</th>
<th>Japan ITS-Spot</th>
<th>EU ETSI CAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position (Longitude, Latitude, Elevation)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>GPS Position Accuracy</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Acceleration (Longitudinal, Lateral)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Vehicle Yaw Rate</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Heading/Direction</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Vehicle Length, Width</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Roadway Type</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Time Stamp</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Brake system Status:</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Brake, traction control, stability control, ABS, brake boost, auxiliary brake</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 4.3: Comparison of basic safety data elements in SAE J2735 BSM Part 1, SAE J2735 Probe Data, Japanese ITS Spot Probe Data and the European CAM. Note: CAM allows a slightly different set of vehicle status elements, see Appendix 7 for a full comparison between BSM and CAM.

Since ISO 24100 text is quite abstract there is an ongoing effort to specify mechanisms to protect the user from being tracked. For details on the research and approaches of protecting the user’s privacy, see Section 6.1.5.
In this chapter we present existing PVD systems which are providing services based on probe vehicle data.

We distinguish between research projects and field trials funded by the EU, between national funded projects, realtime traffic tools run by governmental sites and cities, and between activities of companies.

5.1 EU Funded Projects

In this section we list a number of EU projects and Field Operational Tests (FOTs) in which the probe vehicle data plays a relevant role. A similar list, but more general in its scope is maintained by the FOT-Net Project on the wiki page: http://wiki.fot-net.eu.

Among the discussed projects, in particular the EU projects FOTsis and DRIVEC2X focus on probe data.

5.1.1 FOTsis

FOTsis\(^1\) is a large-scale field operational trial of the road infrastructure capability to operate a number of close-to-market Cooperative Services, in order to assess in detail 1) their effectiveness and 2) their potential for a full-scale deployment on European roads.

FOTsis aims at testing 7 cooperative services as shown in Fig. 5.1. In particular the services S3 and S4 require probe and traffic data collection techniques.

5.1.2 DRIVE C2X

DRIVE C2X\(^2\) focuses on communication among vehicles (vehicle to vehicle), and between vehicles, a roadside and backend infrastructure system (vehicle to infrastructure). Previous projects such as PReVENT, CVIS, SAFESPOT, COOPERS, and PRE-DRIVE C2X have proven the feasibility of safety and traffic efficiency applications based on C2X (Vehicle-to-X (V2X)) communication. DRIVE C2X goes beyond the proof of concept and addresses large-scale field trials under real-world conditions at multiple national test sites across Europe.

The DRIVE C2X Vehicle is equipped with radio hardware based on IEEE 802.11p and UMTS for data exchange with other vehicles or with the roadside infrastructure. The protocol stack supports ad hoc communication based on GeoNetworking, which enables a rapid and efficient message exchange among vehicles using single-hop and multi-hop communication. The system is connected to the vehicle

\(^{1}\)http://www.fotsis.com/

\(^{2}\)http://www.drive-c2x.eu
on-board network (CAN bus) to collect data within the vehicles, so that vehicle data can be exchanged between vehicles. Vehicles also support wireless Internet access, for allowing information to be sent directly to the central component.

Drive C2X addresses many of the C-ITS services (see Figure 5.2), some of them use PVD to determine the traffic and weather condition.

5.1.3 In-Time

In-Time\(^3\) (Intelligent and efficient travel management for European cities) is a FP7 Project (2009-2012) that has the objective to reduce traffic congestion, pollution and energy consumption in transport in cities. For this purpose, a system is developed and demonstrated in 4 pilot cities, including a regional data/service server for the distribution of interoperable intermodal real-time Traffic and Travel Data to an European Traffic Information Service Provider (TISP), see Figure 5.3. The project brings together all the stakeholders necessary for the development of pre- and in-trip multimodal information services for the users: road operators, public transport operators, urban transport management centers.

The collection of traffic data, partly using vehicle probes, is also addressed in the project.

5.1.4 ROADIDEA

The EU ROADIDEA\(^4\) project (2008-2010) studies the European transport service system and tries to analyse all available information sources, ranging from FCD, in-road sensor over to weather information, and identifies how these can be merged and used for various applications.

The Report on the pilot services (D6.5) describes four field trials [20] of which one uses probe data see Figure 5.4.

With regard to data, standardisation and architectures, ROADIDEA identifies four trends; islands of technology, data pool models, vertical integration and finally decentralised networked world. Islands of technology represent the current state of ITSs where each provider has its own, mostly closed and

\(^3\)http://www.in-time-project.eu/
\(^4\)http://www.roadidea.eu

Figure 5.1: Summary of field trials in project FOTsis

![TEST-SITES vs. SERVICES](image-url)
CHAPTER 5. PROBE VEHICLE DATA DEPLOYMENTS

Naturalistic test
(Example, Swedish TS)

Features
2 mobile road side units 802.11p
24 vehicles
45 drivers
100 km test corridors
Data collection 6 months
Totally 0,3 Million km

Use cases
IVS (In Vehicle Signage)
RWW (Road Works Warning)
CBW (Car Breakdown Warning)
WW (Weather Warning)
GLOSA (Green Light Optimal Speed Advisory)

Figure 5.2: DRIVE C2X FOT Sweden - from: J.F. Groenvall, 3rd test site event

TISPs get requests from their User Groups, fetch and merge relevant data from RDSS and provide them to their User Groups

RDSS “translates” different data into a standard format and provides them on a harmonized, standardised level to Transport Information Service Providers (TISPs)

Infrastructure Operators (Road, PT,...) provide continuously up-dated data and services on an agreed data/service quality

Figure 5.3: Project In-Time: Concept of regional data/service server
CHAPTER 5. PROBE VEHICLE DATA DEPLOYMENTS

Table 1 Revised summary of the ROADIDEA pilot sites’ data related issues, final data source sum up.

