INTERNATIONAL HELLENIC UNIVERSITY

A Cooperative Intelligent Transportation System

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SID: 3301110008

SCHOOL OF SCIENCE & TECHNOLOGY
A thesis submitted for the degree of
Master of Science (MSc) in Information and Communication Systems

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Abstract

This thesis was written as a part of the MSc in ICT Systems at the International Hellenic University.

At present, most road traffic monitoring systems utilize dedicated equipment such as cameras, loop detectors and radars that imply significant installation and maintenance costs. Furthermore, the majority of such equipment is fixed and cannot be dynamically relocated according to the needs. Last but not least, loop detectors are prone to errors leading to not accurate and unreliable acquired data.

Global Positioning Systems (GPS) can obtain position and instantaneous velocity measurements of high accuracy that can be processed to obtain traffic information. Moreover, with the use of mobile internet services, the acquired information can be distributed, shrinking the cost of providing real time traffic information for the entire transportation network. However, when dealing with GPS-enabled mobile devices, there are privacy issues that have to be addressed, since the device is ultimately carried by a specific user.

The scope of the current thesis is to describe, design and implement a real-time cooperative monitoring system and to assess the feasibility of such a system based on GPS-enabled phones and devices with network capabilities. The system consists of a mobile application for smartphones and of a web-based system management application.

During this work a full functional mobile application was developed. The application is available on *Google Play (Android Market) named as Drive In Crowd (DRinC).*

The concept of the app is based on the joint contribution of the community of users, with a common goal of improving the life quality of its members and for this reason it is distributed free of charge. The notion of "community project" and crowd sourcing presupposes the voluntary contribution of each member, nevertheless it requires a form of crediting those users who contribute, in contrast to those who simply use it; gamification is used as basic principle.

Keywords: Real-time traffic data, cooperative mobility systems, zero-infrastructure systems, mobile internet, location based services, crowd, gamification, human computation.

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I am particularly grateful for the data provided by Hellenic Institute of Transport (H.I.T), and I would like to acknowledge their invaluable support.

I would also like to thank all my colleagues at H.I.T. for their support during the preparation of this thesis.

Finally, I would like to express my sincerest appreciation to my colleagues and friends for their precious support, help and discussions along with my deepest thanks and appreciations to my family.

Konstantinos Pachatouridis
29/10/2012

Glossary

Term of Abbreviation	Meaning
IT	Information Technology
ITS	Intelligent Transportation Systems
GPS	Global Positioning System
FCD	Floating Car Data
V2V	Vehicle to Vehicle
V2I	Vehicle to Infrastructure
LBS	Location-Based Services
VC	Virtual Checkpoint
DTL	Driver Trip/Trajectory Line

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1. Introduction

Information and Communication Technologies (ICT) have transformed many sectors, ranging from education to health care or public services. Components of intelligent transportation systems (e.g. vehicles, roads, traffic lights, sensors) take advantage of the progress of ICT, by using various sensing and communication technologies to assist transportation authorities and vehicle's drivers in making informative decisions and provide leisure and optimal driving experience.

The continuing development of mobile telephony and its adoption by the public create the appropriate conditions and prospects for the development of services designed to improve everyday life and specifically those which are based on data generated by users (crowd systems) [18]. New trends in the field of technology lead to the increasing production of devices with location-based services and internet connectivity. The use of such data can help to estimate the real-time traffic situation in the road network to more direct and reliable information of the moving driver.

The existing infrastructure supports the recording of the traffic situation using static measurement points (cameras, sensors) where the appropriate equipment is installed. This infrastructure has several disadvantages. Due to the high cost of installation and maintenance of these meters, it is impossible to cover the whole road network or a large part of it. In addition, the static meters disable the dynamic management of their network depending on the conditions formed within the road network. Finally, security issues of personal data of citizens emerge since what is essentially recorded is the location of the citizen and much other personal information as it is recorded by multimedia (video, image).

On a mobile phone connected to a GPS receiver, we can receive data concerning our motion such as our speed, latitude/longitude (position), etc. This data can be sent to a server, via internet connection (GPRS, 3G, LTE, WI-FI), which is responsible to process the data and generate traffic related information.

The aim is to create a crowd-sourced system to assess and calculate the traffic condition of the road network in real time, increasing the percentage of coverage of the network and the accuracy of results while giving great emphasis on security and privacy of the human computation system.

A variety of sampling techniques have been used to collect data from GPS-enabled mobile devices being capable of producing time-stamped geo-position (latitude, longitude, altitude) every three seconds.

An alternative sampling strategy was studied: this strategy that was designed and implemented in this work is based on Virtual Checkpoints (VCs), which act as spatial trigger for devices, to collect measurements and send updates. The structure of a VC consists of two geographical points (start and end coordinates of a line), that create a virtual line across a roadway of interest (Figure 1–1). When the moving device intersects a VC (Figure 1–2), it sends data (Floating Car Data) to a server. Instead of periodic sampling (in time), VCs triggers disclosure of speed and location by sampling in space.

Furthermore, an obvious advantage is that the user's device does not send data every n seconds but only when a trigger of VC occurs, reducing thus considerably the amount of irrelevant data transmitted over the network while preserving user privacy while continues tracing is avoided.

Figure 1–1 Virtual Checkpoint

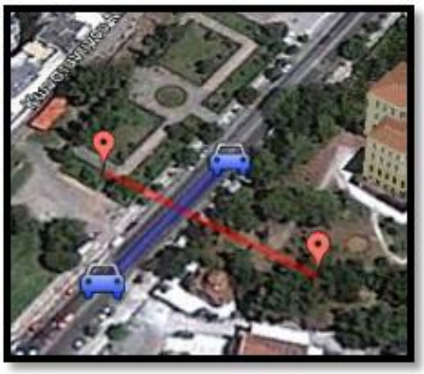


Figure 1–2 Trigger between a Driver Trip Line and Virtual checkpoint

The major task of the project is the design and development of a traffic monitoring system by using smart mobile phones (enabled with internet connectivity and location-based services) for collection of data without the need of any special sensor or communication device. The final product of the system is a mobile application that disseminates to the moving driver the situation of traffic on road network(Figure 1–3) and the estimated travel times for specific journeys in real time(Figure 1–4).

Figure 1–3 Thessaloniki's Real- Time Traffic Info

Figure 1–4 Thessaloniki's Travel Times

The mobile application was developed using PhoneGap's[17] cross-platform development framework. The app currently is in beta testing, and it is available for download on Google Play (Android Market) under the name "DRinC - Drive in Crowd"[1] (Appendix B, Figure 1–5). The app will be distributed soon through Apple's App Store and Windows Market Place. Until November 2012, the app was installed by 67 users; 48 of them active. Moreover, a web site[2] was created to disseminate the project (Appendix C). Mobile application as a part of a community project is being promoted by different means; social media (Facebook's page[3]), mailing lists, e.tc.

Figure 1–5 Drive In Crowd Logo

The notion of "community project" and crowd sourcing presupposes the voluntary contribution of each member. Nevertheless, it requires a form of crediting those users who contribute, in contrast to those who simply use it. In this context, the app makes use of a point collection system ("Karma Points") with respect to gamification notion.

The initial data (travel times) which are presented by the mobile application, are offered by the Hellenic Institute of Transport (H.I.T)[4]. The data provided by H.I.T are real-time information (last five minutes) that presents the travel times for twenty two journeys across the main roads of Thessaloniki. These data are essential while at the first steps of the system, there is not any recorded data, which can be transformed to travel information available to be presented via the mobile app. We are particularly grateful for the data provided by H.I.T, and we would like to acknowledge their invaluable support.

[1] https://play.google.com/store/apps/details?id=konpach.drinc
[2] http://www.drinc.konpach.com
[3] https://www.facebook.com/DriveInCrowd
[4] http://www.hit.certh.gr

Furthermore, system includes a web-based application which is responsible for virtual checkpoint management, user control administration, and mining of crowd sourced data by the system's administrator.

The novelty that lies herein is a very cost-effective and straightforward implementation of a real-time, community-based traffic information system, while addressing important issues such as the protection of driver's personal data, the zero-infrastructure implementation, as the structure of the system ensures the provision of live traffic data.

The deployed system is broadly characterized by five major components:

- a number of GPS-enabled smartphones in vehicles
- a cellular network operator
- cellular phone data collection and management
- a traffic estimation and traffic service provision component

Chapter 2 of this document provides an overview of Intelligent Transportation Systems (ITS), highlighting the key benefits of their implementation and finally providing an overview of Cooperative ITS based on Floating Car Data.

Chapter 3 elaborates with the proposed concept for the traffic monitoring system deployed during this work. Methodology and practical implementation of the system are discussed during this chapter.

Chapter 4 describes the system architecture and the design methodology which was followed to implement the developed system. Furthermore, this chapter highlight the issues arose during the implementation of the systems and the proposed solutions.

Chapter 5 discusses the possible commercial exploitation of the designed system taking into account the community based notion of this implementation. Market research on the customers and the current competitors of this application has been undertaken and the results are then analyzed.

Chapter 6 summarises the results of the implementation of the proposed concept for the traffic monitoring system deployed during this work and, finally makes an effort to classify and format any possible recommendations for further work.

2. Related Work

Information and Communication Technologies (ICT) have transformed many sectors, ranging from education to health care or public services. ICT is now in the stage of transforming also the traditional concepts of transportation systems. Components of transportation systems (e.g. vehicles, roads, traffic lights, sensors) take advantage of the progress of ICT, allowing thus communications through wireless technologies. The use of ICT in the transport sector is known as Intelligent Transportation Systems (ITS) [1].

This chapter provides a complete overview of Intelligent Transportation Systems (ITS), highlighting the key benefits of their implementation and finally providing an overview of Cooperative ITS based on Floating Car Data.

2.1 Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) embrace a wide variety of ITS applications intended to increase safety, reduce the impacts of traffic on the environment, and enhance the management of mobility in order to enable more "intelligent" use of infrastructures and vehicles [1]. ITS include a wide and growing range of applications, which are classified by ERTICO[5] into four broader areas [2]:

- Cooperative Mobility : connected vehicles and infrastructure
- Safe Mobility : providing safe transport operation
- Eco Mobility : reduced impact on energy consumption and the environment
- Info Mobility: real time information for travelers.

ITS applications can be grouped within four summary categories:

- *Advanced Traveler Information Systems (ATIS)* which provide real-time information to travelers through universal access, such as congestion avoidance directions, navigation directions, accidents, schedules and routes for public

[5] http:// http://www.ertico.com/, Intelligent Transportation Systems and Services for Europe

sector services allowing modes of transportation (buses, trains) to share their position providing their departure and arrival time.

- *Advanced Transportation Management Systems (ATMS)* include traffic control devices, such as traffic signals, ramp meters, traffic cameras, variable message signs (VMS) and vehicle detectors.
- *ITS for Smart Ticketing and Pricing* provide services as electronic ticketing and payment, electronic fee collection (EFC), congestion pricing, fee-based express (HOT) lanes, and vehicle miles travelled(VMT) usage based fee systems.
- Integrated Intelligent Transportation Systems such as autonomous systems solutions (only infrastructure or vehicle) and co-operative systems that rely on the cooperation between two or more pillars (e.g. Vehicle to Vehicle - V2V or Vehicle to Infrastructure – V2I) through communication technologies.

2.2 Key benefits of applying ITS

The key benefits of applying ICT on transportation are the increased levels of safety and the security, the efficient use of the road network by reducing congestion, the enhancement of mobility and convenience, the environmental and energy gains and finally all aspects related to economic and employment growth.

Most developments in the past years provided passive services in terms of protecting passengers in the event of an accident, whereas ITS systems are designed to offer proactive (usually referred as active safety systems) services, in order to assist drivers in avoiding or evading the consequences of an accident. Systems that provide safety and security information are considered to be in a pre-mature stage and need to meet wider market acceptance and enforcement in order to achieve measureable impacts on road safety.

ITS optimize the performance of the network infrastructures by maximizing the road capacity and reducing the need of additional infrastructure investments. Using real-time data, obtained by transportation agencies, and real time management schemes, ITS lead to a significant improvement in the quality and fluidity of vehicular traffic. For example, as stated in previous research [2], applying dynamic traffic lights management schemes with the use of real-time data, in U.S, would reduce the stops by 40%, travel times by 25%, fuel consumption by 10% and finally contribute to a decrease in emissions by 22%.

Mobility and convenience are significantly enhanced by the use of ICT in the transport sector. Drivers are informed during their trips about the traffic conditions over the road network, having the ability to choose more effective and sustainable trip routes.

Furthermore, improved traffic flow conditions deliver environmental benefits and even boost an economic growth. In Japan, ITS is a crucial part of the country's objectives to reduce CO_2 emissions, with an objective of 32 million tons reduction below 2001 levels by 2010 and with a total of 22 million tons of savings coming from improved traffic flow and more effective use of vehicles [2].

2.3 ITS implementation constraints and difficulties

Despite the feasibility of implementing ITS and the significant cost-benefit ratios, as stated above, there are a number of challenges involved in the deployment of ITS. Some of these reasons are related to systems' standardization, interdependency, scalability, funding, and political issues. For example, implementing ITS in US and establishing and operating through a management system, is estimated to generate a $29 billion benefit by 2018, with a benefit-cost ratio of 25 to 1. Moreover, the implementation of ITS in South Korea has generated a benefit of $1.3 billion, through the deployment of an electronic toll collection system, with a 11.9 to 1 cost- benefit ratio.

While some ITS applications can be installed and deployed locally, the vast majority of ITS applications, such as computerized smart signals, roadside cameras, and even local traffic operations, certainly the ones which generate major benefits for transportation need to operate at national and not only at local level, and need to actually involve and aggregate different ITS applications, usually originated and managed by different local authorities. One other major stakeholder is the driver, who is not likely to demand on-board devices for his/her vehicle, which are capable of displaying real-time traffic information.

Local transportation agencies play a significant role in ITS deployment. These are entities aiming to construct and maintain infrastructures rather than to manage the road network within their area of jurisdiction or to apply the latest research results related to ITS. Local agencies prefer to deliver immediately perceivable results, by building a new infrastructure or to upgrade existing ones, while ITS provide solutions with long-term returns and benefits. Although ITS face numerous problems, there are many countries, which overcome these problems by applying systems related to their local or national needs.

2.4 Key underlying Technologies which affect ITS

The key underlying technologies which affect ITS and have a great impact on the evolution of ICT in transportation systems are described below.

