Inteligent Traffic Control with Priority for Emergency Vehicles

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Master's thesis / Diplomski rad

2016

Degree Grantor / Ustanova koja je dodijelila akademski / stručni stupanj: **University of Zagreb, Faculty of Transport and Traffic Sciences / Sveučilište u Zagrebu, Fakultet prometnih znanosti**

Permanent link / Trajna poveznica: https://urn.nsk.hr/urn:nbn:hr:119:879217

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UNIVERSITY OF ZAGREB

FACULTY OF TRANSPORT AND TRAFFIC SCIENCES

MASTER'S THESIS

“Intelligent traffic control with priority for emergency vehicles”

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Zagreb, April 2016

SVEUČILIŠTE U ZAGREBU

FAKULTET PROMETNIH ZNANOSTI ZAGREB

DIPLOMSKI RAD

``Inteligentno upravljanje prometom uz dodjelu prioriteta vozilima žurnih službi´´

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Zagreb, travanj 2016

Intelligent traffic control with priority for emergency vehicles

SUMMARY

Advanced traffic management systems in city traffic (traffic light management) give possibility to give priority of passage to selected type of users, such as public transport, VIP users, and emergency services. In Republic of Croatia at present time there is no existent developed adaptive algorithms that can give priority to vehicles of Emergency services through the intersection. During this research solution to give priority passage Emergency vehicles in city traffic, benefit of such advances system will be investigated and proved with a simulation model. In same project cooperative concept will be evaluated (regarding emergency services) which includes a real time vehicle to vehicle and vehicle to infrastructure communication.

KEY WORDS: adaptive traffic management, ITS, emergency services, cooperative traffic management

Inteligentno upravljanje prometom uz dodjelu prioriteta vozilima žurnih službi

SAŽETAK

Napredni sustavi upravljanja gradskom prometnom mrežom (semaforiziranim raskrižjima) omogućuju prioritetni prolazak određenom tipu korisnika kao npr. javni gradski prijevoz, VIP korisnici, žurne službe. U Republici Hrvatskoj za sada nema razrađenih adaptivnih upravljačkih algoritama prema kojima vozila žurnih službi mogu prioritetno proći raskrižjem. Kroz ovo istraživanje razmotrit će se mogućnost prioritetnog prolaska žurnih službi u gradskom prometu, te će se na temelju simulacijskog modela dokazati korist takvog unaprijeđenog sustava. Također, dodatno će se razmotriti i mogućnosti kooperativnog koncepta u odnosu na vozila žurnih službi, što uključuje komunikaciju između vozila i vozila i infrastrukturu stvarnom vremenu.

KLJUČNE RIJEČI: adaptivno upravljanje prometom, ITS, žurne službe, kooperativno upravljanje prometom

Contents

1. Introduction

Republic of Croatia is one of top countries in region with construction and modernization of highways and other road infrastructure. Use of modern transport-related information systems is implemented on all Croatian highways and some freeways (such as regions of Rijeka and Split), especially in tunnel infrastructure that enables a continuous progress towards the integration of transport infrastructure management.

Sadly, city infrastructure does not follow this trend in Croatia. Telematics equipment and traffic light management is mostly outdated and obsolete. This is a major reason for preventing integration of telematics systems in cities. To be a part of the highway and freeway grid, and a full integration of informatics road network, a significant progress and intensive use of modern computer and information technology must be made.

Biggest problem in the Croatian metropolis, Zagreb, is that there is no existent city traffic central management center. Current data exchange methods are manual. Traffic management in city traffic light adaptive management is only implemented locally on some intersections. A good priority to emergency vehicles can be given only after adaptation to new technologies and data infrastructure.

Available solutions are known and can be combined and implemented for adaptive traffic light management. Traffic solutions for public transport are used in many countries and can be adapted and implemented on vehicles that are used by emergency services. Finished solutions and algorithms for adaptive management (SCATS, SCOOT, Utopia, etc.) have implemented modules for priority of emergency services, but are not used because of problems with vehicle detection. In this study, similar city traffic management problems and solutions will be investigated [1].

In next chapter named Functional area of intelligent traffic management ITS areas and structure will be introduced. Whole idea of traffic management is based on ITS, communication between all segments of transport and traffic. Third chapter brings an idea and technology how emergency vehicles can be detected on signalized intersections. Many kinds of detectors are used to bring us information about traffic. Fourth chapter brings details about emergency services in Croatia, their vehicles and duty they perform. Fifth chapter brings example in form of one intersection that is chosen as a best example of most common intersections in Croatia. Model has been made and evaluation of current and adapted traffic control is evaluated in sixth chapter. Seventh chapter gives some of cooperative traffic management systems that can give a solution to problem of prioritizing emergency vehicles intersections.

2. Functional area of intelligent traffic management

Information technology (IT) has already revolutionized many industries, including transportation systems by bringing information to bear on the transportation network. IT will significantly help to solve surface transportation challenges over the next several decades, as an “infostructure” gets built alongside countries’ physical transportation infrastructure. Intelligent Transportation Systems focus on developing and deploying data solutions for traffic problems.

The term Intelligent Transport Systems (ITS) has been introduced in transport and traffic engineering during the 1990s, and can be defined as holistic, control, information and communication upgrade to classical transport and traffic systems enabling significant improvement in the performance, traffic flow, efficiency of passenger and goods transportation, safety and security of transport, reduction of pollution, etc. [2].

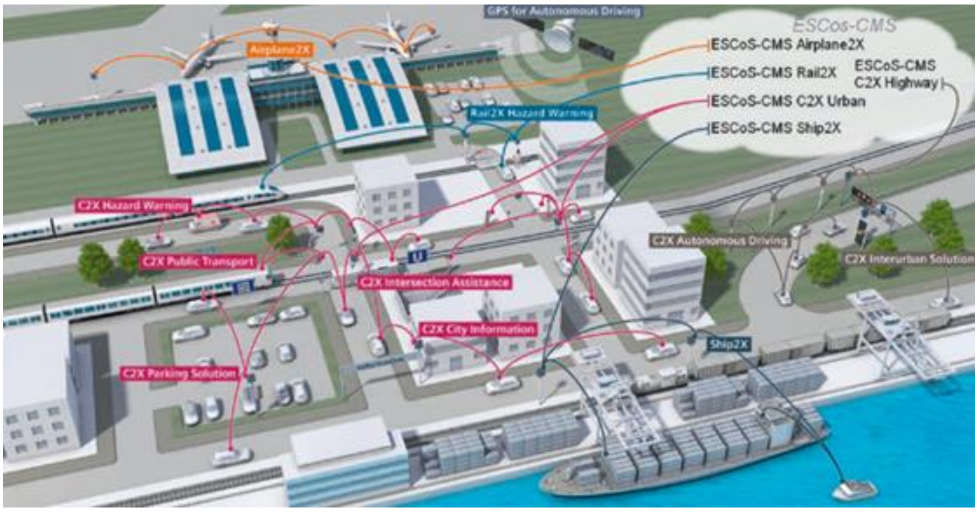

Figure 1 Intelligent transportation systems (ITS) (source: www.mobility.siemens.com, Siemens, April 2016)

The scenarios describe applications of ITS which deploy communications, control, electronics, and computer technologies to improve the performance of highway, transit (rail and bus), and even air and maritime transportation systems as seen on figure 1. Intelligent transportation systems include a wide and growing suite of technologies and applications such as real-time traffic information systems, in-car navigation (telematics) systems, vehicle-to-infrastructure integration (VII), vehicle-to-vehicle integration (V2V), adaptive traffic signal control, ramp metering, electronic toll collection, congestion pricing, fee-based express (HOT) lanes, vehicle usage based mileage fees, and vehicle collision avoidance technologies.

2.1. Special function areas

ITS architecture special function areas of traffic management are defined. In Europe there are 5 ITS areas:

1. Traffic guidance,
2. Incident management,
3. Demand management,
4. Meteorological information,
5. Road maintenance.

2.2. ITS taxonomy areas

The ITS taxonomy includes 11 functional areas:

1. Traveler Information;
2. Traffic Management and Operations;
3. Vehicles;
4. Freight Transport;
5. Public Transport;
6. Emergency;
7. Transport Related Electronic Payment;
8. Road Transport Related Personal Safety;

9. Weather and Environmental Monitoring;
10. Disaster Response Management and Coordination;
11. National Security.

Each functional area consists of interrelated services. Regional (e.g., U.S. State) ITS architectures can include additional services and functions that are not listed in ISO taxonomy of services.

2.3. User service bundles and user services

Travel and Traffic Management

- Pre-trip Travel Information
- On-route Driver Information
- Route Guidance
- Ride Matching and Reservation
- Traveler Services Information
- Traffic Control
- Incident Management
- Travel Demand Management
- Emissions Testing and Mitigation
- Highway-rail Intersection

Public Transportation Management

- Public Transportation Management
- On-route Transit Information
- Personalized Public Transit

- Public Travel Security

Electronic Payment

- Electronic Payment Services

Commercial Vehicle Operations

- Commercial Vehicle Electronic Clearance
- Automated Roadside Safety Inspection
- On-board Safety Monitoring
- Commercial Vehicle Administrative Processes
- Hazardous Material Incident Response
- Commercial Fleet Management

Emergency Management

- Emergency Notification and Personal Security
- Emergency Vehicle Management

Advanced Vehicle Safety Systems

- Longitudinal Collision Avoidance
- Lateral Collision Avoidance
- Intersection Collision Avoidance
- Vision Enhancement for Crash Avoidance
- Safety Readiness
- Pre-crash Restraint Deployment

- Automated Vehicle Operation

Information Management

- Archived Data Function

The User Service Requirements that the ITS Architecture must satisfy are functional expressions of what ITS system that provides this User Service should do. One can consider User Service Requirements as the highest level of functional requirements in ITS system. User Service Requirements give a global picture of what overall needs should be met by ITS systems, but exactly which User Service Requirements are satisfied varies for each ITS system that is actually implemented at the time. Since any national ITS Architecture is merely a guide to designing Intelligent Transportation Systems, each regional and local implementation is unique and requires its own separate set of functional requirements

ITS consist of the application of computers, electronic sensors, communications, and data management for the purpose of effectively and efficiently managing the transportation system to improve transportation mobility, safety, and to provide timely and accurate information to travelers.

Until recently, the building and improvement of transportation infrastructure meant the civil and mechanical construction or expansion of roads, bridges and tunnels, as well as the associated enterprises that provide the vehicles (including public and private transit agencies, trucking, public safety and personal) that travel on the infrastructure. Now, as travel demand steadily increases and the opportunities to build new infrastructure becomes prohibitively expensive because of the high costs and limited resources (including land space), the use of ITS technologies to enhance the effectiveness of existing transport infrastructure and improve operational efficiency of transportation systems becomes increasingly more important.

This makes the deployment of ITS technologies to manage the existing transportation network an attractive alternative. ITS provides improvement in traffic management and enforcement, driver assistance technologies, navigation aids, freight management dispatch systems, information for multimodal commuters, emergency response systems and environmental management. This not only affords users significant reductions in travel costs and time, but saves lives through improved travel safety.

ITS technology can assist in mitigating congestion and improve network management, in particular:

- Providing the tools and techniques to measure congestion
- Providing systems to manage the existing road network better through in-vehicle systems and the infrastructure
- Supporting delivery of real-time traffic and traveler information
- Providing the means to implement road pricing mechanisms
- Increasing capacity of the existing road network

Network monitoring requires that monitoring devices be installed in strategic locations throughout the transportation network to measure and record traffic flow, travel times, accidents and other security incidents, monitor ITS field equipment as well as the effect of traffic congestion on the environment. The detectors and cameras should be connected to a Traffic Management Centre (TMC) where data can be stored and images viewed. The vehicle detectors could be used to automatically select traffic signal timings (real-time traffic responsive control) and to detect incidents on the expressways. Environmental sensors should also be installed to monitor the impact of traffic conditions on air quality.

2.4. Urban Traffic Management and Control (UTMC)

At a more local level, Urban Traffic Management and Control (UTMC) activities build on the use of various traffic management tools (such as SCOOT and SCATS). Cutting edge ITS technology is available to detect both vehicles and pedestrians and to communicate this information to the TMC in order to control the traffic signals and manage traffic flow.

3. Detection of emergency service vehicles on signalized intersections

Third chapter analyses how vehicles are detected by infrastructure. Numerous technologies are used to give us necessary data. Balance between cost and quality of sensor must be evaluated so best results are introduced.

3.1. Evolution of traffic flow sensor technology

In the 1920s, when manually operated traffic signals were being replaced by automatic, pre-timed traffic signal control devices, engineers soon realized they needed a method to collect the traffic data previously obtained visually by the police officer on duty. Among those concerned was Charles Adler, Jr., of Baltimore, MD, a railway signal engineer [3]. He developed a sensor that was activated when a driver sounded his car horn at an instrumented location (fig.2). This device consisted of a microphone mounted in a small box on a nearby utility pole. First installed in 1928 at a Baltimore intersection, Adler's device enabled the first semi-actuated signal installation to assign right-of-way by means of a vehicle sensor. At nearly the same time, Henry A. Haugh, an electrical engineer, developed an in-roadway pressure-sensitive sensor, utilizing two metal plates that acted as electrical contacts. The wheel pressure of passing vehicles brought the plates together. This pressure-sensitive, treadle type sensor proved more popular than the horn-activated sensor. In fact, this sensor enjoyed widespread use for over 30 years as the primary means of detecting vehicles at actuated signals. Adler continued his work with sound detectors and in l931 introduced another sound detector, which employed hollow steel boxes embedded in the intersection approach. These boxes picked up the sound of passing wheels, which was transmitted to microphones. Mechanical problems with the contact-plate sensor led to the introduction of the electro-pneumatic sensor. Although this device found some application, it was costly to install, capable of only passage (motion) detection, and its (axle) counting accuracy was limited by the generation of air pressure waves and capsule contact bounce. In retrospect, it seems unfortunate that the treadle detector, which utilized the most obvious and most easily detected property of vehicles—their weight—could not be economically produced. Snow plows could lift the plate from the roadway, resulting in costly repairs. There was also the expense of reinstalling the detector after roadway resurfacing. These problems led to the search for traffic flow sensors based on more subtle properties such as:

- Sound (acoustic sensors)
- Opacity (optical and infrared sensors and video image processors).
- Geomagnetism (magnetic sensors, magnetometers).
- Reflection of transmitted energy (infrared laser radar, ultrasonic sensors, and microwave radar sensors)
- Electromagnetic induction (inductive-loop detectors)
- Vibration (triboelectric, seismic, and inertia-switch sensors)

Not all of these concepts have been commercially exploited. Today, the inductive-loop detector is, by far, the most widely used sensor in modern traffic control systems. Magnetometers, magnetic sensors, video image processors, microwave and laser radar sensors, ultrasonic, acoustic, and passive infrared sensors are also produced commercially and used for various traffic management applications. The optical sensor has found use for detecting priority and over height vehicles.

