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Influence of Intelligent Transportation Systems on reduction of the environmental negative impact of urban freight transport based on Szczecin example

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Abstract

The need for telematics solutions to support goods transport and distribution in cities is mainly due to the complexity of the processes taking place in urban transport systems and the importance of optimisation of transport operations via ensuring adequate availability of linear and point infrastructure, while reducing the adverse impacts of the transport system on the environment. This paper is focused on an example solution implemented in Szczecin. The basis of this solution is the utilization of mobile devices to support traffic management system. An analysis of the influence of system on the reducing the negative impacts of urban freight transport on the city environment is presented.

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Keywords: city logistics; urban freight transport; Intelligent Transportation Systems; traffic management; transport telematics; environmental impact;

1. Introduction

The ever growing demand for transport results in more and more attention paid to systems that enable efficient management of traffic flows and of the overall functioning of the transportation system. Due to its complexity, city administrators consider using Intelligent Transportation Systems (ITS) solutions as the basis for designing intelligent...
transport networks. The significance of state-of-the-art technologies has been emphasised in one of the classical definitions of the city logistics, proposed by E. Taniguchi, R. G. Thompson and T. Yamada, stating that "city logistics is the process for totally optimising the logistics and transport activities by private companies with the support of advanced information systems in urban areas considering the traffic environment, its congestion, safety and energy savings within the framework of market economy" (Taniguchi, Thompson, Yamada 2001).

The objective of applying telematics in city logistics is optimising the access to logistic nodes and linear infrastructure, leading to reduction of the adverse impacts of human activity on the natural environment. Telematics systems are capable of supporting all areas of transport, vehicles, infrastructure, transport organisation and management, and any intermediary areas between them. Therefore, they are considerably effective and constitute an important element that functionally integrates individual subsystems. The effects of telematics solutions applied in urban freight transport include (Taniguchi et al. 2001):

- reducing freight distribution costs
- increasing productivity of local delivery vehicles
- increasing reliability of commercial vehicle operations
- increasing safety
- increasing the capacity of urban freight systems (without providing additional traffic infrastructure).

The need for telematics solutions to support goods transport and distribution in cities is mainly due to, on the one hand, the complexity of the processes taking place in urban transport systems, and on the other hand, the interweaving and often conflicting expectations of the particular groups of road users and other stakeholders of urban freight transport (city administrators, inhabitants, entrepreneurs and shippers) Here, the main objective is optimising transport operations via ensuring adequate availability of linear and point infrastructure, while reducing the adverse impacts of the transport system on the environment.

Application of such systems has a direct impact on the functioning of the transport system and its effect on the urban environment. Due to effective transport management and traffic flows control it is possible to reduce congestion and shorten the completion times of transport tasks. This in turn results in decreased consumption of petrol and consequently less pollution. Since a vast majority of urban freight transport is done by road vehicles, this translates directly into developing an energy-saving, more environmentally friendly system.

2. Telematics and ITS in city logistics

Intelligent Transportation Systems (ITS) are systems characterised by complex architectures, comprising many functionalities and integrating different kinds of technologies and technical solutions. These especially offer the potential to improve safety, to reduce the congestion as well as to increase the economical productivity by utilization of many services, like travel and traffic management, public transportation management, electronic payment, commercial vehicles operations, emergency management, advanced vehicle safety systems, information management, maintenance and construction management (Karoń, Mikulski 2011). A significant feature of Intelligent Transportation Systems is their modular structure. This makes it possible to implement individual elements in stages, and to concentrate on the ones that are the most vital in given conditions. Within each system it is possible to distinguish individual functional subsystems (usually corresponding to the modules referred to above), directly responsible for carrying out the specified tasks. Efficient functioning of the whole system depends not only on the effectiveness in the area of direct impacts, but also on the cooperation between the subsystems. Thus, Intelligent Transportation Systems are by definition integrated structured systems. However, the cooperation should not be limited only to the local impacts.