- Global Positioning System (GPS)

On- board vehicle units with integrated GPS receivers, receive signal from several satellites to calculate the device's position (and thus the vehicle's position). A receiver uses the signals from several satellites to calculate its position; line-of-sight to the satellites is required (Figure 2–1). Usually location's precision is about 10 m. The only operational system is the American Global Positioning System (GPS), although the EU plans to operate the Galileo system by 2013, while Russia is also active in developing their own system (GLONASS) [20]. These are likely to complement each other and provide a higher precision accuracy.

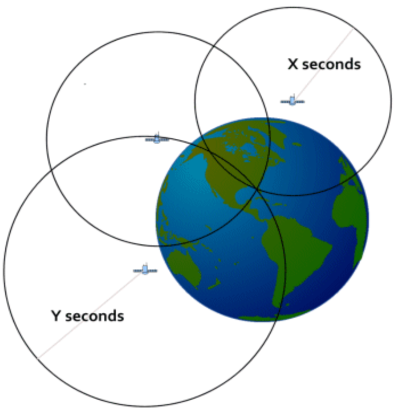


Figure 2–1 Trilateration Process [15]

- Assisted GPS (A-GPS)

Assisted GPS, also known as A-GPS or AGPS, enhances the performance of standard GPS in devices connected to the cellular network. A-GPS improves the location performance of cell phones (and other connected devices) in two ways: First, by obtaining a faster "time to first fix" (TTFF). A-GPS acquires and stores information about the location of satellites via the cellular network so the information does not need to be downloaded via satellite. Secondly, by assisting in identifying the position of a phone or mobile device when GPS signals are weak or not available. GPS satellite signals may be impeded by tall buildings and do not penetrate building interiors well. A-GPS uses proximity to cellular towers to calculate position when GPS signals are not available.

Below (Table 2-1) are described the main differences between GPS and A-GPS, providing a brief comparison.

	GPS	**Assisted-GPS**
Description	The device's position is triangulated based on signals from at least four GPS satellites based on the known position of the satellites, the time that messages from the satellites were sent and the time that they were received.	This is an enhanced form of GPS commonly used on smartphones, in which an "assistance" server on the mobile network provides information such as accurate GPS satellite orbit information, accurate timestamps or possibly snapshots of GPS signals. This can allow GPS accuracy with initial location information within seconds, thereby making it practical for use in LBSs.
Accuracy	5-10 m	5-10 m
Advantages	Highly accurate. No dependency on a mobile network provider.	Highly accurate, and allows GPS to be used in more areas, such as in densely populated areas where clear GPS signals may not be obtainable. Fast location collection.

Disadvantages	Relatively high power requirement, as a GPS receiver needs to operate. It can only be used outdoors where clear satellite signals can be obtained. Depending on the device, it may take a long time (~30 seconds) to lock onto satellite signals.	There is a dependency on the mobile network provider; it can only operate where mobile network reception is available.
	GPS	Assisted GPS

Table 2-1 Summary of GPS-based location collection technologies [12]

- Wireless networks

Wireless networks allow fast communication between vehicles and the roadside, but have a range of only a few hundred meters. However, this range can be extended by each successive vehicle or roadside node passing information onto the next vehicle or node.

- Cellular phone networks

ITS applications can transmit information over standard third or fourth generation (3G or 4G or LTE) mobile telephone networks. Advantages of mobile networks include wide availability, especially in urban areas and along major roads. Mobile telephony is not suitable for some safety-critical applications since there is a delay in communication.

- DSRC (Dedicated Short Range Communications)

DSRC (Dedicated Short Range Communications) is a short to medium range communications service, a channel operating in the 5.8 or 5.9GHz wireless spectrum that supports both public safety and private operations in roadside to vehicle and vehicle to vehicle communication environments. DSRC is meant to be a complement to cellular communications by providing very high data transfer rates in circumstances where minimizing latency in the communication link and isolating relatively small communication zones are important [21].

- Probe vehicles or devices

Prove vehicles (often taxis, public service vehicles or commercial freight fleets) are deployed in several countries to report their speed and location to a traffic management center, where probe data are aggregated to generate a complete picture of traffic flow in road networks and to identify congestion. Extensive research has also been performed into using mobile phones that drivers often carry as a mechanism to generate real-time traffic information, using the GPS-derived location of the phone as it moves along with the vehicle.

2.5 Traffic data collection systems

The development of ITS requires high-quality traffic information in real-time. The traditional traffic monitoring infrastructure, comprised of on-road sensors, consists mainly of dedicated equipment, such as loop detectors, cameras and radars [4]. Installation and maintenance costs prevent the deployment of these technologies across arterial networks and even along highways around the world. Even though installation and maintenance costs are significant, the proportion of malfunctioning and errors keep high (actually 30% out of 25000 detectors daily in California [4].

An alternative or rather complementary approach is the use of Floating Car Data (FCD) systems as a source of high-quality data to existing technologies. These data collection and processing systems are designed to assist in improving safety, efficiency and reliability of transportation systems. They are thus becoming crucial in the development of new ITS.

2.5.1 Infrastructure based data collection systems (traditional)

Traditional traffic count technologies can be split into two categories: intrusive and non-intrusive [5]. The intrusive methods consist of a data recorder and a sensor placed alongside the road. They have been used for many years and the most important of them are described below:

Pneumatic road tubes: rubber tubes are placed across the road lanes to detect vehicles from pressure changes that are produced when a vehicle wheel passes over the tube (Figure 2–2). The pulse of air produced is processed by a counter located on the side of the road. Main drawback of this implementation is that it is prone to extreme environmental conditions and to low speed flows.

Figure 2–2 Pneumatic road tubes[6]

Piezoelectric sensors: the sensors are placed in a groove along roadway surface of the lane(s) monitored (Figure 2–3). The principle is to convert mechanical energy into electrical energy. Piezoelectric sensors are used for high-speed WIM (Weigh-In-Motion) and/or vehicle classification applications.

Figure 2–3 Piezoelectric sensors

Magnetic loops: it is the widely-used technology to collect traffic data. The loops are embedded in roadways in a square formation that generates a magnetic field. The information is generated through a counting device placed on the side of the road (Figure 2–4). Heavy vehicles can damage the device, but it is not affected by bad weather conditions. The implementation and maintenance costs can be expensive.

[6] http://www.bikecommuters.com/2009/11/10/make-it-count/

Figure 2–4 Magnetic loops

Non-intrusive techniques are based on remote observations. Even if manual counting is the most used method, new technologies have recently emerged which seem very promising:

Manual counts: it is the most traditional method where trained observers gather traffic data that cannot be efficiently obtained through automated counts e.g. vehicle occupancy rate, pedestrians and vehicle classifications

Passive and active infra-red (Figure 2–5): the presence, speed and type of vehicles are detected based on the infrared energy radiating from the detection area. The main drawbacks are the performance during bad weather, and limited lane coverage.

Figure 2–5 Infra-red[7]

Passive magnetic: magnetic sensors are placed under or on top of the roadbed. They are designed to count the number of vehicles, the speed and they provide a classification of them. However, in operating conditions the sensors have difficulty differentiating between closely spaced vehicles.

[7] http://www.amaroelectronics.com/seguridad_integral/sistemas_de_alarmas.htm

Microwave radar: this technology can detect moving vehicles and speed (Doppler radar). It records count data, speed and simple vehicle classification and is not affected by weather conditions.

Ultrasonic and passive acoustic devices: These devices are generating sound waves and wait to detect when the signal returns, estimating the time of signal until it returns to the device. The ultrasonic sensors are placed over the lane and, as it is expected, can be affected by temperature or bad weather. The passive acoustic devices are placed alongside the road and can collect vehicle counts, speed and classification data.

Video image detection: video cameras record vehicle numbers, type and speed by means of different video techniques e.g. trip line and tracking (Figure 2–6). The system can be sensitive to meteorological conditions.

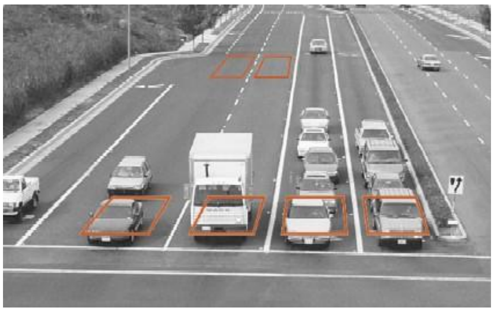


Figure 2–6 Video image detection

2.5.2 Floating Car Data Systems (FCD)

With vehicles becoming ever more equipped with satellite positioning and mobile communication technologies, the opportunities for extended use of Floating Car Data (FCD) are increasing. The basic principle of FCD is to collect real-time traffic data by locating the vehicle via mobile phones or GPS units over the entire road network. This means that every vehicle is equipped with mobile phone or GPS which acts as a sensor for the current traffic conditions of a road network. Data such as car location, speed and direction of travel are sent anonymously to a management center. After being collected and processed, information can be redistributed to drivers during their journey (e.g. information on traffic congestion, alternative routes, real time navigation directions and other advanced travel information services).

FCD are divided in two main categories; those based on cellular and GPS probe data, and those of “in-vehicle” collection methods.

“In vehicle” collection method refers to Automated Vehicle Identification (AVI) techniques, where tags are used whenever a vehicle passes a physical sensor which is placed alongside the road, usually on existing infrastructure. Tags are electronically encoded with a unique identification (ID) number. A common AVI application is the electronic toll collection. An AVI system collects data by using four primary components:

- a probe vehicle equipped with electronic tag generator(transponder)
- an antenna that captures the presence of the transponder
- a reader which bundles data
- a central traffic management facility which collects and utilizes the data.

AVI systems have the ability to collect data continuously without any human interaction. The data collection process depends on the coverage area of the antenna and of sample data characteristics [5].

FCD systems based on cellular technology rely on the ability of phone devices to transmit regularly their position in the road network, which is the same with the position of the vehicle, by triangulation(Figure 2–7) or by other techniques (e.g. handover). Mobile devices have only to be turned on, and it is not necessary that they are used by the drivers during their journeys. This approach delivers relatively accurate information in urban areas where the number of antennas is greater and the distance between them smaller. Contrary to infrastructure based traffic data collection systems and to GPS-based systems, there is no need to install any additional device or software. The location precision is low (about of 300m), and there is a need of a large number of devices to overcome this weakness. However, it is noted that with the expansion of Universal Mobile Telecommunications Systems (UMTS), widely known as 3G, and with the initiatives of fourth generation of cell phone mobile communications standards (4G), the accuracy of data should be enhanced.

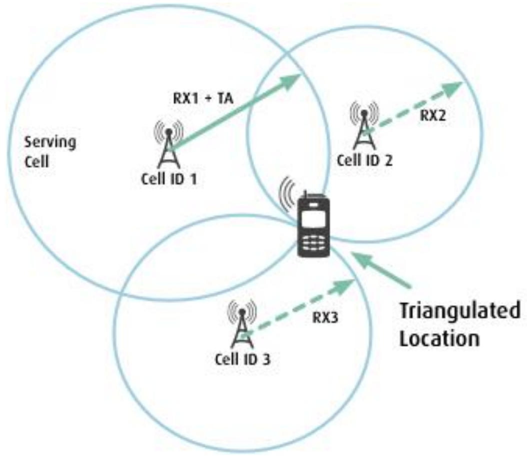


Figure 2–7 Network Data for Location via Triangulation

FCD systems based on GPS become more useful and affordable as the use of GPS enabled devices increases constantly. More and more vehicles are equipped either with integrated GPS receivers or with mobile phones (particularly smartphones) which have, as part of their design, GPS receivers installed. The precision level is relatively high (10 meters) and it is expected to increase (e.g. through the introduction of the Galileo satellite navigation system [7]). The major disadvantage is the limited number of users; however with the extensive use of smartphones and of their applications, which are available at the market of each operator, this shortcoming is expected to be solved. The increased use of smartphones creates thus major opportunities in this field.

2.5.3 FCD advantages and disadvantages

Floating Car Data Systems for traffic and transportation systems data collection have the following *advantages* [16]:

- *Low cost per unit of data*- Once the necessary infrastructure and equipment are acquired and installed, data are collected easily and at low cost. There is no need to set up any other configuration
- *Continuous data collection*- If the infrastructure is permanently operational, data is collected as vehicles continue traveling.
- *Automated data collection*- Data are collected autonomously without any human intervention and are directly sent to a traffic management center.
- *Digital Data*- Data is collected and stored by electronic devices, and is in an appropriate format for any further processing, analysis and calculations.

Floating Car Data Systems have the following *disadvantages* [16]:

- *High implementation cost*- Probe vehicle systems have a high initial cost to purchase necessary telematics' equipment, to install and finally to train personnel to operate it.

- *Fixed infrastructure constraints*- The coverage area has to be strategically located whereas the adjustment of infrastructure it is not financial feasible. Data cannot be collected outside of coverage area without any additional infrastructure expenditure.
- *Scalability*- Probe vehicle systems generally have large implementation costs, and they are most cost-effective for collecting data within a large study area; additional infrastructures have to be constructed and maintained.

- *Privacy Issues*- Even though drivers want to remain anonymous, the trajectory of the journey of the driver can be regenerated by the initial data.

With the development of cooperative systems based on mobile devices which act as traffic sensors, the costs related requirements tend to be bypassed. Moreover, there are several proposed techniques to preserve user privacy. In the next sub-section of this chapter there is an extended review of these issues.

2.5.1 FCD and privacy concerns

FCD systems that use vehicles as active sensors generate and transmit the geographic position of the vehicle periodically to a traffic-control management center. This concept provides full traceability of the driver, repeated self-reporting of possible violations and recording of habits and patterns. While technical issues and challenges have been analyzed and many actions have been proposed and applied, privacy and security issues for distributing position data are still neglected or ignored [8]. While the majority of FCD systems receive data from fleet management companies where privacy is of minor importance, a new trend of FCD based systems on GPS units of individuals, have started to monopolize this sector of ITS. Drivers, through the use of location-based services such as navigation, emergency and electronic toll collection systems would pull private data to traffic management centers. Drivers want to remain anonymous, while FCD service wants to record as many details is possible about the trip, apart from spatial or time sampling strategies. For example, toll systems based on FCD services may need to know the driver's identity for charging purposes.

The impact of privacy concerns can be handled with the appropriate sampling strategy and/or with the design of a transparent architecture, where position and velocity information are extracted from the individual-related data. The data are degraded until a sufficient level of privacy is attained. The degradation approach includes spatial conceal (i.e. block data from specific regions), noise addition to data and location discretization to the nearest grid point.

