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National Automatic Toll Collection System – Pilot Project (Part 2)

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Abstract

This article presents tests results of the pilot project – The functional structure of the National Automated Toll Collection System (NATCS). During the tests OBU automatically charged a fee (toll), taking into account the category of vehicle (admissible mass, the number of axes), the category of emissions, and distance of road travelled. OBU is equipped with GPS, GSM and DSRC modules, which ensure its interoperability with other EETS systems in the EU Member States. The system meets the requirements of 2004/52/EC Directive and the EC Decision from the 6-th of October 2009.

Tests proved high effectiveness of automatic number plate recognition, being 99,9%. The analyses of PDOP (Position Dilution of Precision) parameters showed that 90% had

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the value below 1, and 8% value from 1 to 3. Based on tests, the maximum number of satellites for localization was - 11 and minimum – 5, that create value 99%.

Keywords: EETS, NATCS, DSRC, interoperability

1. Introduction

Motor Transport has developed NATCS functional structure, which was presented in article – part 1.

Tests of the NATCS system, including control of OBU devices, tolling segments at selected sections of roads as well as control gates were conducted in July and August, while vehicles passing through the control gates were registered from 1st July to 30th November 2010. The tests of the system were conducted by the following research team (Fig. 1):

- Motor Transport Institute *(Instytut Transportu Samochodowego)* (Gabriel Nowacki, Anna Niedzicka band Ewa Smoczyńska),
- FELA Management AG (Thomas Kallweit),
- Autoguard SA (Robert Rozesłaniec, Tomasz Garbacz and Krzysztof Pusłowski).

The architecture of the system is in conformity with Directive 2004/52/EC and decision of the European Commission of 6th November 2009 as well as the CE and ISO standards.

Fig. 1. Research Team and elements of the system

2. Tests of the NATCS System

During the test four OBU Tripon EU units were examined, whose task was to detect all events associated with the collection of toll directly in OBU, as well as in the log file and display them on the screen. OBU is also meant to send log files to the proxy server and receive data from the server (data, status information and software updates.) For testing purposes four vehicles were added to the database: Volkswagen Golf – research vehicle of Autoguard, reg. no. WF 93311; Fiat Ducato, vehicle of Autoguard SA, reg. no. WF 4244E, total weight 1 968 kg, number of axles – 2; Volkswagen Crafter, vehicle of Autoguard SA, reg. no. WF 1831E, total weight 3 508 kg, number of axles – 2; Volkswagen Transporter, research vehicle of ITS *(Motor Transport Institute),* reg. no. WH 15904, No of axles – 2.

Out of the several proposed test route options, the Płońsk – Garwolin, Garwolin – Płońsk route was chosen, as the most diverse one that allows for checking the greatest number of elements of the system, including, in the immediate vicinity of the route, both control gates and allowing the use of even three actual segments of expressways (Fig. 2):