<table>
<thead>
<tr>
<th>No.</th>
<th>Responsible partner</th>
<th>Data type</th>
<th>Data provider</th>
<th>Data format</th>
<th>Transfer protocol</th>
<th>Frequency of data provision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Finland: FMI (Pulp Friction)</td>
<td>friction and other road weather data</td>
<td>FMI</td>
<td>ASCII</td>
<td>FTP</td>
<td>1 hour, compatible with Roadidea platform</td>
</tr>
<tr>
<td>2</td>
<td>Sweden: Destia (Gothenburg)</td>
<td>traffic flow, road weather</td>
<td>Vägverket</td>
<td>XML</td>
<td>HTTP SOAP</td>
<td>5-10 min, traffic fluency data integrated to platform. Weather prediction model tested with Roadidea platform</td>
</tr>
<tr>
<td>3</td>
<td>Germany: Pöyry (Hamburg port)</td>
<td>traffic flow</td>
<td>Hamburg Port Authority</td>
<td>XLS</td>
<td>offline</td>
<td>No online case, no data</td>
</tr>
<tr>
<td>4</td>
<td>Italy: ARPAV (Venice fog modelling)</td>
<td>weather and visibility</td>
<td>ARPAV</td>
<td>ASCII</td>
<td>FTP, HTTP</td>
<td>1-hourly, Data is compatible with Roadidea Platform</td>
</tr>
</tbody>
</table>

Figure 5.4: Pilot services in ROADIDEA project

undocumented solution. The data pool model consists of a well defined storage of data, most probably founded publicly or by a non-profit organization. This model however requires close collaboration between the data creator and the entity which store the data on the data format. Implementation can be centralized, distributed. Access can be free as well as licence based. Vertical integration is similar to the data pool approach, with the main difference being that the operator also uses the data for providing services using the data, resulting in a potential risk for conflict of interests. Decentralised networked world allows for exchange of ITS data without a centralized entity.

The project raises the point where users must opt-in before location data is allowed to be collected about them and that an option must be provided which makes it possible to disable the feature on the go, but also points out that an increasing amount of users already provide social networking companies with their location information voluntarily. On the other hand, employees should have the same options as private persons, but there are some services which require tracking, such as fleet management and similar.

According to the European Directive 95/46/EC, sensor data has to be cleaned for any data which could potentially be used to identify an user.

The project recommends that user oriented services and business models should be included in the overall ITS roadmap.

5.1.5 Track&Trade

Track&Trade is a EU funded project which ended in 2006, well before the recent developments on the mobile phone app market, therefore much of the data format definition and harmonization are today obsolete.

The system architecture corresponds to the server based collection, map matching and aggregation processing (the available publications focus on fast map matching).

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http://www.trackandtrade.org
The main contribution of the project is the map matching and the definition of the format in which external parties can store and query data to and from the Track&Trade data mart. This consists of the format in which the data has to be stored. The uploaded data is then map matched. Besides PVD, Track&Trade supports data collection from various data sources, such as loop detectors, weather data, etc.

The protocol format is based on a data format survey conducted through interviews of companies, institutes, projects and initiatives. The data management problems were to compute link-based travel times from PVD traces and historical data.

The PVD based service applications, travel time maps (visualization of travel conditions), travel time prediction, have been demonstrated in field trials in Berlin, Vienna and Athens. The architecture foresees that the server delivers back to the users the derived information, for routing services, fleet management, traffic light switching.

In relation to the survey used to define a suitable data format, Track&Trade reports that only a few queries were actually answered, and that the information which could be found publicly was either obsolete, unsupported or linked to outdated formats and standards. This indicates that there is a lack of willingness to share this type of information. However, the main problem was the diversity of the formats, obsolete or proprietary standards as well as some systems and protocols that were developed for a particular application. Ironically, Track&Trade chose to develop their own data format, which identified 16 attributes, corresponding to minimal requirements [22].

5.1.6 Viajeo

The Project Viajeo, "International Demonstrations of Platform for Transport Planning and Travel Information" integrates the open platform with local components and demonstrates its applications in four cities: Athens, Beijing, Shanghai and Sao Paulo. The project (September 2009 - August 2012) was co-funded by the EC DG Research for Specific International Cooperation Actions (SIGA) and lead by ERTICO, see [41], and also by the company Infotrip.

Among the services in Athens are taxi fleet management and traffic information (alerts), modal trip planning and information for the end user, information for authorities and traffic planners (observatory, web access under http://www.viajeo.imet.gr/).

The traffic data collection in the cities (Athens) uses a combination of fixed and vehicle sources, the latter being the classical Taxi fleet.

5.1.7 PRESERVE

The FP7 project PRESERVE (Preparing secure v2x communication systems), runs between 2011-2014, and is lead by the University of Twente. It aims at the harmonization of V2X security architecture, its implementation, testing and support of FOTs. The partners are: University of Twente, escrypt, Fraunhofer Institute for Secure Information Technology, Fraunhofer Institute for Applied Security, Kungliga Tekniska Hgskolan, Renault and Trialog.

Deliverable D5.1 discusses the deployment issues which were experienced throughout the project, primarily focusing on privacy issues and challenges.

Concerning the privacy protection, also this project observes that frequent changing pseudonyms are not enough, since e.g., CAM messages contain additional vehicle characteristics, which in turn can be used to track the vehicle over multiple pseudonyms.

5.1.8 FREILOT

FREILOT is an EU project (2009-2011) with 4 pilot sites: Bilbao, Helmond, Krakow and Lyon.

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6http://www.viajeo.eu
7http://www.preserve-project.eu/
8http://www.freilot.eu
The project goal is to evaluate the following services:

- Energy Efficient Intersection Control (EEIC) supporting the traffic manager
- Eco-Driving Support (EDS) supporting the driver
- Acceleration and Speed Limiters (AL and SL) optimising vehicle performance
- Delivery Space Booking (DSB) enabling efficient fleet operation

The FREILOT service aims to

- increase energy efficiency drastically in road goods transport in urban areas through a holistic treatment of traffic management, fleet management, the delivery vehicle and the driver, and demonstrate in four linked pilot projects that up to 25% reduction of fuel consumption in urban areas is feasible.
- widely disseminate and share the pilot results with all relevant stakeholders so that the FREILOT service can become a truly pan-European solution for energy efficient, holistic and integrated goods transport in urban areas.
- increase the involvement of fleet operators, cities and other stakeholders in the scheme.