As for the range of impacts, Intelligent Transport Systems may be broken down into three major categories:

- local – operating within a relatively small geographical area, most often a city,
- regional – operating within a subregion (in Poland: gmina or poviat), or a region (in Poland a region should be tantamount to a province area), and
- national – covering the whole country.
The key to their efficient functioning is the integration of the individual levels, in accordance with the hierarchy: regional systems integrate with local ones, while the national system connects the individual regional systems to make one, integrated structure.

The application of Intelligent Transport Systems offers numerous benefits, the most important of them include (Oskarbski, Jamroz, Litwin 2006):

- increasing the capacity of the street network by 20 – 25%,
- improving road traffic safety (decreasing the number of accidents by 40 – 80%),
- reducing travel times and decreasing energy consumption (by 45 – 70%),
- improving the quality of the natural environment (reducing pollutants emissions by 30 – 50%),
- improving the travel comfort and traffic conditions for drivers, collective transport users and pedestrians,
- reducing the costs of road fleet management,
- reducing the costs of road surface repair and maintenance, and
- increasing the economic benefits in the region.

Telematics may support many urban functional areas, and its application has to be considered in various aspects. Urban telematics has been defined as, “…a concise specification of various applications of computer and telecommunication techniques – in order to streamline the urban, i.e. in principle local information systems, municipal services, transport or parking systems (see transport telematics), and also the systems that support the functioning of self-governments or implementing elements of electronic democracy …” (Wydro 2005). Its basic aim is to support the effective management of an urban transport system, using information management. Its improves the quality of the city logistics system via increasing the possibility of controlling the traffic flows in the whole system. Telematics systems applied to support the functioning of the urban freight transport may be broken down into two major categories:

- solutions where telematics systems constitute the basis of their functioning (e.g. freight traffic routing information, intelligent freight traffic routing and integrated logistics tools), and
- solutions where telematics systems constitute a supporting element which improves but are not conditions of their functioning.

Among the solutions that are directly dependent on applying telematics systems, the key ones include (Allen, Thorne and Browne, 2007):

- freight transport management systems (e.g. fleet management systems and tracking and tracing systems):
  - computerised Vehicle Routing and Scheduling: efficient planning by vehicle operators to plan vehicle loads and journeys,
  - navigation systems and traffic control: used to provide specific routing guidance and real-time information about vehicle location, traffic incidents and changes in customers’ requirements,
  - in-Cab Communication systems: these allow the driver to communicate with their company planners and also with customers by voice or computer,
  - slot booking systems: used to co-ordinate and plan goods vehicle arrivals at major sites generating large flows;
- traffic management systems (e.g. access control systems, traffic management and information systems):
  - Urban Traffic Management and Control (UTMC) systems:
    ▪ Urban Traffic Control (UTC) systems to co-ordinate traffic signal timings,
    ▪ Variable message signs (VMS) to communicate information to drivers via roadside signs,
    ▪ Car park occupancy sensors,
    ▪ Journey-time measurement systems via automatic number-plate recognition technology;
  - the provision of mapping or route guidance, and
  - automated vehicle access controls.
3. Influence of ITS on the reduction of pollution based on the example of Szczecin

3.1. Szczecin specificity (based on Strategy of Szczecin development 2025)

Szczecin is the capital city of the West Pomeranian Voivodeship in Poland and is situated on the Oder River close to the Baltic Sea coast. It is the seventh-largest city in Poland with a population of more than 400,000 and is one of the major Polish seaports. It is an eastern part of a historically formed region of Forepomerania (Przedpomorze). The location of the city is defined as strategic one close to the land and sea borders of the European Union, a distance of:

- about 12 km from the border crossing in Kolbaskowo,
- about 7 km from the border crossing in Lubieszyn,
- 65 km from the coastline of the Baltic Sea,
- 130 km from Berlin, 274 km from Copenhagen, 454 km from Stockholm, 507 km from Prague, and 516 km from Warsaw.

The city occupies the area of approximately 300 km², of which 41.8% are green areas, and 23.8% are areas under water (Figure 1). The largest water reservoir is the Dąbie Lake, the only lake in Poland where sea yachts can sail and moor; its area is 65 km². Szczecin is located in an arc around the port and waterside areas. The historic city centre has developed a series of lower density residential areas in recent years, around denser inner districts of apartment blocks.