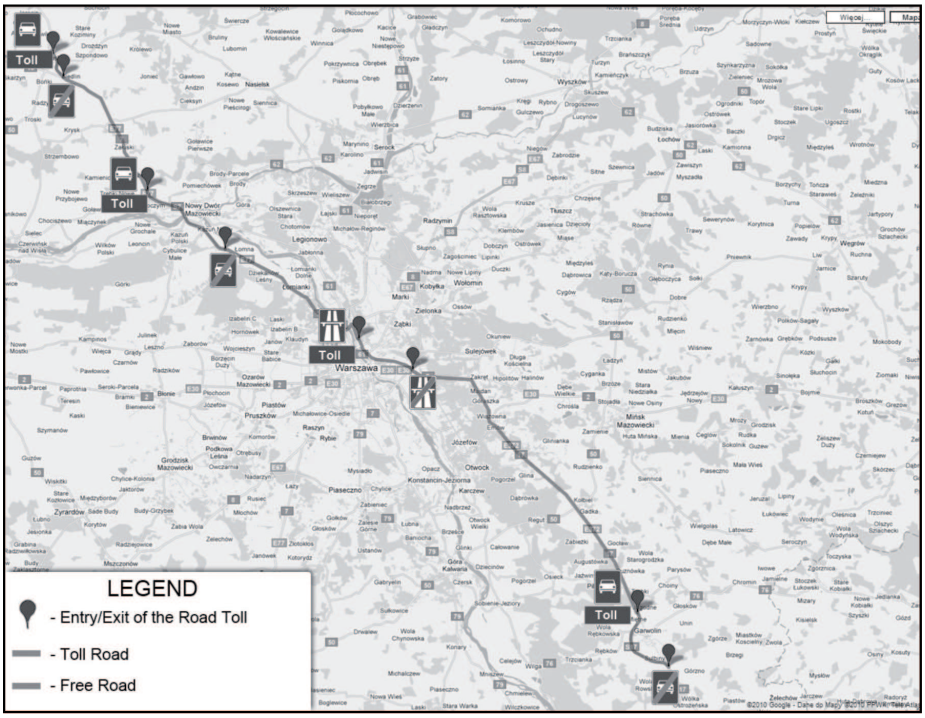

Fig. 2. Test route Płońsk – Garwolin, Garwolin – Płońsk (Figures from 2 to 5 ere prepared by Niedzicka, A. & Smoczyńska, E. with using the map segments from htpp.maps.google.pl). The selected segments of the system are presented on subsequent pages (Fig. 3, 4, 5).

– two segments of expressway S7 (planned route Gdańsk – Rabka with total length of 720 km): eastern bypass of Płońsk (a section of 4,7 km, opened for use on 3rd June 2009), western bypass of Nowy Dwór Mazowiecki (a section of 14,6 km, Zakroczym – Ostrzykowizna – Czosnów),

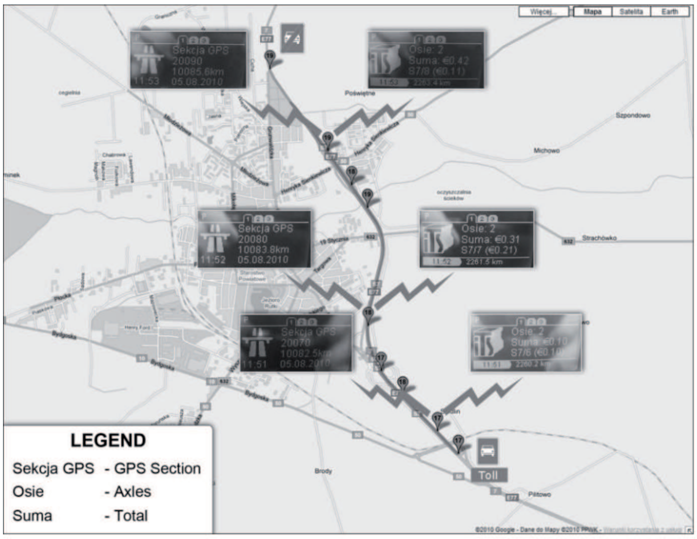

Fig. 3. Segment – bypass of Płońsk, northwards direction (a section of actual expressway S7)

Fig. 4. Segment – Warsaw, southwards direction (route no. 61, virtually classified as a toll motorway), control and supervision gate at the premises of ITS *(Motor Transport Institute)*

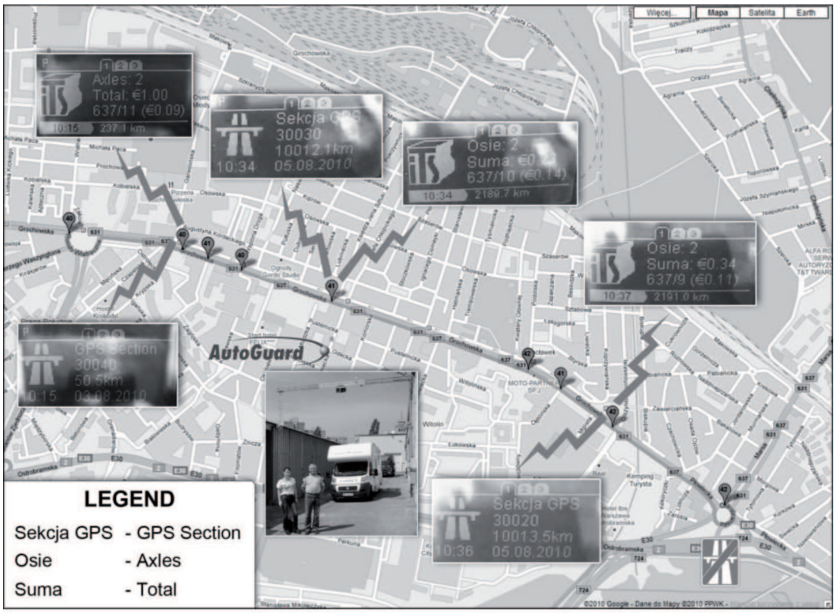

Fig. 5. Segment – Warszawa, Warsaw, southwards direction (route no. 637, virtually classified as a toll motorway), control and supervision gate at the premises of AutoGuard

– one segment of expressway S17 (planned road on the Warsaw – Hrebenne route): bypass of Garwolin of 12,8 km length with two carriageways (each with two lanes and a 2,5 metre wide emergency lane and a 4 metre wide median strip, opened for use on 26th September 2007,
– some segments of the national roads: 61 and 637.