Smooth driving behaviour, optimised planning and routing combine with smooth heavy vehicle targeted traffic control can contribute to achieve higher fuel efficiency, less pollution, higher driver comfort and more efficient use of infrastructure.

5.1.9 INTRO Intelligent Roads

INTRO\textsuperscript{9} is a FP6 research project aiming at developing innovative methods for increased capacity and safety of the road network. This combines sensing technologies and local databases with real-time networking technologies.

The PVD relevant objectives are:

- Traffic and safety monitoring: combination of different sensor data will enable the estimations of entirely new real-time safety parameters and performance indicators to be used in traffic monitoring and early warning systems.
- Intelligent pavement and intelligent vehicles: innovative use and combination of new and existing sensor technologies in pavements and bridges in order to prevent accidents, enhance traffic flows and significantly extend the lifetimes of existing infrastructure. A prolonged lifetime of high capacity roads could thus be obtained using novel methods for early warning detection of deterioration and damage of road surfaces.

In one deliverable \[6\], the road condition measurement application is considered in detail, using probe vehicles. The deliverable concentrates on the data accuracy and type of sensors and the inferred road condition from the measurements, rather than the data collection architecture.

5.1.10 MOBINET

MOBINET - Internet of mobility (2012-2016)\textsuperscript{10} is a large FP7 project, comprising a consortium of 34 partners including a wide range of actors and stakeholders representing the world of transport and mobility service users and providers. MOBINET will address the lack of harmonised services; inaccessibility and incompatibility of transport-related data; fragmentation of end-user subscription

\textsuperscript{9}see http://intro.fehrl.org/
\textsuperscript{10}http://www.ertico.com/europe-wide-platform-for-connected-mobility-services-mobinet

\textit{iMobility Support \& FOT-Net Project}
and payment services; proprietary technologies in user devices. It will develop a service platform for end user service applications (app store), and some services such as eco-traffic management-as-a-service and a multimodal traveller assistant.

Although PVD themes are not explicitly mentioned, the openness of interfaces, and definition of enablers such as PVD collection are in the scope of the project. Moreover, a number of MOBINET partners are mentioned in this study in the PVD context, such as TNO, Info Trip or Infoblu.

5.2 National and regional projects, FOTs

5.2.1 SimTD

The German research project Safe and Intelligent Mobility - Test Field Germany (SimTD, 2010-2013) established a large field trial in and around Frankfurt, Germany. Using 400 vehicles equipped with V2X communication, the project examined the entire spectrum of V2X issues and applications.

The weather hazard warning [17] is one of the various use cases investigated in SimTD, and it is considered here since it uses two V2X communication messages: the DENM and PVD. The latter consists of data sets with timestamp, position, temperature and wiper level. The PVD messages are sent and processed at the road weather center, where more precise DEN can be generated.

In addition, weather hazards are detected by the vehicle sensors leading to following DEN event types: heavy rains, reduced visibility due to fog, slippery road due to ice or snow. Strong winds are detected at the weather center.

Main challenge in the Weather Center is, besides the forwarding of vehicle generated DEN messages, the fusion of all received weather information. Namely, the event detection on infrastructure side is based on DEN messages generated by vehicles, probe values gathered by vehicles and transmitted in PVD messages as well as measurement values, gathered from weather measurement stations, see Figure 5.5.

![Diagram of SimTD Weather hazard warning scenario](image)

**Figure 5.5: SimTD Weather hazard warning scenario [17]**

5.2.2 The Netherlands - Germany - Austria Corridor

In the national ITS action plans of Germany, Austria and the Netherlands Cooperative Intelligent Transport Systems and Services (C-ITS) are an important building block for enhancing road safety as well as for improving transport and energy efficiency. On 10th June 2013 The Ministers of EU
Member States Germany, Austria and The Netherlands have signed a Memorandum of Understanding to realise a corridor Rotterdam-Frankfurt-Vienna by 2015 [1]. Two cooperative ITS services are first planned for use in the Cooperative ITS Corridor Rotterdam Frankfurt/M. Vienna: a) Road works warning (RWW): from the traffic control centres via the road side infrastructure to the drivers, and b) Probe Vehicle Data (PVD): vehicles transmit data about the current situation on the road to the roadside infrastructure and the traffic control centres.

5.2.3 Testfeld Telematik

Testfeld Telematik\textsuperscript{11} is an Austrian FOT on the Austrian motorway triangle A4/S1 and A23, where cooperative services and their user acceptance have been tested (until 2012). The project, funded by the Climate and Energy Funds, had 14 partners (AustriaTech, Audio Mobil, Bayrische Medientechnik, Efkon, Fluidtime, Hitec Marketing, ITS Vienna Region, Kapsch, Siemens, Swarco, TomTom) and has been coordinated by the Austrian road operator ASFINAG.

A number of 3,000 drivers tested cooperative services using 50 vehicles that were equipped with special OBU’s. In this way, the driver receives incident messages, speed limit messages, weather warnings, stop light phase information and commuter information in the cockpit of the vehicle. An app has been developed for this purpose.

5.2.4 PREL U D E Trial in Netherlands

In [45] the author gives an application overview of FCD data based on the PRELUDE trial in Netherlands: 60 cars communicating every 5 minutes a series of GPS positions determined at 10 sec intervals. The map matching to the roads used the Teleatlas maps. The accuracy GPS in 1999 was 11 meters and 6 meters for differential-GPS. The authors describe the value of the derived travel time information for the users: They found the information very useful for determining the departure time and for changing the route during the trip, but less useful for choosing the transportation mode. Among the mentioned applications are:

- travel time calculation and travel times prediction (e.g. 30 minutes)
- using accurate travel times routing strategies using variable signs (or the newer in vehicle signage)
- use in logistics to schedule deliveries, considering historical data (day of the week, weather) in addition to actual travel times
- Travel strategy evaluation using FCD measurements before and after the study or the changes.

5.2.5 ITS Platform, Denmark

The ITS Platform Northern Denmark runs over the period 2010-2014. The project studies the feasibility of a full, running ITS system and seeks to provide an open platform where researchers, public authorities and companies can deploy and test ITS related applications. The system deploys currently 420 active vehicles which actively generate data and evaluate the developed applications [25].

