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The Long Term Cost of GPS/GSM vs. DSRC: How Do They Compare?

By François Malbrunot

In the past five years in Europe, several open road tolling (ORT) systems have been implemented on existing networks in Switzerland, Austria, Germany, and London. It is surprising to note how different the technical and operational features of these systems are. For example, except in Austria, the systems aren't designed to finance new infrastructure directly; rather, their aim is to generate revenues to help finance specific objectives in the transport sector as well as significantly reduce traffic.

During this same period, new toll infrastructure worldwide has been equipped with electronic toll collection (ETC) systems based on dedicated short-range communications (DSRC)[1] technology, with or without barriers in toll plazas or in ORT environments. In Europe, DSRC-based electronic fee collection (EFC) systems are now exclusively using a 5.8GHz frequency (as opposed to 5.9GHz in the U.S.) based on the European standard CEN TC 278, which encompasses on-board vehicle data, payment data, security mechanisms, and authentification (except in Italy).

All the European concessionaires have implemented or are implementing EFC systems for all classes of vehicles, offering limited[2] but efficient interoperability (one contract/one DSRC OBU/one invoice) within each country.

[1] Fifteen to 20 meters in range.

[2] For example, in France on 8,000-kilometer toll motorways and bridges and tunnels; in Italy, 6,000 km; Spain, 2,000 km; and Austria, 2,000 km.

Meanwhile, the European projects PISTA (Pilot on Interoperable Systems for Tolling Applications), MEDIA (Management of Electronic Fee Collection DSRC Interoperability in the Alpine Region), and CESARE III are now paving the way for interoperability across Europe on all toll-road networks.

Outside Europe, all ORT systems require DSRC technology that conforms to CEN TC 278, except in the United States, where noninteroperable RFID (radio frequency identification), such as Title 21 in California or E-ZPass in the Northeast, is used.

Along with the implementation of these new toll collecting systems, a directive adopted in April 2004 by the European Parliament and the European Council designates three technologies for implementing long-term interoperability at the European level: 5.8GHz DSRC, GPS[3], and GSM[4]. The directive doesn't address the functionalities to be achieved, and financial aspects are limited to a cost–benefit analysis scheduled for the end of 2009. The directive gives preference, however, to the GPS/GSM technologies, because they can be implemented without costly investments in ground-based infrastructure equipment or the construction of new toll stations.

This article aims to examine the differences between the GPS/GSM and DSRC approaches, especially comparing 5.8GHz DSRC according to the CEN standard with the multitechnology OBU relevant to GPS, GSM, infrared technology, DSRC, and the like. Also included is a theoretical analysis of the differences in costs between the two technologies, whether for automatic or manual systems.

The information included here is based on public information regarding different free-flow systems (or open road tolling) recently implemented in Europe (Switzerland, Austria, and Germany), the United States, and Chile that led to the establishment of functional and coherent segmentation.

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[3]Global positioning system or global navigation satellite system (GNSS), including GALILEO.

[4]GSM = global system for mobile communications; namely, a mobile phone or cellular network (CN), referring to all-mobile standards.

ORT Functional Segmentation

The functions of all ORT systems can be segmented as follows:

Identification of the payer being tolled, as well as identification of the financial entity guaranteeing payment to the concessionaire or governmental body.

Identification of the vehicle being tolled, which is tied to the payer via:

- Visible characteristics (plate number, vehicle type, and so on) and measurable characteristics (dimensions, weight, number of axles); and
- Characteristics that can't be measured (such as authorized weight and pollution class), to be checked against the vehicle documents.

In both the GPS/GSM and DSRC approaches, corresponding data are stored in the OBU with or without the ability to modify some data.

Identification of the trip being tolled, associated with a specific time and date, in order to identify:

- Passage at a given point within a road network (in either an open- or closed-system context) or in using a bridge or tunnel; and
- Mileage achieved during a given period of time in a specific geographic area and possibly the type of network used, as well as, in some cases, variable vehicle characteristics, such as the presence of a trailer.