Based on the recorded data, transmitted by the vehicle in the form of messages, it was possible to recreate the exact route of the vehicle with the OBU device.

One of the most important parameters determining the accuracy of measurement and transmitted in location messages is PDOP (Position Dilution of Precision) – defect in determination of position precision. PDOP is a coefficient describing the relationship between the error of user's position and the error of satellite position.

The value of any of the parameters equal to 0 means that at any given time measurement of position is impossible due to interference, weak signals from the satellites, too few visible satellites, etc. The smaller the value of this parameter (but greater than zero), the more accurate is the measurement. The following descriptions, signal quality, depending on the value of PDOP, are assumed: 1 (perfect), 2-3 (excellent), 4-6 (good), 7-8 (moderate), 9-20 (poor), above 20 (bad).

The following charts depict the distribution of the PDOP parameter obtained in the tests. The horizontal axis (X) depicts values for PDOP. The vertical axis (Y) depicts the number of measurements (in percentages) during which a given value of PDOP was obtained. The statistics were calculated based on 4627 measurements of position.

For the purposes of NATCS it was assumed that value of PDOP should be 90 percent of excellent (between 0.1 and 3), for more accurate calculations of position.

The presented graphs (Fig. 6) show that the tested OBU with the number of measurements were respectively 90%, of perfect values, and 8% excellent values. The number of results in the category of poor results (PDOP 9,9 – 2%) exactly matches the number of results corresponding to the absence of visible satellites.

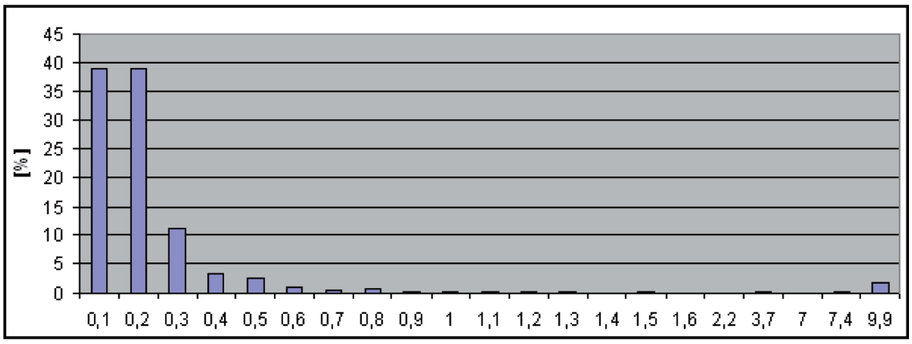

Fig. 6. Distribution of PDOP for all OBU

As stated earlier, the values of the PDOP parameter are conventionally described depending on the value, hence: values greater than 0 and less than 1.0 are considered ideal, and from 2.0 to 3.0 excellent, and above 9.0 poor.

Analysis of the measurement data of the PDOP parameter and the number of satellites used during the test showed that more than 90% of the PDOP measurements were lower than 1, which should provide location accuracy with an error of no more than 6 meters. For 8% of the measurements the PDOP parameter was between 1 and 3, but 2% was poor value (9.9), this happened at the time of activation of OBU and was associated with synchronizing the GPS receiver.

The number of satellites used for measurements of all OBU devices is presented in Fig. 7. For the purposes of NATCS it was assumed that GPS receiver in OBU should track at least 5 satellites, for more accurate calculations and in the event of the loss of signal from one of them.

The presented data shows that the maximum number of satellites used for the purpose of location was 11, and in the case of 99% of measurements at least 5 satellites were used (5-10%, 6-17%, 7-25%, 8-22%, 9-16%, 10-7%, 11-2%).

As part of the project, two DSRC gates with tolling system were prepared. This has allowed for testing of the following functions:

- operation of DSRC microwave devices,
- operation of visual system ANPR system (automatic number plate recognition).

