

# REVIEW OF DIFFERENT APPROACHES TO DISTANCE BASED CHARGING

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## ABSTRACT

Electronic fee collection systems complying with the distance based charging principle use the distance travelled as a main factor to determine the charge. It covers various types of approaches which employ different technologies, methods of journey calculation and road network representations. This paper will provide an overview on possible approaches to distance based charging with the list of examples of existing schemes or trials performed during the last few years. The paper will provide an overall comparison of these approaches in the sense of methods of vehicles journey detection and their accuracy.

## KEYWORDS

GNSS, Distance Based Charging, DSRC, EFC, Accuracy, Map matching, segment-based charging, corridor-based charging

## INTRODUCTION

The distance based charging is a type of electronic fee collection system (EFC). The charge (fee) is imposed on the basis of user's usage of elements (charge objects) of the road network. These elements have to be represented in a way to make the system able to determine them and therefore determine the correct charge. The various types of charging objects have been identified as follows:

- The zone is a polygon-shaped area defined by the set of points and the straight lines between follower zone point in the sequence, including the line between the last and the first zone points.
- The corridor is a set of at least one segment and a sequence of at least two corridor points. The segment is a diagonal polygon-shaped area of such a proportion to correlate the subject to charge. The corridor shall have at least one entry and one exit point.
- The virtual gantry is a set of points; first two of which mark the posts of the virtual gantry. The gantry consists of two adjacent quadrilaterals, being adjacent in the line representing the virtual gantry.

## APPROACHES TO DISTANCE BASED CHARGING

The identification of various solutions in this paper will be based on different methods of matching of location fixes to the geometric representation of the road network. The technology used to obtain the location information may vary as well; and very likely be one or combination of the GNSS, DSRC or the Tachograph/odometer. Regardless of the technology, the presence of the OBU in the vehicle is a common requirement.

### The GNSS Solution

The GNSS based solutions use the GPS receiver as a primary source of the location data. There are then three main methods by which the location information is converted into the distance travelled:-

- Map Matching Method
- Segment Based Method
- Corridor Based Method

#### *Map matching method*

The road network is represented by the digital map, which consists of set of curves in  $R^2$  assumed to be piecewise linear, characterised by an infinite sequence of points  $A^0, A^1 \dots A^n$  where  $A^0$  and  $A^n$  are referred to as the nodes, while the remaining points are referred to as the shape points. The matching process aims to match a location fix to a point on an arc. There are three main methods of matching processes:

- Point-to-point method searches for the closest node or shape point of the map to the location fix. This method is very easy to implement, however very sensitive to how accurate the road network has been digitised.
- Point-to-arc method searches for the closest arc of the map to the location fix. This method gives better results than point-to-point method, however may give incorrect results in some cases, e.g. very dense road network.
- Arc-to-arc method takes a set of location fixes grouped in the shape of the arc and searches for the closest arc of the map. Such an approach is very sensitive to outliers and relies on point-to-point matching method, therefore may be slow in performance. The charge may be calculated on basis of the length of the streets (i.e. arcs) identified during the matching process.

#### *Segment-based method*

The charge object is the corridor. The road network is represented by the set of segments - closed polygons (usually quadrilaterals). Each segment is usually designed to span a section of the road between two entry/exit points. This is to ensure the vehicle entering the segment can only leave it travelling through the whole length of the segment or by making a u-turn. The matching algorithm results into a sequence of segments. The charge is calculated on the basis of the length of segments in the sequence. Segment based charging is used where it cannot be assumed that vehicles will travel the complete length of the corridor i.e. the urban environment .

### ***Corridor-based method***

The charge object is the corridor. The road network is represented by the geometric map, which consists of a set of corridors – closed polygons (usually quadrilaterals of bigger size than segments) – spanning the section of the road between junctions, although it may be defined the way to overlap the road exits or junctions as well. The matching algorithm results into a sequence of corridors representing the journey of the vehicle. The difference between the corridor and segment-based methods is that it is assumed that once a vehicle has enter a corridor it can only travel the full length of the corridor, for example on a motorway network a corridor would be defined between 2 junctions.

### ***Other approaches***

The list of methods described in sections above is surely not definitive. Other methods (though hypothetical) have been suggested as possible approaches:

- The concentric-circles method (zone) - The road network may be stored as a set of concentric circles, each representing a different subject of charge. The charge may be calculated on the basis of the distance vehicle travelled since entering any of the circles (the charge fee may vary between circles).
- The grid-based method (corridor) – The road network may be stored as a set of grids of various sizes, adjacent, covering the subject of charge. The charge may be based on the sequence of grid tiles which vehicle entered during the journey.
- N-laterals-based method (corridor) – This is not a truly approach, however the point is to clarify any geometric shape may be chosen if the road network puts up such a demand.

