AUTOMATYKA • 2011 • Tom 15 • Zeszyt 3

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Towards Design of Web Service Based Vehicle Navigation System

1. Introduction

Intelligent transportation system (ITS) which is able to adapt to changing weather conditions and able to react to accidents and current road situation is an emerging need for every modern society. Investments aiming at improving of traffic flow capacity are very complex and concern actions on many levels, starting from development of Traffic Measurement Systems (TMS) collecting data from roadways, through enhancement of visualisation and detection techniques to improving monitoring, surveillance and incident detection algorithms [22].

The demand for instant and accurate information forced development of advanced traveller information systems (ATIS). With sophisticated electronic devices progressively delivered to society, drivers started to expect much more than verbal updates from Traffic Message Channels. They expect a trustworthy decision support system. Technical progress is discernible on many levels: drivers commonly use short-distance communication (CB radio channels), automotive navigation systems or mobile phones equipped with satellite navigation are substituting unwieldy paper maps. Mobile phones with built-in GPS device as well as PDAs are currently obtainable by majority of modern societies.

Latest trends in mobile development [4, 54] show incorporation of many technologies within one single device (smartphone). Such devices apart from powerful computing unit (1 GHz processor as standard, 2GHz dual-core processor on the way) and different communication devices (built-in GPS, WiFi and Bluetooth antennas) are equipped with fully functional operating system (Android 3.0, Windows Phone 7, iPhone, Symbian etc.).

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As the result, smartphones (or portable PCs called tablets) are multi-tasking environments able to simultaneously and seamlessly access resources in Web. Mobile application tend to be strictly integrated with services in the Cloud, what is being reflected in social web services (e.g. [32, 37]) and in growing popularity of service on-demand architectures.

The number of cars in Poland is systematically increasing – according to [7] a vehicle corresponded to two inhabitants in 2009. Many investments have already been performed in order to improve urban communication, including Cracow [19]. Nonetheless, still a lot of effort needs to be taken to increase the number and improve the quality of roads in Poland, especially in largest cities [13]. Still, the number of investments is insufficient.

In this article we present the results of multi-subject survey undertaken prior to designing a traffic monitoring and vehicle navigation system. Different aspects have been taken up, such as providing a proper map for visualizing areas, through issues connected with vehicle navigation, modern intelligent traffic systems supporting drivers and their impact on drivers decisions. Finally, we present an open source free web service prototype, which was implemented as a mixture of different programming languages, with functionality to find optimal routes (with given traffic metrics) and in order to visualize in real-time traffic state for the city of Kraków (Cracow).

2. State of the art

Development of vehicle navigation system that would provide real-time traffic updates to driver mobile receivers is burdened with high production costs. Deployment of the system requires investments not only on road infrastructure and traffic monitoring system but also on surveillance and traffic lights control. Deployment of Intelligent Transportation System relies also on proper communication between Data Centre, traffic sensors and traffic lights. A scalable web service architecture also needs to be developed in order to maintain increased communication with multiple mobile devices. Last but not least, drivers need to be convinced to listen to and follow ITS guidelines.

2.1. Internet mapping services

There has been a tough competition between internet mapping providers recently, with every company offering free access to map browsing, address locating, as well as source-destination route planning. The interesting fact is that worldwide service providers [38, 46, 52, 62] have been basing their map application on the maps delivered by two main suppliers: Navteq [49] and TeleAtlas [60]. The second one has been taken over in 2008 by automotive system navigation owner TomTom [61], what forced development of maps owned by a company (Google) [40] or to revise existing contracts with map providers (others).

Leading mapping services vendors are still dominant in the market, but there have appeared many companies with local maps (e.g. in Poland [58, 59, 63], in the Netherland [24], in Germany [35], in India [56]). The majority of providers bases their maps on data obtained from local geographic information providers (e.g. in Poland [27, 31, 43]).

There are also some free maps available, which are usually developed by independent communities [50, 28].

2.2. Vehicle systems and traffic measurement

Innovatory programmes, such as eSafety, INVENT, PReVENT aim at supporting driver and traffic management are under development around the world [14, 51]. Advanced driver assistance systems (ADAS, a part of eSafety initiative) was designed to gather and process on-board information from video, laser and radar sensors of the vehicle [14]. Variable Message Signs (VMS), displaying information about traffic are growing in importance and becoming increasingly widespread in route guidance and traffic management [5].