![Figure 1. Szczecin structure. Source: www.zupriz.ps.pl](image)

Szczecin is typical of many Eastern European cities in the post-communist period. After 1989, there was a very rapid increase in car ownership, and this growth continued after 2000. The growth in car ownership was supplanted onto an extensive public transport network of electric trams and diesel powered bus lines. Szczecin has about 784 km of roads, and private cars are now the dominant mode of transport. In 2006, there were 425 vehicles per 1000 inhabitants. By 2009 this number grew to 568 vehicles per 1000 inhabitants, a 34% increase in 4 years. Szczecin has
extensive public transport networks: 96 kilometres of tram lines (47 routes), and 588 kilometres of bus lines (287 routes).

The most important freight hub in Szczecin is the Szczecin Seaport, which is managed by the Szczecin and Świnoujście Seaports Authority. Other hubs are located in the Szczecin harbour. Among them there is Zachodniopomorskie Centrum Logistyczne (West Pomeranian Logistic Centre) which covers an area of 20 ha, and is connected to road and rail infrastructure. There are also freight hubs for containers, dry freight and granite blocks. Together both ports constitute one of the largest port complexes in the Baltic Sea, which is situated on the shortest path connecting Scandinavia with the central and southern Europe. They also lie on the shortest seaway connecting Baltic Finland, Russia, and the Baltic States with Germany and Western Europe. The port in Świnoujście is situated directly on the Baltic Sea shore, whereas the port in Szczecin is located about 65 km inland.

3.2. Transportation system in Szczecin (based on Strategy of Szczecin development 2025)

Szczecin is an important transport junction, where all kinds of transport modes are utilized. Due to the city’s geographical location and functioning of maritime industry, inland water transport is a very important part of the Szczecin transportation system. Also, the city has good connections with other parts of Poland as well as Berlin, Prague, and Budapest by rail transport. The regional airport in Goleniów (about 50 km away from the centre of Szczecin) serves the city and the region as well. Road transport is well developed. Major national roads include A-6 motorway from Berlin and further eastward to Gdańsk. The other basic connection of the city with other areas is provided by the national roads to the:

- South, road No. 3 (Zielona Góra, Lubawa, Prague) and road No. 118 (Kostrzyn, Slubice),
- East, road No. 10 (Stargard Szczeciński, Bydgoszcz),
- North, road No. 115 (Police) and roads Nos. 3 and 6 (Świnoujście and Gdańsk).

The main problems in Szczecin concern environmental pollution that is caused by freight transport and individual cars. The most congested roads are the ones leading to the harbour, which are Gdańska Street, Energetyków Street, the bridge over the Parnica River, as well as the roads to the other parts of Poland (to Lower Silesia, Poznań and Warsaw) and Europe (A6 and E65). The city’s existing street network does not meet the needs of the growing traffic, or the operational requirements of the public transport system. There are serious traffic interruptions in a substantial part of the street network, while the area within which these disturbances occur is growing continually. The absence of a ring-road system means that it is impossible to eliminate transit traffic. It is also impossible to limit goods transportation or the transportation of hazardous loads through the intensively developed areas of the city. The city’s spatial structure, including the size of the area it covers, makes long journeys unavoidable causing intense use of the road system between the left-bank and right-bank districts of Szczecin. The capacity of the main transport axis between the two parts of the city is already intensely exploited. There is no efficient alternative connection in this direction. Autostrada Poznańska St., situated on the perimeter of the city, supplements the road system in spite of its steadily increasing traffic load and the distance between the main destinations and journey starting points as well as the low capacities of the streets linked with it (Batalionów Chłopskich St., Granitowa St.).

Due to the radial street layout it is unavoidable that practically all connections between districts have to pass through the central areas of the city. The Central District street layout, which is not yet a fully-integrated system, does not allow any existing street sections to be used to divert transit traffic to its perimeter. It also restricts the possibilities of developing the public transport system, especially the tram system.

