Telematics System dedicated for Provisioning of On-Line Information about Predicted Occupancy of Highway Parking Areas

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ABSTRACT

More and more often occurs problem with the lack of parking places for trucks over 3.5t, which is related to the increase in the intensity of freight transport. Consequently this can lead to very dangerous situations with parking of trucks because drivers do not have information about the occupancy of the nearest parking. The paper presents an intelligent transportation system, which provides information about the predicted occupancy of parking lots to truck drivers. Providing this information leads to optimizing the use of existing parking areas on the highway network and also makes it easier for drivers to deciding on a suitable location for parking, which ultimately contributes to the fluency and safety of traffic.

Keywords: Electronic Toll, ITS, Parking, Prediction, Telematics.

1. INTRODUCTION

With the lack of parking spaces for heavy goods vehicles face the entire road network in the Czech Republic. The worst situation is on highways, where we often encounter dangerous situations parked truck right onto the ramp to gas stations or their exits. This situation is similar throughout Europe; the importance of this issue is demonstrated by the Action Plan for the Deployment of Intelligent Transport Systems in Europe, which contains measures "Development of appropriate measures including best practice guidelines on secure parking places for trucks and commercial vehicles and instructions for parking and reservation telematics systems". The high traffic intensity raises a number of transportation problems related to the lack of parking spaces, and therefore is accurate and accessible information about available parking spots very valuable in everyday use and also very important for the planning of efficient and safe transport.
The project, which partial result describes this article, is focused on creating a telematics system that will be based on the input data of the toll system to predict the occupancy of individual parking spaces to provide information to optimize the usage of existing parking areas on the highway network. The outputs of the model will be forwarded to appropriate channels for drivers who thereby greatly facilitate decisions about the appropriate place for parking and thus contribute to the overall fluency and traffic safety as a whole.

Reasons for system of increasing the usage of parking facilities for trucks on the highway network in the Czech Republic using prediction models are especially:

- increasing the intensity of freight transport on the highway network in the Czech Republic, for the reason that road freight transport is still cheaper than the railway, resulting in the observed lack of capacity
- 30-40% of road accidents are caused by driver fatigue, due to the extending of driving and ignoring the mandatory rest breaks
- priorities of the EU, increasing parking capacity on highways handles projects as CONNECT, Easyway, Intelligent truck parking, etc.
- inefficient use of parking lots
- uneven distribution of load of parking lots
- driving round highways and finding a parking space, which means the formation of undesirable emissions, congestion on local roads, noise and hazards caused by parking in places that are not intended to (emergency stopping lanes, ramps, etc.)
- lack of information on capacity and current vacancies in the parking areas
- determining the need for construction of new parking lots
- increased demand for parking due to the Just-in-Time
- reduction of investment in transport infrastructure construction, which increases the demand for optimizing the use of existing infrastructure

The expected benefits of implementing an information system to increase parking utilization capacity are divided by system participants, because for each group are different.
The Benefits of implementing the system from the perspective of truck drivers

- knowledge of the current traffic situation before entering to the parking lot
- reduce the risk of stressful situations for drivers due to pressure on compliance with statutory breaks and thus enhance the security (reducing the risk of accidents due to fatigue during driving overtime)
- increased comfort while driving
- higher probability of finding a free parking place - eliminates the need for finding alternative places
- more effective route planning associated with savings of distance traveled and time

The Benefits of implementing the system from the perspective of car park operators

- increase the satisfaction and comfort of drivers
- optimized parking and better use of existing parking capacity
- elimination of the problem of exceeding the capacity of parking areas
- an increase in revenues from products and services offered on the parking lots due to optimized parking
- optimization planning - supplying, staffing shifts, etc.

The Benefits of implementing the system from the perspective of the State

- reduce the externalities arising from traffic accidents, ie. disposal costs, damages, costs for emergency operations, the cost of treating injuries, reducing state revenues due to the loss of the taxpayer (in the case of death)
- reduce the externalities arising due to leaving the highway network (emissions, noise, damage to roads)
- financial savings for the construction and maintenance of highway infrastructure, which arise due to fewer required newly built parking lots and also because there is no need to look for alternative parking outside the toll network
- achieving the objectives of the European "TEN-T" program by using telematics systems
- use of the toll system as a source of current traffic data (composition and characteristics of traffic flow) for the prediction model
- increase traffic safety
- reduce accidents
- increase driver satisfaction
- increase the usage of parking areas, and thus the potential increase in tax revenues (the driver will use more parking at us and there will be motivated to refuel, buy goods and services)

The Benefits of implementing the system from the perspective of roads administrator

- effective planning of maintenance of highways infrastructure
- effective planning the construction of parking areas on the highway network
- reduction of required maintenance and the associated costs on roads close to the highway network
- reducing the number of traffic restrictions associated with the construction and maintenance of new parking areas

2. ARCHITECTURE OF THE INTELLIGENT TRANSPORT SYSTEM FOR PREDICTING OCCUPANCY

Architecture of the telematics system for predicting the occupancy of parking spaces on highways and expressways in the Czech Republic connects the database, prediction model and distribution channels for the providing information to end users.