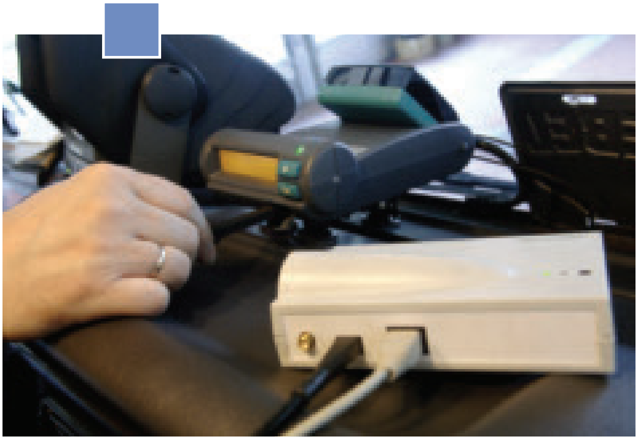
Definition of the transport rate (tariff) table, in order to determine the amount due. This depends on:

- The vehicle's characteristics, as well as its history if any variation occurs during the trip; and
- The kind of trip itself (itinerary, details of sectors driven through) and when the journey took place.

This function yields tariff tables for use in central systems or by the OBU.

Calculation of the amount due for a toll transaction based on the above vehicle data and on:

- The vehicle's presence at a given point, at a given hour, for a given vehicle class;
- Its entry at a given point at a specific hour, and its exit at a given point at a specific hour, for a given vehicle class;
- A certain distance driven during a given period of time in a given geographical zone; and
- Its presence in a given area as detected by the entry time.



Germany: installation of an OBU.

Invoicing/payment/customer management: Using the above information, the toll authority can prepare invoices, collect payments, and follow up on late payments. Additionally, control tools are used to detect fraud, whether it involves the vehicle, the payer, or the road equipment. In both the GPS/GSM and DSRC approaches, all corresponding functions, including customer relations management, are performed by central systems.

Dealing with occasional users: Depending on the system adopted, specific methods must be implemented for dealing with occasional users. Solutions include:

- Giving such users temporary on-board equipment;
- Registering these users at border points;
- Using cameras and license plate recognition technology (video tolling) to send the user a bill in the mail, based on a "pre registration" made by the user phone or internet;
- Delivering “trip tickets” at rest areas, gas stations, and via the Internet or phone; and
- Implementing side lanes equipped with traditional payment systems near the free-flow lanes, a solution frequently adopted in the United States by concessionaires implementing ORT as well as in Norway.

Control/checking (enforcement) systems: With DSRC OBUs as well as multitechnology OBUs, the control operation consists mainly of making sure that:

- Every vehicle is equipped with an OBU, if required;
- Every OBU works properly;
- The OBU data are correct; and
- The OBU is not blacklisted.

This control operation is carried out by mobile or stationary automatic video enforcement systems installed on gantries. The systems capture pictures of "violators" (unequipped vehicles or those with nonconforming OBUs), reading license plates and determining vehicle characteristics.

The automatic-enforcement actions to be undertaken, and the means of implementation, are very similar for both DSRC OBUs and multitechnology OBUs. The level of control necessary and the quantity of equipment needed are independent of the technologies themselves. Rather, they have much more to do with general factors surrounding each technology's use, such as the legal system, the type of users, and the categories of vehicles involved.

Besides the automatic systems, enforcement staff, using cars equipped with portable enforcement systems, can stop violators.

With occasional users (as in Switzerland and Germany, for example), one must check that the driver has preregistered for the trip and that the corresponding information in the EFC operator's database conforms with the vehicle's characteristics.

Technical aspects of OBU and ground-based equipment: OBU equipment and systems must be secure, reliable, certified, and supplied with power. The power supply to the OBU can be secured using a simple battery integrated in the unit and, in multitechnology OBUs, supplemented by the vehicle's battery.

Monolithic DSRC tags don't need strict maintenance checks (a defective OBU is replaced immediately), but multitechnology OBUs require periodic checks by specialized staff trained and equipped to fix them.