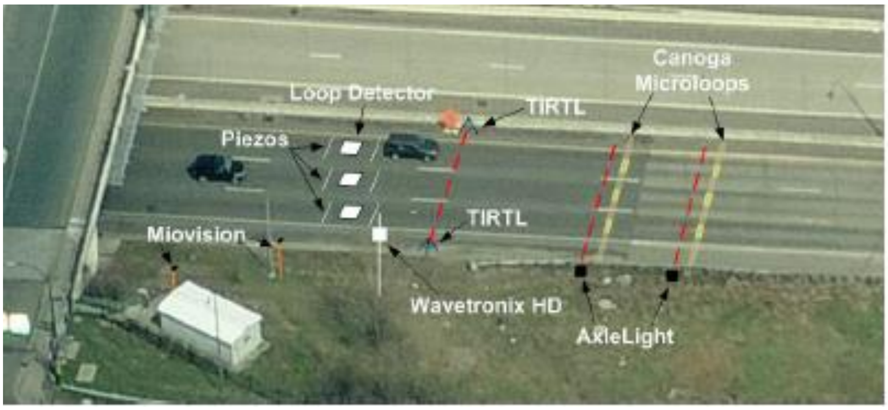

Figure 2 Traffic detectors (source: Ohio state university, April 2016)

3.2. Need for sensor alternatives

While single inductive-loop detectors give direct information concerning vehicle passage and presence, other traffic flow parameters such as density and speed must be inferred from algorithms that interpret or analyze the measured data. When these parameters are calculated from inductive loop data, the values may not have sufficient accuracy for some applications (such as rapid freeway incident detection) or the available information may be inadequate to support the application (such as calculation of link travel time). Furthermore, the operation of inductive-loop detectors is degraded by pavement deterioration, improper installation, and weather-related effects. Street and utility repair may also impair loop integrity. Thus, a good loop installation, acceptance testing, repair, and maintenance program is required to maintain the operational status of an inductive-loop-based vehicle detection system. Evaluations of modern over-roadway sensors show that they provide an alternative to inductive-loop detectors. The traffic flow parameters measured with over-roadway sensors satisfy the accuracy requirements of many current freeway and surface street applications, provided suitable mounting is available. The mounting location must provide an unobstructed view of vehicles for optimum performance. In general, when sensors are installed over the lane of traffic they are intended to monitor, their view and hence their data collection ability is not occluded by other vehicles that are present within the viewing area of the sensor. Over-roadway sensors that are mounted on the side of a roadway and view multiple lanes of traffic at angles perpendicular to or at an oblique angle to the flow direction may experience two types of data anomalies. The first occurs when tall vehicles block the sensor’s view of distant lanes. The occlusion may potentially cause an undercount or false average speed measurement. The second anomaly occurs when tall vehicles project their image into adjacent lanes. When a sensor is sensitive to this effect, it will over count and again may report a misleading average speed. Thus, sensor type, mounting height and location, vehicle mix, road configuration, and sensor viewing angles must be analyzed with respect to the intended application. Some over-roadway sensors may be more susceptible to these anomalies than others.

An emerging potential source of traffic flow data is from cellular telephone companies who monitor the transmitting status of telephones that are engaged in conversations in support of the wireless enhanced all automatic location identification (ALI) directive of the Federal Communications Commission (FCC). Another unconventional source of traffic monitoring data is from nonstationary and airborne platforms. Information gathered from satellite, aircraft, and unmanned aerial vehicles can be used to estimate arterial and freeway traffic characteristics over long time scales and large geographic areas, including those where data were previously unavailable. The spatial coverage provided from air- and satellite-based sensors can potentially support the development of new metrics that better represent highway utilization and congestion.

There is a wide range of sensor technologies available for vehicle detectors. Some of the most common and some developing technologies are described in this section.

3.3. Sensors

Inductive loop

- Flexible design to satisfy large variety of applications
- Mature, well understood technology
- Large experience base
- Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap)
- Insensitive to inclement weather such as rain, fog, and snow
- Provides best accuracy for count data as compared with other commonly used techniques
- Common standard for obtaining accurate occupancy measurements
- High frequency excitation models provide classification data.
- Installation requires pavement cut.
- Improper installation decreases pavement life.
- Installation and maintenance require lane closure.
- Wire loops subject to stresses of traffic and temperature.
- Multiple loops usually required to monitor a location.
- Detection accuracy may decrease when design requires detection of a large variety of vehicle classes.

Magnetometer (two-axis fluxgate magnetometer)

- Less susceptible than loops to stresses of traffic.
- Insensitive to inclement weather such as snow, rain, and fog.
- Some models transmit data over wireless radio frequency (RF) link.

- Installation requires pavement cut
- Improper installation decreases pavement life
- Installation and maintenance require lane closure.
- Models with small detection zones require multiple units for full lane detection.

Magnetic (induction or search coil magnetometer)

- Can be used where loops are not feasible (e.g., bridge decks).
- Some models are installed under roadway without need for pavement cuts. However, boring under roadway is required.
- Insensitive to inclement weather such as snow, rain, and fog.
- Less susceptible than loops to stresses of traffic.
- Installation requires pavement cut or boring under roadway.
- Cannot detect stopped vehicles unless special sensor layouts and signal processing software are used.

Microwave radar

- Typically insensitive to inclement weather at the relatively short ranges encountered in traffic management applications.
- Direct measurement of speed.

Laser radar

- Transmits multiple beams for accurate measurement of vehicle position, speed, and class.
- Multiple lane operation available.
- Operation may be affected by fog when visibility is less than ≈20 feet (ft.) (6 m) or blowing snow is present.
- Installation and maintenance, including periodic lens cleaning, require lane closure.

Passive infrared

- Multi-zone passive sensors measure speed.
- Passive sensor may have reduced vehicle sensitivity in heavy rain, snow and dense fog.
- Some models not recommended for presence detection.

Ultrasonic

- Multiple lane operation available.
- Capable of over-height vehicle detection.
- Large Japanese experience base.
- Environmental conditions such as temperature change and extreme air turbulence can affect performance. Temperature compensation is built into some models.
- Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds.

Acoustic

- Passive detection
- Insensitive to precipitation
- Multiple lane operation available in some models
- Cold temperatures may affect vehicle count accuracy.
- Specific models are not recommended with slow-moving vehicles in stop-and-go traffic.

Video image processor

- Monitors multiple lanes and multiple detection zones/lane
- Easy to add and modify detection zones

- Rich array of data available
- Provides wide-area detection when information gathered at one camera location can be linked to another
- Installation and maintenance, including periodic lens cleaning, require lane closure when camera is mounted over roadway (lane closure may not be required when camera is mounted at side of roadway)
- Performance affected by inclement weather such as fog, rain, and snow; vehicle shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/road contrast; and water, salt grime, icicles, and cobwebs on camera lens
- Reliable nighttime signal actuation requires street lighting
- Requires 30- to 50-ft (9- to 15-m) camera mounting height (in a side-mounting configuration) for optimum presence detection and speed measurement
- Some models susceptible to camera motion caused by strong winds or vibration of camera mounting structure
- Generally cost effective when many detection zones within the camera field of view or specialized data are required.

Technology	Strengths	Weaknesses
Inductive loop	• Flexible design to satisfy large variety of applications. • Mature, well understood technology. • Large experience base. • Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap). • Insensitive to inclement weather such as rain, fog, and snow. • Provides best accuracy for count data as compared with other commonly used techniques. • Common standard for obtaining accurate occupancy measurements. • High frequency excitation models provide classification data.	• Installation requires pavement cut. • Improper installation decreases pavement life. • Installation and maintenance require lane closure. • Wire loops subject to stresses of traffic and temperature. • Multiple loops usually required to monitor a location. • Detection accuracy may decrease when design requires detection of a large variety of vehicle classes.
Magnetometer (two-axis fluxgate magnetometer)	• Less susceptible than loops to stresses of traffic. • Insensitive to inclement weather such as snow, rain, and fog. • Some models transmit data over wireless radio frequency (RF) link.	• Installation requires pavement cut. • Improper installation decreases pavement life. • Installation and maintenance require lane closure. • Models with small detection zones require multiple units for full lane detection.
Magnetic (induction or search coil magnetometer)	• Can be used where loops are not feasible (e.g., bridge decks). • Some models are installed under roadway without need for pavement cuts. However, boring under roadway is required. • Insensitive to inclement weather such as snow, rain, and fog. • Less susceptible than loops to stresses of traffic.	• Installation requires pavement cut or boring under roadway. • Cannot detect stopped vehicles unless special sensor layouts and signal processing software are used.
Microwave radar	• Typically insensitive to inclement weather at the relatively short ranges encountered in traffic management applications. • Direct measurement of speed. • Multiple lane operation available.	• Continuous wave (CW) Doppler sensors cannot detect stopped vehicles.

Table 1 Traffic sensors (source: Traffic sensor handbook [2], April 2016)

Technology	Strengths	Weaknesses
Active infrared (laser radar)	• Transmits multiple beams for accurate measurement of vehicle position, speed, and class. • Multiple lane operation available.	• Operation may be affected by fog when visibility is less than ≈20 feet (ft) (6 m) or blowing snow is present. • Installation and maintenance, including periodic lens cleaning, require lane closure.
Passive infrared	• Multizone passive sensors measure speed.	• Passive sensor may have reduced vehicle sensitivity in heavy rain, snow and dense fog. • Some models not recommended for presence detection.
Ultrasonic	• Multiple lane operation available. • Capable of overheight vehicle detection. • Large Japanese experience base.	• Environmental conditions such as temperature change and extreme air turbulence can affect performance. Temperature compensation is built into some models. • Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds.
Acoustic	• Passive detection. • Insensitive to precipitation. • Multiple lane operation available in some models.	• Cold temperatures may affect vehicle count accuracy. • Specific models are not recommended with slow-moving vehicles in stop-and-go traffic.
Video image processor	• Monitors multiple lanes and multiple detection zones/lane. • Easy to add and modify detection zones. • Rich array of data available. • Provides wide-area detection when information gathered at one camera location can be linked to another.	• Installation and maintenance, including periodic lens cleaning, require lane closure when camera is mounted over roadway (lane closure may not be required when camera is mounted at side of roadway) • Performance affected by inclement weather such as fog, rain, and snow; vehicle shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/road contrast; and water, salt grime, icicles, and cobwebs on camera lens. • Reliable nighttime signal actuation requires street lighting • Requires 30- to 50-ft (9- to 15-m) camera mounting height (in a side-mounting configuration) for optimum presence detection and speed measurement. • Some models susceptible to camera motion caused by strong winds or vibration of camera mounting structure. • Generally cost effective when many detection zones within the camera field of view or specialized data are required.

Table 2 Traffic sensors 2 (source: Traffic sensor handbook, April 2016)

3.4. Modern vehicle sensors

The following discussion provides a broad overview of the operation of in roadway and over-roadway traffic flow sensors most used today. These sensors include inductive-loop detectors, magnetometers, video image processors, microwave radar sensors, laser radar sensors, passive infrared sensors, ultrasonic sensors, and passive acoustic sensors. Typical applications include traffic signal control, freeway ramp metering, freeway mainline control, incident detection, and gathering of vehicle volume and classification data to meet State and Federal reporting requirements. These devices are either installed in, below, or above the roadway.

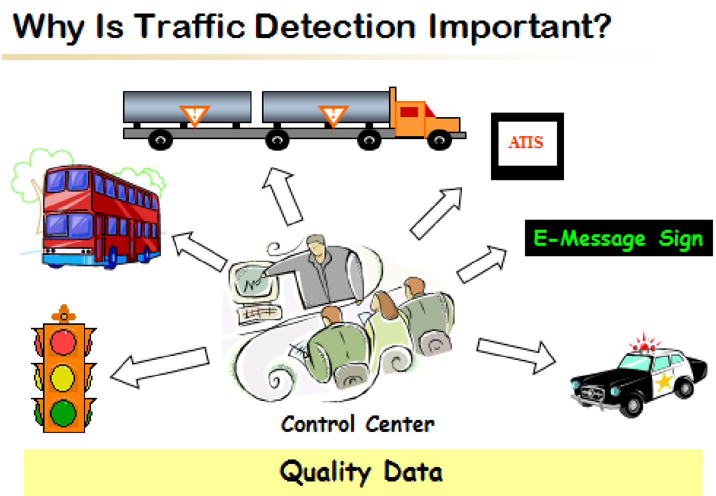

Figure 3 Traffic detection (source: traffic sensor handbook, April 2016)

3.5. Video image processor

Video cameras were introduced to traffic management for roadway surveillance based on their ability to transmit closed-circuit television imagery to a human operator for interpretation. Present-day traffic mangers utilize video image processing to automatically analyze the scene of interest and extract information for traffic surveillance and management. A video image processor (VIP) system typically consists of one or more cameras, a microprocessor-based computer for digitizing and analyzing the imagery, and software for interpreting the images and converting them into traffic flow data. A VIP can replace several in-ground inductive loops, provide detection of vehicles across several lanes, and perhaps lower maintenance costs. Some VIP systems process data from more than one camera and further expand the area over which data are collected (Fig. 3).