### **The Tachograph/Odometer Solution**

This solution uses the information from either the Tachograph or odometer as the primary source of distance travelled by the vehicle. This information needs to be complimented by additional location information to determine distance travelled on a specific road network. This additional information can be provided in a number of ways including DSRC, GNSS or GSM.

### **The DSRC Solution**

This solution can be implemented in one of 2 ways, either as an open or closed system. In a open system DSRC infrastructure is installed on corridors of the road infrastructure and a charge is applied for each corridor passed. In a closed system DSRC infrastructure is installed on entry and exit points of the charge network and the charge is based on the point of entry and exit of the Charged network. A DSRC solution can be used to complement a GNSS system where it is known to be issues with GNSS location information.

## DBC SCHEMES

Various approaches for the DBC system implementation have been discussed in the sections above. All of the above approaches have been used as the basis for operational schemes and in terms of the technology and approach employed, all can be divided into 5 main groups:

- Open DSRC-based scheme (gantries along the journey on the charge object)
- Closed DSRC-based scheme (toll plazas at the entry/exit of the charge object).
- GNSS-based scheme (Thick client, charge calculated by the OBU)
- GNSS-based scheme (Thin client, charge calculated in the back-office)
- Tachograph-based scheme

A few main schemes have been selected and described as suitable representatives of each group.

**Table 1 – Selected schemes categorisation**

Scheme group	Name of the scheme (level)	Country	Roads covered length [15]
Open DSRC-based	MYTO CZ (national scheme)	Czech Republic	1.200 km
	GO Mautsystem für LKW and Bus [13] (national scheme)	Austria	2,080 km
	TIS (only part) [14] (concessionaires' schemes)	France	8.300 km
	Telepass (only part) [12] (concessionaires' schemes)	Italy	5.600 km
Closed DSRC-based	TIS (only part) [14]	France	
	Telepass (only part) [12]	Italy	
GPS-based, Thick client	LKW-MAUT [11] (national scheme)	Germany	12,700 km
Tachograph-based	LSVA [6],[9] (national scheme)	Switzerland	60,000 km

The following table provide structural information on the existing schemes, pointing out the attributes regarding the technology and approach employed, OBU types and vehicle classes subject to charge.

**Table 2 – Existing schemes**

Scheme	Charge object	Distance obtained	Entry/exit detection	Additional distance check	OBU type	Vehicles subject to charge
LSVA Switzerland	Zone	Tachograph	DSRC	GPS	Tachograph	3.5 tonnes and above

TELEPASS Italy	Corridor	DSRC Open & Closed	DSRC	-	DSRC	All vehicles
GO Mautsystem für LKW und Bus Austria	Corridor (def. segments)	DSRC Open	-	-	DSRC	3.5 tonnes and above
TIS France	Zone	DSRC Open & Closed	DSRC	-	DSRC	All vehicles
LKW-MAUT Germany	Corridor	GPS	GPS	Odometer tachograph	Thick client	12 tonnes and above
MYTO CZ Czech Republic	Corridor	DSRC Open	-	-	DSRC	12 tonnes and above

Each individual technology or approach may provide the solution for a scheme with the certain quality while raising a certain amount of the costs. The quality measurement can be various, and as such should reflect the purpose of the scheme in the first place. However, regardless of the quality measures, each scheme raises the expenditure for both the capital and operational matters. As the scheme employs different technology or approach, these two types of cost vary. The following table provides rather very indicative – due to the nature of the information - overview of the investments (includes the capital), operational costs and the gross revenue of the individual schemes (n/a is used where information is not available).

**Table 3 – Costs and revenues of the existing schemes**

Scheme	Investments (€)	OBUs	OPEX yearly (€)	Gross revenue (€)
LSVA Switzerland [6],[9]	189 million (incl. OBUs)	60.000 (Jan 2008)	55 million (7% of revenue)	850 million (2007)
TELEPASS Italy [12]	n/a	4.5 million (2005)	n/a	5.3 billion (2006, 3.1% increase since 2005)
GO Mautsystem für LKW und Bus Austria [13]	750 million (incl. 10 years OPEX) 350 million for the commissioning of the system	900.000 (Jan 2008)	90 million	915 million (2007)
TIS France [14]	1.8 billion (APRR in 2007)	1.2 million (2004)	374 million (20.8 % of investments)	Revenue (Net) 6.8 billion (2006)
LKW-MAUT Germany [11],[16]	More than 1 billion (incl. 10 years OPEX)	610.000 (Jan 2008)	> 20% ~770 million (13 months, excl. enforcement)	3.4 billion (2007)
MYTO CZ Czech Republic	827 million (incl. 10 years OPEX)	200.000 (Jan 2008)	n/a	210 million (2007)

## DBC TRIALS

A trial operation usually precedes the implementation of the real scheme. The trials may have various objectives, e.g. in terms of technical (performance in the selected environment, feasibility, market offers assessment, etc), economic (impact on the

trade or business, costs, etc) and social aspects (public perception, acceptability, etc). The following sections will provide brief overview of selected trials of the distance based charging systems and their objectives.