Because of the complexity of multitechnology OBUs and their integration into the vehicle, the costs involved are relatively high compared with those for DSRC OBUs, in terms of acquisition and installation as well as maintenance and replacement.

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Identifying Toll Trips

DSRC OBUs

With a DSRC OBU, vehicle trips are fully identified via a DSRC beacon that tracks the location of the OBU. For each exchange with a beacon (installed on gantries, bridges, and masts), the associated processor creates a data set including identifier(s) of the OBU, the location of the beacon, the circulated lane, a time stamp of the trip, direction, and so on. Location accuracy depends on the nature and structure of the network and on the number of beacons used. The EFC operator obtains information from the beacons through his or her own communication network, which ties together the fixed equipment and the central site.

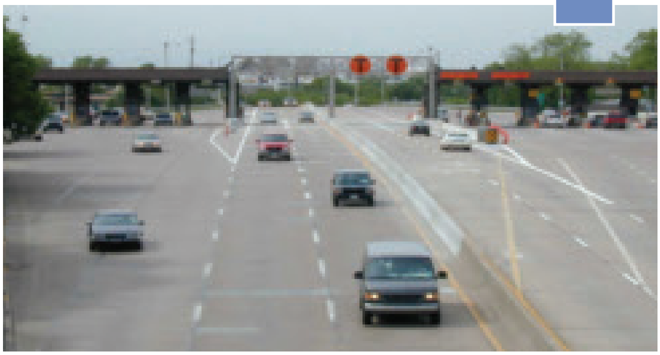
Multitechnology OBUs

With multitechnology OBUs, vehicle trips are identified onboard the vehicle via sensors and corresponding data (especially using cartography). Consequently, depending on the rating system or tariff table implemented, the OBU can:

- Track the trip mileage by period and road type;
- Determine the vehicle's presence at a given point and whether the car is entering, exiting, or passing through the roadway;
- Determine the entire driving itinerary (departure, arrival, network type, distance, time, and more); and
- Retain this information.

Information regarding vehicle location can be transmitted to the EFC operator as is via a cellular network (CN) or used by the OBU to make calculations about the trip. These calculations can then be used in real time for onboard elaboration on payment transactions.

Case Examples



North Texas Tollway Authority: open road tolling with adjacent "traditional" lanes.

Austria/Europass-DSRC OBUs: In this system, the OBU is located by DSRC beacons (approximately 2,000) installed above the road on 800 gantries and bridges. Vehicle data registered in the OBU are transmitted to a beacon through a central site; toll and payment transactions are then performed at the central site. The OBU can also track changes in vehicle characteristics.

Germany/Toll Collect-multitechnology OBUs: In Germany's multitechnology system, vehicle location and trip time and date are determined by the OBU via:

- Signals obtained from the global navigation satellite system (at present, GPS);
- Network roadside equipment (approximately 300 repositioning beacons);
- Sensors placed onboard the vehicle (compass, odometer, vibration sensor); and
- Network cartography, which requires updating in real time via CN communication (at present, GSM).

The location data tell the system that a given vehicle has been driven on a specific section of the road network at a given time. (Currently, there are approximately 5,200 such sections, in one direction, on the German motorway network.) The OBU then uses this information to issue a toll transaction for use in charging the motorist.

Switzerland/LSVA-multitechnology OBUs: On Switzerland's LSVA, the OBU is connected to the vehicle odometer to establish the distance driven in Switzerland only. The GPS is used to validate the odometer information (to protect against fraud) and to switch the OBU on and off at the borders when entering and leaving Switzerland. There is no map onboard, *With DSRC OBUs, unit costs are low (30 to 40 euros in Europe) and their installation takes very little time. This has led some jurisdictions to make the use of ORT or ETC lanes mandatory (as in Austria, on SR-91 in California, and in any free-flow lane in a toll plaza).*

and the GPS isn't used to locate the vehicle. Each month, the mileage driven is obtained from the OBU by means of a "smart card," which is read on a PC to transmit the vehicle data and mileage to the Swiss Customs Authority's central site.