Each OBU has a General Packet Radio Service (GPRS) connection and/or a WLAN connection with the back-end sever. The OBU samples its own position and its acceleration data at an interval of 1 Hz and 10 Hz, respectively and forwards it to the back-end. In case of network outage, the PVD is buffered until it can be sent. The OBU can be remotely updated or even new applications can be installed.

The position, speed, acceleration as well as calculations on the risk and eco factors of the drivers are used for several applications:

- a Driving Log application that gives an overview of all the trips as well as the eco and risk indexes.

\textsuperscript{11}http://www.testfeldtelematik.at

t M o b i l i ty S u ppo rt & F O T - Net P ro j e c t
• Automated Parking Payment,
• Traffic Statistics - designed for road authorities to calculate travel time, congestion levels and so on,
• Customized traffic information application.

5.3 Commercial deployments

We start this list will global players of map services, that own the largest FCD collecting databases in the world.

5.3.1 Nokia HERE

After 2011, Nokia’s product HERE\textsuperscript{12} became the European flagship of intelligent map and navigation systems \cite{4}. It has been (subjectively of course) compared with Google maps and it could outperform the latter in several categories (3D view, traffic information, public transport, multiplatform support, etc.). Concerning the data collection, Nokia disclosed that 1 billion devices (smartphones such as Lumia, cars, computers, etc.) that are using HERE services, can be enabled by the user to also collect anonymized location, activity data and combine it with other reference information.

On the web page, one can see an impressive list of cities in which the HERE traffic services are available.

5.3.2 Google Maps

In 2007 Google extended Google Maps\textsuperscript{13} by adding historical traffic patterns to their maps for the visualisation of road traffic information and in their routing tool. However, this feature was pulled from Google Maps, as it was too inaccurate. In 2012\textsuperscript{2} they extended this feature to be based on probe vehicle data. The data originates from Android smartphones, which are equipped with GPS modules. The location is sent periodically to the Google server where map matching is performed. The user can view the aggregated flow states coloured in green, yellow, red(congestion). Besides visualization, Google can support applications such as Google Navigation (2011) to calculate alternate routes in real-time.

5.3.3 Waze

Acquired in June 2013 by Google, the Israeli company Waze developed a free smartphone navigation information supported by the position information it receives by the users in the community (crowd sourcing). Waze generates traffic information from the GPS positions and informs the users, proposing better route alternatives. As the number of Waze users grows continuously (36 million at end of 2012), it is expected that accurate information will be soon available on all the important roads.

Both Google and Waze technologies, although successfully deployed, are prone to data security and user privacy issues \cite{18}. Whereas Waze is a pure opt-in application, the users of the mobile Google Maps are not clearly notified that their position data is being used to contribute to the accuracy of the service, while just using the Google Maps application.

5.3.4 TomTom HD live

In November 2007, TomTom commercialised its HD Traffic (High Definition) service in the Netherlands to be primarily available with a new product called TomTom One XL HD Traffic. The same operation was launched in the UK, Germany (2008) and France (2009) through a partnership with Vodafone. The subscription based, commercial product TomTom HD Traffic serves improved route guidance to the user based on live traffic data. As this is a commercial product the actual details on when, what is processed are scarce. However, a presentation video provided by TomTom mentions that data is updated every two minutes and that in some locations additional, national road traffic providers data

\textsuperscript{12}http://here.com/traffic/
\textsuperscript{13}maps.google.com
is utilized, e.g. the Danish version of TomTom.com, mentions that one of the sources for TomTom HD Traffic in Norway is provided by Statens Vegvesen [44].

The numbers from 2008[42] show the large scale of this system:

- 500 million speed measurements per day.
- 100 billion speed measurements until date.

### 5.3.5 Coyote

Coyote is a French company that started in 2005, has 100 employees, and claims to serve the largest driver community (50 mio. users, among them 2.2 mio. of paying subscribers) with driver information. The system is proprietary consisting of a central server connected to the coyote clients via GSRS network (cellular), see Figure 5.6. The clients are available on several platforms such as dedicated devices, embedded in the cars, connected navigation systems and mobile phones (free Coyote app). The company was bought by Google in June 2013. The system supports the services: Speed limits on all roads in Europe, Speed Camera locations, Community-observed traffic Incidents, Community presence and quality, Road Safety Services. There are no details available about the probe data delivered to the server, however it includes, besides the periodical location information, also events activated by the user pressing a button on the user interface, such as: observed traffic jam, accident, stopped car, object on the road, etc.

A user survey [24] conducted by Coyote has shown that 76% of Coyote clients are more respectful of speed limits, 92% slow down earlier before road congestions, 44% of people use the service because of road safety aspects (especially for senior group), 94% say the impact of the participation is "weakly disturbing" (50%) or "a little disturbing" (44%), 0% found participation "very disturbing".

### 5.3.6 Infoblu

Infoblu was founded in 2000 as a joint venture of Autostrade (I) and Octo Telematics to exploit the traffic information of Autostrade operator and to develop ITS services for the market.

Today, Infoblue collects GPS data (50 mio. GPS points/day, 80,000 km road coverage in north Italy, both from car and mobile phones), and crowd sourcing data. The GPS data processing consists of cleaning, route matching, speed evaluation) analysis, speed and travel time calculation. After data fusion, the resulting information is delivered via connected services and apps: traffic level of service (LOS), traffic flows, traffic products, see figure 5.7.

The alert management shows where the speed rapidly decreases, the traffic evolution shows a time-space chart in real-time, whereas the travel times are shown in comparison on two different routes (variable sign).

### 5.3.7 Sanef Group

Sanef is a road operator in France, that maintains 1900 km motorway, has almost 1 million toll tags in use in France, processes 90,000 traffic events per year.

The FCD system uses cell phones and on board GPS units, the resulting data traces being used for a) traffic studies and b) real time traffic management.

As an example of traffic studies, [38] mentions the study of speeds on Saturday afternoon in the summer. Studying the queue length, the lost time, one can estimate the impact of speed limit messages.

