The paper deals with the assumptions and test results of NATCS Pilot Project developed by Motor Transport Institute, Autoguard SA, and Fela Management AG. Legislation steps were taken at the EC level because of interoperability problems of European Electronic Tolling Service (EETS) in the EU. Commission has urged member states to conduct studies and pilot projects concerning these issues. Motor Transport Institute has taken up a challenge by developing and testing the pilot project – the functional structure of the NATCS. System has some requirements of EC legislation and it is interoperable with other DSRC and GPS/GSM based systems implemented in member states of the European Union. Test results have shown a high accuracy and efficacy of the system.

**Keywords:** European Electronic Tolling Service (EETS), National Automatic Toll Collection System (NATCS), interoperability

1. Introduction

There are two different types of European Electronic Tolling Service (EETS): Dedicated Short Range Communication (DSRC) and GPS/GSM based systems.

In most EU countries (Austria, France, Spain and Italy) DSRC type systems of electronic tolling are used, that rely on dedicated short range radio (microwave frequency - 5.8 GHz).

The OBU on-board device, operating in the DSRC system is small (size similar to a packet of cigarettes). It is mounted on the windscreen inside the vehicle. However, the device is not very smart, very simple and only performs validation functions (read only), it has no display, and cannot receive or transmit any message. The DSRC system requires a well-developed road infrastructure, at every crossroads, and gates must be installed at entrances to and exits from toll road sections.

In the DSRC system, there are two types’ gates: communication Toll Gates and control gates, because their number is ten times greater than it is the case in the GPS / GSM.

In addition, data transmission is done using wired communications, and then it can take place over the Internet. The DSRC system will not be able to be incorporated into an integrated technology platform, as it will not even be able to collaborate with other national transport systems. Even in the case of the DSRC system, which is provided by Kapsch, each country has a different type of OBU device. Another solution is to apply GSM or GPS systems.

In this system, thanks to the GPS satellite positioning virtual control and tolling points established, the system can operate without the use of control gates. Data are transferred to the system directly from the OBU devices, using GSM communications.

According to the European Commission electronic tolling systems used in the European Union are not interoperable for the following reasons: differences in the concepts of tolling, technology standards, classifications, rates, discrepancies in the interpretation of laws.

The European Commission has taken two mile steps in this regard. The first was Directive 2004/52/EC of the 29th of April, 2004 on the interoperability of electronic road toll systems in the Community [1]. Then there was the decision of the European Commission of the 6th of October, 2009 on definition of the European Electronic Toll Service (EETS), and system architecture [2].

According to the European Commission decision 2009/750/EC, European Electronic Toll Service (EETS) should enable road users to easily pay tolls throughout the whole European Union (EU) thanks to one subscription contract with one Toll Service Provider and one single on-board unit (OBU). The mentioned decision was supported by standard EN ISO 12855 (CEN, Brussels, 05.02.2010) – tolling
interoperability aims at enabling a vehicle to driver through various Toll Domains while having only one OBU operating under contract with Toll Service Provider [5].

Implementation of interoperability is a long-term and precise action. What comes to the fore in the implementation strategy for interoperability is the need for introduction of the EETS system, consisting of the following systems: DSRC, GSM, GNSS1.

The best universal solution in complicated situation in UE is implementation of hybrid system (includes: DSRC, GSM, GPS technology), the researches developed in Czech Republic, NATCS is mentioned type of system.

2. Functional Structure Of NATCS

The research team identified KSAP0's functional structure, which consists of the following elements (Fig. 1):

- Intelligent on-board device called TRIPON-EU, which was installed in test vehicles,
- OBU device installation system using a chip card,
- two control gates (with DSRC modem and a vision tolling system),
- laboratory model of national Centre for automatic tolling KCAPO,
- a proxy server for data exchange between headquarters and the OBU system via GPRS,
- control centre to manage the OBU devices allowing for management of OBU and analyses of data relating to the collection of tolls,
- analytical tools for DSRC, image analysis and classification of vehicles.

The design of the system included the following technologies:

- satellite positioning via GPS, and Galileo in the future,
- wireless communication via GSM (TS 03.60 / 23.060),
- dedicated short range communications – DSRC (5.8 GHz).

![Figure 1. Functional structure of NATCS](image)

The onboard device TRIPON-EU (Fig. 2) is available in two different versions. The test system used the version mounted in a single casing collecting all components, including GPS and GSM antennas. This version is designed for installation on the windscreen of the vehicle.

1 GNSS - Global Navigation Satellite System. GNSS-1 is based on existing segments of the orbit Navstar GPS and Russian GLONASS system. An integral part of the GNSS-1 is a system of differential (DGPS - Differential Global Positioning System). Development of GNSS-1 will be the GNSS-2. The constellation of navigation satellites will include the GPS Navstar satellites of II F type GLONASS M and new European satellites with working name of Galileo.
The OBU device should store the following data: vehicle class, vehicle weight, axles or class of emission, registration numbers and contractual details. Data can be entered into the device using a chip card.