Calculating the Amount Due

DSRC OBUs

With a DSRC OBU, the amount of payment due from the vehicle driver is determined from data obtained from both the OBU and the fixed equipment situated on the road infrastructure. This information is transmitted by the EFC operator's data network to the operator's central site, which is aware of rating rules and tariffs.

Multitechnology OBUs

With multitechnology OBUs, payment amounts can be calculated:

- By the OBU, which knows the updated tariff (the OBU transmits "charged transactions," already calculated at the correct value, to the EFC operator's central site); or
- By the EFC operator's central site directly (the OBU periodically transmits trip and vehicle data to the central site, which calculates the amount due).

Case Examples

Germany/Toll Collect: Here, the multitechnology OBU is able to associate each road-network section with the applicable tariff. Charging transactions are calculated onboard and periodically transmitted by GSM to the central site. The tariff lists are updated in the OBU by a communication link via GSM with the central site.

Austria/Europass: In Austria, the DSRC OBU is located by gantries, and vehicle data are transmitted from the OBU via a beacon to the central site. Charging transactions are determined at the central site using up-to-date tariff tables.

Switzerland/LSVA: After obtaining the vehicle mileage from the multitechnology OBU, the Swiss Customs central site calculates the amount due using updated tariffs.

Dealing with Occasional Users

The ways the European systems handle occasional users depend on the context of toll collection and the type of onboard equipment involved.

DSRC OBUs

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In Austria, occasional users can obtain a temporary OBU for a given amount of time at a point of purchase (of which there are about 210).

Where the infrastructure allows, lanes equipped with traditional payment systems can be incorporated adjacent to the high-speed lanes to serve the occasional user. Many examples of such a setup exist, especially in Norway, Portugal, and the United States.

Multitechnology OBUs

In contrast to DSRC OBUs, unit costs for multitechnology OBUs are high (500 to 800 euros) and their installation takes several hours. As a result, their usage is optional. In Switzerland, for example, the OBU is compulsory only for vehicles registered in the country. Foreign vehicles are manually registered at the Swiss border in order to provide Swiss Customs with documentation of their mileage.

In Germany, OBUs are not compulsory. Occasional users must obtain a prepaid preregistration “passage ticket,” which indicates the vehicle's characteristics, the traveler's itinerary, and the estimated trip duration. These data are transmitted to the central site and made available to the control system for enforcement. The tickets are available at 3,500 dedicated stations installed within fuel stations along a network of 12,000 kilometers. Users can also obtain the tickets via the Internet or by phone.

Valuation and Cost Comparisons

For purposes of this analysis, cost valuation is limited to domains for which the choice between DSRC OBUs and multitechnology OBUs entails significant differences in terms of the following:

- The OBUs themselves;
- Systems, fixed equipment, and associated information, including the gantries and beacons required to locate a DSRC OBU, repositioning beacons, cartography updates, and tariff lists;
- Secondary or manual systems, in instances in which the OBU isn't required;
- Operational costs associated with the OBU (GSM/GPRS communication); and
- Equipment and systems maintenance costs.

For this analysis, the parameters used to define the system are the:

- Number of vehicles subject to tolls;
- Total mileage along toll motorways;
- Average number of traffic lanes in the toll motorways; and
- Number of sections to which a toll is applied (tied to a tariff table in the central system and optionally onboard).

The hypotheses used are summarized in the table to the right. All figures are based on European financial conditions.

The toll motorway network depicted in the table assumes the following (in compliance with European averages):

- Fifty percent of mileage is accrued within two traffic lanes and 50 percent within three traffic lanes; and
- One section (in one direction) occurs every 2 kilometers, for a total of 5,000 sections over 10,000 kilometers.