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14 [http://www.coyotesystems.com](http://www.coyotesystems.com)
15 [http://www.infoblu.it](http://www.infoblu.it)
16 [http://www.sanef.com](http://www.sanef.com)
**Figure 5.6:** Coyote: typical architecture for community probe data collection

**Figure 5.7:** Infoblue platform
Using Tom-Tom technology, Sanef performs FCD studies since 2011 for travel time and speed monitoring in real time (real time speeds for every road segments of 200m length every 2 minutes). With PVD, travel time can be calculated with good accuracy, also outside of the Sanef motorway network (e.g. down to the city centres). In Fig. 5.8 the change in travel time during the day can be observed.

![Travel time between TP Fresnes and Dourges during the day](Image)

**Figure 5.8: Travel time between TP Fresnes and Dourges during the day [38]**

### 5.3.8 Be-mobile

The belgian company Be-mobile offers core expertise in traffic data collection from different sources, also from probe vehicles. This data is processed and aggregated in a "smartmove mobility database", an enabler for solutions on different platforms, for traffic information, alert messages, routing and search, see Figure 5.9.

### 5.3.9 AROBS

The Romanian company AROBS offers various solutions for traffic monitoring, visualization, etc. The product TrackGPS collects floating car data for for fleets. Smailo is a GPS navigation system. The flagship product TraficOK, developed in cooperation with Be-mobile, is a mobile traffic application with routing, notification of traffic events, travel time, community features such as driver event insertion (similarly to Waze), see Figure 5.10.

Realtime traffic information on Romania’s roads is also offered by the company on the site [http://info-trafic-tmc-romania.ro/trafic-live/](http://info-trafic-tmc-romania.ro/trafic-live/).  

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17 http://www.be-mobile.be

18 http://www.arobs.ro/
CHAPTER 5. PROBE VEHICLE DATA DEPLOYMENTS

5.3.10 Infotrip

The greek company Infotrip\(^{19}\) is specialized in traffic planning, management and traffic control. It offers tools for multi-modal routing, fleet management, public transport, management.

Infotrip’s open platform, OMNIA is specifically designed for integrated mobility management. OMNIA provides a uniform interface for any number of traffic control and transport management systems which are plugged-in autonomously or integrated within a common architecture.

Main features are: a) Graphical User Interface, Communication management which allows the data exchange inside the OMNIA platform and at the external systems, b) Large variety of protocols and standards, c) Real time traffic data collection and forecast mobility demand, d) Embedded functionalities for advanced traffic monitoring which includes system component diagnostics.

\(^{19}\)http://www.infotrip.gr
5.3.11 AMV

The Austrian company AMV Networks (anonymous management of vehicle real time information) proposes an own client-server solution for collecting extended FCD composed of a low cost hardware card, able to capture sensor data in different vehicle types, and a server solution. The communication uses a GSM/3G cellular channel. The information on the web site states that the data collected is anonymized and the transmission is encrypted. The credentials (keys) are given to the car owner, so that it can use xFCD personalized applications, of type B2B or business to administration/government such as (traffic control, parking management, city toll/green zone, logbook, service package, etc).

5.3.12 Car manufacturer systems (OEMs)

Car Manufacturer have their own vision of connected car assistance systems and an app platform in the car, that repeats the success of Apple based app stores. The exchange of data which includes the collection of extensive floating car data follows in most cases a proprietary protocol. The introduction of electric cars has intensified the app approach, as additional charging information has to be exchanged.

We consider for example the Connected Drive system developed by BMW. Using an integrated SIM card in the car, a lot of navigation, entertainment or safety (eCall) services are seamless available to BMW drivers. Nevertheless, it is expected however, that in the field of probe data collection, the Car-2-Car Consortium will actively work towards an integrated approach that meets the interests of all stakeholders.

5.4 On-line available realtime data

This separate category should emphasize examples in which data is available free, on-line and is mainly provided by national departments of transport mostly without requiring any registration.

The traffic data is most often obtained from permanent count stations installed on major roads (generally on motorways). Therefore typical parameters are traffic flow and average speed. Further data such as occupancy rate and travel times (e.g. calculated from FCD) can also be collected. Although the raw data is implicitly collected by transport centres for many years, more and more countries are making it available on-line by means of new displaying tools such as Google maps.

5.4.1 Austria

ITS Vienna Region was founded in 2006 as a cooperative traffic management project by the three Austrian provinces Vienna, Lower Austria and Burgenland. Partners of ITS Vienna Region are among others ASFINAG, Wiener Linien, VOR, OEBB, the police, taxi companies, carsharing.at, Vienna City Bike and the OE3 traffic editorial office.

AnachB.at is the new real time trafficinfo service for all means of transport developed by ITS Vienna Region. AnachB.at integrates many data sources in order to provide route planning, it provides multi-modal decision, real-time traffic information and up to 45 minutes forecast. Run by the ITS Vienna region, the system core is a traffic model using input data from public transportation, rail, road operator (fixed sensors), the city of Vienna (stoplights, sensors, cameras), and the FCD data from three taxi fleets. The users can access a routing search application, traffic visualization (http://www.anachb.at/verkehrslage-strasse) as web application or smartphone application. The FCD collection and processing has been result of several previous national projects.

5.4.2 Spain

Since summer 2007, the DGT (Direccion General de Trafico) of the "Ministerio del Interior de Espana" has been providing a large amount of real-time traffic data that are integrated in Google

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22http://infocar.dgt.es/etraffic

iMobility Support & FOT-Net Project
Maps. The user can then easily collect real-time traffic flow and average speed from 4000 traffic sensors located over the Spanish road network. Besides the map and route information, seen in Figure 5.11, it is possible to query historical values available: intensity, composition, occupation rate and average speed.

![Real-time traffic, travel time, around Madrid](image)

**Figure 5.11: Real-time traffic, travel time, around Madrid**

### 5.4.3 Finland

The Finnish Road Administration provides real-time information measured from around 330 automatic counting stations placed along the Finnish road network. Traffic data concern traffic flows and average speed on major roads in Finland over 7 regions: Helsinki area, Tempere, Southern Finland, Jyväskyla, Turlu, Oulu and South-Eastern Finland. Figure 5.12 displays an example of real-time measurements.