Data obtained from the passage of vehicles through the gates were stored in a separate database. Gates used for testing were described as follows:

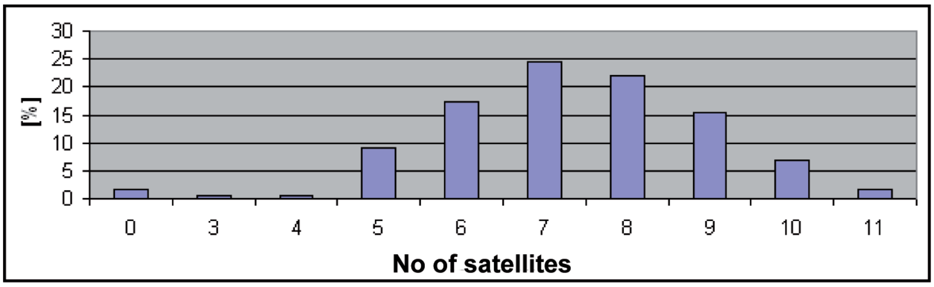

Fig. 7. Number of GPS satellites used for location measurement

– ITS Demo (UID=1000, 2),
– Autoguard Demo (UID=1001, 3).

Based on the tests, tables were developed for each of those gates:

– Image Records – contain records on photographed vehicles (possibly identified by ANPR),
– DSRC Records – contain records on passing vehicles detected by the DSRC system.

From 1st July till 30th November 2010, 2964 vehicles passing through control gates were registered n the database of the system. Not all vehicles were equipped with OBU.

Fig. 8. Picture of research ITS vehicle, registration number WH 15904, taken on 15.07.2010 at 07.22:26, accuracy - 0.960

During the tests at the ITS Demo and Autoguard Demo gates, using the DRSC system, passage of 24 test vehicles was recorded. During the tests at the ITS Demo gate as many as 667 photographs of passing vehicles were taken (e.g. Fig. 8).

Figure 8 presents a photo of a research vehicle of the Motor Transport Institute. The following data were registered in the system: Data (ANPR): 15.07.2010, 07:22:25; Reg. no. (ANPR): WH 15904; Gate ID: 2; Gate name: ITS Demo; Data (DSRC): 15.07.2010, time 07:22:26; Country code: CH; Reg. no. (DSRC): WH 15904; Context data: WH 15904; OBU ID: 340825; Vehicle ID: 123456; Emission class: 1; Vehicle class (dimensions): 1; Vehicle weight: 12 500 kg; Total weight: 12 500 kg; Number of axles: 2; Means of payment – 340825.

Time – photo taken by camera: 07:22:25, date – OBU detected by DSRC sensor 07:22:26. Registration number (DSRC) and the context data refer to assignment of vehicle in the tolling system. In this case full compliance of OBU data with vehicle is required.

During the tests at the Autoguard Demo gate 2297 photographs of passing vehicles were taken. Examples of the vehicle photos are presented in Figures: 9, 10.

Fig. 9. Picture of research Autoguard vehicle, registration number WF 1831E, taken on 29.11.2010, 13:05:27, accuracy: 0.970 (during a snowstorm)

Legend: Date (ANPR): 28.09.2010 09:25:53; Reg. no. (ANPR): WWY 07512; Accuracy: 0.980; Gate ID: 3; Gate name: Autoguard Demo; Date (DSRC): 28.09.2010 09:25:54; Country code: F (France), D (Germany); Registration number (DSRC): WWY 07512; Context data: WWY 07512; OB ID: 1103467888; Vehicle ID:

2147483647; Emission class: 1; Vehicle class: 1; Vehicle weight: 18000; Total weight: 40000; Number of axles: 5; Means of payment: 2147483647.

Fig. 10. Picture of vehicle registration number WWY 07512, taken on 28.09.2010, at 09.25:53, accuracy – 0.980

The registered vehicle was equipped with a French made OBU device – Passango (DSRC) and a German made Toll Collect (GPS/GSM). It was fully identified in the system as a user, which means that the NATCS system is interoperable and can work with both, systems of DSRC type as well as GPS/GSM systems.

During each and every passage the operation of control gates as well as the conformity of the DSRC data with the ANPR (automatic number plate recognition) reading was verified. For the purpose of the second stage the onboard OBU devices were replaced with new ones. Due to a mistake the devices were wrongly installed, however the system immediately discovered the error.