3.6. Sensor details

- Magnetic

Basic Principles of Operation

Magnetometers are passive sensors that detect perturbations in the Earth's magnetic field caused by the metallic components of vehicles. There are two major types of magnetometers: induction magnetometers and dual-axis magnetometers. Induction magnetometers sometimes referred to simply as magnetic detectors, measure changes in the magnetic flux lines when metal components in a vehicle, especially the engine, travel past the detection zone. Other components of a vehicle, such as the alternator, also create changes in the magnetic field. The magnetic flux change can be observed by measuring the corresponding changes in the electric current induced in the sensor. These current fluctuations give an imprint of the vehicle's presence, but cannot detect stopped vehicles. Dual-axis fluxgate magnetometers detect changes in the horizontal and vertical components of the Earth's magnetic field caused by the passage or presence of a vehicle. This type of sensor can detect both moving and stationary vehicles.

Stated Capabilities

Magnetic sensors can detect volume, classification, headway, presence and speed with algorithms or two sensors in a speed trap configuration.

Limitations

Unless installed during new construction, sensors that mount beneath the pavement require directional conduit boring for sensor installation. Some induction magnetometers cannot detect stopped vehicles.

- Radar

Basic Principles of Operation

Radar sensors use a continuous, frequency-modulated or phase-modulated signal to determine the time delay of the return signal, thereby calculating the distance to the detected vehicle. Radar sensors have the additional ability to sense the presence of stationary vehicles and to sense multiple zones through their range finding ability (Fig. 4).

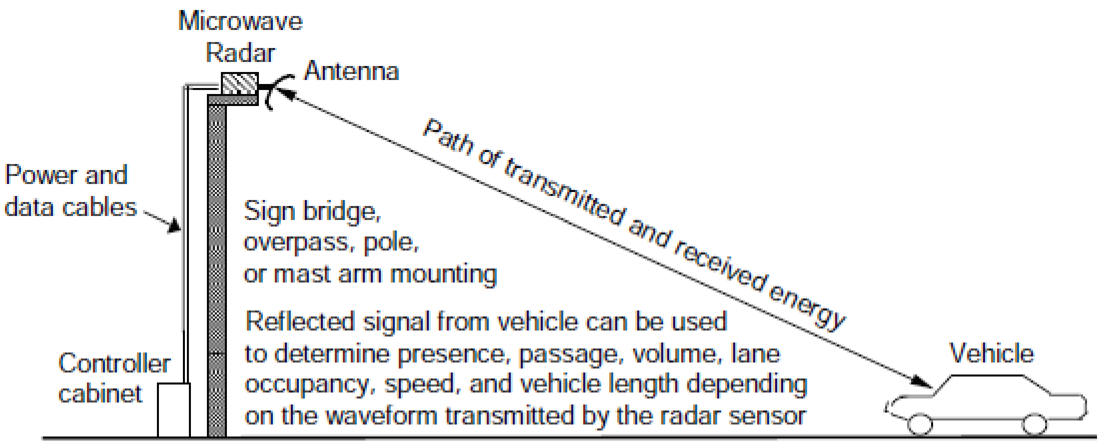

Figure 4 Microwave radar (source: Traffic sensor handbook, April 2016)

Stated Capabilities

Radar sensors can detect volume, presence, classification, speed and headway.

Limitations

Radar sensors can experience dead detection zones and “ghost” vehicles when installed in areas with barriers, fencing, or other obstructions.

- Video

Basic Principles of Operation

Video-based detectors use a microprocessor to analyze the video image input. Different approaches are used by video detection sensors. Some analyze the video image of a target area on the pavement. The change in the image of the target area as a vehicle passes through the target area is processed. Another approach identifies when a target vehicle enters the video field of view and tracks the target vehicle through this field of view. Still other video sensors use a combination of these two approaches.

Stated Capabilities

Videos sensors can be used to collect volume, speed, presence, occupancy, density, queue length, dwell time, headway, turning movements, acceleration, lane changes and classification.

Limitations

Environmental conditions that affect the video image quality can reduce system performance. Such conditions include fog, rain, dust or snow in the air; frost, condensation or dirt on the camera lens; and adverse lighting conditions, such as headlight glare on wet pavement, low-angle sunlight, poor vehicle-road contrast, and headlight reflection on curved roadways. Proper setup and calibration is critical to gathering accurate data and achieving satisfactory performance in poor lighting conditions.

- Video Image Processors

A video image processor (VIP) is a combination of hardware and software which extracts desired information from data provided by an imaging sensor. This imaging sensor can be a conventional TV camera or an infrared camera. A VIP can detect speed, occupancy, count, and presence. Because the VIP produces an image of several lanes, there is potential for a VIP to provide a wealth of traffic information such as vehicle classification and incident detection. A VIP generally operates in the following manner: the operator selects several vehicle detection zones within the field of view (FOV) of the camera. Image processing algorithms are then applied in real time to these zones in order to extract the desired information, such as vehicle speed or occupancy. Advantages of VIPs are that they are mounted above the road instead of in the road, the placement of vehicle detection zones can be made by the operator, the shape of the detection zones can be programmed for specific applications, and the system can be used to track vehicles. Disadvantages are the need to overcome detection artifacts caused by shadows, weather, and reflections from the roadway surface. The disadvantages can be overcome through design and installation of the hardware and design of the software algorithms (Fig. 5).

Figure 5 Thermal camera detectors (source: web page Flir.com, April 2016)

- Infrared Detectors

There are two types of infrared (IR) detectors, active and passive. Active infrared sensors operate by transmitting energy from either a light emitting diode (LED) or a laser diode. An LED is used for a non-imaging active IR detector, and a laser diode is used for an imaging active IR detector. In both types of detectors the LED or laser diode illuminates the target, and the reflected energy is focused onto a detector consisting of a pixel or an array of pixels. The measured data is then processed using various signal-processing algorithms to extract the desired information. Active IR detectors provide count, presence, speed, and occupancy data in both night and day operation. The laser diode type can also be used for vehicle classification because it provides vehicle profile and shape data. A passive infrared system detects energy emitted by objects in the field of view and may use signal-processing algorithms to extract the desired information. It does not emit any energy of its own for the purposes of detection. Passive infrared systems can detect presence, occupancy, and count. Some of the advantages of infrared detectors are that they can be operated during both day and night, and they can be mounted in both side and overhead configurations. Disadvantages are that infrared detectors can be sensitive to inclement weather conditions and ambient light. The choice of detector materials and construction of the system, as well as sophisticated signal processing algorithms, can compensate for the disadvantages.

- Ultrasonic detectors

Ultrasonic detectors have not yet become widely used in the most developed countries, but are already widely used in Japan. Japan uses ultrasonic detectors in traffic applications as much as the U. S. uses inductive loop detectors in traffic applications. There are two types of ultrasonic sensors available, presence-only and speed measuring. Both types operate by transmitting ultrasonic energy and measuring the energy reflected by the target. These measurements are processed to obtain measurements of vehicle presence, speed, and occupancy. The advantages of ultrasonic are that they provide all-weather operation, do not need to be approved by the FCC, and provide fixed or portable mounting fixtures above the road. Their disadvantages include their need to be mounted in a down-looking configuration as perpendicular as possible to the target (as opposed to side mounting), a difficulty in identifying lane-straddling vehicles and vehicles traveling side by side, and susceptibility to high wind speeds. Some of these disadvantages may be compensated for through more sophisticated data processing techniques.

- Microwave/Millimeter wave radar

Microwave detectors have been used extensively in Europe, but not in the United States. They operate by measuring the energy reflected from target vehicles within the field of view. By processing the information received in the reflected energy, the detectors measure speed, occupancy, and presence. Some of the advantages of microwave detectors are that they are a mature technology because of past military applications, they detect velocity directly, and a single detector can cover multiple lanes if it is placed properly and appropriate signal processing techniques are used. In addition, FCC approval is not required if it operates in the

X-band or Ku-band, and the output powers are within specified limits. Some of the disadvantages are unwanted vehicle detection based on reception of side lobe radiation, and false detection due to multipath. Most of these disadvantages can be overcome, in whole or in part, through proper placement of the detectors, signal processing algorithms, and antenna design.

- Passive Acoustic Detector Arrays

Another type of vehicle detector is the passive acoustic array. An array of microphones may be used to determine the passage of a vehicle. The signals from the microphones in the array are processed and correlated to obtain information about vehicle passage. The design of the array determines its directionality and field of detection. These types of detectors have not yet been thoroughly investigated, at least in terms of traffic related applications. Video-conferencing companies have been developing sophisticated microphone arrays for their systems, and it is possible that some of their techniques or designs could be adapted to traffic applications.

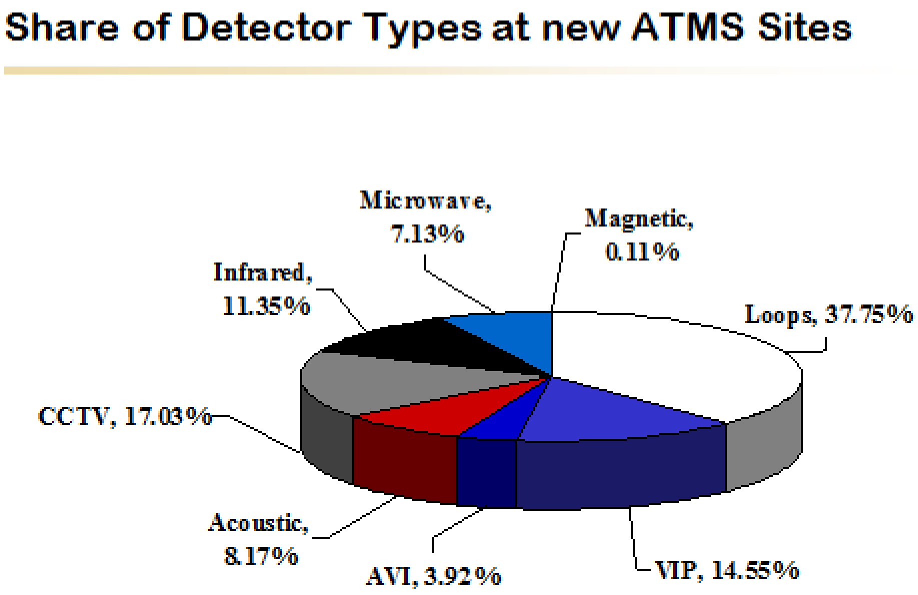

Figure 6 Traffic detection statistics (source: traffic sensor handbook, April 2016)

3.7. Sensor installation

- Piezoelectric detectors

Piezoelectric detectors are very accurate vehicle detectors, but they do not detect presence of a stationary vehicle, unless it has stopped with its wheels on the detector. The piezoelectric sensor consists of a long strip of piezoelectric material enclosed in a protective casing. It can be embedded flush with the pavement, and when a car passes over it compressing the piezoelectric material, a voltage is produced. This sets off the controller. The piezoelectric detector has the advantage of indicating exactly when and where a vehicle passed by because it is a line detector perpendicular to the path of the vehicle. A series of two of them may be used to measure vehicle speed. A disadvantage is that for a permanent installation, they must be embedded in the pavement. Every time the roadway is repaved, or if a pothole appears, the sensor would need to be replaced. These types of sensors are currently being tested on the Beltway in Virginia. AMP is a manufacturer of piezoelectric traffic detectors.

- Photoelectric detectors

Photoelectric devices commonly consist of two components, the light source and the detector. These may both be in the same place, or placed across from each other. When placed across from each other, the detector is activated whenever something obstructs the illumination from the light source. When placed in the together, the detector is activated when light from the light source is reflected from a target and back onto the detector. There is not enough information on these detectors as applied to vehicle detection. They do not appear to be a competitive technology in the field of vehicle detectors at this time.

- Spread-spectrum wideband radar

New wideband spread-spectrum radar has recently been developed at Lawrence Livermore Laboratory. It is a significant development because it is very inexpensive and it has extremely accurate range discrimination. It can also penetrate many types of materials, including concrete. It has a range of about 20 feet, so it may be useful as an inexpensive, single-lane vehicle detector. It is predicted that the sensor, when made in production quantities, would cost much less than $10 per sensor. Because of their accurate range discrimination, they have a very well defined field of detection. They could become a cheap alternative to magnetometer probes. Their ability to detect range provides additional information for future traffic control systems. In addition, Lawrence Livermore has stated that they are developing a broadband transmitter/receiver pair to be used with these sensors. This would eliminate the need for communication lines between the sensor and the controller.

- Inductive loop detectors

Loop detectors are the most widely used technology for vehicle detection in the United States. A loop detector consists of one or more loops of wire embedded in the pavement and connected to a control box. The loop may be excited by a signal ranging in frequency from 10 kHz to 200 kHz. This loop forms an inductive element in combination with the control box. When a vehicle passes over or rests on the loop, the inductance of the loop is reduced. This causes a detection to be signaled in the control box. The advantages of inductive loop detectors are that they are an established technology in the United States, they have a well-defined zone of detection, and they are generally reliable. Disadvantages are that the detectors are very sensitive to the installation process, they can only be installed in good pavement, and they must be reinstalled every time a road is repaved.

- Magnetic Detectors

There are two other types of magnetic detectors, which are used to detect traffic. Both of them are in the form of probes, and they both operate on the principle of a large metal object disturbing a magnetic field, just as inductive loop detectors work. There are both active and passive types. The active type is called a magnetometer. A magnetometer acts in much the same way as an inductive loop detector, except that it consists of a coil of wire wrapped around a magnetic core. It measures the change in the magnetic field caused by the passage of a vehicle. It can be used both for presence and for vehicle passage detection. The passive type of detector simply measures a change in the flux of the earth's magnetic field caused by the passage of a vehicle. These detectors can only detect moving vehicles, so they cannot be used as presence detectors. They have a fairly large detection range and thus can be used to observe multiple lanes of traffic.