The existing street network in the Prawobrzeże District (Pszenna, Walecznych, Dąbeka, Zoologiczna, Niedźwiedzia, Łubinowa, Handlowa Sts.) is not adapted to serve the large complex of housing estates constructed there. One particularly troublesome obstacle to transport (with regard to the lack of flyovers) is the railway line dividing Dąbie from the southern part of the district. What is needed is a supporting east-west connection in the northern part of the district, which would allow the Dąbie district to be freed from pollution caused by heavy vehicles and freight transport traffic.
The poorly developed street system is an obstacle to the development of the northern part of the city. The existing system with its low capacity and in many places poor condition (Krasieńskiego, Duńska, Warcisława and Przyjaciół Żołnierza Sts.) does not guarantee a service corresponding to the level of existing and planned investment projects. The inadequacy of the street system restricts the possibilities of developing the attractive land along the Oder River, and also the land in the vicinity of Lubczyńska St., in the Prawobrzeże District. The present street layout does not ensure an efficient connection of the port with the external road system. Access to the port invariably requires detours through the busiest sections of the street system.

Also, the technical condition of bridges and flyovers is clearly unsatisfactory, and threatens the operation of the basic street system.

Due to the specificity of the Westpomeranian Region which is connected with maritime economy (merchant and fishing ports) and which also features tourist and health resorts, adequately effective organization of goods deliveries becomes a fundamental problem.

Summarizing, it’s possible to indicate the following other problems caused by urban goods transport in Szczecin and West Pomeranian Voivodeship:

- planning and coordination problems,
- lack of integrated transport systems,
- less potential to link with broader policy and regulatory initiatives,
- lack of specific/special transport systems and vehicles utilization,
- lack of opportunity for carrying out value-added activities,
- lack of regulation of relationship between deliverers and suppliers,
- complicated structure of road administration,
- lack of data on deliveries and routes and proper surveys concerning the source of pollution,
- negative environmental and social effects of transport operations,
- worsening inventory control, product availability and customer service,
- operational complexity resulting from the differing storage and handling requirements of a wide range of products,
- worsening control and visibility of the supply chain,
- worsening use of resources at delivery locations, and
- worsening utilization of cargo area of trucks.

Therefore, the main targets of the city policies incorporate environmental protection, improved road safety and security; and improved quality of public transport. The city adopted general guideline principles and priorities on transport policy from 2006, and the public transport development plan up to 2015 was passed in 2010, recognising the importance of the environment, safety and security for future mobility in the city.

3.3. ITS in Szczecin (based on internal documents of Szczecin city council)

The major goal of implementing a traffic management system in Szczecin was to increase the fluidity of the traffic flow on the roads leading to the city centre, being part of the existing transport corridors along Trasa Gdańska, by supplying road users with real time information on the current and forecast congestion as well as information on traffic incidents and alternative routes, as a result of which it will be possible to shorten the travel time along Trasa Gdańska.

Under this project, elements of the ITS were designed, supplied, installed, integrated and activated, thus creating a system that makes it possible to actively manage the traffic in the city within the implementation area, with an impact on the Szczecin Metropolitan Area.

The system consists of application and execution elements. The application element comprises the Urban Management Transportation System (UMTS) along with the individual subsystems designed for monitoring and active management of the road traffic. The system is built on the basis of the client-server technology. In the Traffic Control Centre, the system operators define, implement and configure the parameters which, using specific systemic algorithms, following the survey data processing, are used for inter alia the purposes of informing in real time the
drivers and traffic participants on the traffic conditions, including any congestion, mean travel times for individual road sections, and the weather conditions. The data is distributed both to the system operators in the Traffic Control Centre and the mobile information portal available on the internet, as well as to the execution part, i.e. the devices located within the right-of-way which can be used by traffic participants when driving.

Figure 2. Urban Management Transportation System. Source: szr.szczecin.pl/utms/index

Also, the system covers defined traffic incidents and other situations that may have an impact on the road traffic, such as special events. The system is equipped with traffic prediction functions based on a traffic model, which makes it possible to generate forecasts for specified time intervals, and which are useful in route planning. Operators have at their disposal specialised engineering and simulation tools that support the traffic control functions. The system features fully adaptive traffic control algorithms which make it possible to increase the traffic flow at selected intersections in situations when drivers will be using alternative routes.