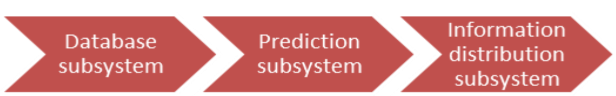

Fig. 1 Architecture of the system for predicting occupancy

Architecture of the telematics system consists of three basic subsystems:

- database subsystem - data primarily consists of transactional data from electronic toll collection system, which are provided on-line (or at intervals close to on-line transmission) to prediction subsystem;
- prediction subsystem – the core of this subsystem consists of a predictive model that calculates by defined algorithms the probable occupancy of parking spaces on the highway network based on the data
- Information distribution subsystem – this subsystem uses the results of prediction model that processes and distributes intelligible information to end users.

Database Subsystem
Subsystem of database combines data from data sources, both historical data and current data. This data are stored in the operational database in which the data are preprocessed so those with them are able to run a prediction model to predict the occupancy of parking lots on the highway network in the Czech Republic. Especially it is the calculation of driving time each detected vehicle and calculates intensity in each toll section.
Data base draws data from the following sources.

- the primary source are transactional data from electronic toll collection system, namely: a) historical data, which are recorded to operational database one-off; b) actual data, which are sent to the production database on-line c) telematics data (speed and composition of traffic flow), which are sent to the production database in batches;
- secondary sources are a) data from detection sensors located at the entrance and exit of the selected parking lot, used to calibrate the prediction model, these data are sent to the production database on-line as an individual transactions and batch for a defined time intervals, b) data from manual vehicle census at selected parking lots serving the calibration and validation of the prediction model; c) data from automatic vehicle census at selected parking lots from mobile surveillance vehicle of toll collection system; d) other traffic data, e.g. data from traffic sensors on highways etc.

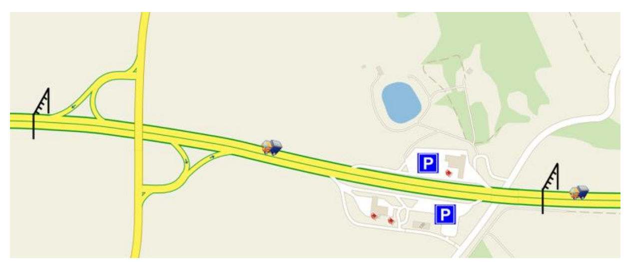

Fig. 2 Simplified diagram of the highway network with the location of parking areas, toll gates, entrance and exit ramps

Prediction Subsystem
The prediction subsystem is the core of the entire system. It is connected to the subsystem of database over which implements the defined prediction algorithms.
The predictions are calculated in systems derived on the basis of fully formalized statistical methodology. At the core of the whole approach is the fact that value which is needed to predict, i.e. the number of free parking spaces, is directly unobservable. The prediction of this value should be constructed on the basis of correct algorithms derived from models for time series of observable variables. Basically, it is an estimate of the status-type model, which we deal with in a few steps. First, we construct the proxy variable for the latent number of vehicles parked on the parking lot at a time from the observed data on the passage of vehicles through toll gates. For

the proxy variable we build a statistical model completely describing its dynamic and probabilistic behavior. Unknown parameters of the model of a particular class we estimate from the historical data from a passage through the toll gates. After more statistically demanding estimate the unknown parameters of the data (identification), the model has been fixed and used for routine, already simply available, predictions with parameters fixed at estimated values. With extended operation will be appropriate in the context of the entire system service (e.g. annually) to "re-learn" model, i.e. to re-estimate the parameters, or modify (or choose an entirely new) class model. According to our previous tests the stability of the estimated parameters using several months of data is significant and re-learning is not a critical requirement. From the estimated model we derive using the theory of Markov chains (Resnick, 1992 Klebaner, 2005) method for calculating the prediction of the number of vehicles parked on the parking lot for a set of necessary horizons. For fast and efficient implementation of predictive calculations in real traffic, we use a method based on Monte Carlo simulations. Prediction of the number of free parking spaces is obtained as the difference between extended parking capacity and prediction of parked vehicles, and for each of the required horizons. Prediction of the number of free parking spaces is using the subsystem distribution information transmitted to end users. Solution of the prediction system has been described in [1], [2] and [3].