### 5.4.4 Germany

The Traffic Information System presents the current traffic situation and traffic forecasts (30 min and 60 min) on the motorway network in North Rhein Westphalia (2250 km length). The traffic simulation model is fed by real-time traffic data (vehicle speed and traffic flow) collected from 2500 automatic traffic data detection units updated every minute. This project was initiated by the Ministry of Transport, Energy and Spatial Planning of Nordrhein-Westfalen. It is one of the most relevant and reliable source of road traffic forecasts in Europe. Also, the Bavarian Ministry of the Interior (http://www.bayerninfo.de/) makes available real-time traffic data covering the main cities of the region. Real-time speed measurements are provided as well as traffic forecasts. Note that GPS-based FCD information from taxi fleets are used to collect traffic data.

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*iMobility Support & FOT-Net Project*
Figure 5.12: Real-time Road condition and weather information in Finland

Figure 5.13: Real-time traffic data in North Rhein Westphalia, Germany
5.4.5 Italy

In Italy, OCTO Telematics together with Infoblu make available on-line real-time speed and number of vehicles on the Italian motorways network ("Autostrade") as well as in the area of major cities. The user has to register on the webpage http://traffico.octotelematics.it. Traffic data is provided from the largest FCD fleet in Europe i.e. hundred of thousands of anonymous customers equipped with company’s GPS. The dataset may afterwards be used by navigation systems (TomTom and Garmin in Italy) and contribute to the route planning optimisation.

5.4.6 Belgium

The Belgian Federal Government developed the START/SITTER System in order to collect real-time traffic data that are imported each minute from the three Belgian regions (http://www.start-sitter.be/). The system provides real-time traffic variables such as flow of vehicles, average speed and occupancy rate over the whole Belgian highway network. It enables any visualisation in time and geography based on as the basic values per minute as the derived averages over 6, 15 and 60 minutes and the 6-22 and 0-24 h day values. Historical traffic data can also be downloaded from the year 1999.

5.4.7 United Kingdom

In the UK, it is possible to get a wide number of real-time traffic data from the Highways Agency (under http://www.trafficengland.com/). The available information includes: a) current and forecast average speeds, b) delays, incidents, congestion, roadworks, adverse weather, future events and future roadworks, c) speed compared to forecast speed for changes to regular journeys, see Figure 5.14, d) current and forecast journey disruptions, e) traffic camera images and roadside messages.

![Figure 5.14: Real-time traffic data: speed versus forecast comparison (by Traffic England)](image)

5.4.8 Portugal

Traffic data for the whole country is available on the website of "Estradas" (http://www.estradas.pt/) which are released by the SICIT (Sistema Integrado de Controlo e Informacao de Trafego). The tools include a map, alerts and traffic messages, route calculation, etc.

5.4.9 Summary of PVD projects and commercial activities

The PVD activities presented in the previous sections are summarized in two Tables: Table 5.2 shows the projects with a few key facts, and Table 5.1 lists the commercial PVD systems and products, most of them with European origin.

iMobility Support & FOT-Net Project
<table>
<thead>
<tr>
<th>Name</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>AnachB</td>
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<tr>
<td>Coyote</td>
<td>FR</td>
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<tr>
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<td>IT</td>
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<td>Sanef</td>
<td>FR</td>
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<td>GR</td>
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<tr>
<td>AMV</td>
<td>A</td>
</tr>
<tr>
<td>Nokia HERE</td>
<td>FIN</td>
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<td>Google Maps</td>
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<td>TomTom HD live</td>
<td>NL</td>
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<td>Waze</td>
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Table 5.1: Summary of described PVD products and commercial systems (with focus Europe)

<table>
<thead>
<tr>
<th>Project Name</th>
<th>European</th>
<th>National</th>
<th>No. of Partners</th>
<th>No. of Countries</th>
<th>No. of Test Sites</th>
<th>When/Duration</th>
<th>C-ITS</th>
<th>Cellular</th>
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Table 5.2: Summary of the discussed projects
5.5 Probe vehicle Data and the EC Policy Framework

Realization of probe data collection, and, based on this information, the realization of better traffic control will reduce the number of traffic jam hours on the roads. This goal is closely related to Climate change and Environmental technologies, which are included in the EU policy.

Considering the DIRECTIVE 2010/40/EU on the framework for deployment of ITS, probe data collection is though not addressed directly, but one of the identified priority actions is the provision of EU-wide real-time traffic information services, and PVD collection is one important means to achieve this goal.

5.6 Functions that use Probe Vehicle Data

The following list tries to decompose the different applications of probe data in individual functions. The list includes material from [46].
<table>
<thead>
<tr>
<th>Function</th>
<th>Description, examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic estimate (travel time, speed, congestion)</td>
<td>use in traveler information</td>
</tr>
<tr>
<td>Traffic management measures</td>
<td>usage of PVD to evaluate tolling on express ways has shown a change of speed during peak times that favours surprisingly the no-tolling approach (Japan)</td>
</tr>
<tr>
<td>Speed limit</td>
<td>dynamically adjust and coordinate vehicle speeds in response to congestion, incidents, and road conditions to maximize throughput and reduce crashes</td>
</tr>
<tr>
<td>Identify accident-prone locations (near miss incidents)</td>
<td>measure speed, acceleration, brake status, yaw rate, weather conditions</td>
</tr>
<tr>
<td>Identify road closures</td>
<td>in case of disaster (earthquake) probe data indicated passable routes. The same could be used in case of floods or heavy snow.</td>
</tr>
<tr>
<td>Detect stopped vehicles on the road</td>
<td>e.g. WAZE, user reporting</td>
</tr>
<tr>
<td>Identify duration of congestion</td>
<td>forecasting required</td>
</tr>
<tr>
<td>Determine traction conditions</td>
<td>(e.g. slippery road, road inspection)</td>
</tr>
<tr>
<td>Incident management</td>
<td>planning emergency response</td>
</tr>
<tr>
<td>Route guidance</td>
<td>dynamic and controlled proposal of alternative routes, avoiding their congestion too.</td>
</tr>
<tr>
<td>Multimodal intelligent traffic signal systems</td>
<td>comprehensive traffic signal system for complex arterial networks including passenger vehicles, transit, pedestrians, freight, and emergency vehicles.</td>
</tr>
<tr>
<td>Freight operations</td>
<td>e.g. Probe data from logistic vehicles are collected free of charge by the infrastructure and relayed to logistic centres in near realtime.</td>
</tr>
<tr>
<td>Road maintenance (snow)</td>
<td>the emergency service will follow the detection of snow conditions delivered by PVD, and based on temperature, precipitation, visibility and speed.</td>
</tr>
<tr>
<td>Pavement maintenance</td>
<td>Use PVD collection in order to measure the quality of the pavement. Using four sensors, the vertical acceleration, roll rate, pitch rate, and suspension deflection, the method can be used to detect potholes or large bumps in the road.</td>
</tr>
<tr>
<td>Dynamic low emission zone</td>
<td>geographically defined area which seeks to restrict or deter access by specific categories of high-polluting vehicles within the zone for the purpose of improving the air quality within the geographic area. Includes the applications: Dynamic Emissions Pricing, Connected Eco-Driving, and Multi-Modal Traveler Information.</td>
</tr>
<tr>
<td>Eco monitoring</td>
<td>sensing individual CMG emissions. The emission of pollutants seems to follow the 80-20 rule: 80% of the emissions are produced by 20% of the vehicles, due to incomplete combustion. Monitor these cars using floating car data and send them to tune their motors.</td>
</tr>
</tbody>
</table>