The execution element (located in the right-of-way) comprises variable message boards which enable the display of complex contents, road signs and diagrams – five locations, and variable message signs (VMS) intended for displaying road signs and short messages – 10 locations. For the purposes of data collection, the system uses various kinds of sensors, including: video detection to survey and evaluate the traffic conditions over a specified road section with a possibility to specify travel times, laser detection for assessing the road surface condition, optic detection for adaptive traffic control. Video monitoring of traffic conditions is done by high-speed cameras. Data is processed by steering and controlling devices. All data is transmitted to the system server room located in the Traffic Control Centre, and stored in the form of a data centre. For the purposes of data transmission, a mixed communication system has been established, based on wired communication means – fibre optic cables, and GPS/UMTS wireless communication. The system is supplied with electric power from the municipal power network, while the data centre is equipped with a back-up power supply from the Szczecin Municipal Office’s UPS/generator.

The Traffic Management System for Szczecin consists of a number of independent functional elements interconnected by means of a TCP/IP network or GSM/GPRS communication to the Monitoring and Control Centre located in the building of the Szczecin Municipal Office. The system is composed of:

- The Subsystem of Information for Travellers – ensures the possibility to transmit to road traffic participants, in real time, variable messages in the form of text and graphics,
- The Subsystem of Traffic Detection – provides information on the traffic conditions in the controlled area, e.g. the number of travelling vehicles, estimated length of the queue at the controlled intersections and the travel time in the area controlled by the system,
- The Subsystem of Mobile Information – software being an integral part of the Subsystem of Information for Travellers within the functional scope,
- The Subsystem of Communication – it combines all the major elements of the Traffic Management System, and
- The Traffic Control Centre.

The architecture implemented in each subsystem is dispersed, and its elements are installed in the streets and intersections and, at a master level, in the Control Centre (Figure 3). In the IT aspect, the system architecture consists of:

- Travel Time Server – that maintains all the collected, processed and saved data on travel time measurements,
- Variable Message Signs (VMS) Server – that serves all the collected, processed and saved data regarding transmission of the information to drivers and receiving the status data from VMSs (i.e. temperature, activity status),
- Traffic Measurement Server – that maintains all the collected, processed and saved data on traffic measurements,
- Back-up Server – that is a back-up server which may process all the necessary data and replace the Travel Time Server, the Variable Message Signs Server or the Traffic Measurement Server in real time,
- data memory – the matrix which saves all the data entering the system and processed by the system,
- operators’ work stations,
- protected WWW Internet Portal for Travellers – a firewall protected website for travellers,
- devices installed in the right-of-way (traffic measurement facilities, ANPR cameras, video detection cameras and variable message signs).

Figure 3. The structure of Szczecin ITS. Source: own work based on internal documents of Szczecin city council.
The Internet Portal consists of key modules that are used in the majority of the system functionalities management and control, external interfaces and independent modules for the independently used functions. The portal core consists of the following modules:

- **Common Graphical User Interface (CGUI)** which displays data regarding the system using GIS data made available by the GIS module,
- **Data collection module** which collects data from the field facilities and stores them for processing later,
- **Road network module** – it enables dynamic changes in the road network,
- **Traffic forecasting module** which uses the data collected by the data collection module and the road network module online in order to present the correct forecast for the road traffic,
- **CCTV module** which enables real-time display of video images from specified devices in the Common Graphical User Interface (CGUI), and also enables remote camera control,
- **VMS module** makes it possible to manage Variable Message Signs installed in the system, and
- **The subsystem of external interfaces consists of three major modules:**
  - **WWW internet interface** – the interface used by internet users of the system;
  - **DATEX interface** – the interface for communicating data connected with road traffic to other systems;
  - **RDS/TMC** – the interface for communicating data connected with road traffic to other systems.

The system also includes several independent modules that are used in the whole software system:

- **GIS module** – responsible for the management of geographical data as well as displaying data on request, and
- **Video recording and storing module** – responsible for recording and storing video material from cameras.