The prediction subsystem is implemented in the first version of the telematics system as a script in the statistical software "R". This script implements algorithms for the minimum and maximum prediction horizons from 5 minutes to 150 minutes with a time step of 5 minutes.

Prediction process is performed at regular intervals and the results of the process are recorded in the table in the operational database where they are available to end users through distribution channels.

For each parking lot is available the information about the GPS position, the maximum capacity, detail of gas station or other information. This information is static and changes only when the layout changes such as reconstruction. For each parking lot are regularly at 10 minute intervals calculated prediction of the state of occupancy in several prediction horizon. In the functional sample we predict for the four parking lots on the highway D5. The prediction subsystem additionally maintains the entire history of the calculations of predicted occupancy for the all monitored parking lots. Historical data are another source of verification and validation of the prediction model.

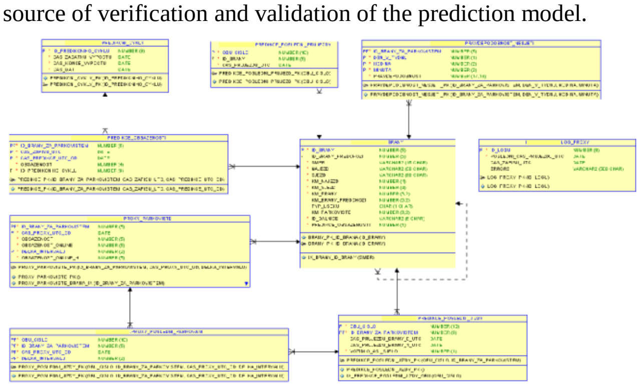

Fig. 3 Relational schema of the production database

Table of occupancy prediction for the parking lot contains the following parameters:

- ID of parking lot
- date and time of update
- prediction horizons – from a computational reasons the prediction is calculated for several horizons (windows), not continuously for each time point. The maximum prediction horizon is 150 minutes. Horizons are divided in 5 minutes and counting since the last update time,
- predicted occupancy status – for each forecast horizon is on the basis of the developed model calculated the predicted occupancy. Aggregate channel then assign a specified color according to the following table (Tab.1) to predicted occupancy.

Occupancy [%]	color
<0,60)	green
<60,80)	yellow
<80,+∞)	red

Tab. 1 Occupancy intervals and their color for drivers

The last interval is really up to infinity (better expressed greater than 100%) because the drivers are able to park in parking lots more vehicles than there are parking (marked) spaces.

Information Distribution Subsystem

Subsystem of distribution of information is from the end user perspective crucial component of the entire system. Distribution channels are the only interface between the telematics system and end-user, i.e. truck drivers. Selecting the appropriate information channel therefore fundamentally affects the efficiency of the entire system and the acceptability of the system by the drivers. Nowadays there are more and more options to display and distribute information.

For intelligent parking system is necessary to resolve the distribution of information channels that are suitable for this type of system. Distribution channel must be selected properly to be effective for distributing information and also for end users, truck drivers, acceptable.

3. PROTOTYPE OF A MOBILE APPLICATION

The developed prototype of mobile application communicates with the communication layer of prediction system and displays the acquired prediction of the parking lots in the driving direction, as shown in the following figure.

The application is adjusted so that it can be tested without the presence on the D5 highway, thanks to manually input the current position on the highway D5 and average vehicle speeds, which are input parameters for prediction of occupancy parking lots along the route.

Fig. 4 An example of the mobile application in the vehicle

Data exchange between applications and production database is based on XML document.

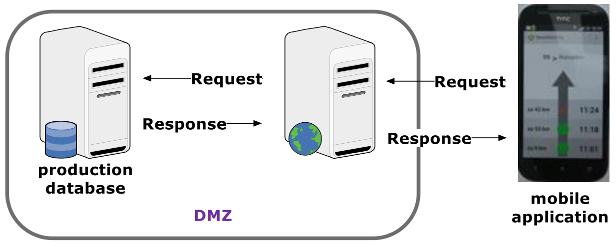

Fig. 5 An example of the request and response of mobile application

For example request for list of highways:

```
<?xml version="1.0" encoding="UTF-8"?>
<S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
  <S:Header/>
  <S:Body>
   <Request method="getHighwayList"/>
  </S:Body>
</S:Envelope>
```

