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Technical Infrastructure for Monitoring the Transportation of Oversized and Dangerous Goods

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Abstract — The paper presents the technical infrastructure of the system for monitoring the road transportation of oversized and dangerous goods. It describes the basic components of the system – vehicle sensor network, vehicle on-board unit (OBU), monitoring centre and wireless communication system. Moreover, it specifies some important system parameters, especially the period of sending the data about the state / condition of goods to the monitoring centre.

I. Introduction

The transportation of dangerous goods by road network is a potential and everyday threat to people and the surroundings of the roads used for such operations. It is a matter of international importance because the transportation of dangerous goods, as well as the transportation of other goods, is carried out regardless countries´ borders.

From the viewpoint of legislation, the transportation of dangerous goods by roads in Europe is regulated by an international agreement, the ADR (European Agreement Concerning the International Carriage of Dangerous Goods by Road) [5]. This agreement divides dangerous goods into nine classes, see TABLE I.

TABLE I.
Classification of Dangerous Substances in Accordance with ADR

Class	Description
1	Explosive substances and articles
2	Gases
3	Flammable liquids
4.1	Flammable solids, self-reactive substances and solid desensitized explosives
4.2	Substances liable to spontaneous combustion
4.3	Substances which, in contact with water, emit flammable gases
5.1	Oxidizing substances
5.2	Organic peroxides
6.1	Toxic substances
6.2	Infectious substances
7	Radioactive material
8	Corrosive substances
9	Miscellaneous dangerous substances and articles

An oversized load is (in the Slovak Republic) defined by the Paragraph no. 14 of the Regulation no. 464/2009 of the Ministry of Transport, Construction and Regional Development of the Slovak Republic. A vehicle transporting an oversized load is a vehicle the dimensions of which exceed at least one of following dimensions: width - 3 m, height - 4.3 m, length - 23 m.

The objective of research and development tasks described below is to determine the requirements for technical infrastructure of information system for the monitoring of the oversized and dangerous goods transportation and to determine whether it is possible to use the existing infrastructure of GPS/GSM based electronic toll collection system in the Slovak Republic for this purpose.

II. Related work

The problem of real time monitoring of the dangerous goods transportation is solved by several research teams due to its importance. These researches have some common factors – the coordinates of transported goods are being acquired by the GPS system, the dangerous goods is being monitored by sensor network (wired or wireless) and data are being transferred into the monitoring centre via GSM/3G network (the work [17] applies satellite network INMARSAT instead of GSM/3G). As wireless sensor network the ZigBee technology is commonly being used [10], [14]. The vehicle on-board units are based on single chip microcontroller or ARM processor core in the cited works.

III. Architecture of THE System

To decrease the risk during transportation, there is a complex information system which will monitor the oversized and dangerous goods in real time, and which will be interconnected on-line with an integrated emergency system.

We have analyzed many European projects recently, and consequently we have determined the following architecture qualities:

- Modularity
- Flexibility

- Possibility to be used in heterogeneous environment
- Interoperability
- Use of open standards
- Performance
- Language independency
- System reliability
- Information security and safety
- User interface usability
- Service intelligence

The system architecture was designed according to the attributes listed above; to create the system we used methods described in [9]. The system was created with focus on its maximal modularity, a module can be replaced without having to change the rest of the system, e. g. the communication system can use another protocol.

The basic requirements on such information system can be summarized in several points:

- Provision of information about dangerous goods and about manipulation with them
- Real time monitoring the dangerous goods status by a sensor network
- Wireless mobile data and voice connection with the emergency system in case of damage or a traffic accident
- Checking the accuracy and punctuality of dangerous goods delivery.

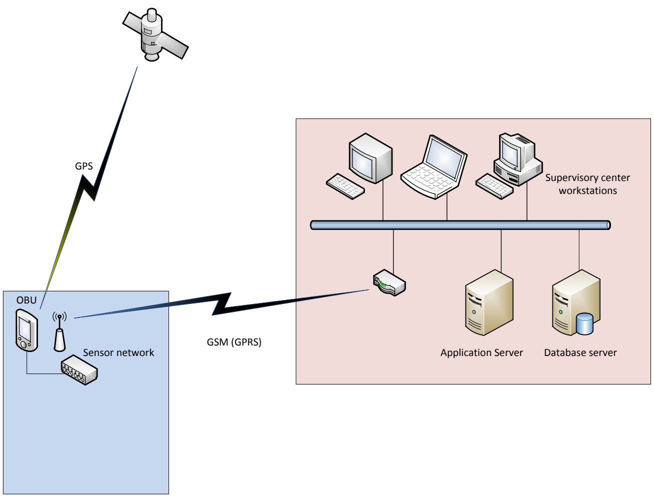

Fig. 1 Architecture of the system for monitoring oversized and dangerous goods transportation