The progress is being made also in vehicle detection techniques. Traditionally, traffic information was provided from different sensors, such as such as inductive loops, microwave or laser radars, infrared devices, acoustic arrays and magnetic detectors [3, 9, 11, 15, 20, 22]. Recently, vision-based traffic measurement systems (VTMS) communicated by WiFi with data centres have started to become an increasing important in automatic traffic data acquisition. The main advantage of VTMS are low cost and variety of information provided (including flow rate, density, throughput, occupancy) as well as their flexibility and portability. Traffic measurement result in VTMS is accomplished by vehicle detection, their tracking and afterwards evaluation of traffic parameter [22, 23].

2.3. Automotive navigation

Vehicle navigation may support intelligent traffic systems on two different levels: as *a priori* route planning (e.g. in transport companies to optimise routes for their vehicle fleet or by a user before his departure) or during the drive, to assist driver with updated information about the route.

Vehicle Route Planning Software used for delivery planning and determining fleet routing is commonly provided as a web service solution in Software as a Service (SaaS) architecture [16]. Complex online solutions are offered by [25, 55], the integration of mainframe with mobile devices is becoming a standard [30, 42]. The actual challenge in the market nowadays is to perform re-optimisation of routes in real time.

On-board automotive navigation devices usually provide three major information screens: a map of an area, a list of manoeuvres with sequence of turn directions and turn-by-turn guidance that "pops up" before the turn point is reached [12]. The display and control differ between models of different vendors of portable automotive vehicle navigation systems (including TomTom [tomtom], Garmin [33], Navman [48], Road Angel [53], Magellan [45] and others [17, 26]). Some innovative trends in the market offer online navigation dedicated for mobile devices [39, 47] or support drivers exchange of traffic events [57].

2.4. Impact of traffic information on drivers behaviour

Different studies have been conducted about the route choice of drivers that are receiving information from Advanced Traveller Information Systems (ATIS) [1, 2, 6]. One of the most widely accepted technique is Network User Equilibrium which assumes that within a graph (simulating roads connected by intersections) all travelling drivers have a perfect knowledge of travelling costs with every possible path and they behave in order to minimize their cost [18]. This model remains controversial because of the following arguments [1]:

- Braess' paradox: even if every user achieved his Network User Equilibrium, the total cost of all users decisions in network may not be optimal,
- even if the minimal network cost was found and users were provided with proper information, still their reactions to ATIS suggestions is unknown,
- not all drivers may be equipped with ATIS devises, what may impact network performance,
- too many drivers may respond to ATIS suggestions, what may cause an overreaction in network and result in transferring congestion from one path to another.

The studies conducted on influence of information sent from ATIS on drivers decision show, that drivers route choice doesn't base entirely on information received from one source, but is a multi-objective process. Drivers choosing their route base their decision on journey time, number of intersections on the path, traffic safety as well as on their personal habits [2]. Earlier experiences and trustworthiness of ATIS are also a factor [21]. The researches have shown, that drivers that are facing unexpected traffic delays are more willing to change their routes with advises provided by ATIS [10].

3. The concept

The concept of web service based vehicle navigation system, that we intend to design, is presented on Figure 1. The central ITS Data Centre is responsible for collecting traffic information from different road sensors, VTMS'es as well as vehicle positions of cars equipped with mobile navigation devices. Basing on the data, ITS Data Centre computes traffic intensity, and determines routing paths for all vehicles. Optimal path instructions are sent and distributed to every driver. Traffic information is displayed simultaneously on a website.

Deployment of the system is an extremely expensive process as it requires many investments in city infrastructure (cameras, inductive loops etc.) on multiple roads within the city. Such a system may be realized only if extensive funding is available. Unfortunately, lack of financial support forces to implement a narrowed solution: an open-source and cost-free platform dedicated to visualize results of traffic simulation.