Also the operation of the control gates was tested – mainly with respect to the detection of various vehicle speeds. Thanks to this, it was possible to adjust the software and then to check the newly replaced onboard OBU devices with respect to the correctness of detection of vehicles coming up to the control gate at especially low selected speeds. The system detects vehicles travelling at speeds of 1 to 200 km/h.

Discrepancies between indications of impulses from the road or tachograph were verified – depending on the vehicle – and the GNSS readings. The verification was performed using the "Delta Tacho". Thanks to that it was determined that in the case of Volkswagen Transporter the tachograph readings were 2-3% lower than the satellite measurements, while in Autoguard's vehicle the road impulses were 2-3% higher than the satellite measurements. This fact shows that in the case of loss of GNSS signals, one can measure distance on the basis on devices checking if the passage of vehicle through a tolling point took place via the appropriate route.

Furthermore another parameter was checked – the correctness of detection of irregularities by the OBU onboard unit by disconnecting the tachograph signal, and then purposeful incorrect switching on of this signal while driving. The unit acted correctly and the red diode came on – thus showing a malfunction – instead of the green diode until the time of stoppage.

We also verified attempts to pull out on the route between the segments as well as attempts to drive via alternative routes and secondary passages through segments and gates.

In addition to testing the drives and checking the functionality, the efficacy of the gates was checked, recording all vehicles passing at the premises of ITS *(Motor Transport Institute)* and at the premises of the AutoGuard company in various weather conditions and at various times of day. The efficacy of automatic detection of number plates was 98%. Errors in recognition related only to invisible letters ("lost") and not wrongly recognised ones. This was mainly due to the reflections of the sun, which indicates that an adjustment of parameters could eliminate this problem almost completely. The system control centre has a post for analysis of unrecognised registration number plates, which accurately detects the vehicle registration numbers, and thanks to this the efficacy of the system increases to 99.9%. In one case, a passenger car number plate was obscured by the semi trailer of the preceding vehicle, as a result of which the first two letters were not read. In this case, the right solution might be to change the camera angle.

During the test run and the other functional tests we verified the system by finding individual weaknesses that were reported as needing rectification. It should be emphasised that some of the improvements were implemented in real time – adjustment of parameters, fixing of minor errors. Other amendments required time – from one hour up to several hours to fix, such as remote modification of the vehicle data in the OBU or change of segment definition.

All objections were resolved on an ongoing basis, thus allowing us to trust the efficacy of such a system in practice. Contact with the operators of the system was fast and seamless. The testes also proved that any attempts to "deceive" the system or any atypical action resulted in correct responses served in the prescribed manner. The compatibility of the system and the OBU devices with the interoperability requirements of the European Union allows one to hope that the idea of a single device, single contract and single invoice is realistic.

The lack of a developed infrastructure – with a minimum of supervision and control infrastructure – and the ease and flexibility of changing the definition of segments and the addition or exclusion of alternative routes, classifications and remote changes in key parameters shows the superiority of the GNSS/GSM solutions over solutions requiring the communication infrastructure for each tolling point or segment, such as the systems based on direct DSRC communication.

During the test actual segments of expressways S7 and 17 were used. In addition, segments of roads No. 637 and No. 61 within the boundaries of Warsaw were classified as toll roads. The ability to define any classification of virtual segments is another element that shows the flexibility of the system, potentially also in terms of defining the same tolls for primary routes and alternative routes. In addition, the segments were defined in terms of individual directions (different number of segments, tolling points in various locations).

All the segments were identified correctly by the onboard devices, and there were no problems in this respect. Each segment consisted of three points, and in order for each one of them to count, all three segments had to be detected by the OBU device. As a result of this drivers who will cut through toll roads, or only pass through them, will not be registered in the system.

The tests were successful and confirmed the efficacy of the selected solutions in accordance with the assumptions of the project.

3. Security of the System

Electronic tolling systems process sensitive personal data, vehicle traffic data and financial transfers. Therefore, safety aspects are very important. Many standard interfaces such as GSM or WAN/Internet offer a variety of security mechanisms (e.g. secure *https* protocols) and one should make use of them.

The basic problem is to secure some data reported in the tolling process on the entire route of transmission (*end to end*). In other words, data generated at the beginning of the communication channel (e.g. onboard OBU device) delivered to the destination through various intermediate links and media should be fully protected during transmission regardless of any applicable security mechanisms used in the individual links/media.