Table 5.3: Functionalities and applications related to Probe Vehicle Data
Chapter 6

CHALLENGES AND CONCLUDING REMARKS

6.1 Challenges for future probe systems

In this section we first present a number of metrics for the evaluation of PVD and derived challenges for a mass deployment in the future.

6.1.1 Flexibility

We define with flexibility in the probe data collection, the ability for a system to collect a certain type of data, at a certain time, on a certain road location.

Most of the probe collection systems are not flexible and collect always data. The result is an increase in the communication costs, the processing and storage costs, although the quality and confidence of the data is variable, depending on the travelled routes and on the number of the vehicles in the fleet (e.g. taxis).

For traffic flow measurements, a more flexible approach would be to collect as much probes as needed for a good estimate, especially if the service penetration in the future will reach that of mobile phones.

The Amsterdam Group proposal to collect probes between any two neighbouring road side units allows the system to deny the upload of data if the relevance is low or if the wireless channel load is high. The flexibility of this approach is however limited as only data attributes in the CAM (or DENM) message are foreseen to be uploaded, and because only the road segments connecting two RSUs can be monitored (and not for instance an alternative route).

The flexibility required by road operators can be achieved to our opinion only through intelligent use of PDRM command messages. The mentioned Controlled Probing 3.3.2 exploits this flexibility: it is conceived as a tool in the hand of the road administrations to target the monitoring to hot spot areas, and to select the PVD resolution, depending on the application that needs the data.

6.1.2 Accuracy

The accuracy of probing data depends of course on the accuracy of the measurements and the quality of the individual sensors, but on the system level, it is a function of the number of probes that can be collected in a time unit per road length unit.

Accuracy depends therefore on the traffic intensity, probing system coverage and on the sensor sampling time. In general, a trade-off between scalability and accuracy is made: an anywhere & anytime probe data collection is in most cases done with a sampling time larger than 30 seconds, because of the high data volume.

For certain type of PVD applications, such as scanning the state of the pavement or the user behaviour...
at a crossing, this sampling rate is not sufficient. Another solution is to use triggered events, such as in case of hard braking, instead of periodic sampling the sensors.

In case of the large scale GPS traces collected by Nokia, Google, etc., it seems that the derived accuracy is reached by the high number of vehicles and not through high sampling rate.

### 6.1.3 Scalability

In this discussion, scalability refers to the possibility to collect large amounts of data that are created either by large number of vehicles, in a large geographical region served by the road operator, with a large number of road side units used to receive the data.

The current GPS tracking technology via the cellular networks prove to be scalable, as both the bandwidth of UMTS/LTE channels, and the central processing power do not pose problems.

In case of cooperative ITS using IEEE 802.11p protocol, research shows that even CAM and DEN messages can produce congestion at network level and mechanisms as decentralized congestion control (DCC) are needed. Massive deployment and large penetration of the probe data service will cause that in addition to CAM/DENM, PVD messages will be uploaded at the RSU node by each vehicle, therefore DCC mechanisms should apply as well.

The controlled probing concept with N simultaneously active probe enabled road segments will always scale, as N can be controlled, and grows with the size of the infrastructure RSU network. Distributed load sharing among the RSU nodes and first aggregation reduces the data load.

### 6.1.4 Timeliness

With timeliness we mean low data latency, that is the time elapsed from the moment of the measurement by the car until the (aggregated) data is delivered to the traffic control center, where it can be used by different applications such as traffic control, prediction, travel time calculation and dissemination back to to the drivers, etc.

At the first sight, fleet based, cellular communicating, always connected PVD systems would provide a low delay, because the data can be sent immediately after the measurement. We have however shown [33] that this advantage is diminished by two factors: a) the sampling time is in such systems large, e.g. 30 seconds-2 minutes or even longer, b) in case of low PVD penetration, the central system has to wait several minutes to receive additional values in order to produce a certain confidence of the measured data (which consists mainly of timestamp and GPS location). [45] discusses the delay between measurement and the time the travel information is available to the users.

The latest GPS tracking applications seem to have the scalable infrastructure to cope with a full penetration of smart phone applications among the vehicle drivers, and still keep the latency low.

In the C-ITS approach (and in the described controlled probing) an entire trace is uploaded when a vehicle passes the RSU. The oldest data corresponds to the travelled distance from the start location of the measurement. In case of traffic congestion this delay increases and timeliness is reduced. Some probes may arrive too late to be considered by the probe aggregation algorithm. In such a case, where the car is temporarily disconnected from the RSU, in order to reduce the latency of probe data, car2car relaying or delivery via an additional cellular channel should be considered.