There are a lot of studies related to measurements' quality and privacy under these degradation approaches, and this issue can be cast as a sampling strategy optimization problem ([9], [10]).

2.6 Cooperative ITS

Nowadays, the emphasis in transportation research turns to Cooperative ITS, in which the vehicles communicate each other (V2V) and/or with the infrastructure (V2I) [3]. Cooperative ITS can greatly increase the quality and reliability of information about the vehicles, their location and the road environment through the availability to interact locally with each other (Vehicle2Vehicle) or/and with roadside equipment (Vehicle2Infrastructure), usually a roadside sensor. Collection and sharing of real-time data would lead to transport efficiency with increased traveler support and safety [22].

2.6.1 Introduction to Cooperative ITS

The basic idea is that vehicles are equipped with onboard units with enabled wireless communication features; thus, they can receive information from roadside infrastructure, process information, and provide it to the driver or/and to passengers. In addition, each pillar can communicate information with other vehicles or with roadside infrastructure equipped with the right technology. Information is passed wirelessly through a variety of short and long range communication media (such as the mobile phone network, DSRC).

The major applications based on the V2V and V2I are mainly separated into two categories [1]:

- Cooperative Intersection Collision Avoidance Systems (CICAS)
- Intelligent Speed Adaptation Systems (ISA)

Some implementations of such systems and proposed concepts are referred below:

- Receiving of alerts and/or notifications related to road safety directly from other vehicles (vehicle to vehicle - V2V)
- Optimal speed notification when a vehicle reaches an intersection, such as to meet a green signal (infrastructure to vehicle - I2V)
- Reversible lanes due to traffic flow (V2I and I2V)
- Local danger / hazard warning, accident avoidance (V2V ,V2I).

Vehicle-to-infrastructure systems are well-known and widely deployed during the last decades. Japan's "Smartway" and the United States "IntelliDrive" are designed to enhance drivers to avoid accidents (primary and secondary).

The objective of "IntelliDrive" has been to install and deploy a communication infrastructure that supports V2I and V2V communication for a variety of vehicle safety applications and transportation operations [10]. IntelliDrive envisioned that using DSCR-enabled tags or sensors, if widely deployed in vehicles, would enable the pillars to communicate each other, delivering a wide range of applications like cooperative intersection collision avoidance systems (CICAS) in which two (or more) DSRC-equipped vehicles at an intersection would be in continuous communication, being enabled to predict a collision (based on the vehicles' speeds and trajectories) and would warn the drivers of an impending collision or even communicate directly with the vehicles to brake them. This consolidation platform, combining both type of cooperative systems, would enable a number of additional ITS applications, including adaptive signal timing, dynamic re-routing of traffic through variable message signs, lane departure warnings, curve speed warnings, and automatic detection of roadway hazards, such as potholes, or weather-related conditions, such as icing.

Given the position of a vehicle in each interval, we are able to calculate its speed. Based on a digital speed limit map, we are able to provide another one vehicle-to-infrastructure application, a major part of Intelligent Speed Adaption (ISA) systems, where the application compares the vehicle's velocity with the speed limit of the related to its position road. The system could either warn the driver to slow down or be designed to automatically slow the vehicle through automatic intervention. France is currently testing the deployment of an ISA system that would automatically slow fast-moving vehicles in extreme weather conditions, such as blizzards or icing.

Extended research is conducted to support energy efficiency applying latest V2I and V2V communication technologies [1]. ”Eco-Move”, EU co-funded research project of the 7th Framework Programme, has the potential to provide an integrated solution comprising eco-driving support and eco-traffic management. Another one project (pilot) is Cooperative Systems for Sustainable Mobility and Energy Efficiency (COSMO), which aims to assess energy efficiency, measuring the effect of a range of innovative traffic management systems not only on fuel consumption and traffic emissions, but also the energy used to operate road-side equipment [11].

2.6.2 Role of Mobile Phone Devices in Cooperative systems

Mobile device tends to be a powerful device which acts as an aggregate point of various integrated services. Mobile devices are designed to meet portability and mobility needs. During the last years, with the increased interest in the development of sophisticated operating systems for mobile devices (iOS, Google Inc. Android, Windows Phone, etc.), all hardware manufacturers include in the basic features of their products a GPS chipset. Developers of applications for mobile devices take advantage of this feature, and the application programming interfaces (APIs) offered and design a variety of applications providing Location Based Services (LBS) [12].

The basic characteristics of smartphones with respect to LBSs are listed below:

- Easy access to location information
- Push notification availability
- Support of other technologies such as Bluetooth peer-to-peer communication that may be used by specific applications.

LBS exploit the knowledge about where a user is located providing information related to his/her current geographic position. First-generation LBSs were reactive and client-server focused; thus, a user asked an application or a system for information and received a response. Second-generation LBSs, as part of WEB 2.0 [13], are more proactive and interactive between users; thus,a user can receive information without any human intervention.

By the end of 2012, there could be more smart mobile devices on the planet than humans, and by 2016 there could be 10 billion smartphones [14]. In the future, everyone would own a smart mobile device with extended capabilities, as they were already described. Moreover, with the increase of metropolitan wireless access networks and with the penetration of mobile data services (LTE), everyone would communicate information via his/her mobile device.

Although a significant number of vehicle manufacturers provide products with integrated telematics units (In-vehicle intelligence), there is a major number of vehicles (those which are already running, and those which are designed to be placed on the market shortly) which do not have any capability to provide directly LBS. Asking drivers to purchase an on board telematics unit is not an efficient choice, while drivers already owning a device with the same and probably extended features.

There is a major opportunity for cooperative ITS with the significant penetration rate growth of smart mobile devices in the market, as every vehicle would be able to collect data related to its journey, send this information via mobile data services or through wireless networks and eventually receive information related to its environment with respect to ITS.

2.7 Summary

This chapter identifies and describes significant progress made until today related to Intelligent Transport Systems together with applications and projects either already developed or proposed to be implemented soon. Furthermore, there is an extended assessment of cooperative traffic data collection systems and especially those which are based on Floating Car Data. Finally, the prospects of the development of cooperative data collection system using mobile devices as probe sensors have also been examined.

The current thesis proposes and implements a transportation data collection system based on the Cooperative Intelligent Transportation Systems sensors, by using Global Positioning System enabled devices; users as probe vehicles. A new concept of Virtual Checkpoint (VC) is proposed for preserving user privacy and efficient utilization of user's mobile device resources.

3. The traffic monitoring system description

3.1 Introduction

The continuing development of mobile telephony and its adoption by the public create the appropriate conditions and prospects for the development of services designed to improve everyday life. New trends in the field of technology lead to the increasing production of devices that provide geographic data services (location-based services) and Internet connectivity. The use of such data can help to estimate the real-time traffic situation in the road network to more direct and reliable information of the moving driver.

Currently, the existing infrastructure supports the recording of the traffic situation using static measurement points (i.e. cameras, sensors) provide that the appropriate equipment is installed. However, this infrastructure has several disadvantages. Due to the high installation and maintenance costs, it is impossible to cover the whole road network or a large part of it. Additionally, the static meters disable the dynamic management depending on the conditions formed within the road network. Finally, security issues of personal data for the citizens emerge since what is essentially recorded is the location of the citizen and much other personal information as it is recorded by multimedia (video, image).

The aim of this thesis is to create a system that assesses and calculates the traffic condition of the road network in real time, increasing the percentage of coverage of the network and the accuracy of results while giving great emphasis on security and privacy of the citizen-user system.

In order to implement properly the system, the concept of the virtual line is employed. This line basically consists of a sequence of data in which the location and speed of the driver in motion are recorded.

The system is concerned about the design and development of an application for mobile phones with Internet connectivity and the support of geographic data services (location based services). The final product of the system is an application that provides the moving driver with real-time traffic information.

3.2 The Concept- Methodology

The VC is essentially a line placed virtually over a road segment (Figure 3–1) which is part of the road network which is involved in the calculation of traffic. When the user intersects this point, a trigger is occurred and the application on the user's mobile device sends the speed and position to the server.

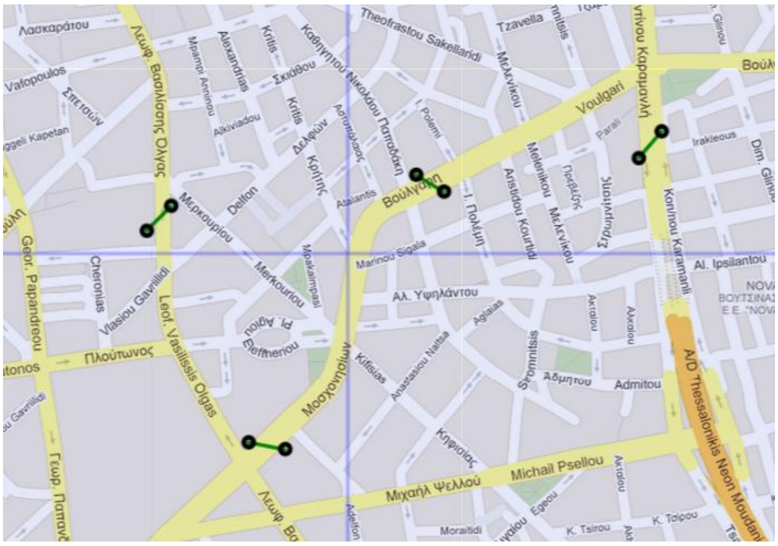


Figure 3–1 VC (green) over the road network

The key features of this implementation are described as follows:

Spatial instead of temporal data: Basically, the data collected to calculate the traffic are spatial instead of temporal data, and they are collected at specific virtual spots ("Virtual Checkpoints" – VCs), which have been defined by the system administrator and have been recognized as more important than others. They can be changed dynamically according to the requirements through the application's control management system.

User Privacy: The location data collected from the users are only identified by the current Virtual Checkpoint ID and not by the ID of the user's mobile device, so no privacy-invasive extended trajectories are collected. Furthermore, the VCs trigger detection mechanism does not guarantee that a user would trigger every VC in the trajectory generated by his/her journey; minimizing the probability of geographical continuous measurement.

Network coverage: With the proper placement of the VCs on the map, we can get information on almost the whole road network. There is no limitation about the region or the country. The system responds to every location and is fed by the users.

Zero-Infrastructure system: Through the dynamic nature of this implementation, it is possible to change the location of the VCs according to the needs (e.g. insufficient information on some points). With the establishment of a control center, we can change, add or replace some VCs in a real-time manner, affecting all the clients, which collaborate to produce data. There is no need to allocate resources for any physical equipment or device.

Assess the feasibility of a real-time traffic monitoring system: The use of the GPS-enabled mobile phones provides sufficient and accurate data for the precise travel time and average velocity estimation.

Cooperative Vehicle-infrastructure system: Users are used as sensors, using their mobile devices, to feed the system with real-time traffic data. A minimum amount of active users has to be allocated for the proper function of the system.

3.3 Application process

The operation of this application is divided into two different levels: The application is involved in the update of the traffic situation on the streets by sending information to a remote server (when a trigger of a VC occurs) which takes on to assess the traffic situation on the road network by applying transport-related algorithms. This information, obtained through GPS, is related to the location of the device and the speed of the driver, while ensuring the protection of the user's personal data.

In this mode, the mobile application users are not actively involved; they are informed about their participation in this community project, at the start of the application. The application receives data for traffic status of the road network and depicts it in embedded map by using appropriate colors to represent the live traffic (Figure 3–2.) Users can see the traffic levels on the map of the area they demand, and they can plan their trip choosing the route with the best traffic conditions.

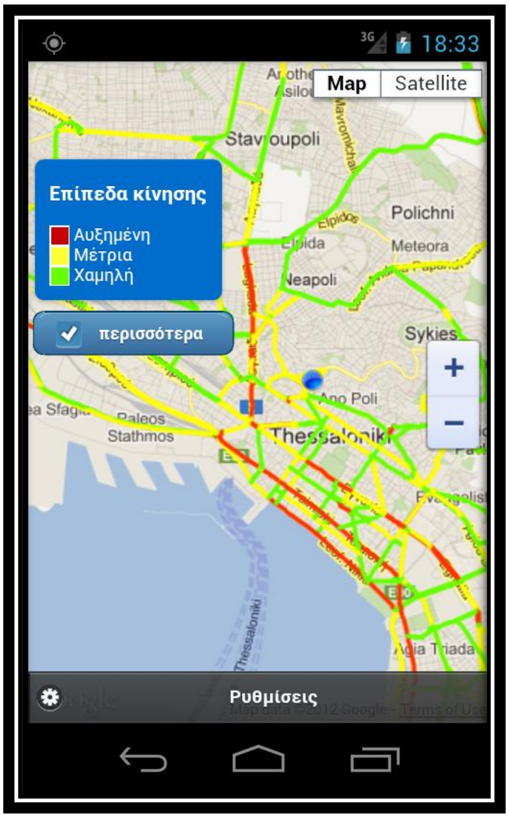


Figure 3–2 Traffic representation using colors

This paragraph describes the data monitoring functionality which has been deployed to support the application. The mobile application operates as follows:

- The application receives the position of the moving driver from the GPS receiver at regular intervals. A driver trajectory is generated through the use of two location stamps picked up after some seconds. Next, a check, whether this trajectory intersect a Virtual Checkpoint is conducted. These lines are defined based on criteria that serve the procedures for the assessment of traffic status by the system administrator. If this check is true, then the application sends to the server the necessary information (position, speed, direction). That way there is no continuous recording of the driver's location (personal data protection) and the cost of using the service is minimized due to the non-continuous transmission of data; the mobile device sends data to the server at the specific point at an explicit time, when and where the trigger fired (Figure 1–2).

When the server receives the data package, it takes on dividing it in user authentication and traffic-related data. User authentication is conducted using tokens generated by the web server. The first data are processed only for statistical study on the performance of the system depending on the number of users that have enabled the application and certification purposes. The geographic data along with speed are diverted to another instance of the server that is responsible for applying the algorithms that estimate traffic conditions. The separation of the authentication data and the collected data ensures the security and privacy.

How the service is provided through the server to the application: The server that provides traffic-related data (traffic info and journey times) undertakes to send information to users who have activated the application. The data is obtained by the application and is represented on the embedded map.

Moreover, there is another service that is responsible for sending updates about the area which each user operates. This update may refer to a change of a VC (on/off, reallocation of the VC) or to any additional information regarding to monitoring process. Additionally, areas may be changed either dynamically (e.g. after updating for false information depending on the needs), or statically after specific transportation analysis / calculations.