The core of the whole information system are the on-board unit (OBU), sensor network and monitoring centre. The OBU monitors the physical parameters of the transported goods by means of a sensor network in real time. The data about the goods together with the vehicle position are transferred by GSM/GPRS network to the monitoring centre for evaluation. A similar complex information system, the architecture of which is shown in Fig. 1, was solved and realized by authors in Project CONNECT [2]; at present the solution is focused on the simplification of the system and on utilizing the existing infrastructure for the electronic toll collection.

IV. Monitoring The Dangerous Goods Parameters

A. Determination of the period of sending the information about the goods status

To determine the period of sending the data about the goods status to the monitoring centre, we can use the mean arrival time of emergency services. The basic aim is that the period of sending the data should not significantly affect the mea arrival time. For the calculation we can assume that the mean arrival time $E(T_A)$=10 minutes, i. e. 600 seconds. The situation is shown in Fig. 2. The non-zero period T of the data sending increases the arrival time T_A by the delay τ. Because the moment of an accident occurrence is random, the delay τ is a random quantity with uniform probability distribution with probability density f(t)=1/T on the interval <0, T>. The mean value of the delay τ is then given by the expression

$$E(\tau) = \int_0^T t f(t) dt = \frac{T}{2} \tag{1}$$

As it results from the above expression and from Fig. 2, the mean arrival time $E(T_A)$ will be increased by the influence of a non-zero period of data sending by the value $E(\tau)$, i. e. by a half of the period T.

This mean arrival time $E(T_A)$ increase must be negligible in comparison with the value of $E(T_A)$. Let it be 1 % of $E(T_A)$, i. e. 6 seconds. The period of data sending then can be calculated from the expression (1), and it is T=12 seconds, i. e. the information on the status of dangerous goods must be sent to the monitoring centre every 12 seconds.

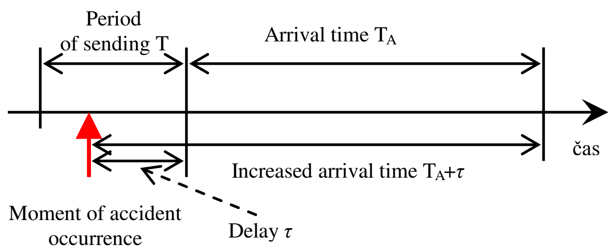

Fig. 2 Increase of the arrival time by the influence of data sending period

The period of the dangerous goods status sampling by the vehicle sensor network can be determined by a similar calculation, i. e. it must be significantly shorter than the sending period T. Considering that the times are approximately one second or less, the influence on the arrival time of emergency services is not significant any more, therefore the sampling period of the dangerous goods state can be determined in conformity with the period of GPS data acquisition, which is one second for conventional industrial GPS modules.

B. Sensor network for monitoring goods status

For real time monitoring of dangerous goods status the vehicle must be equipped with the network of sensors which measure the physical quantities according to the class of the transported goods (TABLE I). For these purposes sensor units were designed. They measure the concentration of gases (see block diagram in Fig. 3) [11], [16], temperature, pressure and inclination (turnover) of the vehicle [15].

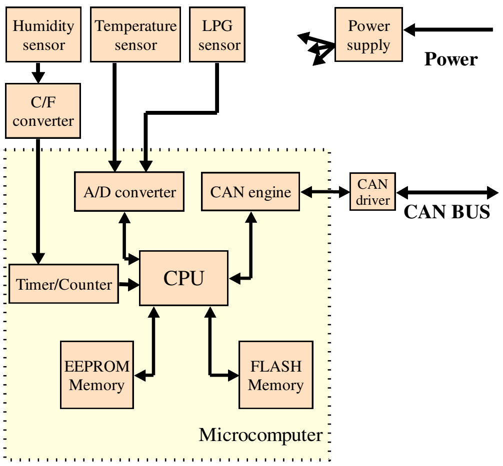

Fig. 3 Block diagram of LPG sensor

The sensors communicate via CAN (Controller Area Network) bus which appears to be the most suitable solution for this purpose because it is often applied as a communication bus in motor vehicles. Because the standardization of vehicles transporting dangerous goods is needed, the authors propose to incorporate the data from sensor network for monitoring the dangerous goods into the diagnostic interface FMS (Fleet Management System) [6]. The individual physical quantities which reflect the goods status would be accessible for OBU just via the FMS interface under appropriate identification numbers of variables. The resolution of such variables need not be higher than 8 bits because their purpose is only to detect the predefined threshold exceeding [4]. The adequate repeating period of these variables can be 1 second, as it was analysed in the previous sub-chapter.