The GPS module used in OBU devices supports computing navigation (DR, dead reckoning) to improve the accuracy of positioning.

GPS data (from satellites), supplemented by the results of computing navigation are used as input for detection of on-ground facilities. Detected events are logged in the event file. The European EGNOS system can be enabled or disabled through the configuration file activated at the time of start-up. The device is designed to cooperate with Galileo.

Data recorded by the OBU onboard unit are transmitted to the internal components of the EETS system, using GPRS technology (packet data transmission system used in GSM technology). The data transmission between the mobile onboard units and the internal elements of the system takes place via a proxy server, which operates completely independently of the billing and accounting system. Data is transferred in batches, which means that one does not need to maintain a permanent connection between onboard devices and the internal components of the system. This is one of the biggest advantages of the concept of smart clients. GPRS allows for even greater reduction of communications costs.

Tripon EU independently analyses the data (GPS location data, vehicle defined data, data on tariffs - fixed schedule of fees and other data) that are remotely transmitted, in real time, to the server. Data about events related to billing, and events relating the control and supervision, are limited to a minimum, which significantly increases the throughput of the system and reduces the operating costs.

Depending on the required precision and an additional control, TRIPON-EU can operate in two positioning modes: using signals from GPS and assisted by a signal trace from other onboard equipment. In order to verify system capabilities in both vehicles OBU devices were checked using only the GPS signal and in conjunction with an additional device, from which passage signal was received. The comparison indicated a small discrepancy between the satellite positioning signal and the passage signal, indicating these by "Delta Tacho +x%" messages.

On-board equipment TRIPON-EU uses built-in GSM antennas, there is no need for external antennas. The SIM card installed inside cannot be replaced by the user. For the convenience of testing, using the S button (send) one may activate a GPRS communication session at any time without having to wait for the next automatically initiated session. The onboard device TRIPON-EU can receive short text messages.

Each received message can be: confirmed, denied, confirmed by way of a predetermined message or deleted by the driver.

For this purpose, appropriate options in the menu are provided. This functionality has been included to easily demonstrate the potentially available value added services that can be implemented on the platform TRIPON-EU.

The device board TRIPON-EU is equipped with a DSRC module (5.8 GHz, IR) DSRC (Dedicated Short-Range Communications). In cross-border traffic OBU device enables collaboration with GPS/GSM tolling systems (Germany, Slovakia) or DSRC systems used in other countries (Austria, Czech Republic, Italy, Spain, France). The basic standard used in these types of systems (DSRC) is the ISO EN 15509 standard (Media Transactions). The onboard unit TRIPON-EU makes use of such transactions in order to illustrate the possibility of tolling in cooperation with the vision system – ANPR.

Transactions can be configured in such manner, as to support DSRC attributes that are necessary in a specified tolling implementation.

Each onboard unit TRIPON-EU is equipped with a Smart Card interface, which can be used for calibration and initialisation purposes. When configuring the test system Smart Cards will be used for:
initiating onboard units with contract data, configuring parameters of onboard equipment, all operations with the use of cards can also be initiated via the GSM link.

The concept of toll control gates in the system tested in Poland is based on experiences Fela company, collected during the operation of the Swiss system. The following devices are installed on control gates (Fig. 3):

- DSRC locator to carry out transactions with the traffic lane controller (according to EN 15509 standard),
- vision system ANPR (automatic number plate recognition and photographic documentation (ANPR, only from the front)
- local driver software for the registration fee collection.

![Figure 3. Control gate at Motor Transport Institute in Warsaw](image)

The DSRC locator conducts standard DSRC transactions (in accordance with CEN TC278/EN155509) detecting every vehicle passing through the gate.

Essentially the contract data are recorded, including registration numbers and characteristics of the vehicle. The data collected should include in particular: the registration number and characteristics of the vehicle. These data are essential in the process of collection of fees – i.e. they are compared with the data coming from the ANPR (automatic number plate recognition). The DSRC locator is mounted on the top of the gate, about 5-6 metres above the road. In addition to the beacon the so-called “traffic lane driver software” should be installed on the gate, which will process data from the locator and control its operation during the transaction. The data should be periodically sent via Ethernet to the system’s central unit.

Depending on the location of gates and/or traffic conditions one can apply a variety of other triggering signals. The monochromatic ANPR camera will be equipped with an image converter with a resolution of 1620 x 1220 pixels and Gig-E interface. The controller installed inside the camera casing: transmits triggering signals to the camera/impulse source of infrared radiation, converts the signals from light sensor, based on signals from the light sensor generates the parameter settings of the camera / impulse source, controls the temperature in the camera casing (turn on/turn off the heating/cooling).

A photo of vehicle is transmitted to tolling server from a given traffic lane for further processing and is analysed in order to read the registration numbers. At the same time, it will serve as documentation if it is necessary to start tolling procedures.

To enable fully automatic gate operation, an ambient light sensor is used, whose signal is based on the control of the camera and the impulse infrared radiation source. The sensor is oriented on the detection of vehicles and has a dynamic range from 3 to 30,000 lux.