The software is based on the open architecture principle, applying a free software and generally available products. The system is built in J2EE technology based on ESB (Enterprise Service Bus) free software implementation. In accordance with the general features of the system, all the modules are integrated with ESB, which allows for any future extensions.

3.4. The solution to support the functioning of the Traffic Management System in Szczecin

The major objective of this measure was to balance the traffic flow at the direct connection of Szczecin centre with the right-hand part of the city as well as to decrease the number of cars travelling through them by rerouting traffic to the roads on the border of the city. The most used road to the city centre goes over two bridges, which are chronically congested during peak hours. Also, this is the shortest path to reach the destinations located in the west and northwest from the city, including the town of Police with a major chemical production plant (Zakłady Chemiczne “POLICE” SA.). Starting in November 2012, a traffic monitoring system and large displays on the access roads to the bridges were installed. Now drivers on either side of the bridges are informed, as they approach the bridges, which bridge has less traffic congestion. At the beginning, the information on displays was not clear and hard to read. According to the opinions from the drivers it wasn’t useful and they didn’t make use of the information. The discussion during the round table meetings helped to optimize the efficiency of the data displayed on the VMS. Now the information on the VMS is much simpler and driver-friendly (Figure 4).

The major idea of the system’s improvement was the development of the mobile application presented below. As the VMSs are placed close to the bridges, most drivers can’t reroute their journeys in case of severe congestion. The mobile application, which displays the information from the VMS, helps drivers make the decision much earlier, when it’s still possible to choose a different route to the western and northwest areas beyond the centre of Szczecin.

The Szczecin Traffic Manager application was developed to support drivers moving around the city of Szczecin, by making available to them the messages displayed on Variable Message Signs installed in the city and being part of the above described Traffic Management System for Szczecin.
For the application to function correctly it is necessary to have permanent access to the internet enabling data package transmission as well as a Wi-Fi connection. An operating GPS module is also required. Moreover, the device to operate the application (smartphone or tablet) must be equipped with an accelerometer and magnetometer.

The program applies Google Maps API, the access to which is based on using the Google Play Services library. The data display module downloads data from the variable message signs and displays them on the map using the functions offered by Google Maps. The application operates different functions simultaneously. To serve enquiry execution, the Asynchronous Http Client library is used, and it makes it possible to make enquiries outside the main function of the program, therefore both functions are carried out simultaneously. The information derived from the VMS is presented in the XML format by means of the service made available to the public by the operator, named UTMS (UTI Traffic Management System). It is then parsed by means of the embedded DocumentBuilderFactory library and displayed in the designated places within the application module.

Additionally, the application also has an access to the cameras used in the system. By means of the AsyncHttpClient parser and a properly set function using a cyclical clock, images from six cameras in Szczecin are received and returned.

A very useful function is the possibility of tracking the user’s location and displaying signs appropriate for the location. The GPS receiver embedded in the device downloads the user’s location, which is followed by displaying the nearest (within the radius of 1000 m) electronic board showing the traffic intensity. Changing the phones position changes the camera rotation in “Z” axis, based on the phones compass function. Another function is speed measurement established on the basis of changing the GPS location.

The application can operate in three basic modes (Figure 5a):

- **manual** (Figure 5b) – giving the opportunity to get familiar with the information provided on individual VMS signs, by indicating a specific sign; in addition, it is possible to hide the display of large (with information on suggested routes) or small (with information about the speed limit) VMS signs,
- **automatic** – the current GPS position of the vehicle is displayed while driving and the application displays VMS signs, which are closest to the user (the range is defined in the program); additional functionality is speed measurement, and
- **video-streaming** – images displayed in real-time from cameras placed in six locations in Szczecin, which allows for orientation of the current traffic situation.

Figure 4. The example information on VMS in Szczecin. Source: szr.szczecin.pl/utms/index
The mobile application is in the alpha test stage (the components codes are tested and analysed). It will be free of charge and could be used on all devices with the Android system.