3.4 Practical benefits and social impact

One of the main characteristics of the developing system is the creation of an information system for traffic estimation utilizing the users and therefore, their mobile phones as meters.

So, with a minimum cost (everyone has a mobile phone, and increasingly with integrated GPS receiver) we have a large number of dynamic meters involved in the process of gathering information (Zero-infrastructure systems), contrary to static meters (sensors, etc.) that and can be installed related to huge cost of installation and maintenance. Additionally, the continuous development of telecommunications and the ever growing spread of smart mobile devices facilitate the conditions in the market for using the Internet and its services on mobile devices at low cost. The bigger the number of users is, the more secure and reliable information on traffic conditions we will have (in the concept of Cooperative mobility systems).

4. System Architecture and Design

4.1 Introduction

System design and development are based on a 3-tier architecture. Three-tier is a client–server architecture in which the user interface, functional process logic ("business rules"), computer data storage and data access are developed and maintained as independent modules, most often on separate platforms. The three-tier model is software architecture and a software design pattern.

Apart from the usual advantages of modular software with well-defined interfaces, the three-tier architecture is intended to allow any of the three tiers to be upgraded or replaced independently as requirements or according to a technology change. For example, a change of the operating system in the presentation tier would only affect the user interface code.

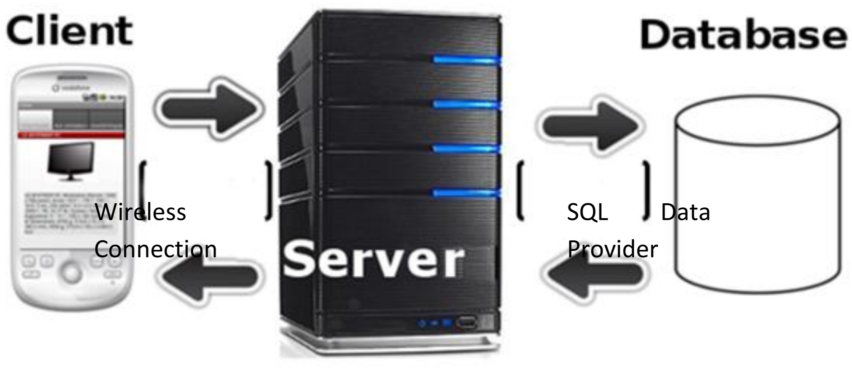


Figure 4–1 3-tier Architecture

Typically, the user interface runs on a desktop PC, workstation or on a mobile device and uses a standard graphical user interface. Functional process logic may consist of one or more separate modules running on a workstation or application server, and an RDBMS running on a database server or mainframe. RDBMS contains the computer storage logic.

The developed system has the following three tiers:

- Presentation tier

The mobile device application is part of this level. The functions of this application are connecting to the device's GPS, the storage of the latest data of the system, the sending / receiving data to / from the application server and then the depiction of the traffic conditions on the user's screen. Furthermore, a management system has been developed, a web application, to provide all the available tools for VC management.

- Application Server

The server of which this level essentially consists is responsible for communicating the application (presentation tier) to the database system. This level includes functions crucial for the proper functioning of the system, such as user authentication, verification of data and mediation for sending and receiving data from the database to the application. Application server actually makes the web services available to system users.

- Data’s tier

This level refers to the database responsible for storing data necessary for the use and operation of the system and data obtained from it. The database supports spatial libraries which are essentials for the development of location-based information systems.

4.2 System design

4.2.1 Presentation tier

The functions at this level have to do with the operation of the application and its communication with the application server. These functions are the following: user authentication, database creation / load, connection to GPS, VC data update, application core process, traffic-related data presentation.

- User authentication: The first form that appears when the user starts the application is the user authentication. The user fills in username and moves to the next form. First of all, a certification of user identification is conducted and then data is sent to inform the system that it has added another user in the system (Figure 4–2).

Figure 4–2 Register Page Screenshot

- Database creation/load: At the first use of the application at each device an internal database, for storing data VC data (VC Data Table) is created. In the next use of the application, the database already exists and simply a connection to it is established. This database allows the storage of data used by the application and can be removed during the uninstall process of the application from the user device.
- Connection to GPS: The application undertakes to connect to GPS via the internal controller of the application development framework.
- VC Data Update: The application through the connection to the GPS device acquires data relating to geographic location (longitude, latitude) and sends a query to the server to verify that the information recorded in the internal database is the latest available. If new updates are available, it undertakes to renew them.
- Application core process: The application periodically checks whether the user’s current location is a point that participates in the assessment of the

traffic status of the system. If so it shall send to the server data related to geographic position and speed of the movement.

- Traffic Presentation: The application periodically contacts the server to obtain information about the traffic-related data and in turn undertakes to display it to the user (map or plain text, incident report) (Figure 4–3) (Figure 4–4) (Figure 4–5 Instant Incident Report).

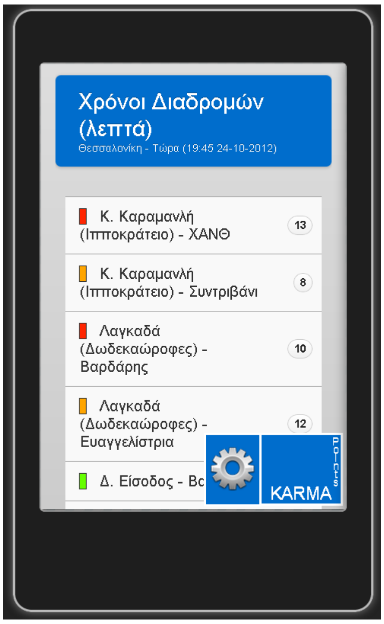


Figure 4–3 Travel times in plain text

Figure 4–4 Live Traffic Map

Figure 4–5 Instant Incident Report

Below is the **activity diagram** of the client application

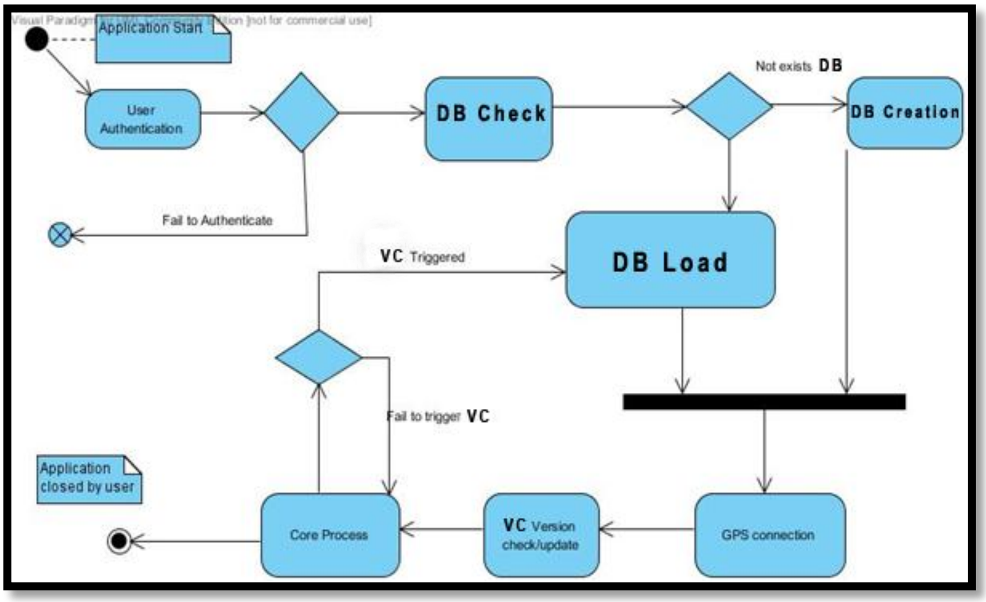


Figure 4–6 System Activity Diagram

4.2.2 Application server

The server responsible for communication, exchange of data between application and database belongs to this level. The actions performed at this level support functions of the presentation tier, such as user authentication, VC data update, traffic presentation.

4.2.3 Database Server

The database server is responsible for storing data, which initially was created to support the system and that which were derived using the system. The database server via the application server provides data to the application of the user's mobile phone. Operations performed on the database server have to do with calculations about the location of the driver, and especially the area (VC Area) they are located to.

4.3 System implementation

The application for mobile devices developed using PhoneGap [18], a cross platform framework for building mobile device applications for a variety of operating systems such as iOS, Android, Blackberry, Windows Phone, Palm WebOS, Bada and Symbian using HTML, CSS and Javascript. The application server uses is Internet Information Service 7.5 using .Net framework. Microsoft SQL Server was used as the database server.

4.3.1 Presentation tier

Data Storage: PhoneGap framework for device storage implementation is based on the W3C Web SQL Database Specification and W3C Web Storage API Specification. When application runs for first time the creation of the DB takes place as it is necessary to store data. This data refers to the VCs where the mobile application automatically sends information to the server, the user authentication data which are submitted by the user and the VC data version number.

Sample code:

```
db = window.openDatabase("VSC", "1.0", "VSC DB", 1000000);

                  db.transaction(function (tx) {
                      tx.executeSql('CREATE  TABLE  IF  NOT  EXISTS
VSCVer                              sion (AreaId, VersionNo)');
                      tx.executeSql('CREATE TABLE IF NOT EXISTS Virtu
                             alSpotCheckpoints  (id,description,  LatDi
                                     rection,LonDirection,geomAsText)');
                      tx.executeSql('SELECT * FROM VSCVersion ', [],
function (tc, results) {
                           //on success
}
});
```

Connection to GPS: PhoneGap location access framework is based on the W3C Geolocation API Specification. The following code snippet is an example of how the Geolocation API is implemented.

Sample code:

```
var options = { enableHighAccuracy: true, maximumAge: 4000, timeout: 1000 };
                var getPosCounter = 0;
                watchPosToShowToMap              =              naviga-
tor.geolocation.watchPosition(function (pos) {
                    //on successs
                }, function (error) {
                    //on error
```

Web connection: The application communicates with the server to send and receive data using wireless connection provided by the device. The connection is made by jQuery Ajax request using HTTP POST protocol Requests to a web server.

Sample code:

```
$.ajax({
                    type: "POST",
                    url:
"http://localhost/VSCControlWebService/WebService1.asmx/GetTravelTime
s",
                    data: dat,
                    contentType: "application/json; charset=utf-8",
                    dataType: "json",
                    complete: function (m, c) {
```

*Traffic Presentation***:** The depiction of motion in the application is made by using Google map services (JavaScript API). The application pulls the server for data about traffic on the traffic network.

Sample code:

```
var script = document.createElement("script");
                    script.type = "text/javascript";
                    script.src                                          =
"http://maps.googleapis.com/maps/api/js?sensor=true&callback=initial
ize";
                    document.body.appendChild(script);
```

The operation of the application core process is described at the end of the chapter for better understanding of the process.

4.3.2 Application server

.NET Framework is used for server programming. Internet Information Server 7.5 is used as the application server. The connection of the database with the application of the user, for data transfer, is not possible without using application web services. The services were developed to support the functions of the mobile device and the communication with the database.

The functions supported by the application server are:

– VC Update Process

The application, at the beginning of its operation, sends to the application server the point where it is located, its position, and the version number of VC Data Table. This version number is indicated by a serial number that changes with every change made to data in the VC Table database. The application server checks, whether user's version corresponds with database's one. If not, it bears to read the data from the database, converts it into JSON format and sends it to the user's device as a response to the request of the application.

Sample code:

[{"ID":2,"G":"40.64058736255712
22.93422479623416,40.64110027560281
22.93466482156373","A":1,"L":1},{"ID":52,"G":"40.64093743106244
22.925362777648957,40.642209022062104
22.9261570739136","A":0,"L":1},{"ID":53,"G":"40.638560185583934
22.931134891449005,40.63955480440638
22.932251052795436","A":0,"L":1},{"ID":6,"G":"40.62988903513262
22.954625678001435,40.63062271631413 22.955462889610317","A":0,"L":-
1},{"ID":7,"G":"40.62755210994412 22.95797843927005,40.62805869015517
22.95913751596072","A":1,"L":0},{"ID":48,"G":"40.60101372450033
22.963600349365265,40.60140327943068
22.965038375793483","A":1,"L":0},{"ID":49,"G":"40.604418654845425
22.963128280578644,40.60459668296361 22.964523391662624","A":1,"L":0}];

This structure essentially represents a line on the geographical axis system. The attributes A and L are used to define the preferred direction for this checkpoint. An explanation of these attributes and their usefulness follows in one of the next sub-chapters.

– Update for traffic information to a specific VC

The application during its function detects that the user passed a specific point (trigger) and undertakes to send data about the state of motion (speed of the driver) at this point. The application server bears to serve the request of the application for traffic update at the specific VC and promotes the information (VC id, speed) to the database server. Upon completion of this operation the execution of the operation of VC update process is carried out as well, in order to ensure that the application of the user stays updated throughout the duration of use.

– Distribution of traffic-related information

The data obtained by each user is used in the process of calculating the traffic situation on the road network. This data through the service of this application is transferred into the application of the mobile phone which then bears to portray it. This data structure consists of points that portray a road and the property that characterizes the state of this road. This property takes the values 1,2,3 describing the movement as free, dense and saturated, respectively.

– Separation of user authentication data and her/his geographic position

In any communication between the application and the application server, the user authentication is conducted using a token which was generated at user login state. This information is separated from information on the driver's position within the network in order to secure the privacy of the user.

1.1.1 Database Server

Figure 4–7 provides an overview of the system's database tables created to support the system functionality.