Response with list of highways:

```
<?xml version="1.0" encoding="UTF-8"?>
<S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
  <S:Header/>
  <S:Body>
   <Response method="getHighwayList">
    <HighwayList>
      < Highway>
        < HighwayName>D5</ HighwayName>
        <HighwayFrom>Praha</HighwayFrom>
        <HighwayTo>Rozvadov</HighwayTo>
        <HighwayLength>151</HighwayLength>
      </Highway>
    </HighwayList>
   </Response>
  </S:Body>
</S:Envelope>
```

4. KEY PERFORMANCE INDICATORS

System key performance indicators dedicated to quantify occupancy prediction can be alienated into two categories – the operational and the functional category.

The operational performance indicators indicate the characteristics on the operation of the system. The functional performance indicators indicate characteristics of system functions provisioning with regard to the purpose of predicting occupancy.

The operating category includes the following indicators of performance:

- failure time
- reliability of operation
- failure rate (instability)
- activation time of availability

The functional category includes the following indicators of performance:

- rate of erroneous prediction of occupancy
- duration of response
- stability of serviceability
- loss rates
- safety

Most of those indicators have been described in [4], however, for this specific application for the prediction of occupancy of parking is important to quantify and define quality of prediction. For this purpose, it has been defined key performance indicators "Rate of Erroneous Prediction of Occupancy".

Rate of Erroneous Prediction of Occupancy

The rate of erroneous prediction of occupancy reflects the ability of telematics system to don't serve wrong prediction of occupancy to a maximum allowable limit that can be defined as the probability

$$P\left(\left(r_{e,\langle 0,T\rangle} - R_{\langle 0,T\rangle}\right) \leq \varepsilon_e\right) > \gamma_e \quad , \qquad (1)$$

that where the difference between the number of wrong prediction of occupancy $r_{e,\langle 0,T\rangle}$ and tolerated maximum number of wrong prediction of occupancy $R_{\langle 0,T\rangle}$ will do not exceed the value ε_e on the probability level γ_e during within a time interval $\langle 0,T\rangle$.

5. PILOT MEASUREMENTS

We operated system for several months and we have done extended number of measurements/observations. On following figure, you can see the estimated predictions for one specific parking place (on 59th km of highway D5) for 36 hours and also the real number of parked cars.

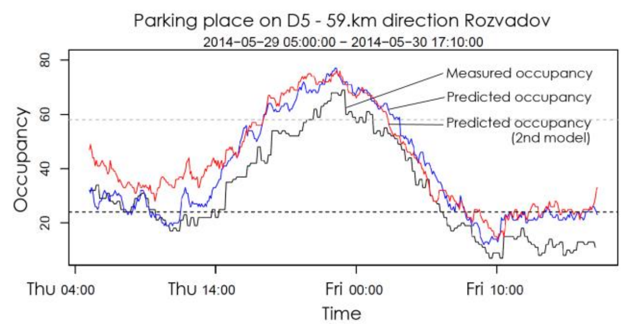

Fig. 6 Graph of prediction of occupancy and manual measured occupancy

Extended number of the real occupancy measurements covers practically all relevant parking areas. Obtained data have been processed to enable the final model calibration. Each parking area has got a specific conditions and it is necessary to calibrate each parking area separately. Additionally, in each parking area there is number of places not officially accepted and marked as parking lot, however, frequently used by trucks drivers. Trucks drivers quite frequently illegally use also dedicated for busses parking lots, or two or more personal car parking lots are occupied by trucks. Trucks use to be parked in the area of the gas stations, as well.

Presented model based on tall data does not have ability do separate number of regular and irregular parked trucks, but the only all trucks being in the area. This is one of the reasons why we describe relevant parking availability based on "traffic light" type of information with traditional choice of three colors. Relevant decision processes on lights colors can effectively reflect all these mentioned both legal as well as illegal irregularities.

So far the results of processed test are promising and after the next step of one or more calibration steps there is no doubt that presented model will be applicable for the practical application it was designed for.

6. CONCLUSIONS

The proposed telematics system, designed to provide information for truck drivers about the predicted occupancy for the nearest parking, was presented. For the verification of the quality of the prediction model data obtained by manual measurement in the parking lots were exclusively used. All the other tested methods like Doppler based or DSRC based mobile units have not been acceptable due to their insufficient for this application system performance. The quality of the prediction has been evaluated based on in paper defined performance indicator "Rate of Erroneous Prediction of Occupancy". The present phase of the project is being focused on the final validation and verification of the prediction model.

7. ACKNOWLEDGMENT

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