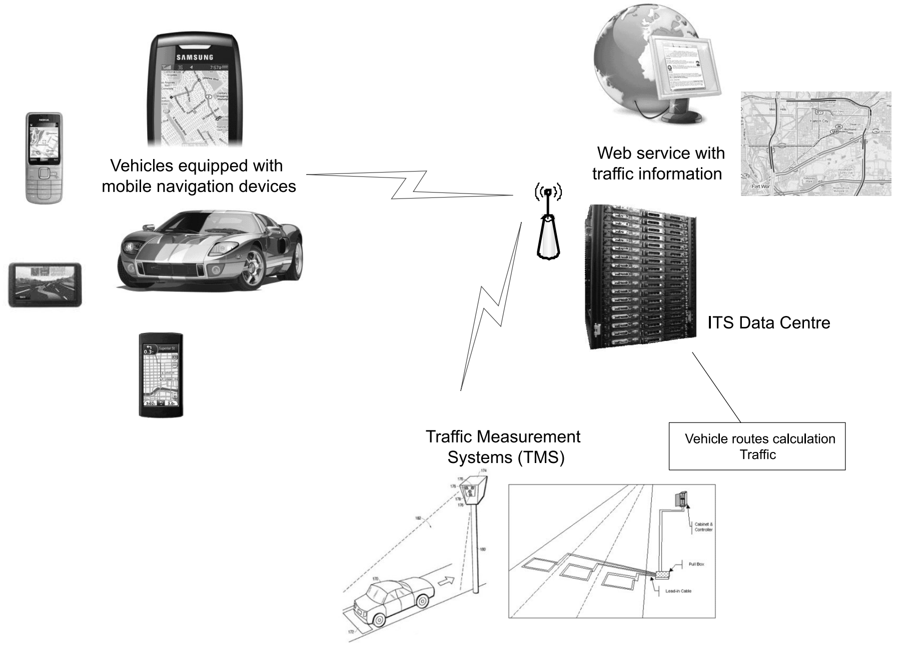

Fig. 1. The concept of web service based vehicle navigation system

The heart of the program is simulation server, which serves as artificial ITS Data Centre. According to proposed model, it calculates number of cars on different road segments, determines the traffic coefficient of each of the roads and sends actualization frames to web service through data access tier. The changes in traffic intensity may be observed by the users on the website. The prototype has been thoroughly described in the following chapters.

4. The prototype

The prototypical application was designed and implemented in three-tier architecture:

- simulation server (in Java technology) – which calculates traffic on each road, based on defined model and the road situation. It also finds fastest route between two points,
- data access tier (PHP with Zend Framework) – which intercepts AJAX requests from presentation tier, requests simulation server via socket for traffic actualizations and returns a JSON response to presentation tier,
- presentation tier (JavaScript with advAjax) – a website with embedded Google Map on which traffic results are visualized with different colours.

The communication between the layers has been presented on Figure 2.

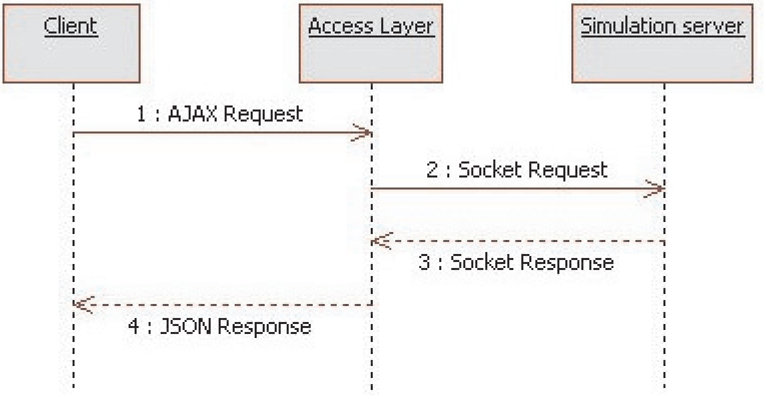

Fig. 2. The communication between Client, Access Layer and Simulation Server implemented in prototype

Web service is prepared to handle navigation request for optimal route between any two points within the map. The optimal route is determined by A* (A star) path finding algorithm [8] with metrics described in Chapter 4.3. The response (i.e. list of nodes the driver needs to pass to reach aim of his journey) is serialized and sent to the driver.

4.1. Map and traffic navigation

For determining vehicle routes and visualizing traffic, we used a geographical data representation format, called Polish Map Format (PFM). Its name origins from the nationality of its author (Stanisław Kozicki) – the creator of cGPSMapper [28]. Development of the program boosted development of free maps and supporting software for many cities around the world, e.g. GPSMapEdit [34].

Text based notation of PFM allows to store information about geographic position, type and attributes of different objects: points (e.g. buildings), points of interests (POIs, e.g. hotel, hospital), polylines (sequences of points, e.g. street) and polygons (areas, e.g. lake, forest). Source file (usually with .mp extension) may be compiled and easily converted to other popular map formats, e.g. Keyhole Markup Language (KML) used by Google Earth and Google Maps [44] or ported into Garmin devices (as .img files) [41].