The advantage of both of these types of magnetic detectors is that they can be used where point or small-area location of a vehicle is necessary. For example, on a bridge, inductive loop detectors would be disrupted by the steel struts, and it is necessary to have a point detector. One of their disadvantages is that multiple detectors need to be installed to detect smaller vehicles, such as motorcycles.

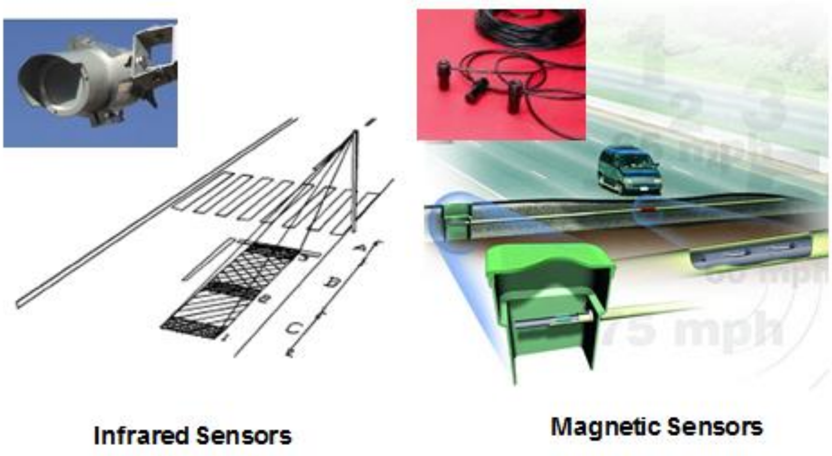

Figure 7 Traffic detection example (source: traffic sensor handbook, April 2016)

- Acceleration detectors

For the left-turn collision countermeasure system, it is necessary to determine the acceleration of the vehicle, so that it can be determined whether or not the vehicle is slowing to make a left turn. Using Doppler information, the range rate of a vehicle may be determined, but it does not appear that any radar currently being marketed for traffic applications measure the range rate. A simple method is to have three detectors in a linear formation. Measurements from these three detectors will provide an approximation of the acceleration of the vehicle from which the system may determine whether or not to activate the left-turn ahead warning.

4. Overview of emergency services and their operations in Republic of Croatia

In order for intelligent management to work it is important to identify vehicles of emergency services which are going to have priority. Next chapter brings overview of emergency services.

4.1. Fire department

Fire department uses variety of vehicles. Alongside basic fire fighting vehicles, many special vehicles are used for many tasks that firefighting department has (rescue on elevations, HAZMAT, etc.). Fire department vehicles are colored red; they have blue rotating lights, sound signalization and required technical characteristics so they can function as required (speed, caring capacity, terrain capabilities, engine power, etc.). Vehicle is made of carriage and upper build like water tank, pumps, and special firefighting gear.

Figure 8 Fire department vehicles (source: www.vatrogasni-portal, April 2016)

Republic of Croatia in service for rescue, protection and fire emergencies uses 455 specialized vehicles distributed among 55 public fire departments, cities and municipalities**.** Voluntary fire departments for fire emergencies use regular cars and vans. Technical equipment of public fire department units is only partly covering Croatia and it is regulated by Rule book of minimum technical equipment and fire department gear ("NN" 43/96.). Status and number of vehicles used in rescue, firefighting and protection in Croatia used by professional firefighting units is:

Ministry of internal affairs data:

1	water tanker	74
2	water and foam vehicle carrier	30
3	water, foam and powder vehicle carrier	11
4	ladder vehicle	29
5	technical intervention vehicle heavy	16
6	technical intervention vehicle light	42
7	attack vehicle	61
8	forest fire vehicle	36
9	powder carrier vehicle	16
10	powder carrier trailer	2
11	command vehicle	46
12	cargo and semi cargo vehicle 3,5-7,5t	10
13	different professional vehicles	82
	Total:	455

Table 3 Fire department vehicles (Source: IZVJEŠĆE O BROJU I STANJU VOZILA VATROGASNE NAMJENE U REPUBLICI HRVATSKOJ, April 2016)

to 5 years of age	8
5-10 years of age	62
10-15 years of age	160
15-20 years of age	107
more than 20 years of age	118
Total:	455

Table 4 Fire department vehicles by age (Source: IZVJEŠĆE O BROJU I STANJU VOZILA VATROGASNE NAMJENE U REPUBLICI HRVATSKOJ, April 2016)

Average age of fire department vehicles in Croatia is over 6 years. Using data for all vehicles including those with special use, average of vehicle age is over 20 years.

Croatia has statistics of about 15 fires a day. In average year about 80 percent of fires are caused by humans (72% because of negligence and lack of attention, 2.5% because of child play and 4%unintentionally.) There are 2700 building fires a year. Most causes of outdoor fires is burning of plants and plants waste (42%). About 80 percent of fires start with human intervention because of:

- lack of attention
- negligence
- deliberate fire starting
- children play
- use of tools and mechanical equipment

Fire department does not just put out fires. When there is explosion, HAZMAT, elevator accidents, traffic accident, ecological pollution or any other type of accident you have to call fire department. Fire department call center will help you by dispatching fire unit or help you with advice how to deal with emergency.

In 2014 Croatia had 21.450 fire department happenings. 29.711 fire department interventions were dispatched consisting of 115.935 fire fighters with 31.901 vehicles. In interventions 475.973 working hours were used. Using data service „Fire department network“ and his constant upgrading it is expected to get correct data about fire fighters interventions and all activities in fire department.

Croatian fire department union invested big efforts in last few years for production of informatization system that will be used as a tool in every day work. Development of ICT tools is in progress and will be modeled to fill all user needs.

Project with HAKOM: Tracking of vehicles and fire fighters on intervention. Croatian fire department union (“Hrvatska Vatrogasna Zajednica” (HVZ)) has enlisted this project and got HAKOM financing. This system enables tracking of vehicles and fire fighters on their interventions. System is web based and enables tracking through web site with mobile phone, tablet or computer. Possibility of tracking is enhanced by use of GIS tools (map drawing, layers, importing form different systems). New system including mobile phone tracking is in progress using TETRA and MOTOTRBO systems enabling video and picture sending and receiving between command center and field units. System is made by RAPTOR Security Systems, and it is based on GIS platform GISCLOUD.

Figure 9 Fire department vehicle tracking (source: www.vatrogasni-portal.hr, April 2016)

4.2. Emergency medical service

Croatia has 21 emergency medical centers with 919 medical teams consisting of 3.152 employees. 731 MD, 1.453 nurses and technicians and 968 drivers.

Car pool is about 777 vehicles. Vehicles are in average 10 years old with more than 250.000 km in average. Every day new vehicles are introduced.

Basic vehicle color is yellow, RAL 1016, they have retroreflective markings: Star of life, blue 6 prong star, red RAL 3024 HMS sigh, letters HITNA RAL 3024 mirrored image on front, blue rotational lights on top, sound signal and have to fill strict technical requirements.

Figure 10 Emergency medical service vehicles, (source: www.zagreb.hr, April 2016)

April 12th 2002.new informatization and communication system was brought into service. System integrates response units, receiving calls, analysis, dispatching, radio communication, tracking of vehicles via GPS, digital telephone center that records radio and telephone communication. System brought radical change and it is combining modern technology for specific task. It gives help for rational time and human resources use, reliability, backup and collecting data for all users. System was ordered by Ministry of health and it was financed by World Bank. Radio communicational part was done by Motorola GmbH (Swiss), for tracking system and integration GISDATA (Zagreb, Croatia). In middle of 2004**.** Computer service was introduced that services administration and ambulance. Computers are networked and data is used and backup that gives us unified system from start to end of emergency medical service.

4.3. Police department

Motorization of the Police department in Croatia had already begun in 1913, when the first vehicle was procured for service needs. In every country there are three public services everybody knows of. Their telephone numbers are easy to recognize and remember and their vehicles are categorized as right of way vehicles. These are the vehicles that produce sound and light signals and make drivers get out of their way. There is no unique rule as regards the manner of painting and colors used for such vehicles. However, it is interesting to see that in most of the countries around the world fire-fighting vehicles are red, ambulances are mostly either white or yellow, whereas police vehicles come in various colors, yet the same in every country. Apart from car plates, distinction of police vehicles from other traffic vehicles in Croatia goes back to the mid-1950s. Today police has most advanced service vehicles among all public services.

Number of police vehicles in Croatia is secret information so it cannot be stated in this study.

Figure 11 Police vehicles (source: www.mup.hr, April 2016)

Basic color of police vehicles is white RAL 9010 or silver 9006, registration tag POLICIJA, registration tag with numbers (Fig. 19). Drawing or reflective sticker: POLICIJA MUP RH, blue color, RAL 5013, reflective stripe on side of same color. Sound emitter with different tones and a radiophone. On the roof there must be one or 2 rotational blue lights, in some cases with screen that can produce lighted letters and commands. They can have police emergency phone number on their side. Vehicles can be partially marked or unmarked but lights and sound emitters are installed on all vehicles. Ministry of internal affairs is responsible for protection, rescue and public order and safety. Problems of public safety are punishable behavior (acts of crime and misdemeanors, etc.), accidents and natural disasters (fire, pollution, epidemics, terrorism, war, etc.) that endanger life, personal integrity, private property, economy or values of democratic society with endangering tragic or catastrophic consequences.

Police department does all jobs regarding protection of life, personal integrity, personal property, from acts of crime: stopping and preventing criminal behavior, finding persons suspected for criminal acts and misdemeanors, securing reach for courts and government, finding illegal acquired goods, locating missing persons and items, surveillance and securing of public gatherings, surveillance of national border, air traffic and sea traffic, surveillance of foreign citizens in Croatia, securing of protected persons, objects and spaces, securing incarcerated and arrested persons, anti-mine protection, special police and other activities

4.4. Mountain rescue service

Croatian mountain rescue service is national, voluntary, expert, humanitarian and non-politic group whose goals are accident prevention, rescue and first aid help in mountain and inaccessible areas in extraordinary circumstances when special expert knowledge is needed or special rescue technical equipment to preserve life, health and property. This nonprofit service is of key importance for Croatia gathering mountain rescuers in 24 stations of HGSS covering whole national area.

Figure 12 Mountain rescue vehicles (source: www.mup.hr, April 2016)

All emergency vehicles are used in serious situations. They are a tool that can decide between life and death and help in prevention in loss of material property. That is why it is important to obey right of passage for that vehicles in traffic.

5. Example of adaptive traffic management with priority for emergency vehicles

Getting traffic solutions based on data in real traffic experiment is impossible. Complexity and scale of real traffic situations is making that impossible. Traffic is always flowing and we cannot make experiments on real traffic so models are used. In this chapter model of typical intersection is introduced, tools and process is brought and model made, analyzed and evaluated. Because of complexity of simulation model and vast amount of traffic data, one intersection for data collection and evaluation was selected for this research.

5.1. Emergency service vehicles priority strategies

Advanced adaptive control of signalized intersections in this case includes providing green lights to emergency services vehicles. Three main approaches in PTP assignments are defined as [4]:

- passive approach
- unconditional approach
- active approach.

The predefined signal plans are used when implementing passive priority approach which contributes to reducing vehicle travel times. Passive priority approach does not need the presence of that vehicle or notification of its arrival to a signalized intersection. Specific passive priority techniques include cycle length reduction and phase splitting.

Vehicles have unconditional priority given on signalized intersection no matter which phase of the cycle is active. After the end of the active phase (considering minimal safety/passenger green times), green light for vehicles is immediately activated. Unconditional approach is widely used for emergency and VIP vehicles priority assignment.

Active priority techniques are activated only when public transport vehicle is present at signalized intersection, or when priority demand is sent to the control center. After the demand is sent, the priority technique is activated within the limits of minimal safety parameters

.

Active approach techniques include green phase extension, early green phase (red truncation), green phase insertion, phase rotation or substitution and selective strategies.

- Green phase extension

If vehicle approaches a signalized intersection, and green light is active, it can be extended for the time a public transport vehicle needs to pass through the intersection. Maximum extension limit is used to limit the impact on cross-street vehicles. Different projects and references define maximum green extension times which in implemented scenarios differ from 10 s to 20 s.

- Early green phase (red truncation)

If vehicle approaches a signalized intersection, and red light is active, it can be shortened so that early green phase can be activated. Maximum red truncation values are lower than green extension values because red truncation depends on the inter-green matrix (minimum time necessary for Emergency services vehicle approaches a signalized intersection (with three or more signal phases) it is possible to insert green light (which is not in the signal expected in the cycle) for the approaching public transport vehicle. A certain phase of the signal cycle can be withdrawn when there is no traffic load on the respective lane. In that case, it is possible to activate green light for the approaching public transport vehicle and reduce public transport vehicle delay. After vehicle detection, the system calculates the predicted pedestrians to cross the road).

- Green phase insertion

5.2. Model

Models are simplified representations fragments in real life. Their function is to give an insight in complex interactions in real world so we can make conclusions about what will happen (most probable) if changes occur in that real world or in parts of that world. Models in traffic modeling are mathematical models in form of mathematical formulas that show behavior of dependent variable Y (e.g.; number of vehicles on some street) comes out of one or few independent variables X (e.g.; percentage of motor vehicles, price of fuel) and parameter a. Those parameters describe sensitivity of Y on changes in X.

Traffic models are used to define potential actions that can influence on traffic system for analysis of efficiency of methods used and for quantification of consequences because of methods used in traffic system. They give insight in complex interactions and give possibility of detection of elements that have key role in system. They also give opportunity to determine sensitivity of dependent variables on changes in independent variables.

Traffic models can be used in "what-if" situations so they can show influence of some changes in system and system surroundings or they can be used as an instrument to design particular traffic objects in goal to maximize efficiency [5].

Strategy example of priority allocation for emergency vehicles can be made with real traffic data and by making simulation model. Based on calibrated simulation model it is possible to make algorithms of allocation priority for emergency service vehicles and compare results with normal model state. For example model intersection between Svetice and Zvonimirova Street is used because it is complexed intersection on route to 2 major hospitals and it is nearby Police and Fire department statins so implementation of adaptive algorithm, is needed.