V. On-Board Unit

The most important part of the architecture is an on-board unit. The unit can be built on various hardware platforms (see TABLE II). The main purpose of the unit is to collect all relevant information from a vehicle and send them to the monitoring centre.

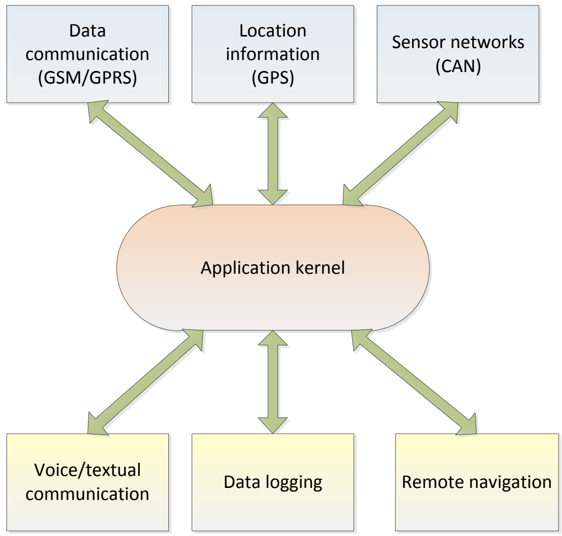

Fig. 4 Block diagram of OBU

It is evident that the following parameters must be monitored during dangerous goods transportation (listed in order of priority):

- Vehicle position (GPS coordinates)
- Status of goods (detection of leakages of volatile substances, temperature, pressure, vehicle turn over etc.)
- Operational parameters of vehicle (speed etc.)

Additional functions of the on-board unit can bring added value to the system and increase the driver's comfort, however, they are not primarily necessary to be included in OBU. We suggested the following add-on functions:

- Bidirectional communication with the monitoring centre, voice or textual. This kind of communication can be integrated to the on-board unit, if a GSM modem with voice support is used. If we have a broadband data connection, the voice can be transferred as data. If there is no possibility of voice communication, a textual communication can be used instead. This kind of communication cannot be bidirectional for security reasons (the driver cannot participate in the textual conversation.
- Remote navigation from the monitoring centre can configure a navigation system which can navigate the vehicle to its destination. In case of a route change (a traffic jam, car accident) the monitoring centre is able to change the route using an alternative one. There is a navigation software which can be remotely controlled from an external application (e.g. Sygic).
- A black-box function enables to collect all information and store them to a persistent storage. If there is a car accident, all unsent information can be retrieved from the storage. A black-box module can include a camera system, which can save pictures or video for a later incident reconstruction.

Of course, the data must be periodically sent to the monitoring centre during the transportation. Evidently the only way is to utilize the GSM/GPRS network of some provider. Taking these initial requirements into account, the basic requirements on the functionality and interfaces of the OBU can be determined as follow:

- Detection of the vehicle position by the GPS receiver requires the interface RS-232 or USB with corresponding drivers.
- Data transfer via the mobile network GSM/GPRS requires the industrial communication module GSM, usually with the RS-232 interface.
- The detection of dangerous goods status requires a vehicle equipped with sensor network. The sensor network can be built on the basis of some widely used industrial buses, e. g. Controller Area Network. Then OBU must be equipped with a corresponding interface.
- The operational parameters of the vehicle can be acquired from the FMS interface, which is integrated into new trucks.

Various possibilities of the hardware solution of OBU for monitoring dangerous goods transportation, their main advantages and disadvantages are summarized in TABLE II. On principle, all the hardware platforms enable to execute the basic function of OBU, i. e. monitoring the vehicle position, not all platforms can execute the supplementary function of goods status monitoring via the sensor network.