Each interface can use for standard security mechanisms: separate security mechanisms in GSM links, separate mechanisms in DSRC, and separate ones in the case of Internet connections. These mechanisms ensure secure transmission of data over a specific interface and are important in the case of many top-level interfaces, such as those used in the internal system components.

The security of the whole system must be based on separate mechanisms to protect data transmitted by the various links and media throughout the entire route of transmission – from the source right to the place of destination. They should be independent of any security mechanisms used in the interfaces. Such *end-to-end* security mechanisms must be specifically appropriate for a particular system. For this purpose, the FELA Company uses a standard infrastructure for the public encryption keys. This concept was tested in Switzerland, in the implemented tolling system for heavy vehicles, in which a dedicated and secure Certification Authority – CA was created.

Figure 11 shows the use of *end-to-end* security. It is based on standard RSA encryption algorithms, using pairs of public/private key and security certificates. Such security features allow for safe transmission of secure data to any destination.

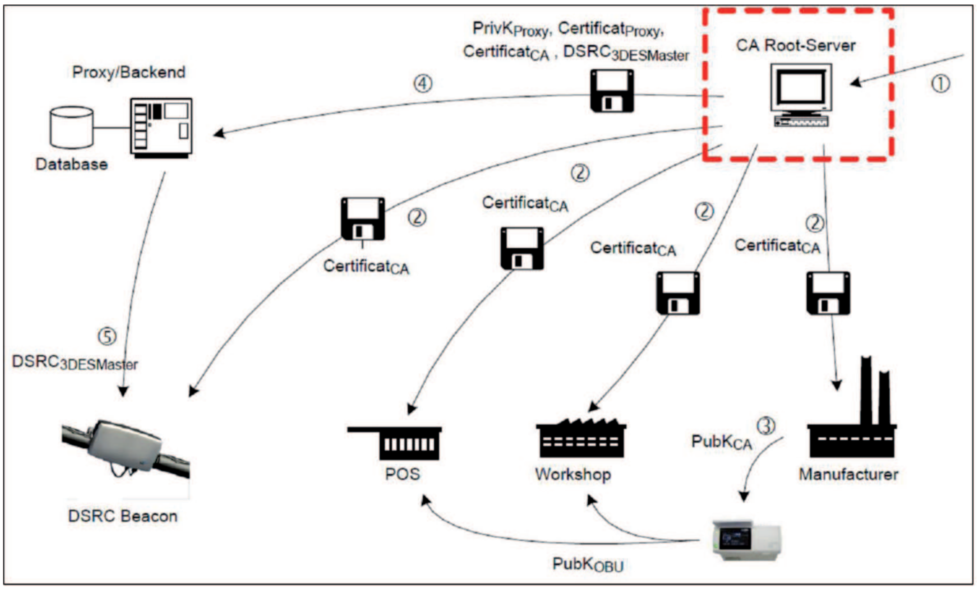

Fig. 11. Basic security system architecture (Kallweit, T. 2010)

Certain processes are to some extent critical, e.g. generation of specific encryption keys such as DSRC *Master Key*. Access to the Certification Authority must be fully secure and controlled so as to allow it to be obtained only by certain trusted people.

Security was achieved through the following undertakings:

1) The Certification Authority has generated a DSRC Master Key, which was used to start the system up.
2) Through certificates, each element of the system received from the Certification Authority a Pub Key and a DSRC start-up key. They were delivered to the individual elements, or otherwise these elements downloaded their certificates via Internet.
3) The manufacturer the OBU onboard units installed a public key of the Certification Authority (CA Pub Key) as well as a unique DSRC key, in each and every OBU device.
4) The Proxy server/internal elements of the system received CA certificates, Proxy certificate, private keys and a DSRC Master Key. This operation was secured: the transfer of these keys usually takes place via special Smart Cards.

5) Internal elements of the system distribute the DSRC Master Keys to all DSRC locators. Upon start-up of the security system the DSRC Master Key for all onboard OBU devices was updated via a secure communication channel with the internal elements. Thanks to this the use of the initial DSRC key by the manufacturer of the OBU device is not associated with any excessive risk as the key will be replaced as soon as the device establishes communication with the internal elements of the system.
6) Upon receipt of the CA certificate with the CA public key, each element of the system generates its own pair of public/private key and sends its public key back to the internal elements of the system. From now on, all communication is secure (end-to-end security).