Proper development of priority algorithm (specific to this intersection) it is necessary to define impact on signal logic do same or similar level of service can be maintained.

5.3. Tool for computer modeling: PTV Vissim

Whether comparing junction geometries, analyzing public transport priority schemes or considering the effects of certain signaling – PTV Vissim allows you to simulate traffic patterns exactly. Motorized private transport, goods transport, rail and road related public transport, pedestrians and cyclists – as the world's leading software for microscopic traffic simulation, PTV Vissim displays all road users and their interactions in one model. Scientifically sound motion models provide a realistic modelling of all road users [6].

PTV Vissim is a microscopic simulation tool for city traffic infrastructure modeling, traffic and pedestrian traffic. Correct and punctual model depends mostly on quality of vehicle behavior in simulated traffic grid. Difference from other simulation tool that use constant vehicle speed and deterministic following logic, Vissim uses psychophysical model of driver behavior that was developed by Rainer Widemann in 1974 on University of Karlsruhe.

PTV Vissim simulates traffic flow by moving units "driver-vehicle" through defined traffic grid. Every driver in grid with specific characteristics is assigned to specific vehicle, while defined technical possibilities of each vehicle are used (e.g.; maximum vehicle speed, acceleration and deceleration, etc.). Attributes that describe every unit "driver-vehicle" can be categorized in three basic groups:

1. technical vehicle specifications – vehicle length, maximum speed, potential acceleration and deceleration, position of vehicle in traffic grid, current speed and acceleration, etc.

2. behavior of "driver-vehicle" unit – psychophysical thresholds of driver senses (judgement of specific traffic situations, driver aggression, etc.)

3. dependence of "driver-vehicle" units – interaction between vehicles in a cue in same and neighbor lanes, interaction between road, vehicle and next intersection, interaction with upcoming intersection, etc.

The software offers flexibility in several respects: the concept of links and connectors allows users to model geometries with any level of complexity. Attributes for driver and vehicle characteristics enable individual parameterization. Furthermore, a large number of interfaces provide seamless integration with other systems for signal controllers, traffic management or emissions models.

PTV Vissim is rounded off with comprehensive analysis options, creating a powerful tool for the evaluation and planning of urban and extra-urban transport infrastructure. For example, the simulation software may be used to create detailed computational results or impressive 3D animations for different scenarios. It is the perfect way to present convincing and comprehensible planned infrastructure measures to decision-makers and the public.

VisVAP module was used to produce algorithm for actuated traffic signal control. VisVAP (short for "Visual VAP") is an easy to use tool for defining the program logic of VAP signal. VAP (vehicle actuated programming) enables PTV Vissim to simulate programmable traffic actuated signal controls, both phase or stage based. During PTV Vissim simulation runs or in the test mode, VAP interprets the control logic commands and creates the signal control commands for the PTV Vissim network. At the same time, actual detector variables are retrieved from the simulation and processed in the logic. The VAP control logic is described in a text file (*.VAP) using a simple programming language. It can also be exported from VisVAP. The VAP signal data set (*.PUA) can either be comfortably exported from Vissig or generated manually in a text editor. The range of application stretches from single junction controls over public transport pre-emption to network or corridor controls and even VMS applications such as variable speed control or temporary use of should lanes [7].

Algorithms of adaptive control with priority for emergency vehicles are made in addition module PTV VisVAP (Eng. VAP - Vehicle Actuated Programming) that gives opportunity for algorithm development using object programing and use of program logic in diagram flowchart. Flow of implementation of made algorithms in simulation model is shown on figure 13.

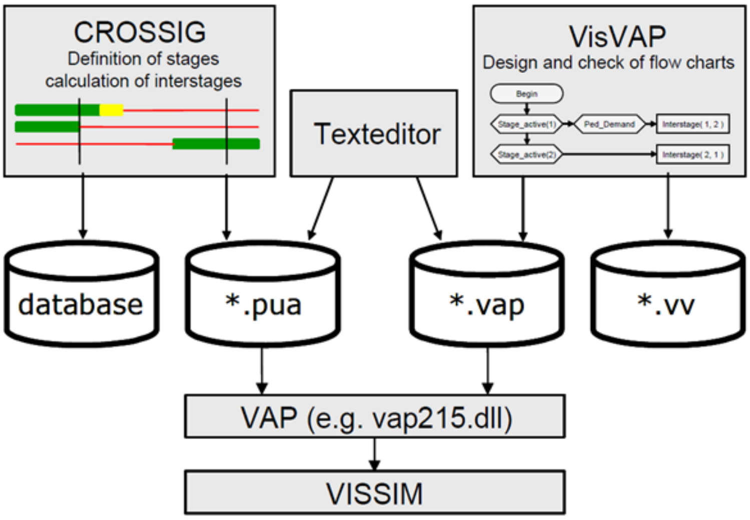

Figure 13 Steps of adaptive control algorithm implementation in simulation model (source: PTV – Planung Transport Verkehr AG: VisVAP 2.16 User Manual, 2006.)

Operation logic of each signal device (defined by ASCII data file extension *.pua) and adaptive control flow chart, (data file containing C++ algorithm code extension *.vap), are entered in simulation model. Starting simulation defined adaptive control chart flow is observed. All steps of algorithm implementation are used on starting state and it is basically the same (number of vehicles, static routing, etc.).

5.4. Input data

Vehicle counting was done by video camera traffic recording. Base data was produces in excel program. Data sheets with vehicle numbers show peak hour and traffic flow on each link that are needed for input in Vissim.

	SOUTBOUND									NORTHBOUND								
sat/min	left			straight			right			left			straight			right		
start 07:30	p.veh.	hv	bus	p.veh.	hv	bus	p.veh.	hv	bus	p.veh.	hv	bus	p.veh.	hv	bus	p.veh.	hv	bus
7:45	5	0	0	187	1	1	38	0	0	13	3	0	107	0	0	36	0	0
8:00	3	0	0	144	0	0	37	0	0	19	0	0	103	0	2	40	0	0
8:15	3	0	0	158	2	0	40	0	0	14	0	0	93	0	0	23	0	0
8:30	0	0	0	132	0	0	30	0	0	15	1	0	132	3	0	39	0	0
8:45	1	0	0	135	0	0	33	0	0	3	0	0	94	1	0	25	1	0
9:00	0	0	0	118	1	0	31	0	0	11	0	1	106	2	0	29	0	0
9:15	0	0	0	113	4	0	33	0	0	18	1	0	94	3	0	29	0	0
9:30	1	0	0	133	1	0	37	1	0	15	0	0	79	1	0	12	0	0

WESTBOUND										EASTBOUND									
left			straight				right			left			straight				right		
p.veh.	hv	bus	p.veh.	hv	bus	TRAM	p.veh.	hv	bus	p.veh.	hv	bus	p.veh.	hv	bus	TRAM	p.veh.	hv	bus
22	1	0	149	1	0	6	46	0	0	85	2	0	97	0	0	5	29	1	0
23	1	1	125	0	0	4	45	0	0	64	0	0	83	0	0	6	47	0	0
14	0	0	114	0	0	5	34	3	0	45	0	0	101	1	0	6	73	1	0
19	0	0	100	1	0	6	24	1	0	26	1	0	88	0	0	6	66	0	0
13	0	2	124	0	0	4	25	0	0	30	0	0	84	0	0	4	58	0	0
18	0	0	82	0	0	6	12	0	0	40	0	0	99	0	0	5	0	0	0
20	1	0	91	1	0	6	11	0	0	31	0	0	86	1	0	5	79	0	0
18	1	1	88	1	1	3	14	0	0	25	0	0	98	2	0	1	76	0	0

	right			straight			left			right			straight			left		
start 16:30	p.veh.	hv	bus	p.veh.	hv	bus	p.veh.	hv	bus	p.veh.	hv	bus	p.veh.	hv	bus	p.veh.	hv	bus
16:45	2	0	0	106	1	2	56	0	0	17	1	0	119	0	0	25	0	0
17:00	4	0	0	119	1	0	54	0	0	26	0	0	106	0	0	23	0	0
17:15	2	0	0	108	0	0	41	0	0	28	0	0	128	1	0	26	0	0
17:30	2	0	0	85	1	0	58	0	0	43	0	0	74	0	0	28	0	0
17:45	2	0	0	78	0	0	42	0	0	27	0	0	109	0	0	15	0	0
18:00	1	0	0	84	0	0	28	0	0	29	0	1	99	1	0	17	0	0
18:15	2	0	1	86	0	0	29	0	0	26	0	0	85	0	0	28	0	0
18:30	1	0	0	67	0	0	25	0	0	21	0	0	75	0	0	19	0	0

right			straight				left			right			straight				left		
p.veh.	hv	bus	p.veh.	hv	bus	TRAM	p.veh.	hv	bus	p.veh.	hv	bus	p.veh.	hv	bus	TRAM	p.veh.	hv	bus
14	0	0	69	1	0	5	26	0	0	30	2	0	191	1	0	4	85	1	0
10	1	1	45	0	1	5	23	0	0	28	0	0	179	0	1	4	86	1	1
8	0	0	57	0	0	4	30	3	0	23	0	0	170	0	1	4	90	0	0
11	0	0	100	1	0	6	24	1	0	25	0	1	172	0	0	5	61	0	0
13	0	0	56	0	0	3	32	2	0	23	0	0	163	1	0	4	77	0	0
9	0	0	81	0	0	4	24	0	0	32	0	0	157	0	0	5	83	0	0
10	1	1	50	0	0	4	20	0	0	11	0	0	144	1	0	5	77	0	0
12	0	0	56	0	0	3	16	0	0	11	0	0	119	0	0	3	77	0	0

Table 5 Vehicle counting (source: author, April 2016)

5.5. Making a model of intersection

PTV Vissim is very user friendly software. Start of procedure is loading background form a file. In this case AutoCAD drawing was made and loaded from a file. After adapting background to specific scale traffic infrastructure is laid on it. Links represent streets and connectors connecting streets that make intersection. After entering desired speed in intersection priority rules are decided for each conflict point on intersection. Since traffic signals are used, priority rules are not needed. Signal plan is made and signal heads are put on their locations.

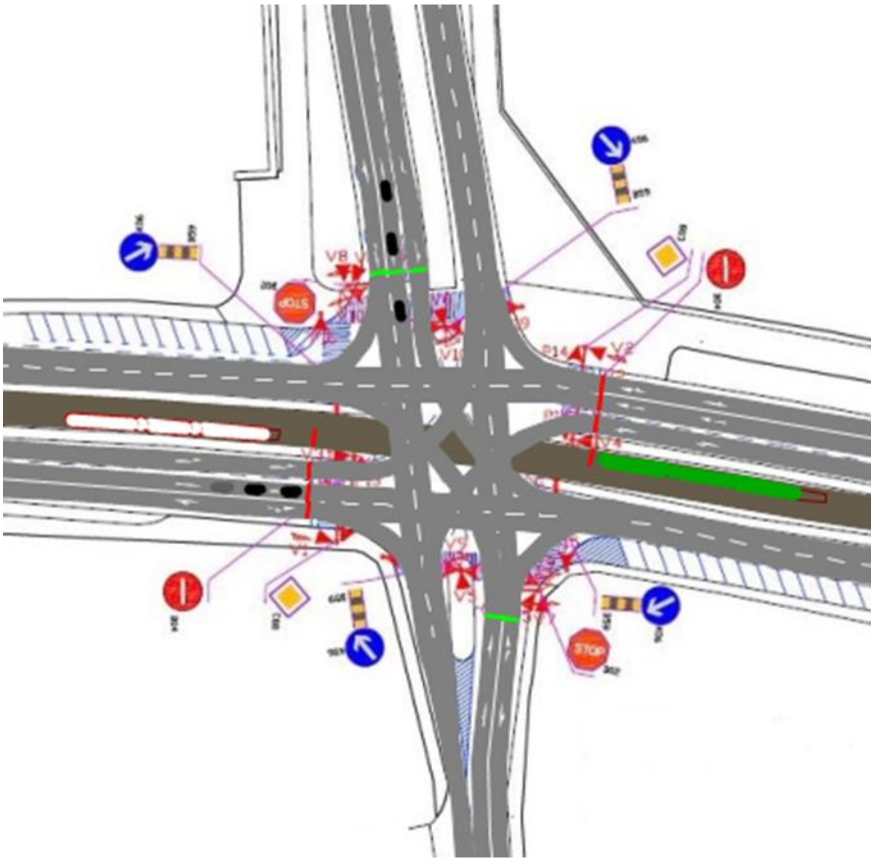

Figure 14 Vissim traffic model, Zvonimirova and Svetice street intersection (source: author, April 2016)

Each signal head is dedicated to its signal command. Vehicle inputs are made based on traffic counting table.

Figure 15 Vissim traffic signal model (source: author, April 2016)

Vehicle flow is routed by percentage of vehicles changing direction. Public transport and stations are made and time tables for public transport generated. After putting detectors, adaptive algorithm was made and 2 models are made for evaluation. Present state model and model with adaptive algorithm that gives priority to emergency vehicles. Adaptive algorithm upon detection of selected vehicle makes green light longer or cuts immediately on green light for that link. Simulation is started and evaluated in data results (Fig. 14). Duration of this model is 4200 seconds.

Good priority allocation algorithm development (specified to that intersection), it is necessary to define level of how much influence on signal logic it has so that LOS is maintained.

Two basic techniques are used:

1. green extension – in case that emergency vehicle sends demand for priority and its green is active,

2. red truncation/early green – in case when emergency service vehicle sends priority demand and any other faze is active.

When emergency service vehicle is not demanding priority normal signal plan is in use.