### 6.1.5 Privacy of floating car data

The protection of user data is probably the most important issue, if the PVD service is going to be accepted by users. Data from fleets and roadside-based travel time measurements are not privacy relevant [13], compared to a dataset of a private user that describes a trip from her home to some destination.

Further research has to be done to find feasible solutions to aggregation of raw traces in the vehicle or at least already at the RSU, to find trade-offs between data accuracy and linkability to the user,
or to insure that the "anonymity set" is large enough when releasing the data.

Most FCD approaches discussed in this work are far away from these privacy properties, especially the tracking by cellular phone applications. User consent for enabling tracking is foreseen in the applications, but disabling it, it will restrain the functions of the map and navigation system. Moreover, asking for user consent even if required by ISO 24100 and OECD privacy principles, will drastically reduce the deployment of PVD collection.

Cooperative approaches intend to pay more attention to privacy issues than commercial GPS tracking ones. Tracking the users only on a road segment, as in the controlled probing proposal, reduces the danger since a) origin and destination of the trip are in general not included in the trace, and b) aggregation is done in the RSU network, no storage of individual traces is done (can be defined as obligation in a privacy policy). The problem of efficient and generic travel time deduction while protecting user privacy remains however a research challenge.

6.1.6 Ownership of the data

Questions concerning the data ownership are also of high importance. Who owns the PVD data? Should it be shared among the actors? This is a critical issue that has to be tackled in the short-term, given the impressive deployment of the market.

A first trend in the right direction is to publish real-time traffic data which is processed from PVD, as mentioned in Chapter 7, using local platforms or Google Maps. This however does not mean that the collected (and anonymized) raw data itself is open to be accessed by third party applications.

6.2 Concluding remarks

6.2.1 Standardisation

It seems that Europe has not yet decided on a PVD message standard to be followed. The alternatives are: a) use the well defined Probe Data message in the American SAE J2735, b) a new defined probe data message defined by ETSI, so that the specification is harmonized with the other defined messages CAM and DENM. The input for this specification is likely to come from the current work of the Amsterdam Group, c) adopt the results of ISO/CEN work.

Concerning the planned work at ISO, following has been discussed at the ISO TC204 WG16/WG18 meeting in June 2013:

- the standard documents ISO 22837 and ISO 29284 will be adapted: the format and data structure character of the description should be a part of the ITS data dictionary.
- a document "The Service Architecture of Probe Vehicle Systems" is proposed (responsible ISO/TC204/WG16). The group requires that the data should be managed as a single service in the facility layer of the ITS station, to distinguish from functionality required in the application layer.
- CEN/TC278/WG16 (+ ISO/TC204, and SAE) will work on a document called "Using V2I and I2V Communications for applications based on Probe Vehicle Data (PVD, PDM)" to be approved in June 2014.

For probe data, several networks should be considered: dedicated short range communication, cellular (3G, LTE) and Wimax. However, the service interactions will be different for each network, in particular the push/pull aspect: whereas for the ITS G5 case, the data can be pulled by the RSU (if the data is needed) with an announcement or a special PDM broadcast message received by all cars in the coverage range, in the cellular case the data can be pushed in regular intervals by the vehicle.

Additionally, it seems that the existing PVD standardization documents are based by what the car can provide; speed, jaw rate, air temperature and so on, and especially closely tied to the safety
messages: CAM and BSM. Another approach would be to plan for extendible data formats and use what is needed. For example, it would be useful for electric car applications to know the current battery status of a vehicle. Another example is that of a multimodal routing application making use of standardized PVD messages from public transport means.

### 6.2.2 PVD related projects and systems

Surprisingly, only few projects actively consider how to reduce the amount of redundant probe vehicle data/floating car data. As long as the data is event based rather than “just” raw sensor data, this might be considered unimportant, as the important part is to disseminate e.g., congestion building up, and since this is ever changing all data is important. However, a significant number of applications make use of and collect raw sensor data centrally so effort should be made to reduce unnecessary communication. One explanation for this could be that the penetration rate of capable devices has not yet reached a critical point, and in cases such as Google Maps and Waze, the communication costs are actually covered by the user, leaving only the processing costs for the service provider.

On national level, most countries in Europe have websites run by ministeries or by national road operators on which the user can perform a number of functions:

- view traffic situations and statistics (travel time)
- view a prognosis of traffic condition
- view traffic incidents, environmental conditions

Most of the providers use consolidated information from fixed sensors, and floating car data.

### 6.2.3 Competing markets

When one considers Probe Data collected by a mobile phone (nomad device) and consists mainly of GPS time-stamped locations, the situation is quite clear: the technology works, scales, and the market, in the next years belongs to the internet giants and map companies Nokia, Google, Waze, TomTom, etc. Also innovation continues steadily, for instance with community and Waze-like tools in which users actively report events and edit an outdated map.

Traffic monitoring including prediction, and traveller services in cities and highways is completely covered by these companies. In the light of this situation, the older results, projects and field trials, e.g. before 2007 are in most cases obsolete. The main deficits of the GPS trackers are the lack of privacy and the fact that the collected and anonymized data is not made available to other stakeholders. Instead, it remains mainly in american data centers.

Probe vehicle data is more than mobility data (GPS traces). In this market segment, in which a stronger integration with the vehicle and its CAN bus is required, the road operators and the automakers are now trying to place probe related cooperative-ITS services. It is also obvious that road operators, governments and cities have different interests and mandates than the commercial map and internet companies: keeping a high road level of service through advanced traffic control, providing safety, and a standardized access to this type of data. The users of the C-ITS service applications that collect various PVD elements, are often the administrations themselves.

Therefore, the deployment of the first C-ITS applications as soon as 2015 is an unique occasion for building a PVD collection standardized framework. In this framework, flexibility, security, privacy protection mechanisms and open access of PVD are indispensable for the success of probe data systems in Europe.
Bibliography


Chapter 7

Full Comparison Between ETSI and SAE Safety Messages
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Table 7.1: The table shows the comparison between the ETSI and SAE standards indicating the corresponding fields if available. The representations is organized according to the ETSI CAM message and its containers. The mentioned SAE elements are all part of Part I.