4. Analysis of the influence of ITS in Szczecin

The areas west and northwest from the centre of Szczecin (Dołuje, Bezrzecze, Wołczkowo, Dobra, Pilichowo) are developing very fast. These are the residential areas of Szczecin with many recently completed developments (especially housing estates). Also, in this area there are warehouses and businesses. Therefore, a large part of construction-related transport is carried out in that direction. It is estimated that on average about 30% of supply in this area is delivery to construction sites of new housing estates located in these villages. Most of this traffic now travels through the centre of Szczecin (Figure 6). This is the shortest route, but during the peak time the traffic jams increase the travel time by about 20-40% (according to the experience of Szczecin’s stakeholders as well as the analysis made by the municipality).
Making use of the mobile application will help to change the decisions regarding route and use the alternative one (Figure 7). The alternative route is about 5 km longer.

Also, the traffic to Police (the chemical plant) goes through the bridges in the city centre (Figure 8a). The most important problem is that in many cases this is the hazardous freight transport.
Improvement in the traffic flows started from the successful implementation of the Traffic Management System which continuously monitors the traffic flow on both bridges and provides the respective traffic and guidance information on displays along the access roads. Thus, freight vehicle drivers are directed to the less congested of the two bridges. This leads to improved traffic flow on both bridges, avoiding dense traffic and outright congestion. Consequently, the journey times, congestion related pollution, fuel consumption and overall operating costs are reduced. An ex-post evaluation has been carried out by the municipality of Szczecin, showing that traffic speeds on the bridges improved by 36%. While this is a very significant traffic improvement, the challenge is to estimate the impacts of this on urban freight transport as a whole.

With this aim and based on the urban freight traffic model developed for Szczecin, the number of freight vehicle kilometres travelled on the bridges was calculated. Even though it is only a 3 km road stretch (including the access ramps) it is important that almost all the freight trips to/from the city centre go over these bridges.

Additionally, due to the use of the mobile application, drivers are able to choose the alternative route to reach the destinations in the west and northwest areas behind the centre of Szczecin. It led to a reduction in the number of cars travelling through the city centre and helped to reduce their journey time by avoiding traffic jams in the peak hours.

Experiments regarding the use of the mobile application were made in Szczecin. The major objective of the survey was to analyse how many drivers would be ready to change their route if they received information on traffic jams on the bridges in the centre. According to the results, about 20% of them were interested in the idea. Taking into account the potential use of the mobile application, it was possible to analyse the reduction in the number of freight vehicles entering the city centre. In the analysis, two kinds of vehicles as well as the relevant pollution emissions were included (Table 1):

- heavy goods vehicle (HGV) with a gross combination weight of over 3,500 kilograms, and
- light goods vehicles (LGV) with a gross combination weight of below 3,500 kilograms.

### Table 1. Pollution emitted by LGH and HGV. Source: European... 2013.

<table>
<thead>
<tr>
<th>Pollution</th>
<th>LGV</th>
<th>HGV</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>0,17</td>
<td>0,28</td>
</tr>
<tr>
<td>NOx</td>
<td>1,29</td>
<td>8,46</td>
</tr>
<tr>
<td>CO</td>
<td>3,45</td>
<td>5,50</td>
</tr>
<tr>
<td>CO2</td>
<td>314,4</td>
<td>655</td>
</tr>
</tbody>
</table>
Tables 2 shows the scenario without the utilization of Traffic Management System and the mobile application. The number of vehicles in each category was estimated on the basis of traffic analysis made by municipality in Szczecin. The total kilometres travelled by freight transport was calculated as the average values of O-D Matrix.

Table 2. Results for scenario without the utilization of Traffic Management System and the mobile application. Source: own work.