TABLE II.
COMPARISON OF VARIOUS HARDWARE PLATFORMS FOR OBU REALIZATION

Platform	Advantages	Disadvantages
Single chip microprocessor	Customized solution, low cost hardware, robustness	Need of HW and SW development, single-purpose system
Vehicle computer x86	Versatility, scalability, robustness, availability of interfaces and drivers	Price, no turnover detection without external sensor
Vehicle computer ARM	Versatility, scalability, robustness	Smaller assortment of interfaces and drivers, no turnover detection without external sensor
Tablet / mobile phone	Availability, price, built-in accelerometer to detect turnover	Closed HW system, demanding connectivity of sensor network, poor climate and mechanical resistance
Toll OBU	Verified and applied system, price, robustness	Closed HW system, unknown possibility of sensor network connection without modification of HW

The solution based on the vehicle computer with x86 architecture (Fig. 5 a) has the broadest possibilities. This platform is universal, scalable and upgradable by new functionalities and new external sensors. In future, this solution would integrate functionalities which are provided by individual OBUs at present, for example a digital tachograph, navigation system and toll OBU.

If only monitoring the vehicle position without monitoring the goods status is acceptable (i. e. without sensor network), it is advantageous to use the toll OBU, which is already widely used in trucks (Fig. 5 b). This OBU has a sufficient hardware to ensure an additional functionality. It will be necessary to modify the toll OBU software, so that the position data can be sent to the monitoring centre periodically with 12-second periods (see the analysis in the previous chapter).

Fig. 5 a) Vehicle computer IEI VTT-1000, b) Toll OBU

VI. MONITORING CENTRE

The monitoring centre serves as a system for collecting, monitoring and evaluating the data about vehicles and load status. The system receives and stores all data sent from the vehicles, and if there is a chance of a bidirectional communication, it sends the data to the on-board unit. It also archives all data, and creates the on-demand statistics.

The integrated map system shows the current position of the monitored vehicles and the status of the load. There are interfaces to other systems, and they can read the data for their specific needs.

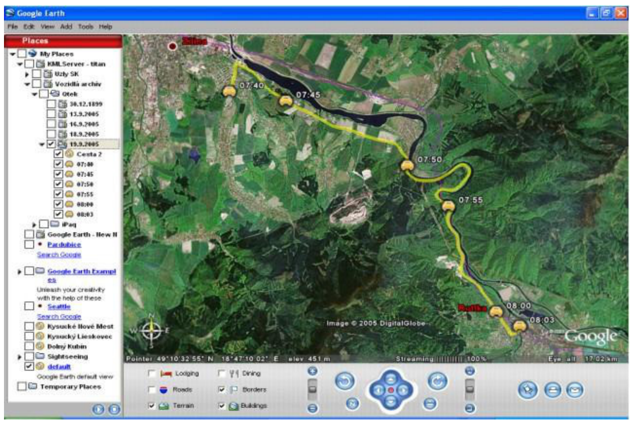

Fig. 6 Route display in Google Earth application

We can summarize all of the basic requirements on the monitoring centre as follow:

- Collecting the data about the start and end of transportation
- Collecting the data about the current vehicle position

- Collecting the data about the vehicle and load status
- Data archiving for later analysis
- Display of the current vehicle position
- Display of the current vehicle and load status
- Display alerts about overrun values
- Display of the archived rides
- Display of statistical information

The monitoring centre should consist of maps, presentation module, application server and data-storage system.

The presentation module can be realised as:

- Standard application (Google Earth/Maps, ESRI, etc.) (Fig. 6) – Pros: easy to use and up-date the maps and application, Cons: simple API for further development – low ability of customization.
- Own application with maps (Ortophoto maps, digital maps, etc.) – Pros: Rich application without the constraints of API, Cons: complicated development and up-dating.

The application server should contain services for the presentation modules, a communication system with OBU and a communication system with an application for route planning.

The architecture of the application server and communication system according [13] can be:

- Distributed system without centralized controlling – suitable for smaller systems with high security.
- Distributed system based on events – suitable for big systems with large numbers of vehicles.
- Distributed system of type MESH – suitable for the interconnection of national system with a complex monitoring system.

All data should be saved in the database. For this kind of system, the best choice for the database system can be:

- Relational database – if the system should also be used for analyzing and data-mining the archived data.
- Distributed database – usually relational [7], [8]
- Object-oriented database – in case the system contains algorithms that work with the data in a form of objects, and the system is expected to be highly loaded (to avoid ORM-object relation mapping) [12].

VII. Conclusion

In the article we have tried to present a proposal for a comprehensive system for monitoring the transportation of oversized and dangerous goods. We have described the requirements for sensor networks, on-board unit and monitoring centre.

We also tried to suggest possible alternatives to the implementation of the subsystems, and point out their advantages and disadvantages.

The system is designed to make maximum use of existing technologies and units. The article has the ambition to bring the methodology of how to design systems of a similar nature.

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