The following table summarises the technology, environment, charge objects definitions and the subject of the assessment of selected trials.

**Table 4 – Summary of the trials**

<b>Trials Stages (duration)</b>	<b>Technology</b>	<b>Environment</b>	<b>Charge object definition</b>	<b>Subjects of the assessment</b>
London Stage 1 [1] (2003-2004)	GPS	Urban (London)	Zone	GPS accuracy
London Stage 2 [2], [3] (2005-2006)	GPS	Urban (London)	Corridor (def. as segment)	GPS, matching and billing algorithms accuracy
Netherlands [4] (2007, 4 weeks)	GPS Odometer	Urban/interurban	Corridor Zone	GPS and distance accuracy
Valencia [5] (before 2004)	GPS	Urban, inter-urban, mountains, tunnels	Corridor Virtual gantry Zone	GPS and matching algorithm accuracy
Copenhagen [8] (2000-2004, 2 years)	GPS	Urban (Copenhagen)	Zone (map matching algorithm)	Driver behaviour changes, impact of the urban environment
Bristol [8] (2000-2004, 3 months)	GPS	Urban and inter-urban (Bristol)	Corridor	GPS accuracy in urban canyons
Gothenburg [8] (2000-2004, 1 year)	GPS	Urban (Gothenburg)	Zone (map matching algorithm)	Effects on the congestion level, environmental improvement and mobility management

One of the crucial factors tested within the trial is the accuracy of the GPS in the tested environment. The following table provides a summary on the accuracy, distance and charging or billing errors measured from the data collected during the individual trials. Some of the data were either not published or not available.

**Table 5 – The errors classes measured within the individual trials**

<b>Trial</b>	<b>Error class/category</b>	<b>Description</b>	<b>Value</b>
London Stage 1 [1]	GPS Accuracy errors	Average location error	9.7m
		Maximum location error	> 1km
		Zone buffer size for the confidence level of 75% that the vehicle detected inside has been really inside	14m
		Zone buffer size for the confidence level of 90% that the vehicle detected inside has been really inside	28m
		Zone buffer size for the confidence level of 99% that the vehicle detected inside has been really inside	57m
		Maximum zone buffer size for the confidence level of 99%	>= 250m
London Stage 2	GPS Accuracy errors	Average location error	6.67m

[2][3]		Lowest overall location error	5.11m
	Matching algorithm errors	Average of segments correctly matched (map-matching algorithm 1)	83.6%
		Segments incorrectly matched (map-matching algorithm 1)	4.2%
		Average of segments correctly matched (map-matching algorithm 2)	96.8%
		Segments incorrectly matched (map-matching algorithm 2)	1%
	Charging/Billing errors	Average billing 1 error (into pence)	6.68% 17.5 pence
		Lowest billing 1 average magnitude error (into pence)	0.86% 2.7 pence
		Average billing 2 error (into pence)	3.43% 9.4 pence
		Lowest billing 2 average magnitude error (into pence)	0.82% 2.6 pence
	Dutch trials [4]	Distance errors	Absolute distance error (GPS + odometer)
Overall distance error (GPS only)			< 5% (1.2% - 4.5%)
Charging/Billing errors		n/a	
Valencia [5]	GPS accuracy errors	Corridor detection rate (width 15m)	90.9%
		Corridor detection rate (width 20m)	98.2%
		Entry point radius detection rate (radius 20m)	96.4%
		Entry point radius detection rate (radius 30m)	100%
		Virtual gantry detection rate	100%
	Distance errors	Medium/Maximum distance computation error in the zone with good visibility	1.9%/6.6%
		Medium/Maximum distance computation error in the zone with coarse visibility	5.9%/16.7%

## CONCLUSION

Both the DSRC solution and the GNSS solution are suitable for distance based charging on the inter-urban road networks, the Tachograph solution is suitable for the charging of distance travelled within a defined area.

The challenge remains for finding a solution for distance based charging by road type on complex road networks such as urban centres, such a solution needs to overcome the challenges to existing solutions such as:-

- Requirements for roadside infrastructure
- Accuracy of GNSS location information
- Ability to identify road type
- Connection to vehicle systems

The results from the GNSS trials that have been conducted in recent years show that the accuracy of GNSS based solutions is improving, and that hybrid solutions that combine all three solutions are approaching the required levels of accuracy for billing Users.

The requirement that challenges existing solutions today is the ability to charge distance by road type and this remains the focus of distance based charging trials.

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