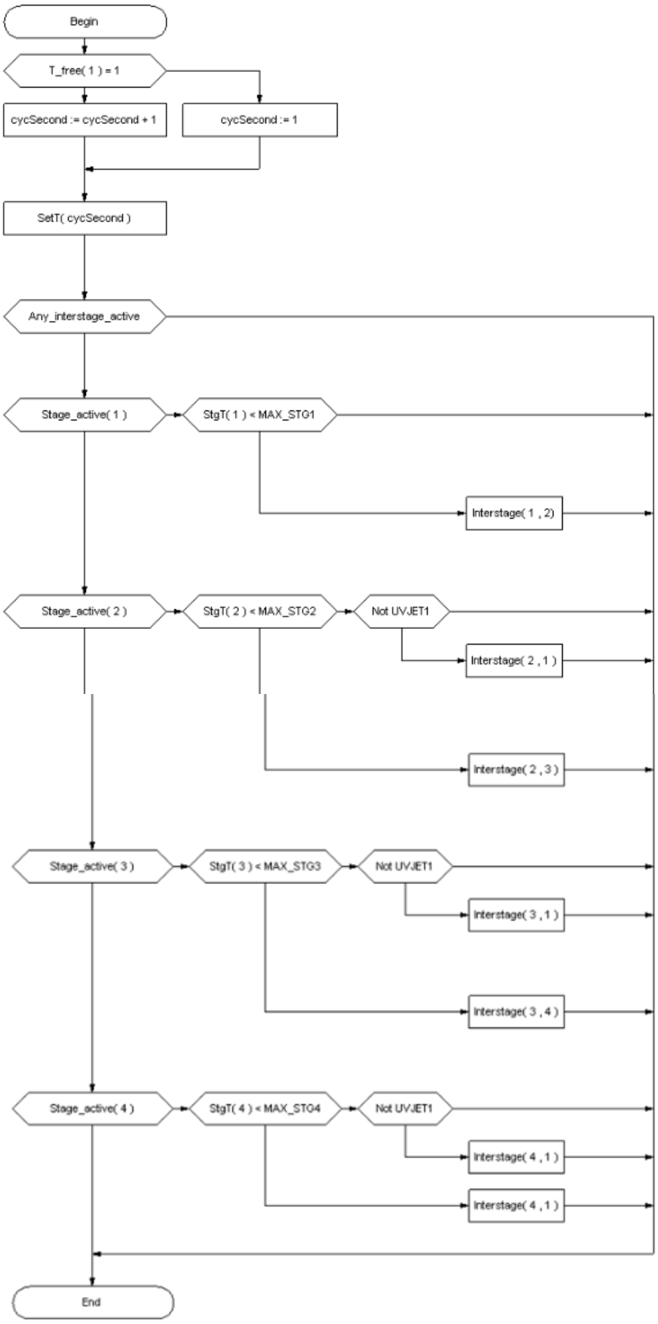

Figure 16 Vissim flow chart (source: author, April 2016)

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Stochastic method of traffic system demands use of variability for tools used. Wiedemann model of traffic following that PTV VISSIM simulation tool uses gives opportunity to adjust number of parameters (functions and distributions) so desired level of model stochasticity is achieved.

Acceleration and deceleration methods:

PTV VISSIM simulation tool does not use one acceleration and deceleration value, it uses functions to simulate real driver behavior. They are defined as real time speed values – engines with internal combustion have biggest acceleration values at low speeds. For every unit that travels on grid it is necessary to add two values of acceleration and two values of deceleration:

- Max acceleration – biggest possible technical achieved value that is used only in specific situation when vehicle is traveling on steep climbs
- Desired acceleration – used in other circumstances
- Max deceleration – biggest value of technical possible deceleration that is adjusted 0.1 [m/s2] for every positive slope value and -0.1[m/s2] for every negative slope value
- Desired deceleration - function of desired deceleration is necessary for definition of unit

Distribution of desired speed

It is very important parameter that has significant impact on street capacity and travel speed possible and it is possible to set one for each vehicle. In case that other vehicle is stopping driver, speed in simulation model will be same as defined desired speed (with small stochastic oscillations). In case when specific vehicle speed in traffic flow is lower that vehicle (obeying traffic rules) will try to overtake slower vehicle.

Driving behavior

Driving behavior in PTV Vissim simulation tool can be defined for each traffic link. Based on traffic link data they can be categorized: city grid, freeway/highway, pedestrian lane, bike lane, etc. It can be in 4 states of driving based on Widermann mode:

1. free driving – driver is moving by defined traffic lanes using speed that oscillate around defined speed – speed in real traffic cannot be constant.

2. approaching – driving process in which driver adjust speed to slower vehicles in front so difference between two vehicles is zero and safety distance is reached.

3. following – driver follows vehicle in front maintaining safety distance without significant deceleration or acceleration

4. braking – middle to hard deceleration if safety distance is low

Lane change driving behavior:

1. necessary change – necessary lane change because of route change
2. free change – lane change because of lane occupancy, higher travel speed.

6. Evaluation of simulation model results

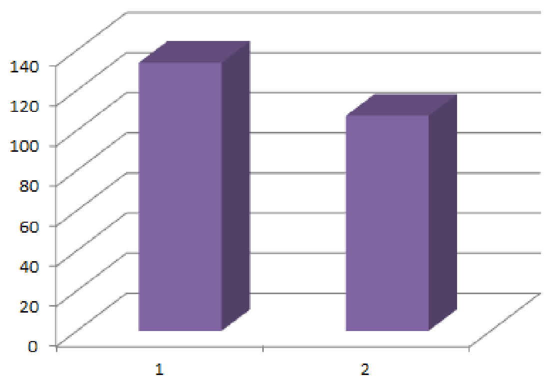
After running model simulation numerous times conclusion is made. Emergency vehicle is set in model and simulation through adaptive signal light control gives priority to that vehicle. Green light is extended or special signal management steps in and takes over control of signal light for desired route on emergency vehicle.

In last section process of simulation model development is shown and basic setup. Basic setup with adaptive control is explained for emergency services vehicles that is first influencing travel time through mentioned intersection.

Adaptive control influences road traffic directly because signal plans on coordinated intersections are not fixed and coordinated according to demands of road traffic. Priority allocation technic of emergency vehicles changes length of signal phases but is limited to minimum pedestrian green light.

6.1. Emergency services vehicle average travel time

Most important variable that shows adaptive algorithm use on traffic light managed intersections is average travel time through intersection. Total emergency services travel time is measured for each direction and average values are calculated. In all directions average travel time was 133.81 seconds and after implementation of adaptive algorithm travel time is 107.3 seconds which time shorter is by 26.51 seconds.



Graf 1 Graphic of emergency service vehicles average travel time in basic and adaptive intersection signal control (source: author, April 2016)

Average emergency vehicle travel time form basic model and model with adaptive signal control that gives priority to selected vehicles it is readable that with correct adaptive signal control implementation it is possible to shorten travel time through modeled intersection. That is result of few variables.

a) Short time of simulation duration is just 60 minutes in morning peak hour and full impact of adaptive control can be calculated through longer time period.

b) We have used one intersection and to get more accurate data, bigger traffic intersection grid should be used to show more significant travel time saving.

c) Adaptive control with priority for emergency service vehicles directly influences on emergency vehicle travel times in the end it influences users of emergency vehicle users by shortening response time of emergency service vehicles.

Travel time of emergency vehicles is shorter so travel speed is also increased. Speed for base model is 27.99 km/h and for model with implemented algorithms is 29.38 km/h in total 1.38 percent increase. Chart 2 shows difference between average speed on basic intersection and intersection with implemented algorithm

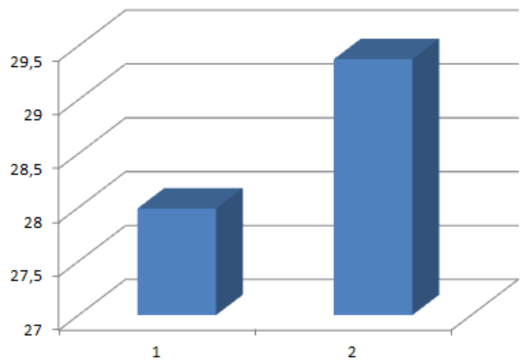


Chart 2 Graphic of emergency service vehicles average speed in basic and adaptive intersection signal control (source: author, April 2016)

Emergency service vehicle average speed in intersection is expectedly increased. Better results could not be achieved because it is impossible to know in what time is selected vehicle going to arrive on intersection. That is stochastic value and it is randomly generated.

6.2. Level of service

With adaptive signal control and priority for emergency vehicles fixed signal control is changed. Direct coordination between surrounding intersections is lost. Because of that adaptive signal control has its limits. In case of selected intersection base LOS is C. After implementing adaptive signal control waiting times are increased but LOS did not change because this intersection is not too complex for adaptive control of this kind and number of emergency service vehicles that they can change LOS. LOS for basic intersection is 26.46 and model with adaptive control 27.88.

LOS	Signalized Intersection	Unsignalized Intersection
A	≤10 sec	≤10 sec
B	10–20 sec	10–15 sec
C	20–35 sec	15–25 sec
D	35–55 sec	25–35 sec
E	55–80 sec	35–50 sec
F	≥80 sec	≥50 sec

Table 6 LOS (source: www.wikipedia.org, April 2016)

6.3. Average stop time

Besides other parameters it is very important to determine how long Emergency vehicle spent standing still waiting for passage through the intersection. Average stop time on basic intersection is 2.5 sec and average stop time on adaptive signal controlled intersection is 1.5 seconds.

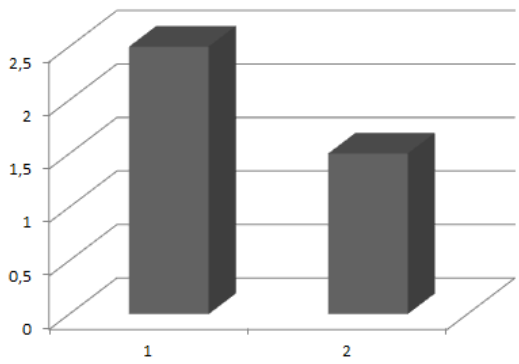


Chart 3 Graphic of emergency service vehicles stop time in basic and adaptive intersection signal control (source: author, April 2016)

From chart 3 it is easy readable that stop time is almost cut in half. Waiting time is very important because it is cumulative. On each grid intersection waiting time is accumulated. Since there is a great improvement on waiting time duration on this intersection it is reasonable to conclude that waiting time on whole route will be greatly shortened.

7. Cooperative traffic management systems

The traffic infrastructure has a set of operational tools for the TM to influence a given traffic situation. As example city traffic flows are highly depend on the traffic lights, which are part of the infrastructure. The controllable infrastructure can be roughly classified into the following categories:

• traffic control lights

• speed limits

• lane control

• information boards.

These tools are controlled by actions. An action can be the activation of a different control plan for the intersection traffic signals. The combination of actions is a traffic control strategy. As city traffic situation are reoccurring, the TM has a set of preconfigured traffic control strategies. Each is for a specific traffic situation and is a coordinated plan for all intersection. Strategies can for example change when congestion and emissions are getting critical in certain areas or changes are set up to work with time-depending traffic volume. The TM constantly observes the traffic situation, which is described by current traffic data and forecasts [8]. Traffic data represents traffic volumes, traffic distribution, the active infrastructure settings, weather conditions, road works, congestion, emissions status and can be measured by sensors. The traffic volume roughly follows a day- and week time pattern and can be anticipated from historical data (Fig 17).

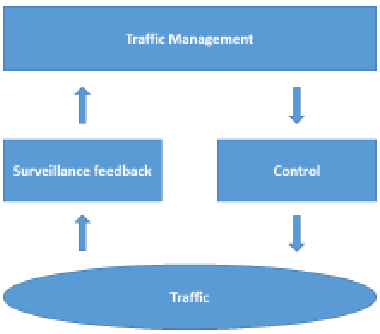


Figure 17 Traffic control actions (source: web page, euro control, April 2016)

Together with the current traffic data the TM can compute detailed short term traffic and emissions forecast. The traffic situation is altered by events. Events are for example traffic accidents, sudden congestion or changes in traffic and weather. Events, especially accidents and congestion, can change the traffic situation fast. A lot of research has been made on the optimization of traffic junctions, which have the highest effect on city traffic. Traffic light phases can be altered in sequence and cycle time. They can have a fixed-time strategy for given time of the day or a traffic responsive strategy, which adapts to current intersection traffic load. The intersection can work isolated or within a coordinated traffic control strategy, thus building a network out intersection for coordinating traffic light phases. This allows for example synchronized green phases, which accelerates traffic flows significantly. Speed limits are used to reduce traffic flows into already congested areas. The traffic management can close or open street lanes if the road infrastructure allows this. The decision process by TM can be modeled as control system. The TM continuously monitors the traffic situation. Whenever the current traffic situation warrants a change of the traffic control strategy TM takes the associated strategy changes to ensure the best possible mobility, transition into the next traffic situation. The ability to react quickly to traffic events is critical for an efficient and successful TM. This allows the best chances to keep the traffic in a free flow mode and prohibit a traffic break down. The decisions by the TM can suddenly change traffic flows. Even though, this has direct influence on routing, these TM traffic information are not communicated to companies or private persons. This research looks into if the routing efficiency of a service provider can be improved with an active communication between the service and the traffic control management. Consequently, we have identified the following TM information that could be beneficial when communicated to the service:

- traffic situation
- traffic control strategy
- traffic forecast.

The main objective is to establish communication between three main subsystems of traffic system: driver, vehicle and infrastructure so that they can cooperate in real time traffic environment (Fig. 18).