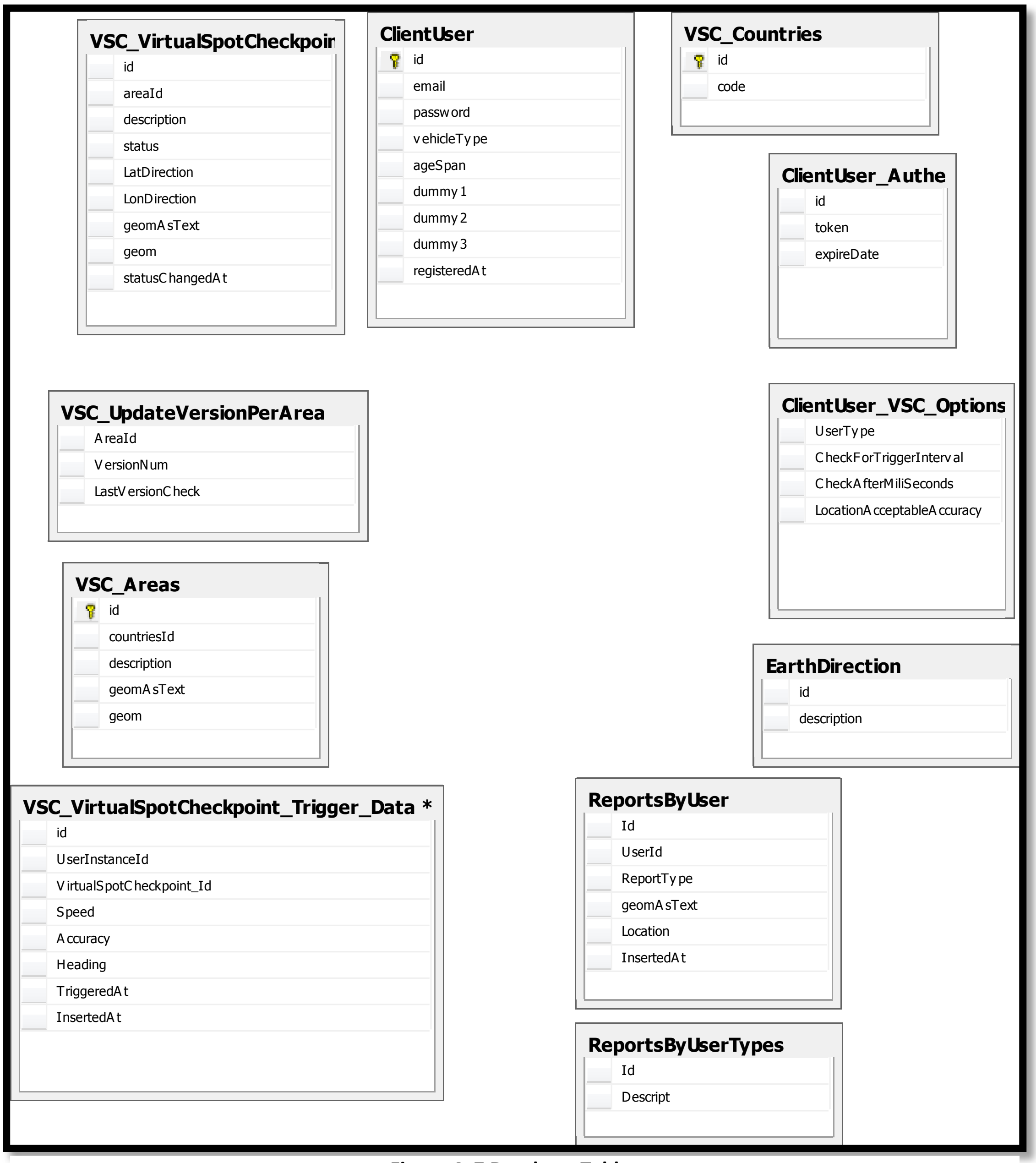


Figure 4–7 Database Tables

Table:	VSC_**VirtualSpotCheckPoint**

Description:	Contains data related to Virtual Checkpoint.

Table:	VSC_Areas, VC_Countries
Description:	Contains data related to areas where each VC is located. Used to follow update versions for VC data. Areas are located in a country tuple. Worldwide expansion of the system is supported with this functionality.

Table:	VSC_Client, ClientUser_AuthenticationToken
Description:	Contains data related to each user and supports authentication process.

Table:	VSC_VirtualSpotCheckpoint_Trigger_Data, ReportsByUser, ReportsByUserTypes
Description:	Tables that contain data of VCs triggered by user, or reports generated.

Table:	ClientUser_VSC_Options
Description:	Table that serves application with options about its functionality.

4.4 System implementation discussion

Below are described the main issues that have been analyzed and tackled during the system implementation and design.

4.4.1 The concept of the Virtual Checkpoint

The proposed traffic monitoring system builds on the novel concept of a Virtual Checkpoint (VC) which is a line in geographic space that, when crossed, triggers a client's location update to the traffic monitoring server. More specifically, it is defined by [id; x1; y1; x2; y2; d] where id, is the trip line ID, x1, y1, x2, and y2 are the (x; y) coordinates of two-line endpoints, and d is a default direction vector (e.g., N-S or E-W). When a vehicle traverses the trip line, an update is pushed to the server, including the timestamp, the VC id, the speed, and the direction of crossing.

The trip lines are pre-generated and stored in client's device. Virtual Checkpoints control disclosure of location updates by sampling in space rather than sampling in time, since clients generate updates at predefined geographic locations, compared to sending updates at periodic time intervals. The rationale for this approach is that in certain locations, traffic information is more valuable and certain locations are more privacy-sensitive than others. Through careful placement of trip lines, the system can thus better manage data quality and privacy than through a uniform sampling interval. In addition, the ability to store trip lines on the clients can reduce the dependency on trustworthy infrastructure for coordination.

4.4.2 Application core process- How to detect a trigger

The main purpose of the mobile application is to send information about the traffic condition at predetermined measurement points (VC). The VC as mentioned above is essentially a virtual line on a road. Their placement has been done perpendicularly to the road of interest (Figure 4–8).

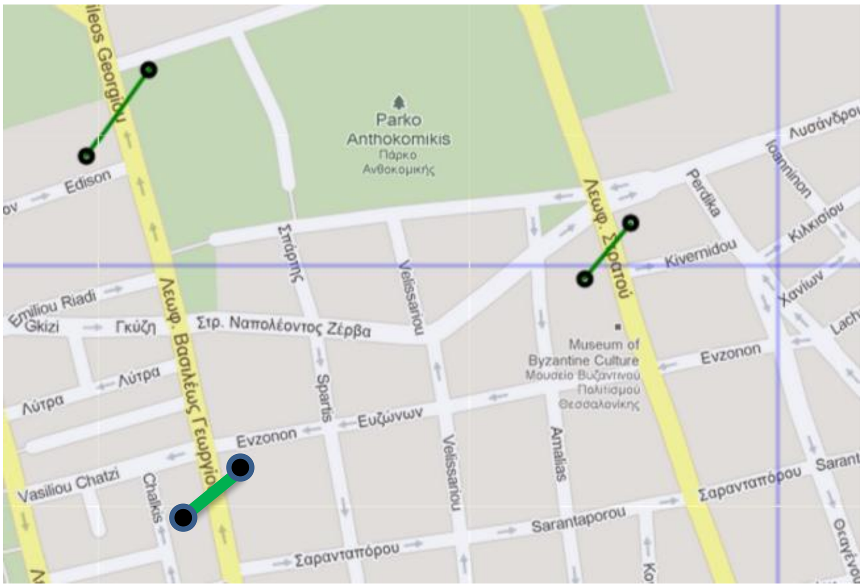


Figure 4–8 Vertical placement VC (green lines)

The vertical placement was designed to allow checking by the application that the user is passing at that moment by her/his vehicle the trigger point. To detect this, the following technique has been used. The VC is actually a line with two geographical points, the beginning and the end of it. By receiving from GPS at regular intervals the driver's position, latitude and longitude, we form a Driver Trip Line/Trajectory (DTL) assuming beginning of the line, the first point and end the next one. To detect if the user has passed a VC what happens is to check whether these two lines (VC, DTL) intersect at some point and then whether that point is a point located in the VC (Figure 4–10) as they can intersect and beyond it(Figure 4–10). The algorithm used for trigger detection is included in Appendix A.

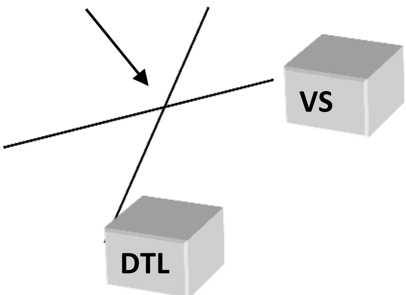


Figure 4–10 Intersection point inside VSC

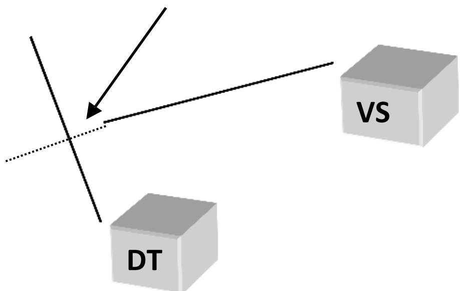


Figure 4–9 Intersection point outside VSC

This means that certainly some points which the driver passed would not be recorded, although this is part of the system and a desired factor. Additional not recording may occur due to non-precision GPS signal that may appear. This is a desirable factor as not only continuous transmission of information to the server does not occur (low cost) but there is also no complete record of the path of the driver (privacy issues).

4.4.3 Capturing the movement direction

Through the operation of the application core process described above is checked when the driver has gone through the VC. The VC covers the entire width of the road in order to absorb the differences marked by GPS. The result of this implementation is to receive information on the two-way traffic on some streets. This creates the problem of separation of information. To allow the separation the procedure described below was followed.

During the creation of VC, inclusion of direction has been done on the geographical axis system, we are interested in. This entry was done by using attributes such as latD (latitude direction), lonD (longitude direction) that is the direction in longitude and latitude respectively (Figure 4–11).

Results | Spatial results | Messages

	id	areaId	description	status	LatDirection	LonDirection	geomAsText	geom	statusChangedAt
1	42	2	Chalkidikis, Themi 570 01, Greece	1	0	1	40.5594604244703 23.006236743865998,40.56120017...	0xE610000001 1420F032BB98013740A64031669C474440006...	2012-08-10 14:45:37.437
2	2	1	Εθνική Οδός 2 4, Θεσσαλονίκη, Ελλάδα	1	1	1	40.6405873625571 2 22.9342247962341 6,40.641100275...	0xE6100000011420F0325B29EF3640F53446C4FE5144408056...	2012-07-27 10:29:36.670
3	52	1	Sapfous 45-51, Thessaloniki 546 27, Greece	1	0	1	40.64093743106244 22.925362777648957,40.64220902...	0xE6100000011420F03293E4EC36400499DC3C0A524440006...	2012-08-10 15:20:41.347
4	43	2	Chalkidikis, Themi 570 01, Greece	1	0	1	40.5576019625840 1 23.01014204019168,40.558673266...	0xE6100000011420F032AB98023740EBBD48805F474440006...	2012-08-10 14:45:45.727
5	53	1	26is Oktovriou 18, Thessaloniki 546 27, Greece	1	0	1	40.63856018558393 4 22.93113489144900 5,40.6395548...	0xE6100000011420F032DB5EEE36402BCE1457BC51444000...	2012-08-10 15:21:07.860
6	6	1	Εγνατία 154, Θεσσαλονίκη 546 21, Ελλάδα	1	0	-1	40.62988903513262 22.95462567800143 5,40.63062271...	0xE6100000011420F0325962F4364076003334A0504440006B...	2012-08-10 16:39:37.970
7	7	1	Εγνατία 156, Θεσσαλονίκη 546 21, Ελλάδα	1	1	0	40.62755210994412 22.9579784392700 5,40.628058690...	0xE6100000011420F032133EF53640765FA6A053504440006B...	2012-08-10 16:39:17.587
8	48	1	Marasli 38-46, Thessaloniki 542 48, Greece	1	1	0	40.6010137245003 3 22.963600349365265,40.60140327...	0xE6100000011420F03283AEF636408A968904EE4C4440006...	2012-08-10 22:02:31.100
9	49	1	Κωνσταντίνου Καραμανλή 112-118, Θεσσαλονίκη 542 ...	1	1	0	40.604418654845425 22.963128280578644,40.6045966...	0xE6100000011420F032938FF63640A3D329975D4D4440006...	2012-08-26 01:36:43.480
10	10	2	Θερμοπυλων, Πυλαία Χορτιάτης 570 10, Ελλάδα	1	1	1	40.62180308882009 23.05065412515262,40.634588797...	0xE6100000011420F032ABF70C37405C845D3E974F4440006...	2012-08-08 12:37:55.347
11	23	2	Χαλκιδικής, Θέρμη 570 01, Ελλάδα	1	0	1	40.5653778146791 2 22.998619270263703,40.56580565...	0xE6100000011420F03283A5FF364023F7DB4C5E484440006...	2012-08-10 14:44:34.510
12	45	2	Chalkidikis, Themi, Greece	1	-1	0	40.5669772948765 8 22.9951592206344 9,40.566337558...	0xE6100000011420F032C1C2FE3640E48845B692484440006...	2012-08-10 16:31:17.467
13	14	1	Αλεξάνδρου Παπαναστασίου 41, Θεσσαλονίκη 544 53, ...	1	1	0	40.6133170855091 4 22.962527465759308,40.61349680...	0xE6100000011420F0323368F636407E2B9C2C814E4440006...	2012-08-10 16:38:34.847
14	15	1	Στρατηγού Μακρυγιάννη 5-11, Θεσσαλονίκη 546 35, Ελ...	1	0	-1	40.6328935330659 8 22.9484941481933 9,40.634115492...	0xE6100000011420F03283D0F23640242FC1A70251444000 6...	2012-08-10 16:39:46.393
15	44	2		1	1	1	40.55509132688677 5 23.013467979370148,40.5562113...	0xE6100000011420F032A372033740CFA28B3B0D474440006...	2012-08-24 13:41:42.757
16	46	2	Chalkidikis, Themi 570 01, Greece	1	1	0	40.5652494470979 4 22.9947515248642 28,40.56591365...	0xE6100000011420F03209A8FE364012AF08185A484440006...	2012-08-10 16:31:27.390
17	54	1		1	0	1	40.6361665720727 5 22.9338600158081 36,40.63698194...	0xE6100000011420F0327311EF364032EEFEE76D514440006...	2012-08-10 15:21:46.083
18	19	1	Συγγρού 17-21, Θεσσαλονίκη 546 30, Ελλάδα	1	0	1	40.6379740024555 1 22.93911714547732 6,40.63833359...	0xE6100000011420F032FB69F03640501FD221A9514440006...	2012-08-10 15:35:49.083
19	20	1		1	0	-1	40.6357432029289 1 22.94422407144168,40.636281714...	0xE6100000011420F032ABB8F13640F29D840860514440006...	2012-08-10 16:42:05.863
20	21	1	Πλάτωνος 7, Θεσσαλονίκη, Ελλάδα	1	1	1	40.6342125382373 6 22.94639129632571 4,40.63515803...	0xE6100000011420F032B346F23640A7385FE02D514440006...	2012-08-10 15:40:57.000

Query executed successfully. | KONPACHHIT\KONPACHHIT (10.5... | IMET\KPachatouridis (56) | master | 00:00:00 | 99 ro

Ln 1 Col 1

Figure 4–11 VC Data Structure

Taking into account the geographical axis (Figure 4–12) system, we conclude that during its movement towards the east longitude increases while moving to the north latitude is increasing.