All data collected at toll control are transmitted to tolling system servers and are made available in the tolling controlling software.
This software enables viewing all collected images, results/details of ANPR algorithm operations and DSRC results.

The laboratory model of National Centre for Automatic Tolling (KCAPO) comprises of the following elements:

- Three PCs – one dedicated as a database server, the second one serves as application software server, while the third one is a user terminal,
- application and system software,
- databases,
- software and physical interfaces (between KCAPO and OBU, between KCAPO and control gates),
- user interface (online WWW service).

In the proposed solution the proxy server is the main element of the service provider’s interface. It supports and controls OBU’s sending and receiving of all data. The system operates using Linux and ensures stable operation.

The task of the proxy server should include communication only, but also including SW updates of OBU devices. Toll tariff tables and geographic objects displayed on OBU’s screen should be sent from a proxy server to the OBU. Data received from the OBU should be checked for consistency, and then made available for analysis.

Databases in KCAPO are divided into the following groups: data on users, vehicles and tariffs, Physical Inventory, Dynamic Inventory.

The design defines a total of six major interfaces that are included in the proposed test system with OBU on-board device.

1. Installation and maintenance contract for on-board equipment. OBU is configured using Smartcards.
2. Connecting to the vehicle. OBU is connected with the following points in the installation of vehicle: power, ground, ignition, and tachograph.
3. OBU user interface. The screen displays the following information: the symbol of context (collection area) Toll (P for Poland), graphical representation of the Polish context of the toll (for example, outline of the borders of the country) declared number of vehicle axles, the total value of toll charged per vehicle run, amount due for passage of the current segment, the time and the amount of kilometres travelled from the time of installation.
4. DSRC Interface (5.8 GHz, IR) is used to conduct standard transactions with DSRC devices that are installed at tolling gate.
5. Data interface (from the tolling operator to the provider of the system). This is an “internal” interface because in the test system there are no isolated places for toll collectors and suppliers of the system.
6. The tolling procedure was demonstrated with the use of DSRC antennas and ANPR cameras (Automatic Number Plate Recognition) on a test gate installed on a single lane.

3. Tests Results of NATCS

Tests of the KSAPO 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 being registered from the 1st July to 30th November, 2010. The tests of the system were conducted by the following research team:

- Motor Transport Institute (Instytut Transportu Samochodowego) (Gabriel Nowacki, Anna Niedziacka, Ewa Smoczyńska),
- FELA Management AG (Thomas Kallweit),
- Autoguard SA (Robert Rożesłaniec, Tomasz Garbacz, 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.

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.

Out of the several proposed test route options we chose the Płońsk – Garwolin, Garwolin – Płońsk route, 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 the both control gates and allowing the use of as many as three actual segments of expressways:

- two segments of expressway S7, eastern bypass of Płońsk (a section of 4.7 km), western bypass of Nowy Dwór Mazowiecki (a section of 14.6 km, Zakroczym – Ostrzykowizna – Czosnów),
– one segment of expressway S17, bypass of Garwolin of 12.8 km length with two carriageways,
– two segments of National Roads.

On the basis of 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), > 20 (bad).

The data of the PDOP parameter obtained in the tests was presented on Figure 4. 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 stats were calculated based on 4627 measurements of position.

![Figure 4. Results of PDOP](image)

Average value of PDOP for all OBU was 90 % of perfect and 8% excellent values. Analysis of the measurement data of the PDOP parameter and the number of satellites used during the test showed that 90% of the PDOP measurements were lower than 1, which should provide accuracy of location accuracy with error of no more than 6 meters.

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

The presented data shows that the maximum number of satellites used in for the purpose of location was 11, and in the case of 99% of measurements at least 5 satellites were used (the detailed results of satellites: 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).

![Figure 5. Number of used satellites for localization](image)

Data obtained from the passage of vehicles through the gates were stored in a separate database. Gates used for testing were described as follows:
The registered vehicle was equipped with a French made OBU device – Passango (DSRC). It was fully identified in the system as a user, which means that the KSAPO 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 small selected speeds. The system detects vehicles travelling at speeds of 1 to 200 km/h.

In addition to test the drives and the checking of the functionality of the, 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 99.9%. 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.

4. Conclusions

During the test of NATCS phase, from the 1st of July till 30th of November, 2010, 2964 vehicles passing through control gates were being 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 functional structure of NATCS is according to directive 2004/52/EC, decision of European Commission from 6-th October 2009 and CEN standards.

The efficacy of automatic detection of number plates was 98%, and thanks to proceeding data by analyse stand, 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 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 NATCS turned out to be flexible when it comes to extending toll collection to every road category, every category of vehicle and, what's more, in terms of cost efficiency in implementation and operation. Another advantage is an absence of the need for new road infrastructure (gantries), while the operators can keep using the existing infrastructure. System works without toll booths, extra lanes, speed restrictions or complex structures along toll roads. Furthermore the system ability to support other value-added services on the same technology platform will be discussed.

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 four Tripon – EU OBU’s, 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.

Acknowledgement

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

References