The results of this cost analysis are compared in the figures below. Figure 1 depicts a scenario using a 10,000-kilometer motorway network, while Figure 2 illustrates a 2,500-kilometer network. The results show that the

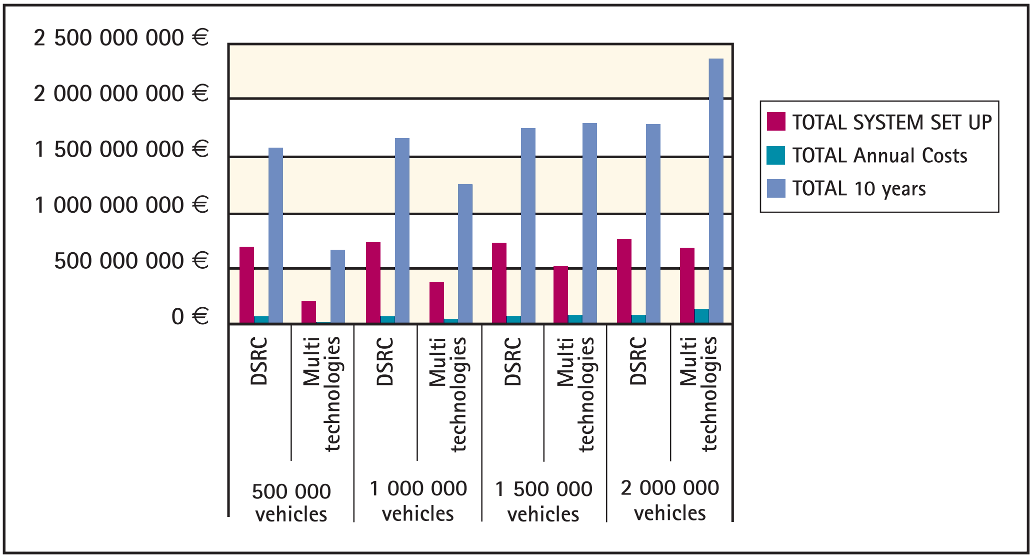
	DSRC Free Flow	Multi technologies Free Flow (Localisation On Board
	Comment	Comment
TOTAL SYSTEM SET UP – Supported by EFC Operator / Contract Issuer		
OBU	100% of vehicles are equipped	60% of vehicles are equipped
OBU Acquisition	OBU (With support) is compulsory - Unit price 30 Euros	OBU (With support) is **not** compulsory - Unit price 500 to 800 Euros
OBU Personnalisation	OBU are personalised in Customer service Centres for the cost of 10 Euros	Done during the installation
Localisation		
Number of relocalisation beacon		Every 50 kilometers (cost includes support)
Central system for maintaining the map of the network and associated tarif		Hardware and software
Localisation/transaction beacon & RSE	One beacon per lane, per sector	
Gantries for DSRC beacons	One per sector (all included)	
Manual system		
Number of terminal for journey declaration		One every 4 km
Central system for mannaging the manual system, Including Software development		Hardware and software
TOTAL OTHER COSTS – Supported by the customer / user		
OBU Installation	OBU are installed by the driver in 10 minutes	4 hours time in a garage (certified)
Non availability of the vehicle		6 hours at 50 Euros
Setting-up of the network of the certified garages		One garage for 500 vehicles
ANNUAL TOTAL (Operational and Maintenance Costs)		
Operational Costs		
OBU/Central system - GSM Costs		
Communication for transactions		Annual fee per link vehicle/ central system (Flat fee 10 Mbytes per year with GPRS)
Communcation for remote update of OBU (map, tariff)		
Communication between DSRC RSE and Central System	It is supposed, an internal communication network is existing	

Maintenance

DSRC OBU (Average Life time: 4 years)	25% of the OBU cost per year	
Multitechnologies OBU		15% per year including periodic replacement
Manual terminals		10% per year including periodic replacement
Relocalisation beacon		10% per year
Localisation/transaction beacon & RSE	12% per year	
Gantries	3% per year	

costs of multitechnology are lower than those of DSRC for the 10,000-kilometer network as long as the number of vehicles subject to toll doesn't exceed 1.5 million. For a 2,500-kilometer network, however, the cost of multitechnology exceeds that of DSRC with as few as 500,000 vehicles.