Change or adding of new keys to DRSC Master Keys. DSRC *Master Key* is a 3DES encryption key used in wireless DSRC communication. To enable establishing of secure communication, each onboard OBU device must be equipped with an individual DES key, generated based on the primary 3DES *Master Key*. Each and every DSRC locator of the OBU onboard device is equipped by its manufacturer with a standard key that is used during the start up of the system. Once the device has established a secure encrypted communication according to RSA standard, the internal elements of the system will provide it with an individual key. Normally, DES keys are customised by adding the serial number of the OBU device. Thanks to this, the initialisation process and the activation of the OBU device does not pose a major threat, as it does not require the transmission of data necessary to generate individual DES keys in a communication session with the internal elements of the system. Individual DES keys can then be transferred via a GSM connection at the earliest possible opportunity. Another important aspect here is that such a mechanism is necessary anyway in the case of replacement of DSRC key (e.g. if a given onboard device must be configured in another tolling system which does not utilise the DSRC technique).

Secure activation process of the onboard equipment. During activation at the point of service (POS) or workshop, onboard OBU device generates/activates its pair of keys (private/public), and transmits the public key to the internal circuits of the system. The safest procedure is to sign the transmitted OBU public key with a private POS or workshop key. With this solution, no user will be able to transmit a fake OBU key without the assistance of a certified POS or a workshop. Such a solution will make it very difficult for potential hackers to pose as members establishing connection with the internal elements of the systems via protected channels, because in the case of fraud, identification of a certified partner, who assisted in getting a false key, would be quite simple and that partner would not be able to deny this. In addition to the cryptographic mechanisms, the security of the system is ensured by other means, e.g. registration of unique IDs, SIM card numbers and other data relating to OBU devices. This data provided by the manufacturers was registered before the release of the onboard devices to users. Such registration allows the verification of reporting OBU onboard devices via internal elements of the tolling system.

4. Conclusions

From 1st July till 30th November 2010, 2964 vehicles passing through control gates were registered in the database of the system. In addition to testing the drives and checking the functionality, the efficacy of the gates was checked, recording all vehicles passing at the premises of Motor Transport Institute and at the premises of the AutoGuard company in various weather conditions and at various times of day. The efficacy of automatic detection of number plates was 98%. Errors in recognition related only to invisible letters ("lost") and not wrongly recognised ones. The system control centre has a post for the analysis of unrecognised number plates, which accurately detects the vehicle registration numbers, and thanks to this the efficacy of the system increases to 99.9%.

Analysis of the measurement data of the PDOP parameter and the number of satellites used during the test showed that more than 90% of the PDOP measurements were lower than 1, and 8% had value from 1 to 3.

For the purposes of NATCS it was assumed that GPS receiver in OBU should track at least 5 satellites, for more accurate calculations and in the event of the loss of signal from one of them. Tests results showed that in the case of 99% of measurements at least 5 satellites were used for the purpose of location (the detailed results of satellites: (5-10%, 6-17%, 7-25%, 8-22%, 9-16%, 10-7%, 11-2%).

All objections were resolved on an ongoing basis, thus allowing us to trust the efficacy of such a system in practice. Contact with the operators of the system was fast and seamless. The tests also proved that any attempts to "deceive" the system or any none-typical actions resulted in correct responses in the prescribed manner. The compatibility of the system and the OBU devices with the interoperability requirements of the European Union allows one to hope that the idea of a single device, single contract and single invoice is realistic.

The researches clearly confirm that under the existing conditions (development of new technologies, Directive 2010/40 and the European Commission's decision of 6*th* October 2009), a tolling system, using GPS satellite positioning and GSM will be the best future solution for each EU Member State, particularly in terms of interoperability and flexibility when toll systems may be used for more categories of roads (or all roads) and each category of vehicle.

Tests of NATCS project has been a complete success. The system uses GPS/GSM technologies, but also recognises devices such as DSRC and OBU. During tests, the system recognised French made DSRC Passango device and a German made Toll Collect device of the GPS / GSM type, installed in a vehicle which did not participate in the test, but accidentally ran through the control gate. This implies that the

NATCS system is interoperable and can cooperate with both GPS/GSM systems as well as with DSRC types of systems existing in other EU Member States.

The paper has been prepared with framework of NATCS Pilot Project, N R10 0001 04.

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