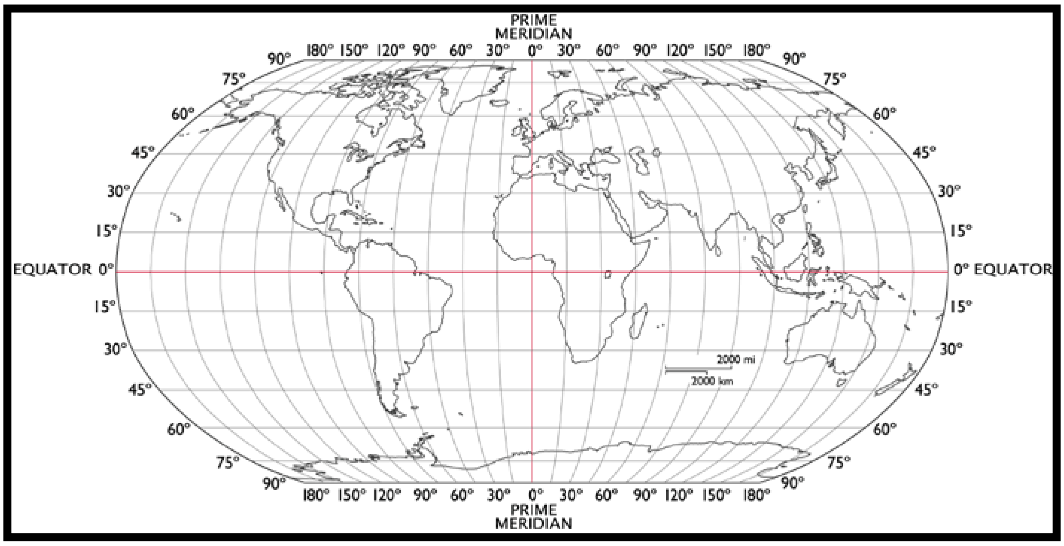


Figure 4–12 Geographical axis system

For a part of the road, we want to take data, with the driver's movement at the east end to the equator, put the attribute latD to 1. If according to the placement of the road on the geographical map,we are not interested in the movement of the driver as to the longitude, then we put the property lonD to 0. Having calculated the two points from the DTL, start point and end point, we define the latD and the lonD of the movement of the driver. Comparing these values with those of VC that a user triggered, we determined whether the driver passed by the VC towards the direction,we are interested in.

4.4.4 Need of classification of VCs in areas.

To reduce the volume of the dispatched information to the user and for the better functioning of the system, the grouping of VCs into their respective geographical areas is done. The creation of these areas has to be determined after research and studies for every area of interest with respect to the individual characteristics of each of them. For purposes of testing and implementation of the system, the separation of Thessaloniki (Greece) was done in 2 regions (city central area, city suburbs) (Figure 4–13).

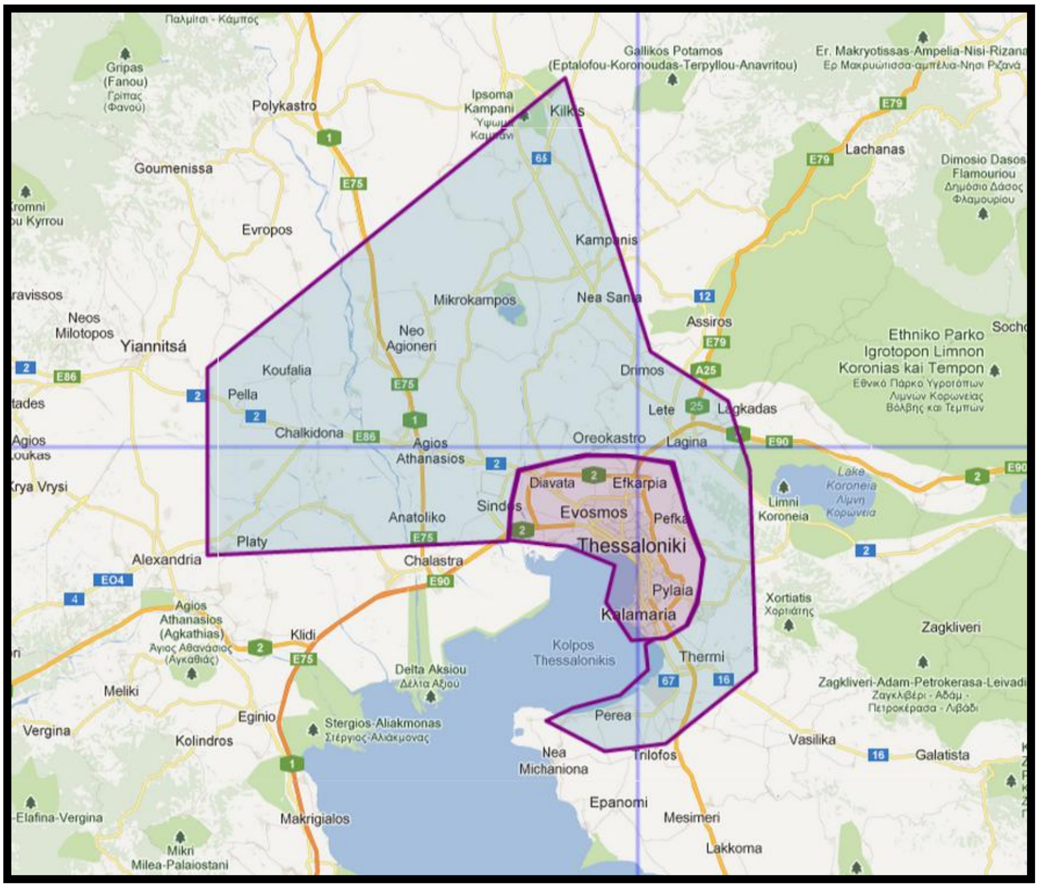


Figure 4–13 Separation of Thessaloniki in two areas

This has resulted in that for the operation of the application, a smaller amount of data is required depending on the position of the moving driver. When the application establishes a connection to the central web server, a check is conducted in the area in which that moment the driver is located, and the system adapts to it. With this implementation, the computational requirements of the application and the volume of the information sent are significantly reduced.

4.5 Virtual Checkpoint Management console

As it was already stated, the system is based on the virtual checkpoint concept. In order to make feasible the management of the system, it was created a web based- management control center. This control center is responsible for the management of VC areas and for the management of virtual checkpoints. Furthermore, it provides monitoring tools, such as active user's overview, user generated reports and, finally the triggered VCs by the users.

The administration console was developed using asp .NET framework. Google maps API was used as a reference map for the creation of areas and VCs. Below are described the main functionalities of the management control system.

- User Authentication: Only authenticated users have access to the management system. Access is granted after communication with the system administrator. User logs into administration console via a form, by completing username and a password (Figure 4–14).

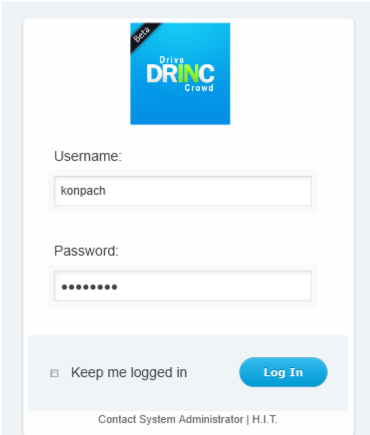
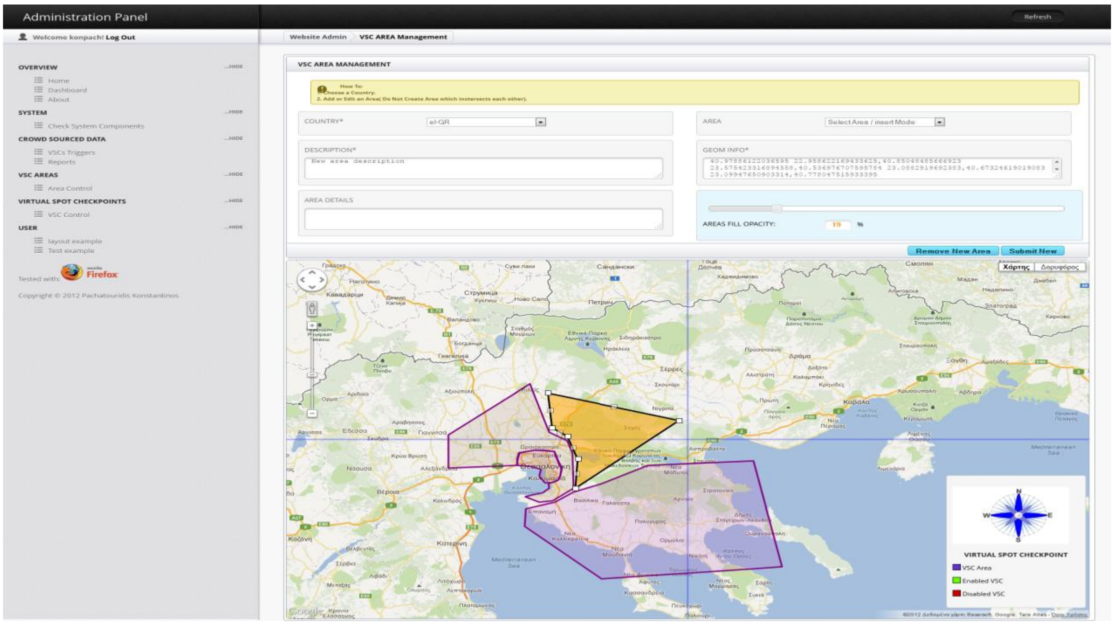


Figure 4–14 Login Form of Management Control Center

- VC Area Creation: This section of the administration console is responsible to provide to the administrator the appropriate tools to create-edit and delete VC areas with respect to classification process as it was described at sub-chapter 4.4.4. The administrator uses the tool to design an area, over google maps background. Furthermore, the admin can add a country field for being able to have a better management experience by classifying the areas by the country of origin.



- Virtual Checkpoint management tool: These tools provide the administrator the appropriate functions to create-edit and delete a virtual checkpoint. User actually draws a line over a road network (Figure 4–15). Each drawn VC is located automatically to an area, which the administrator has already created.

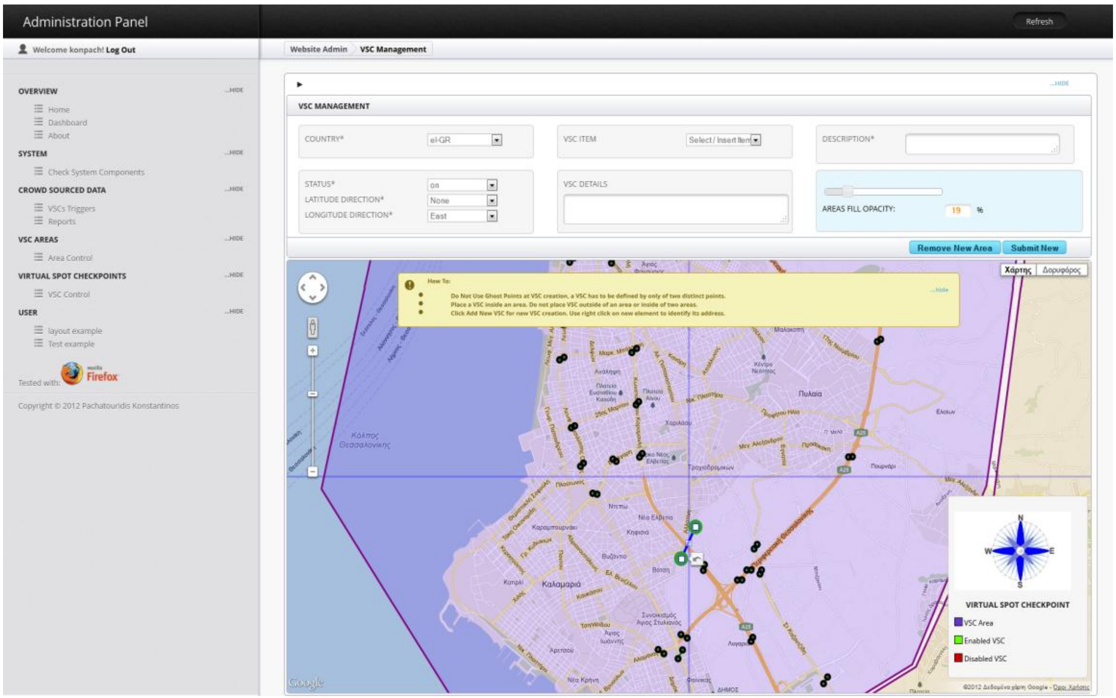


Figure 4–15 VC Management Tool

Apart from that it is required to include additional information, as the desired direction of the probe vehicle (by setting the longitude/latitude direction), a description and the status (active or inactive) of the VC.

- Crowded sourced generated data: This tool provides a listing of reports (Figure 4–16) and VCs triggers (Figure 4–17) generated by users.