Figure 1 *Cost Evaluation for a Motorway Network of 10,000 Kilometers*



One can also examine at what point, for a given number of vehicles subject to tolls, implementing a DSRC system makes more economic sense than adopting multitechnology OBUs (see Figure 3 for an example using 1 million vehicles.

According to figure 3, taking into account the costs supported by customers/users, for a system involving 1 million vehicles subject to tolls, the motorway network must be greater than 10,000 kilometers before a multitechnology system becomes more cost-effective than a DSRC system.

Additional costs stemming from an increasing number of vehicles subject to toll collection are limited with DSRC, but they explode with multitechnology OBUs because of the global costs of outfitting OBUs and the cost of telecommunications (charging transactions, updating of tariff lists and road maps, and so on).

Figure 2 *Cost Evaluation for a Motorway Network of 2,500 Kilometers*

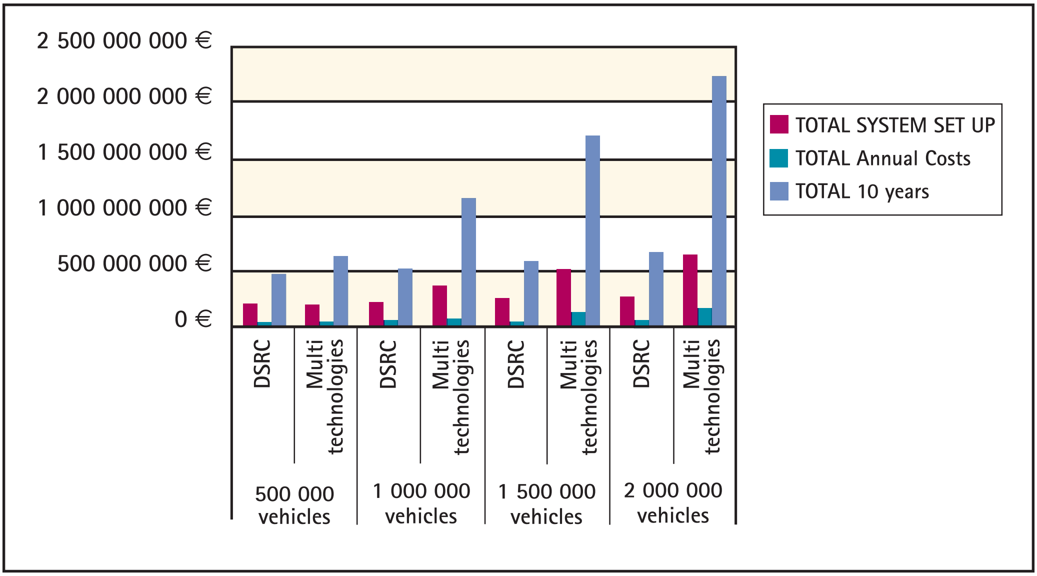
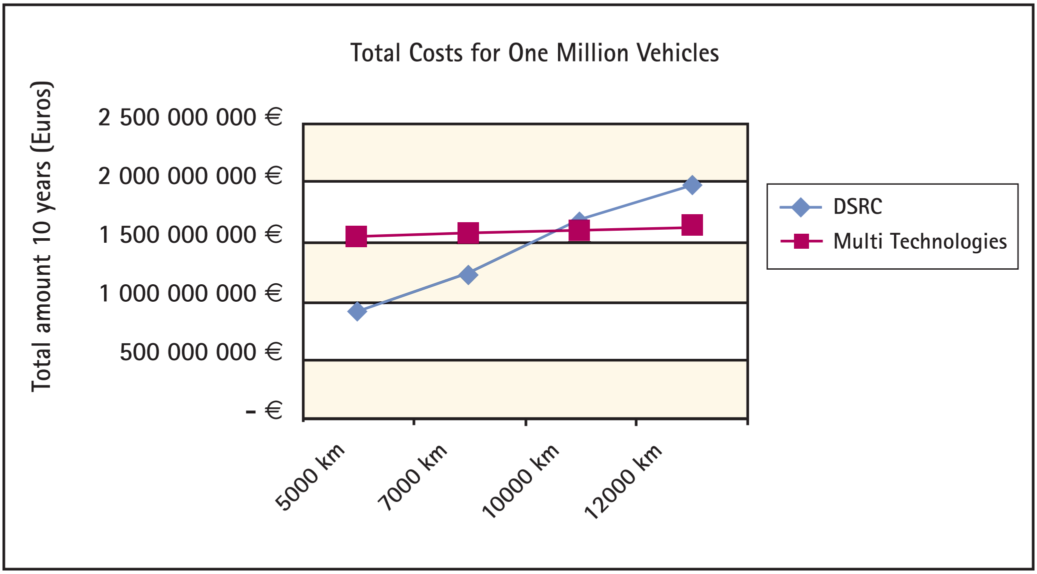