<table>
<thead>
<tr>
<th>Deliveries</th>
<th>Average freight trip distances</th>
<th>Vehicle kilometres</th>
<th>Total emissions of UFT in pilot city (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># of trips</td>
<td>km</td>
<td>total km travelled</td>
</tr>
<tr>
<td>Household oriented</td>
<td>48 642</td>
<td>14.9</td>
<td>726 262</td>
</tr>
<tr>
<td>Retail &amp; services</td>
<td>121 605</td>
<td>12.7</td>
<td>1 548 032</td>
</tr>
<tr>
<td>Industrial</td>
<td>36 482</td>
<td>6.0</td>
<td>217 870</td>
</tr>
<tr>
<td>Construction</td>
<td>36 482</td>
<td>11.2</td>
<td>408 992</td>
</tr>
<tr>
<td>Total</td>
<td>243 210</td>
<td></td>
<td>2 901 156</td>
</tr>
</tbody>
</table>

Overall, the impacts of using the mobile application supported by the Traffic Management System in Szczecin are quite substantial. Pollutant emissions and fuel consumption were reduced by 23% and 2.34% respectively (this big difference is the result of adequately small distance of the journeys over the bridges – about 3 km) and freight operating costs by 6.36%. The most important decrease was achieved in the number of vehicles entering the pilot city (Table 4).

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Table 3. Results for scenario with the utilization of Traffic Management System and the mobile application. Source: own work.

<table>
<thead>
<tr>
<th>Deliveries</th>
<th>Average freight trip distances</th>
<th>Vehicle kilometres</th>
<th>Total emissions of UFT in pilot city (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># of trips</td>
<td>km</td>
<td>total km travelled</td>
</tr>
<tr>
<td>Household oriented</td>
<td>41 346</td>
<td>14.9</td>
<td>617 323</td>
</tr>
<tr>
<td>Retail &amp; services</td>
<td>103 364</td>
<td>12.7</td>
<td>1 315 827</td>
</tr>
<tr>
<td>Industrial</td>
<td>28 273</td>
<td>6.0</td>
<td>168 849</td>
</tr>
<tr>
<td>Construction</td>
<td>20 065</td>
<td>11.2</td>
<td>224 946</td>
</tr>
<tr>
<td>Total</td>
<td>193 048</td>
<td></td>
<td>2 326 945</td>
</tr>
</tbody>
</table>

Overall, the impacts of using the mobile application supported by the Traffic Management System in Szczecin are quite substantial. Pollutant emissions and fuel consumption were reduced by 23% and 2.34% respectively (this big difference is the result of adequately small distance of the journeys over the bridges – about 3 km) and freight operating costs by 6.36%. The most important decrease was achieved in the number of vehicles entering the pilot city (Table 4).

Table 4. The estimated results of utilization of mobile application supported Traffic Management System in Szczecin.

<table>
<thead>
<tr>
<th>Performance indicator</th>
<th>Impact assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollutant emissions (CO, CO2, NOx, PM10)</td>
<td>-23,18%</td>
</tr>
<tr>
<td>Number of freight vehicles entering the pilot city</td>
<td>-20,63%</td>
</tr>
<tr>
<td>Vehicle kilometres/month</td>
<td>-19,79%</td>
</tr>
<tr>
<td>Fossil fuel consumption</td>
<td>-2,37%</td>
</tr>
<tr>
<td>Freight operating costs</td>
<td>-6,34%</td>
</tr>
</tbody>
</table>
Even though both values are estimates, since the estimation was based on a field experiment, the results seem to be absolutely appropriate. Due to this measure, 36% improvement in the freight vehicle flow as well as the estimated rerouting the 20% of trips naturally result in 23% less pollutant emissions.

5. Conclusions

As the example of the city of Szczecin shows, application of ITS solutions enables a significant reduction in negative impacts of road transport on the city environment. Due to increasing the traffic flow and limiting the congestion it is possible to significantly reduce fuel consumption, and consequently pollution. The usefulness of this kind of system is enhanced by the fact that there are more and more solutions using mobile devices.

The application intended for mobile devices makes it possible to plan the route much more in advance and to select, early enough, the route that will make the journey time shorter. In view of the fact that mobile equipment is widely used, the applications are comfortable to use and do not require the application of any additional technical solutions.

It must be stressed that combining the systems based on using typical telematics solutions, such as traffic detectors, variable message signs, and real time road incidents data processing systems, with solutions focused on mobile technologies, considerably extends their capabilities and usefulness.

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