Considering its adaptation to traffic modelling, Polish Map Format includes basic information needed for navigation purposes, such as road categories (from local roads to major highways) with direction attributes (one-way or bidirectional types), speed limits and road signs (mandatory, obligatory and prohibitory signs). Each road may be visible at different zoom levels, what is especially important for transparency of view during navigation. Unfortunately Polish Map Format doesn't provide information on number of traffic lanes – they need to be supplemented manually in system or determined by the road class (what not always is trustworthy).

4.2. Visualization of traffic

For visualisation purposes, popular Google Maps [38] was used as a background layer for traffic visualization on the website, as it offered a clearly designed programming API.

During the simulation, main roads traffic is visualised only, although all roads on the map are taken into account. A special structure stores information about roads, intersections and prohibitory signs. Capacity is assigned to every road segment, depending on its length (distance) and road class (with automatic assumption of number of lanes). For every vehicle, a 5 meter distance is considered (what is a compromise between cars and long vehicles, such as trucks and buses).

Simulation begins with loading data from a map file saved in Polish Map Format and initialisation of road connection graph (every road is initially filled in 1/3). The number of cars is calculated. The following steps are executed during each iteration:

1) every road is browsed by algorithm. One-way roads are browsed in single and bidirectional roads in both directions (according with traffic signs). For every segment of the road, adjacent roads are considered as potentially new segments for a vehicle (all in accordance with traffic regulations – i.e. if left turn is prohibited on intersection, vehicle may only move straight or turn right).
2) the next step of a vehicle is predicted randomly from all possible new locations. If there is enough space on the segment, a random number of cars (ranging from 0 to 4) is moved into their new positions.
3) if a dead end of the road is encountered by a vehicle (i.e. vehicle reached the end of a road or got to border of a map), its destructor is called and vehicle is considered as parked (or outside the city).
4) the total number of vehicles on the map is determined, based on a congestion factor. If there are less vehicles than the lower limit, new vehicles are randomly added to a map, according with probability that bases on population density in Cracow, calculated on election results in 2006 [29]. During the preparation stage, all the election local addresses were decoded with Google Geocoder [36]. If there are more vehicles than the upper limit, randomly picked vehicles are removed from simulation (they are considered as parked).
5) simulation time is updated.

4.3. Vehicle navigation

Simulation server is equipped with a module that finds an optimal routing for requested paths. A popular heuristic algorithm for graph search and pathfinding called A* (A star) is used [8].

The cost of driving on the specific route is determined by path segments of the route. Cost of travelling through a segment depends on its speed limit, number of cars using the road (if more vehicles, then the car drives slower) and a distance of a segment. There is also an optional parameter that allows to react on demand (road works, accidents etc.). The cost function for segment x of the road is determined by $r(x)$, defined as (1):

$$r(x) = \alpha \frac{dist(x) \cdot cars(x)}{speed(x)} \tag{1}$$

where:

- α – a parameter not used normally ($\alpha = 1$), useful in special cases (such as a reported accident on the road etc.),
- $dist(x)$ – distance of segment x,
- $cars(x)$ – number of cars on the segment x,
- $speed(x)$ – maximal speed limit on segment x.

The cost of travelling by path X, leading from defined starting point to specified destination and notated as $p_{sd}(X)$ is calculated as cumulative cost of all segments of the path (2):

$$p_{sd}(X) = \sum_{x \in X} r(x) \tag{2}$$

The best path from source to destination defined as $opt(d)$ is obtained by minimisation of all paths X leading from source to destination (3):

$$p_{sd} = \min_{X \in G} (p_{sd}(X) = \min_{X \in G} \left(\sum_{x \in X} r(x) \right) \tag{3}$$

5. Summary

Currently, simulation server and presentation tier (visualization layout) allows to test different models for simulation purposes. It provides a neat environment, especially for development of agent-based simulations. Multi-threaded Java server is able to serve the needs of many incoming simultaneous requests for road traffic at specific location. Navigation module calculates an optimal route between points according to determined metrics.

An exemplary screen from the application working in web browser window is presented on Figure 3.