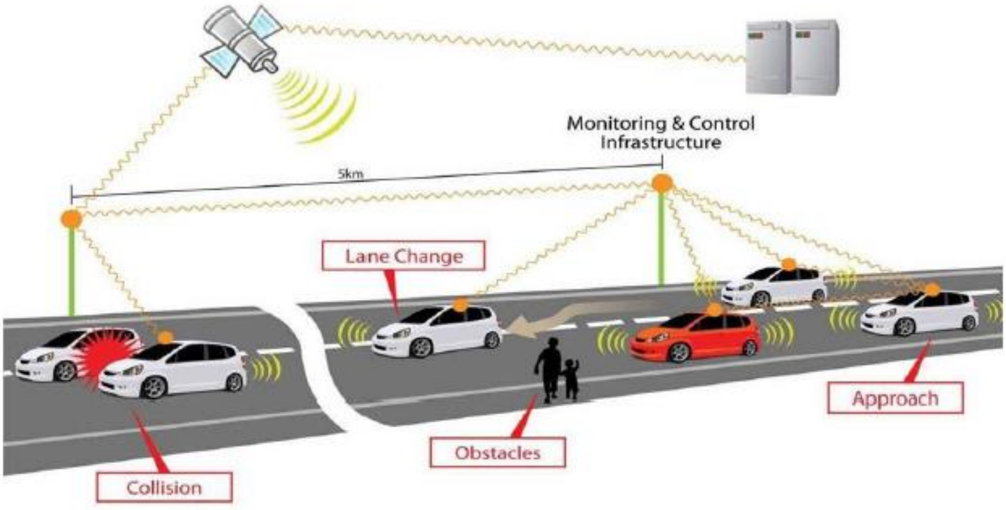


Figure 18 Communication between users (source: www.eurocontrol.com, April 2016)

This section presents the group of wireless access technologies considered and provides the set of functionalities implemented in the platform and how accurate they are modeled looking at the requirements and considering scalability and computational efficiency aspects. It is worth noting that implements a variety of wireless technologies, ranging from short-range and ad-hoc communications (ITS-G5, also referred as 802.11p or WAVE) to broadcast technologies (DVB), as well as cellular systems (UMTS and WiMAX). ITS-G5 does not require communication infrastructure and is specifically designed to effectively operate in vehicular environments, cellular technologies employ base stations through which communication take place. On the other hand, DVB, as a broadcast technology, allows data transmissions over large areas and to multiple users. This section introduces the currently implemented technologies: ITS-G5, WiMAX and UMTS [9].

Wireless vehicular cooperative systems are a promising solution to improve road traffic management through the exchange of traffic information among vehicles and with road infrastructure. Through the use of wireless vehicular communications, cooperative systems will be able to assist the driver allowing the detection of road dangerous situations and road traffic congestions. In addition, the adoption of vehicular communications can be used to ubiquitously provide real-time traffic information and re-route vehicles over optimal paths. In spite of the huge potential benefits that cooperative vehicular systems can bring, there is yet the need to demonstrate the impact of cooperative technologies, in particular with regard to traffic management. The evaluation of road traffic policies requires large-scale studies over long periods of time, which cannot ever be conducted through Field Operational Test (FOTs) equipping a limited set of vehicles. To overcome these current limitations, the EU FP iTETRIS (an Integrated Wireless and Traffic Platform for Real-Time Road Traffic Management Solutions, project is developing an integrated simulation platform allowing for large-scale studies on the impact and potential of cooperative vehicular communication technologies to dynamically and efficiently manage road traffic. To achieve its objectives, iTETRIS integrates two widely used open source platforms, SUMO and ns-3. SUMO reproduces vehicles ‘movement taking into account the road topology and traffic rules, ns-3 is employed as the wireless network simulator to model the exchange of messages through V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) communications. Focus is on the architecture and implementation details of the iTETRIS wireless simulation platform. From the simulator design perspective, iTETRIS presents several challenges, which mainly arise from the fact that iTETRIS is a multi-technology platform which includes short and long-range communication systems, cellular and ad-hoc technologies as well as an extensive set of communication protocols. Given the demanding scalability requirements of iTETRIS, there exists a challenging trade-off between the level of implementation detail of the communication modules, and the efficiency and simplification of the design required for conducting computationally efficient large-scale simulations. In the implementation and design process of the iTETRIS platform both of these aspects are considered. In this context, and apart from other design approaches aimed at reducing implementation complexity, iTETRIS characterizes the physical layer of the communication protocol stack through PER (Packet Error Rate) look-up tables obtained from link level simulations. Therefore, the physical layer models in the network simulator can be simplified and computational calculation times can be lowered (Fig 19).

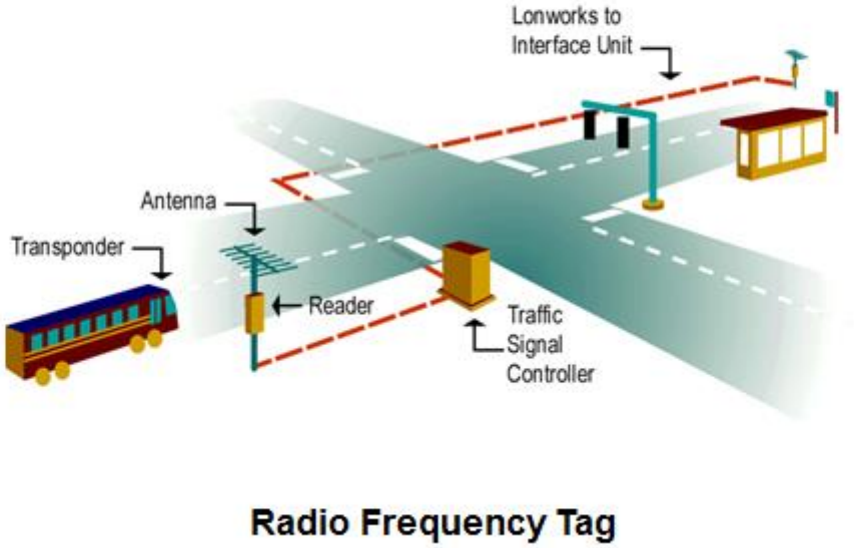


Figure 19 Radio frequency tag (source: http://www.fhwa.dot.gov, April 2016)

The iTETRIS wireless communication architecture is being developed following ETSI standards for Intelligent Transportation Systems (ITS). Since ETSI standards are not fully completed yet, input from other projects and initiatives such as COOPERS, CVIS and SAFESPOT, the Car2Car Communication Consortium, IETF, ISO, IEEE and SAE are also being considered in order to make sure that the iTETRIS platform is aligned with the major international and research standardization efforts [10]. The ITS system defined specifies a new type of communication system dedicated to transportation scenarios, which to a large extent is independent from specific communication technologies and user applications. The ITS Communications Architecture covers various communication media and related protocols for the physical and data link layers. The architecture will then include algorithms to select at each point in time the most appropriate communication technology. Different networking modes are identified, such as geo-routing, specific light overhead ITS protocols and IPv6 networking with new additions for mobility support. Each networking protocol may be connected to a specific dedicated ITS transport protocol or may connect to already existing transport protocols (e.g.; UDP, TCP). The facilities block collects a set of common functionalities, which are shared by several applications for various tasks. The facilities provide data structures to store, aggregate and maintain data of different type and source, and make them available to be accessed. The set of facilities are classified into application support, information support and communication support facilities depending on the nature of the functionalities they offer. The applications block presents the ITS user applications making use of the communication services provided by the underlying protocol stack. The Management entity is responsible for the configuration of an ITS station and for cross-layer information exchange among the different layers. Some of the main functionalities include the dynamic and optimum mapping of user applications on communication interfaces, the monitoring and managing of the set of communication interfaces, the management of transmission permissions and priorities, and the management of service advertisements depending on application specifications. The Security entity provides security services to the communication protocol stack and to the management entity (Fig. 20).

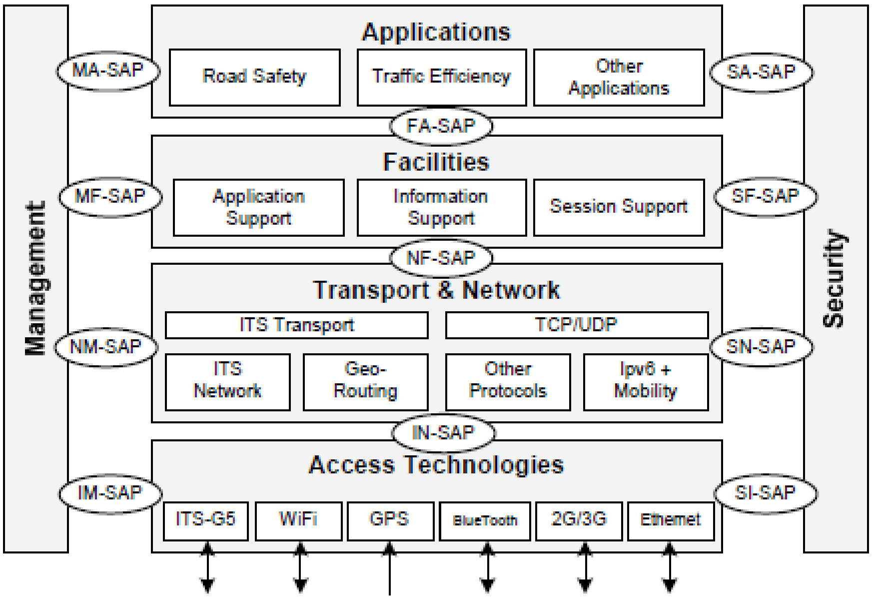


Figure 20 Communication (source: www. eurocontrol.com, April 2016)

Presented here is the iTETRIS heterogeneous wireless simulation platform that is being developed with the main objective of meeting the existing need to demonstrate the large-scale impact of cooperative technologies on traffic management. The iTETRIS platform will allow investigating V2V and V2I communications in multi-technology environments as well as their potential to improve traffic management. Platform design aspects essential to conduct computationally efficient large-scale simulations have also been considered, providing implementation details devoted to reduce the complexity of the communication modules (ITSG5, WiMAX and UMTS). Given the importance of realistically modeling the radio communication link in simulation research, this paper has also focused on the ITS-G5A PHY layer characterization and has presented BER and PER performance curves for V2V communications in highway scenarios.

Cooperative systems’ is the generic name given to a new generation of ITS made possible by short range data exchange between road vehicles, and between vehicles and the infrastructure (roadside units) in real time. By making it possible to use the vehicles themselves as ‘sensors’ (Fig. 21) vastly enriched data (Floating Car Data) becomes available to road operators. This brings the potential of significant advantages in both the urban and interurban road environment, including:

- improvement in the efficiency of traffic flows, since better information is available for traffic control and management systems;
- greatly enriched information services about the road environment for drivers, and hence valuable support to driving decisions;
- in the safety area, Cooperative Systems open the way to safety-critical applications that require vehicles to be “always connected”.

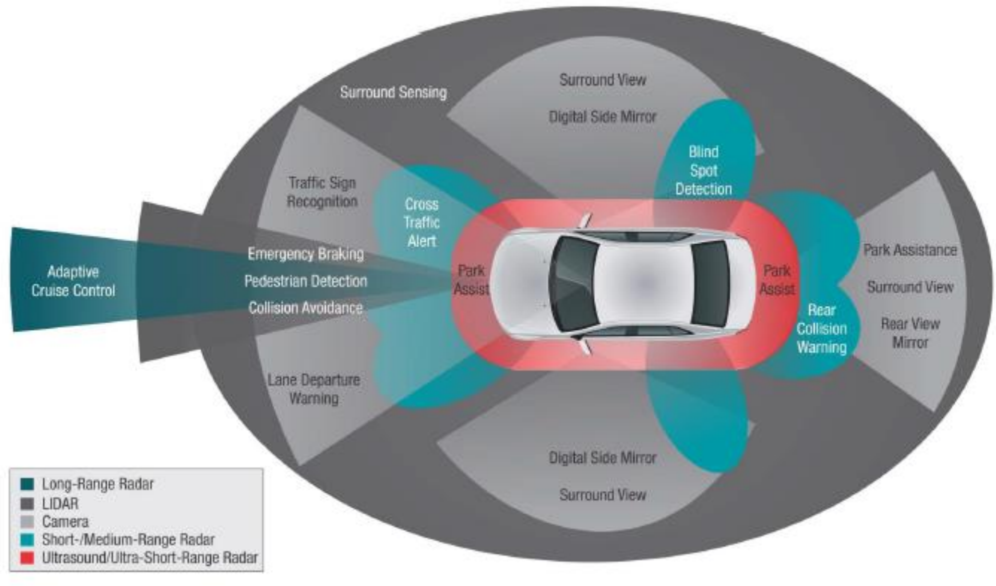


Figure 21 Vehicle information system (source: www.eurocontrol.com. April 2016)

Typical examples of benefits of using of this kind of technology consist of continuous assistance to drivers e.g. in keeping a safe distance between vehicles, in forecasting traffic congestion on the planned route; and speed advice when approaching intersections (green light support). Cooperative systems are potentially valuable for several types of application relevant to Large Scale Events. These systems installed on some vehicles, for instance emergency vehicles, public transport vehicles, heavy trucks or trucks with dangerous goods, are a helpful instrument of management of exceptional events. The priority application leads to a manipulated switching of traffic lights. The application aims at a more fluid and safe intersection crossing for the vehicle categories set by the authorities. The application can be used in all kinds of urban areas but also in particular during large scale events.

With regard to emergency vehicles could for example be equipped with onboard units to enable direct communication with traffic control systems to permit priority at signalized intersections and special route guidance depending on real time traffic conditions.

Emergency vehicles are usually prioritized (against other road-users) at intersections on predefined routes (Fig. 19). The cooperative priority application can increase traffic safety at the intersections and flexibility of route choice. Drivers of the non-prioritized vehicles as well as pedestrians and cyclists will have an unambiguous red signal instead of current practices of an emergency siren which is often difficult to interpret in terms of its location. Additionally, current emergency vehicle services are usually based on pre-defined routes and do not allow alternative routes. The Priority Application can increase flexibility of route choice since the software can be uploaded to any cooperative intersection and thus the route choices can be enlarged. The real-time traffic situation can be considered and the suggested route can bring about a reduction in travel time for the emergency vehicles (Fig. 22).

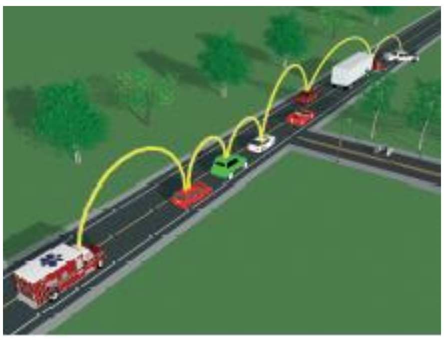


Figure 22 Emergency vehicles prioritizing (source: www.eurocontrol.com, April 2016)

Additional cooperative system applications are also relevant for large events such as information services for drivers, available via VMS (overhead gantries) or onboard, could for example integrate event information with real-time traffic and parking status as well as congestion warnings. In relation to conventional systems, the usefulness of the displayed messages would be improved as a result of the availability of more detailed real-time and vehicle-specific information (Fig. 23).