Descript	InsertedAt	geomGoogle
Accident	23/10/2012 3:16:05 μμ	40.5679325 22.9965773
Accident	23/10/2012 2:55:52 μμ	40.567845383333335 22.996402333333336
Accident	23/10/2012 2:52:18 μμ	40.567857483333334 22.996457616666667
Accident	22/10/2012 7:44:52 μμ	40.60093034 22.96088206
Accident	22/10/2012 7:33:23 μμ	40.56769853 22.99663721
Accident	22/10/2012 7:31:27 μμ	40.56766796 22.99657344
Accident	21/10/2012 9:33:30 μμ	40.601679 22.96987657
Accident	21/10/2012 5:52:00 μμ	40.61323127 22.96327755
Accident	21/10/2012 12:07:06 πμ	40.9467024 24.4212453
Accident	20/10/2012 8:45:18 μμ	40.608674666666666 22.9790998
Accident	20/10/2012 8:45:09 μμ	40.60867615 22.978569224999998
Accident	20/10/2012 8:44:50 μμ	40.608674666666666 22.9790998
Accident	20/10/2012 8:42:23 μμ	40.608674666666666 22.9790998
Accident	20/10/2012 4:22:43 μμ	40.600651742857146 22.9612733
Accident	20/10/2012 2:08:25 μμ	40.57674124 22.97025924
Accident	20/10/2012 1:04:46 πμ	40.60255672 22.95886265
Accident	19/10/2012 7:28:14 μμ	40.587819857142854 22.96798982857143
Accident	19/10/2012 9:47:07 πμ	40.7871413 22.4102345
Accident	19/10/2012 9:46:56 πμ	40.7871413 22.4102345
Accident	18/10/2012 9:50:28 πμ	38.04960575263329 23.788112084835067
Accident	18/10/2012 9:04:13 πμ	40.5735368 22.99012612
Accident	18/10/2012 8:43:12 πμ	40.641347725 22.945002825
Accident	18/10/2012 12:07:40 πμ	40.6006271 22.961246266666667
Accident	17/10/2012 7:33:39 μμ	40.5367122 23.0075756
Accident	17/10/2012 7:33:36 μμ	40.5367122 23.0075756
Accident	17/10/2012 6:20:07 μμ	40.5367096 23.0075639

Figure 4–16 User generated reports

InsD	VSCID	TriggeredAt	InsertedAt	Speed	Accuracy	Heading
kUw-d0MOvGB0mz4CDxVWqFtW78QA6tXJIRboozQXHk6-DOIUI9pFD6bNS5ZIFIVe	20	24/10/2012 8:47:49 πμ	24/10/2012 8:47:48 πμ	-1	1032	-1
kUw-d0MOvGB0mz4CDxVWqFtW78QA6tXJIRboozQXHk6-DOIUI9pFD6bNS5ZIFIVe	19	24/10/2012 8:40:45 πμ	24/10/2012 8:40:46 πμ	-1	1194	-1
NMaDkVy49zDiSBBxKJXU41Q-i3XV0VTB1xuu3fZ6QvhLv3XXHUbwBD38AKZ7I0TN	49	23/10/2012 3:14:10 μμ	23/10/2012 3:14:11 μμ	-2	453	-1
AStyQZ-HRTJzG3pTwTqXdn-rTBcqWaivpe5h1TXMuumvSTRLatWftJtSSzWgfZQK	49	23/10/2012 2:52:49 μμ	23/10/2012 2:52:53 μμ	-2	412	-1
tgNTL9gOLIWzVU8DfzuTHPzJrKXSsHOaeDdcsL2kRIX8XnVvMI2-1OrJed9cyFca	19	22/10/2012 7:40:20 μμ	22/10/2012 7:37:24 μμ	62	5	355
tgNTL9gOLIWzVU8DfzuTHPzJrKXSsHOaeDdcsL2kRIX8XnVvMI2-1OrJed9cyFca	17	22/10/2012 7:39:21 μμ	22/10/2012 7:36:24 μμ	92	6	319
FKJrtDMTeoQVI7q7WHPNbsvKekSzCKyAsHPuRuATzzelUPesBsXBflsAc551KchF	23	22/10/2012 8:56:53 πμ	22/10/2012 8:53:58 πμ	53	6	143
5W5o6mIeNuWerUzXgmoPbpXHdkWT1EX8dGdG49y8KTD3oEtAtmez6GantDw4DZwu	8	21/10/2012 9:29:41 μμ	21/10/2012 9:27:13 μμ	1	680	123
5W5o6mIeNuWerUzXgmoPbpXHdkWT1EX8dGdG49y8KTD3oEtAtmez6GantDw4DZwu	6	21/10/2012 9:29:41 μμ	21/10/2012 9:27:12 μμ	1	680	123
KsHFdAzFBn3wL6luFLBnGpP27roIEGaU7NKiWDW0W2WWx5PZv2xrBLL8ktexOEXS	37	21/10/2012 5:59:41 μμ	21/10/2012 5:57:10 μμ	7	3	296
KsHFdAzFBn3wL6luFLBnGpP27roIEGaU7NKiWDW0W2WWx5PZv2xrBLL8ktexOEXS	35	21/10/2012 5:55:50 μμ	21/10/2012 5:53:19 μμ	25	5	356
KsHFdAzFBn3wL6luFLBnGpP27roIEGaU7NKiWDW0W2WWx5PZv2xrBLL8ktexOEXS	22	21/10/2012 5:54:08 μμ	21/10/2012 5:51:37 μμ	49	4	352
TCw4qTu-AdlmVR8TFJfTWp4zIzOV585K-5rEqzZcmuJOG01OS9gHm3bxk3gBP5pX	5	21/10/2012 2:26:30 μμ	21/10/2012 2:26:31 μμ	99	5	275
TCw4qTu-AdlmVR8TFJfTWp4zIzOV585K-5rEqzZcmuJOG01OS9gHm3bxk3gBP5pX	4	21/10/2012 2:25:49 μμ	21/10/2012 2:25:51 μμ	100	5	9
TCw4qTu-AdlmVR8TFJfTWp4zIzOV585K-5rEqzZcmuJOG01OS9gHm3bxk3gBP5pX	3	21/10/2012 2:25:00 μμ	21/10/2012 2:25:01 μμ	105	5	29
TCw4qTu-AdlmVR8TFJfTWp4zIzOV585K-5rEqzZcmuJOG01OS9gHm3bxk3gBP5pX	41	21/10/2012 2:23:12 μμ	21/10/2012 2:23:14 μμ	63	5	47
TCw4qTu-AdlmVR8TFJfTWp4zIzOV585K-5rEqzZcmuJOG01OS9gHm3bxk3gBP5pX	18	21/10/2012 2:13:58 μμ	21/10/2012 2:14:00 μμ	103	5	227
H2PNAChpnM1FbVphWIGZ25ncpHIf-CrZicu5mRX1S9wgG2fZc3ZsEsy8dR07KDti	33	21/10/2012 12:55:44 πμ	21/10/2012 12:53:18 πμ	43	8	355
H2PNAChpnM1FbVphWIGZ25ncpHIf-CrZicu5mRX1S9wgG2fZc3ZsEsy8dR07KDti	34	21/10/2012 12:52:39 πμ	21/10/2012 12:50:16 πμ	31	21	8
7v74VGSLIqxZE0apGtisdhAUBKp3AiK561OcRtzq0ztbAaGQz-y79JJ4P3morQ5b	3	20/10/2012 6:33:50 μμ	20/10/2012 6:33:53 μμ	84	5	28
7v74VGSLIqxZE0apGtisdhAUBKp3AiK561OcRtzq0ztbAaGQz-y79JJ4P3morQ5b	41	20/10/2012 6:32:02 μμ	20/10/2012 6:32:09 μμ	39	260	24
7v74VGSLIqxZE0apGtisdhAUBKp3AiK561OcRtzq0ztbAaGQz-y79JJ4P3morQ5b	41	20/10/2012 6:31:49 μμ	20/10/2012 6:31:52 μμ	53	5	48
7v74VGSLIqxZE0apGtisdhAUBKp3AiK561OcRtzq0ztbAaGQz-y79JJ4P3morQ5b	42	20/10/2012 6:26:34 μμ	20/10/2012 6:26:37 μμ	24	5	76
kfg74u9-E3cadi2w6Bm3x2TTVTg6X-HT4aAdf3TNTd7EOkal3vDTGE549qp72FTK	44	20/10/2012 2:23:21 μμ	20/10/2012 2:23:28 μμ	40	5	154
uDewJuiP-E51-tPKk26AccmX0QsLDL8lbdksWlmT60Lu12kCzk5udlouggkQ23QI	3	20/10/2012 3:06:18 πμ	20/10/2012 3:06:19 πμ	97	5	30
uDewJuiP-E51-tPKk26AccmX0QsLDL8lbdksWlmT60Lu12kCzk5udlouggkQ23QI	2	20/10/2012 3:05:06 πμ	20/10/2012 3:05:09 πμ	98	5	45
uDewJuiP-E51-tPKk26AccmX0QsLDL8lbdksWlmT60Lu12kCzk5udlouggkQ23QI	41	20/10/2012 3:04:30 πμ	20/10/2012 3:04:32 πμ	79	5	46
uDewJuiP-E51-tPKk26AccmX0QsLDL8lbdksWlmT60Lu12kCzk5udlouggkQ23QI	42	20/10/2012 3:04:12 πμ	20/10/2012 3:04:14 πμ	46	6	73
Z1gVcCsZkoaCapUB0oldtOx-dlUs684u1ZKGiqXC1yl-JTqvk3QPHbiOhxUeqxPf	36	19/10/2012 10:12:40 μμ	19/10/2012 10:10:14 μμ	20	4	329
Z1gVcCsZkoaCapUB0oldtOx-dlUs684u1ZKGiqXC1yl-JTqvk3QPHbiOhxUeqxPf	22	19/10/2012 10:09:19 μμ	19/10/2012 10:06:52 μμ	46	7	354

Figure 4–17 VCs triggers

- System check module: This tool provides the ability to check the system components, such as the web/application server and the database server (Figure 4–18).

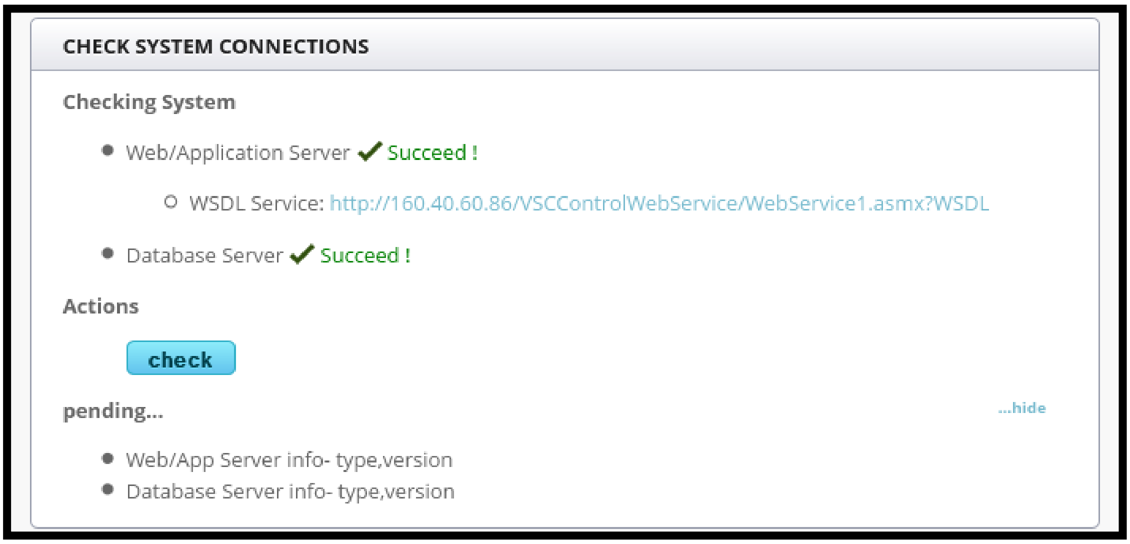


Figure 4–18 Check System Components

4.6 Summary

The implemented system was designed following the 3-tier architecture model. The application server is deployed as a web server, which actually can serve various applications in future developments. The Presentation tier application can be hosted in different platforms as a cross-platform implementation was followed; The VC triggers component can be used as an external plug-in in various applications. Finally, issues arose about VC trigger detection, direction of the probe vehicle were studied and solved.

5. Commercial Exploitation Issues

5.1 Overview

The commercial success of a system, such as the one implemented for this thesis, depends on a number of different factors, such as competition, cost, functionality, target group, etc. Market research on the customers and the current competitors of this application has been undertaken, and the results are analyzed. Implementation cost and user privacy issues involved both directly and indirectly to the operation are also taken into account for this study. The current chapter also refers to the benefits of developing this system (prototypes, maturity of innovation, contribution to the improvement of everyday life, etc.) while a SWOT [19] analysis of the system is carried out.

5.1.1 Novelty of the proposed system

Although there are a number of similar approaches developed, the proposed system has several new characteristics that distinguish it from the competition on an international level. All the relevant applications (both those provided via mobile phones, and those offered by personal pilots) are based on traffic data coming from expensive and difficult to maintain systems for recording movement (inductive loops, traffic measuring cameras,etc.). The main advantage of this project is that it requires no infrastructure to function as the ”measuring stations” are the users themselves, and therefore, given an adequate number of users, it can work on virtually every road network, not just in Thessaloniki. The pilot was deployed for Thessaloniki because of the existing infrastructure that provides the application with real-time, traffic data collected by sensors on the main roads around the city center.

5.1.2 Technological maturity

The maturity level of the proposed innovative application is quite high, as no specific future actions are required both for development and actual use. At the level of acceptance by users, the service is very mature, given the ever increasing use of information services and devices for the traffic on road networks.

5.1.3 Business-ready implementation feasibility

The possibilities of practical implementation of the proposed system are excellent, with great potential for success and acceptance by users. The proposed system is entirely designed to be put into practice by a wide community of drivers owning a GPS and data enabled smart mobile devices.

5.1.4 Evaluation of commercial exploitation

The potential commercialization of the proposed system, first of all, depends on its acceptance by an adequate number of users, which could be estimated through a preliminary inquiry in the market. The consultation with mobile phone companies on matters relating to the proper service offered by the system to users is mandatory. As there are no other special requirements, the commercial exploitation of the system can begin immediately. The potential users, however, should be relatively informed through appropriate channels of communication / advertising. The system can be used commercially in various ways, either by institutions / individuals who develop / evolve it or via mobile phone companies that deal with services of travel information.

5.1.5 Contribution to the country's extroversion

The contribution of the proposed system in the extroversion of the country may be firstly, regarded positive. The proposed system can be easily used by users abroad because of the general concept that governs it; it is independent of specific spatial constraints for its implementation. Thus, if the application receives real commercial exploitation, there will be the possibility of promoting know-how and technology developed in Greece outwards, contributing thus to the extroversion of the country. Also, because of particular interest and utilitarian purpose of the service provided through the system, it is likely that there will be interest from either individuals or mobile telephone companies or information providers for traveling abroad to exchange knowledge or cooperation in the provision of the respective service to other countries.

5.1.6 Sustainable growth

The system's contribution to the sustainability vision is quite straightforward; drivers receive real-time traffic information, and therefore, they avoid traffic jams, significantly reducing their travel time, fuel consumption, emissions, etc.

5.1.7 Social impact

The system is estimated to contribute very positively to improve the daily lives of citizens - both those who move about and all the others - in different ways as shown below:

- Avoidance of traffic congested road sections
- Avoidance of environmentally aggravated road sections
- Reduction of the time lost during a journey, due to traffic congestion
- Reduction of emissions from vehicles
- Improvement of the environmental conditions due to the better vehicle traffic on the network.
- Creation of a fulfilling sense of participation in a community of users who both nurture and exploit the information of other users in total.