The algorithms used in simulation have not been compared to real data, therefore it's hard to assess their accuracy. Driving experience of the authors suggest that although the traffic intensity calculation is quite accurate, the roads don't necessarily jam in all the segments determined by the simulation, especially in rush hours. This could be an effect of full randomization of starting and destination points of each car within the system. Possibly, if routes were adapted to well-known residential and working districts of the city of Cracow and traffic fluctuations was determined accordingly, the result of the simulation would be more trustworthy. The increased number of cars between the districts could increase algorithm accuracy mainly in rush hours. Nonetheless, without obtaining real data from available systems, this dispute remains theoretical.

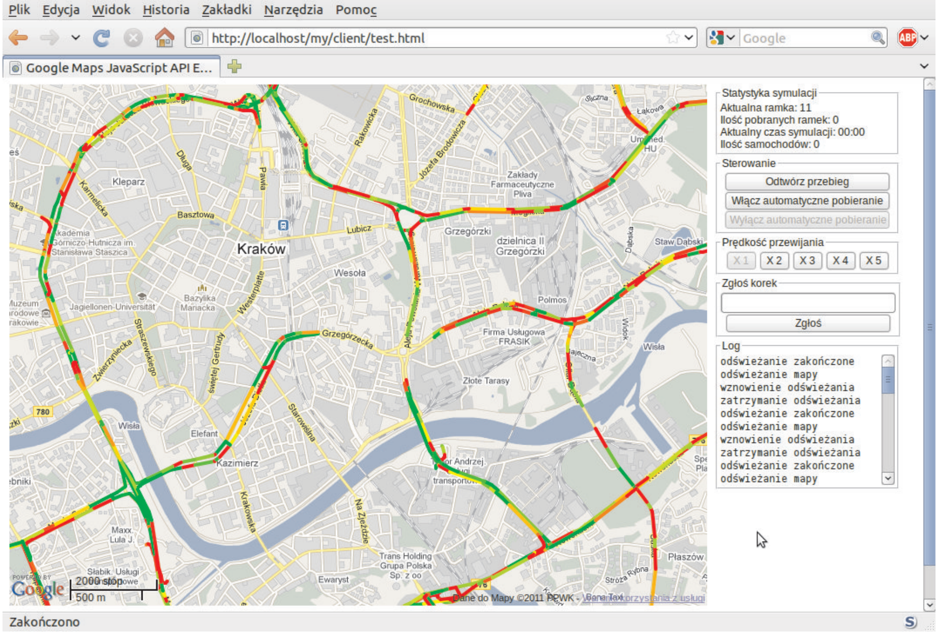

Fig. 3. An exemplary screen of a traffic visualization based on Polish Map Format and Google Maps API. Centre of city of Cracow

Application of Polish Map Format (PFM) as the base for network is appropriate, but to the certain extent. The quality of maps in PFM remains unsatisfactory – not all nodes of the roads are connected, some intersections are missing. Visualization using Google Maps is quite effective, but many simultaneous updates take their time. Time to refresh the map with new traffic data is excessive, possibly colouring of specially designed maps on local server may offer a quicker solution.

6. Conclusions and perspectives

The motive of this study was to summarise world and local trends in Poland in vehicle navigation technology and briefly comment the current stage of development of web service based system developed for traffic simulation. A prototype of ITS Data Centre was developed and may be used as platform for testing multiple traffic models. It is adapted in order to cooperate with mobile agents and to respond the route finding requests, as well as to visualize traffic intensity.

In order to gradually improve scalability of the application, porting the whole application into J2EE architecture could be considered. The architecture was intentionally designed with different programming languages and cannot be considered as optimal.

Considering navigation purposes, Google Maps licensing agreement disallows to use the software for navigation purposes. The necessity to obtain consent for commercial usage of Google Maps follows the policy of the company – Google provide free navigation for mobile phones equipped with Android OS. Therefore usage of open source maps such as Polish Map Format or OpenStreetMap in presentation layer should be considered in order to develop commercial solution. Porting the mapping service towards loosely licenced technologies could also boost the time for map refreshes – Google Maps requires to connect to external Google data storages with map images.

One of the aspects that hasn't been discussed in this article is designing and implementing a mobile application for the smartphones. The authors silently assumed, that each car is equipped with mobile device that sends data about its location. One of major perspectives of the project is to implement the mobile application synchronized with the server. The application should offer user interface for determining and presenting the route, options to override ITS suggestions and functionalities of asking the server for an optimal route. It should also report traffic intensity during the travel by calculating GPS position and speed. The application should also contain "on walk" mode, activated when driver leaves the vehicle, which would unsubscribe device from receiving and sending actualization frames from the server.

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