Figure 3 *Cost Evaluation for a Motorway Network with 1 Million Vehicles Subject to Tolls*



Determining the Best Option

Based on the preceding analysis, onboard technology is valuable only if the number of vehicles subject to tolls is relatively limited *and* the size of the toll-road network is greater than 10,000 kilometers.

For networks of limited size, the cost difference between multitechnology OBUs and DSRC is quite large. For a network of 2,500 kilometers, for instance, with 2 million vehicles subject to tolls, the cost would be nearly 2.3 billion euros over 10 years for multitechnology versus only about 700 million euros for DSRC (see Figure 2).

With the technology currently available, even in large networks of 10,000 kilometers or more, it's not profitable to implement a multitechnology toll-collection system that subjects more than 1 million or 2 million vehicles to tolls.

When tolls are collected in a given country or region within a complex network covering any type of road, a solution such as the Swiss LSVA is particularly economical because of its system of certified odometer readings without the need for accurate location identifiers.

Additionally, DSRC OBUs could reasonably be made mandatory because of their low cost and easy-to-repair nature, which precludes the need for installing manual systems. For the occasional user, as described earlier, a prepaid OBU can be offered as well.

The adequacy of the choices made by the German, Swiss, and Austrian systems is reinforced by this analysis:

- Multitechnology OBUs in Germany, for a wide network (12,000 kilometers), with a rather low number of vehicles of more than 12 metric tons (900,000 vehicles);
- Certified kilometric counting in Switzerland for a limited number of vehicles, on any type of road completed, with a simple manual system handled by Swiss Customs; and
- 5.8GHz DSRC in Austria, for a relatively great number of vehicles of more than 3.5 metric tons (500,000 vehicles) on a network of limited size (2,000 kilometers).

In conclusion, from an economical point of view, it is probable that in the future multitechnology OBUs will be restricted to vehicles of more than 12 metric tons in order to limit the number of vehicles subject to tolls. These OBUs will work in the 5.8GHz CEN DSRC mode, in kilometric counting systems, and with accurate onboard vehicle location detection, depending on the context.

Onboard technology is valuable only if the number of vehicles subject to tolls is relatively limited and the size of the toll-road network is greater than 10,000 kilometers.

The functions obtained from an autonomous DSRC OBU (one not connected to equipment or the vehicle battery), useful to all classes of vehicles (even those with two wheels), or from a DSRC module integrated in multi-technology OBUs, will for a long time continue to offer a very efficient solution for collecting tolls. They will also allow a highly secured means of payment for additional services, such as parking, fuel, and other drive-in commodities. Traffic management and security functions can also be managed with these DSRC functions.

Regarding multitechnology OBUs (secured and devoted to toll collection), a certain level of cost optimization could be attained in the future through the sharing of some components, sensors, and/or communication modules with onboard equipment used for fleet management operations and security operations. This last issue is well in line with the actions undertaken by the European Community in the framework of the Road Charging Interoperability project and the outstanding specification and normalization processes currently being developed under this project.

François Malbrunot is managing director of LOGMA, a consulting company based in Versailles, France. Among other activities, he has served as a consultant in the French ETC system, TIS, since 1996 as well as in numerous European projects. He can be reached at francois.malbrunot@wanadoo.fr.