5.2 Community based project

The concept of the app is based on the joint contribution of the community of users, with a common goal of improving the life quality of its members and for this reason it is distributed free of charge. The notion of "community project" and crowd sourcing presupposes the voluntary contribution of each member; it requires, nevertheless, a form of crediting those users who contribute, in contrast to those who simply use it. In this context, the app makes use of a point collection system (gamification[8]). Below are described the main notions around the crowd sourced applications and the gamification concept.

[8] Gamification is the use of game mechanics and game design techniques in non-game contexts. Typically gamification applies to non-game applications and processes [24].

5.2.1 Crowd sourced application and gamification

The term crowd sourcing first coined in a wired magazine article by Jeff Howe [26] and the subject of his book. The following definition is offered at Howe's web site: "Crowdsourcing is the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in the form of an open call." One of the major gaps of current ITS traffic monitoring implementations is the inability to capture events generated by vehicles (a report, the current location). The basic idea of applying the crowd source concept to the described traffic monitoring system is to use the crowd with smart mobile phones to enable certain ITS applications(travel times computation, user generated reports) without the need of any special sensors or communication devices, both in-vehicle and on-road (zero-infrastructure).

One of the key challenges to guarantee the optimal usage of a crowd sourced system is how to recruit qualified crowd workers. The answer is that they need incentives; although it is not always easy to find the right ones. Using money is easiest, strait forward, and almost works, even though this requires a vast budget users may trend to cheat for a better pay. Using money incentives can increase quantity, but they may destroy other pre-existing motivations and decrease the quality. One way of motivating users to work hard without paying money is the gamification.

Gamification ads game play elements for non-game application services and systems using game theory and mechanics. Until the end of 2015, Venture Beat forecast[9] shows that 50% of companies that manage research and innovation will use gamification, while 1.6$ billion would be spent in gamification development. People love gaming while the opposite of game is not to work; it's a depression.

The developed mobile application uses a point collection system (with respect to gamification) as follows: The more a user uses the app, and therefore contributes by submitting traffic data, the more "Karma Points" s/he is awarded (**Error! Reference ource not found.**). In the future, users who overcome a minimum amount of points will be awarded with access to real-time traffic data, whereas users who do not contribute will have access to hourly data. While beta testing is in process karma points just simulate the final version functionality.

[9] Venture Beat, Bloom BusinessWeek,M2Research

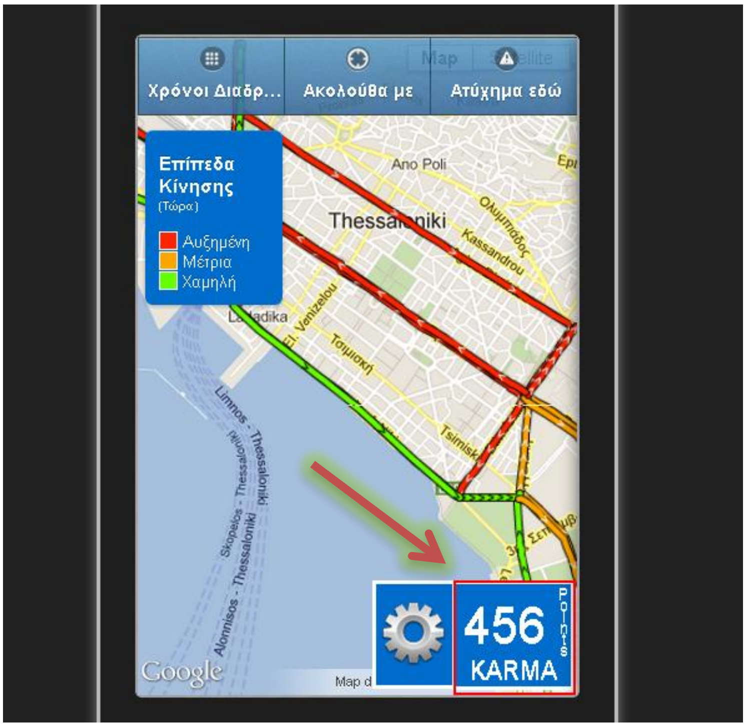


Figure 5–1 Karma Points (gamification)

5.3 SWOT Analysis

SWOT is the acronym for Strengths, Weaknesses, Opportunities and Threats. A SWOT analysis is a general technique which has been applied to this system, which involves generating and recording the strengths, weaknesses, opportunities and threats of the designed system. The objective of this thesis was the design and implementation of a Traffic Estimation system. Therefore, the SWOT analysis assumes that the system has been completed and is ready for installation. A detailed discussion of each part of the SWOT analysis is provided below.

5.3.1 Strengths

Zero-infrastructure system: An advantage of the system is the zero structure of the infrastructure. To implement the system only the existing infrastructure is required. The usage of the users as dynamic meters replaces the static meters of the existing infrastructure.

Low Cost: Due to the zero structure of the system's infrastructure, the cost of operation concerns only the use of service of sending / receiving data by the providers of mobile telephony. This cost is quite small compared to the cost of installation and maintenance of meters around the road network.

Real-time data: The structure of the system ensures the evaluation of the traffic conditions of the road network in real time, providing the user with immediate updates.

Dynamic character of the system application: The structure of the system with the use of VCs offers the possibility to study the efficiency and effectiveness of the system and in the next stage, the change of the measurement points and frequency of data collection according to the results of these procedures. Moreover, due to the structure of the system, its usage and application in each geographic region are possible. The only requirement here is to design new VCs through the management console which is available as a part of the system.

5.3.2 Weaknesses

Cost of using data services: The use of the system requires the user's connection to the Internet and the use of data services. Telecommunication providers apply different pricing policies which, according to every indication, provide the user with quite economic packages of data services because of increased competitiveness. The cost of usage might once have been a prohibitive drawback to the development of web systems of this kind, but now it is observed that this fact is changing as the mobile internet cost is constantly dropping. Today, most mobile telephony providers in Greece offer a low-end mobile data plan that includes 100MB data for a price around €5. This package is more than enough for the vast majority of users of DRinC(mobile app). Therefore, we believe that the overall usage cost is so low and it wouldn’t prohibit a large number of people adopting it, given the fact that already. According to a study conducted in 2011[10], in Greece 24.6% of mobile phone owners were also active subscribers of 3G (mobile data) services, thereby for a large number of people it would have zero extra cost to their monthly bill.

10 http://www.observatory.gr/files/meletes/A100526_%CE%A0%CF%81%CE%BF%CF%86%CE%AF%CE%BB%20%CF%87%CF%81%CE%B7%CF%83%CF%84%CF%8E%CE%BD%20internet%202010.pdf

5.3.3 Opportunities

Originality: All the relative applications that inform users on traffic conditions on road networks are based on traffic data coming from expensive and difficult to maintain systems for recording movement (inductive loops, traffic measuring cameras, etc.). The proposed system requires no infrastructure to function as the 'measuring stations' are the users themselves while the system operates completely anonymously and can thus work on all road networks, not just on those which, until now provided (because of the existing infrastructure) the respective information services.

5.3.4 Threads

*Collaborative system***-** *community based project***:** The structure of the system presupposes the participation of many users for proper testing, study and operation of the system. The collaborative character of the implementation adds a weakness in the system, which through proper organization and promotion of the project can be overcome and transformed to a great opportunity. Furthermore, applying a gamification principle, as it was already described, would decrease the possibility of failure.

5.4 Summary

The system proposed and developed for the purposes of this thesis and the preliminary SWOT analysis, is considered to have a lot of opportunities and high potential for implementation and operation. The low cost of implementation because of the zero infrastructure requirements and the increasingly accessible to the user data services create such conditions for testing and implementation of the system. Although the collaborative nature of the implementation poses difficulties and disadvantages, it creates the conditions for real-time update and dynamic management of the system.

6. Conclusions and Further Work

The scope of this thesis is the design and implementation of a real-time road traffic information system. The aim was to create a zero-infrastructure system that offers the user the possibility of up-to-date information about the traffic conditions on the roads. Zero-infrastructure is supported by the usability of the users of the system as dynamic meters (sensors). Utilising a novel concept, the Virtual Checkpoints, the structure of the system shows a dynamic character, while ensuring the low cost of implementation and protection of privacy. In this chapter, we summarise our work, present our conclusions as well as some recommendations for further research and development.

6.1 Conclusions

This section evaluates the introduction of the Virtual Checkpoint concept described and used in the system which is implemented in the framework of this work. The concept of the project is based on Virtual Checkpoint methodology. We observed that GPS position errors due to low accuracy or to not continuous position data, in the time domain, lead to false crossing triggers. In order for us to overcome this problem, we applied certain filters, such as the time difference between the two positions for creating the driver trip line and the length of the driver trip line with respect to the given time difference between two continuous positions.

Another field test was to validate the speed accuracy which was recorded by the user's device. Speed measurements are sent by the wireless access provider to the web server every time a probe vehicle triggers a VC. During the experiment, every time a trigger fired, the speed of the vehicle (by the speedometer) was recorded. On average, the vehicle speedometer reported a speed of 8km/h faster than the GPS device. Note here that a certain speedometer error rate is common in all passenger vehicles. Most speedometers have tolerances of some ±10%, mainly due to variations in tire diameter [23].

One issue concerning, not only the presented approach but all similar approaches, is user privacy. Although the VC concept preserves user privacy and tries to minimize the continuous tracking, by using a proxy server which distinguishes the information between user profile and location data, a question is how to improve location privacy within cellular networks. This thesis does not address these issues while they are out of its scope.

The placement of the VCs on the network for testing the system was done without any particular method, but the effective use of the system requires a further study by transport experts. System collects traffic-related data only for the area of Thessaloniki, as only this area is configured and managed from the system administration panel.

During the testing of the system in real conditions, it was found that the application had been successfully performing all the procedures of connection to the GPS, authentication of user, updating the VC table and sending data to the server during the passage through a VC. Poor performance was observed during the depiction of the traffic on the road using Google Map services due to a delay in transferring packets while the used map is not provided in offline mode. When using WLAN services no malfunction to the service was observed.

The experiment of using mobile devices as traffic sensors demonstrated that it is feasible to use the concept of VC for real time-traffic data collection, while preserving individual's privacy when collecting data.

Mobile application's beta version is uploaded to Google Play (mobile app market of Android). Until November 2012, the app was installed by 67 users; 48 of them active. Promotion through social media, web page and mailing lists does not lead to positive results, while only ± 5% of overall target group size installed the application. It is obvious that better promotion of the community-based character of the project is required.

6.2 Recommendations for Further Work

In this subsection, we record ideas and practices to optimize the system. These improvements concern both the technical aspects of the implementation as well as the design of the system. Some improvements and recommendation for further work are described below.

1. Particular steps are necessary for data usage reduction and for quality control of probe vehicle data:
    a. Insert of necessary information to the base system (VC areas and checkpoints). For each region the administrator has to define an area of interest and the checkpoints (VCs) that are contained in it.
    b. Adjust collected data to match base map (if desired). Apply map matching or appropriate software algorithms that “snap” the real-time data to the base map information.
    c. Compute travel times for a desired path. Every path that contains segment between two consecutives VCs must be analyzed and travel time has to be derived by the real-time data obtained by the users.
    d. Evaluation of locations where GPS signals are temporarily lost. In the absence of a dead-reckoning system, the path of a traveling vehicle may be lost when GPS signals are blocked. It has to be considered that VCs have to be placed in regions where GPS signal is strength with the highest possible accuracy.
2. It was observed that using PhoneGap’s framework to build cross-platform mobile application the map component did not render smoothly and fast. It has to be analyzed the possibility of creating a plugin to use the native map component of each platform. This will greatly improve user experience enhancing thus user adoption and popularity.
3. Specific network data usage modes of operation have to be considered to undertake both high and low usage policies. Users, who are unable to use high network data services due to high cost, have to choose a low data plan mode while they start the application. This functionality has to be developed.
4. As soon as the system has acquired and created an appropriate sample of collected data in terms of the size of the data collected, it would be feasible to apply a quality control measurement and to validate the sampling method used and determine if there is any further need of applying any different sampling strategy like temporal sampling, spatial sampling or sampling in space.

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Appendicies

A. VC trigger detection algorithm

```
var finalDiff = 1;

///CHECKING TRIGGER HERE //
var   x1   =   firstPosition.coords.latitude,   x2   =   secondPosi-
tion.coords.latitude, x3 = VSCs[i].SLat, x4 = VSCs[i].ELat;
var   y1   =   firstPosition.coords.longitude,   y2   =   secondPosi-
tion.coords.longitude, y3 = VSCs[i].SLon, y4 = VSCs[i].ELon;
var z1 = (x1 - x2), z2 = (x3 - x4), z3 = (y1 - y2), z4 = (y3 - y4);
var d = z1 * z4 - z3 * z2;

// If d is zero, there is no intersection
if (d == 0) {
finalDiff = 0;
} else {
// Get the x and y
var pre = (x1 * y2 - y1 * x2), post = (x3 * y4 - y3 * x4);
var x = (pre * z2 - z1 * post) / d;
var y = (pre * z4 - z3 * post) / d;

// Check if the x and y coordinates are within both lines
if (x < Math.min(x1, x2) || x > Math.max(x1, x2) || x < Math.min(x3, x4)
|| x > Math.max(x3, x4)) finalDiff = 0;
if (y < Math.min(y1, y2) || y > Math.max(y1, y2) || y < Math.min(y3, y4)
|| y > Math.max(y3, y4)) finalDiff = 0;

var latDirection = x2 - x1;
if (latDirection > 0)
latDirection = 1
else if (latDirection < 0)
latDirection = -1;

var lonDirection = y2 - y1;
if (lonDirection > 0)
lonDirection = 1
else if (lonDirection < 0)
lonDirection = -1;

///CHECKING iF Direction Is the desired one //


if (finalDiff == 1) {
if ((VSCs[i].latDirection != 0 && VSCs[i].latDirection != latDirection)
|| (VSCs[i].lonDirection != 0 && VSCs[i].lonDirection != lonDirection))
}
}
}
}
```

B. Drive In Crowd Mobile Application Screenshots

Live Traffic Map

Real Time Travel Times

Instant Incident Report

C. Drive In Crowd project web site (http://www.drinc.konpach.com)

Web Site Intro Page

Web Site About Page