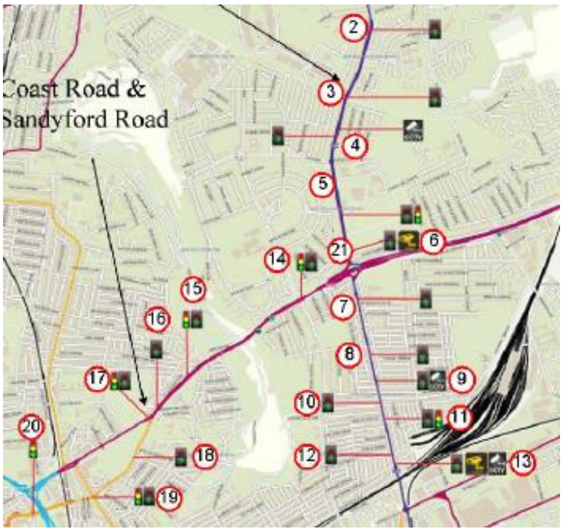


Figure 23 Route information (source: www euro control, April 2016)

Options: cooperative Systems fall into two main categories: those that depend on vehicle-to infrastructure (V2I) communications and those that require vehicle-to-vehicle (V2V) communication. Both types of system are still in the experimental stage, but while the first commercial applications of the former are likely to be widely available before 2015, the latter are expected to take rather longer before becoming available on the market.

Cooperative Urban Applications: this aim to improve the efficiency of use of the urban road network and quality of information for drivers. Among the systems being currently tested is enhanced intersection management, which gives approaching vehicles recommended speed advice to ensure they obtain a green light.

Examples: the Speed Profile Application consists of recommending a speed or acceleration/deceleration rate to the driver based on their current speed and the state of the network. Signal stage information is implemented by the traffic control system of the city and is communicated to the driver as a speed advisory message. The application aims at smoothing the traffic flow.

Benefits: an individual vehicle fitted with the application benefits from improved performance in terms of fuel consumption and consequently of pollution emissions. When the penetration rate of the application is higher, the benefit can be extended across the network – for example to create dynamic green waves – which will ultimately improve network efficiency.

Flexible bus lane application: dedicated lanes or bus lanes for public transport improve the speed of public transport services, but they take up a lot of space, leaving unused capacity in crowded cities that eventually can be used also for any other vehicles on demand the main objective of this application is to increase the road capacity on certain road sections in urban areas by providing temporary access to bus lanes to selected vehicles, while ensuring an undisturbed passage of public transport vehicles. Certainly, the usage of reserved bus lanes by certain private vehicle categories can be permitted in line with local traffic management policies. For instance: certain freight companies can be granted access to the bus lanes if they have certain 'green' credentials, in order to encourage environmentally friendly behavior from freight companies; or car-sharing vehicles could have access to the bus lane if the project is being launched in order to encourage users to try out the system.

Micro-routing: the Micro-Routing Application provides urban routing advice for drivers (freight and private drivers) taking into consideration factors such as pollution levels, weather forecast, events (e.g., football match) or local congestion.

Benefits: fewer stops and less time delay at intersections for the vehicles and less travel time from origin to destination. These benefits are at first individual but also improve the network performance as a result of better balancing of traffic. Furthermore, noise levels and emissions will decrease. The application is most useful at intersections on main arterial routes.

Cooperative Inter-Urban Applications: these are used on inter-urban highways to guarantee cooperation between vehicle and infrastructure. The main objective of these devices is to optimize traffic flow, ensuring a high level of local response to traffic fluctuation and particular events.

Pre-trip and On-Planning: drivers can plan their trips across the Inter-urban road network according to their need to travel, their specific origin and destination within the Inter-urban road network, plus the current and forecast traffic conditions. In addition Drivers can change their previously prepared trip plans, or produce plans for the first time, whilst their journeys are in progress.

On-trip seamless service with tracking and rerouting if needed: the Service Center takes care of Drivers' requests providing information and (re)routing guidance depending on individual Driver preferences and Vehicle characteristics.

Vehicle Data feeding to Traffic Control Centers: the collection of Vehicle and planning data enhances the determination of current and forecast traffic conditions so that they can be combined and used in the preparation of trip plans. This data can also be used to calculate strategies to assist with the management of the traffic using the Inter-urban road network.

Driving advice: provides the driver with information about driving conditions for the part of the road network that is immediately ahead of the vehicle's current position and trajectory. The intention is to give drivers advanced warning of any changes to the conditions under which they are currently driving, e.g. changes in weather conditions, road conditions and speed limits, plus advanced notification of traffic queues, whether they are a product of the current traffic conditions, or due to an incident of some type.

Ghost driver detection and management: Enables ghost drivers to be detected either by roadside units, vehicles, or their drivers. Once detected traffic managers can initiate the appropriate action to warn approaching vehicles and the recovery of the ghost driving vehicle by the emergency services. Warnings of "ghost driver ahead" can also be provided directly to approaching vehicles.

Benefits: increasing traffic efficiency with traffic congestion control resulting in reduced transport time, fuel consumption and thus contributing to improving the environment. In addition it increases road safety by reducing the number of accidents as well as reducing the impact in case of non-avoidable accidents

Technologies: the key technologies required to support the implementation of cooperative systems relate to the communications network and the positioning and map referencing technologies. With regard to the communication technologies the choice will be critical. If continuity of cooperative system-enabled services are to be ensured internationally, there will need to be agreement on the technology selected. Currently there are several candidates.

- M5 radio communication at 5GHz frequency bands supports omni-directional communication between moving objects with a minimum data rate of 6 Mbps up to 300 meters radius. It can be used for communication from vehicle-to-vehicle and from roadside unit-to-vehicle, in low-directive conditions.
- Infrared light communication complements the previous technology by providing highly directive beams with a typical performance of 2 Mbps up to 100 m range.
- MM radio communication at frequencies above 40 GHz allows much higher data rates (on the order of GBPS) in the range of several hundred meters.
- CALM 2G/3G cellular radio technology.
- Dedicated Short Range Communication System (DSRC), based on a short range data communication (5.8GHz), is used to permit communication between road side units and OBU (onboard units) installed on vehicles.
- LTE a technology for use of cooperative systems is coming.

LTE is marketed as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements. In relation to the positioning, maps and local referencing, these technologies combine the use of positioning systems (e.g.; GPS, EGNOS, Inertial Sensors, or RF signal triangulation) and enhanced map-solutions in order to establish the dynamic location of vehicles. To enable the correct positioning of moving vehicles on the road network, a map-matching technique must be used to ensure the ‘matching’ of location information from different sources. The OBU needs to be equipped with a GPS receiver and to enable the exchange of data between vehicle OBU and the RSU (vehicle-to-infrastructure technologies) or between OBUs (vehicle-to vehicle technologies) of the vehicle travelling on the same road, allows sharing of information among users, and a quickly and dynamic update of them according to traffic condition changes. With regard to fleet management, communication technologies are fundamental for the exchange of information between vehicles within a fleet or between the vehicles and the management center. DSRC technologies are also used for the recognizing and tracking of parcels in loading/unloading operation. Positioning technologies and enhanced maps are necessary to locate vehicles and give them advice concerning routing guidance.

Integration potential: cooperative applications in the urban context could for example be integrated with applications related to the intersection management and to access control. Data provided by vehicle-to-vehicle or vehicle–to-infrastructure communication systems can then be transferred to a Traffic Management Centre which integrates all the available data coming from different sources, and implements strategic solutions to influence traffic condition (dynamic management of traffic lights, access control and variable message signals, Fig. 24).

Figure 24 Traffic conditions overview (source: www.eurocontrol.com April 2016)

In the inter-urban context, functional integration of Cooperative Systems with information services operated by Traffic Information Centers can greatly improve the management of traffic flows on motorways and avoid traffic congestion (Fig. 25). This makes it possible to combine real-time data from vehicles traveling on the network with information from other sources. The research project lays its focus on telematics services based on data receivable from road infrastructure, public transport and individual vehicles and used for supporting traffic participation in a safe, efficient and sustainable manner.

The cooperative system services include:

Informing the driver about:

- current speed limits
- road
- blocked lanes or re-routing
- obstacles like broken down vehicles
- departure times of public transport and airplanes as well as about the capacities of Park and Ride services
- the suitable speed to pass the next traffic light in green phase

Warning the driver if:

- a motorcycle is approaching and risks to be overlooked in blind angle
- he is approaching the end of a traffic jam
- a vehicle in front suddenly slows down
- bad weather causes locally dangerous road conditions like aquaplaning or black ice

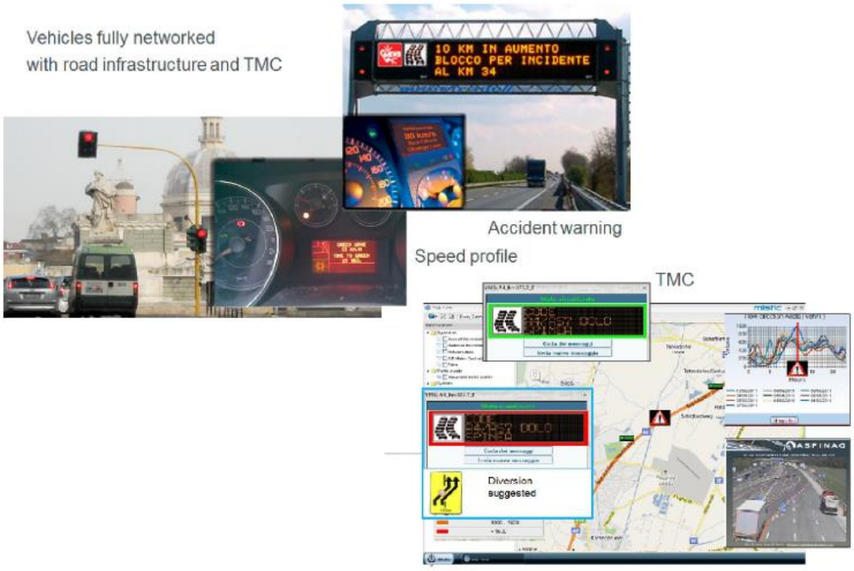


Figure 25 Cooperative management (source: www.eurocontrol.com, April 2016)

Implementation: in the urban contest, cooperative applications can be implemented at three different system levels (Fig 25):

- cooperative network management: area traffic management is optimized by recommending the best route to the drivers according to their destination and the current traffic conditions on the network
- cooperative area routing: in case of local disturbances in the traffic condition (e.g.; due to accidents or special event) cooperative applications can make it possible to alert approaching vehicles and suggest a new route
- cooperative local traffic control: the cooperation between vehicles and enhanced local intersection control make simpler the creation of green waves. At this level information provided to the user are related to speed profile and to condition of the neighboring intersections

Priority “Cooperative Systems for Road Transport” The fundamental enabling technology for cooperative systems is a “universal communications module” that can interface to existing in-vehicle systems, and to existing roadside installations, and that can maintain a continuous wireless high-capacity data channel. The CVIS module uses existing bearers such as 2.5/3G cellular phone and DSRC, which are specifically designed for the new “Wi-Fi for mobiles” wireless local networking supporting both vehicle to vehicle and roadside infrastructure communications.

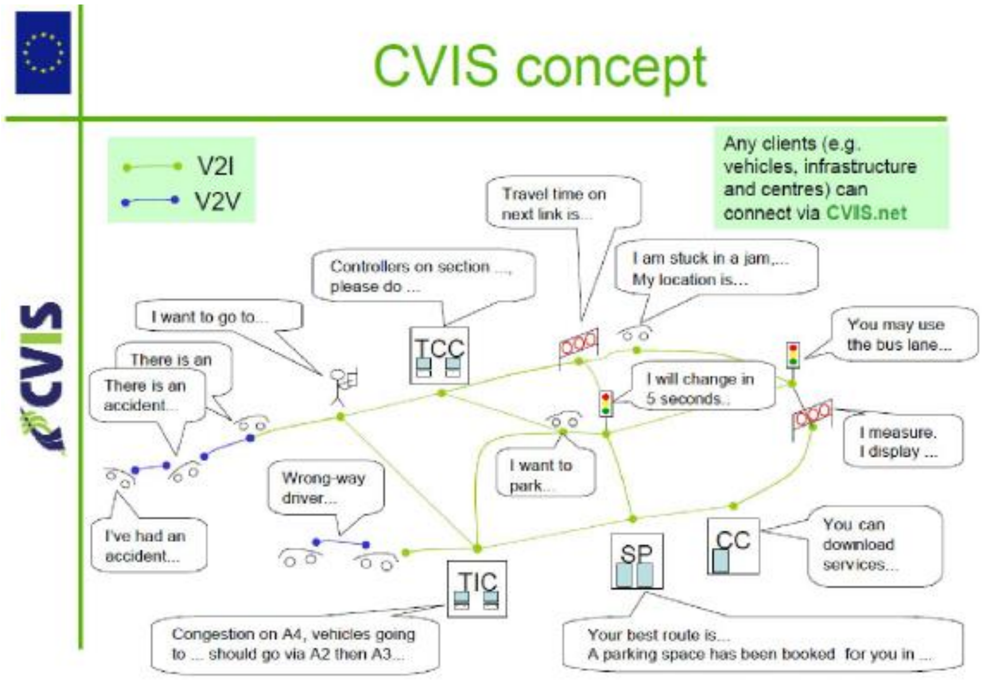


Figure 26 CVIS project (source: www. eurocontrol.com, April 2016)

This means that an operator, service provider or other nearby vehicle will be able to address a vehicle in entirely new ways, such as by location or by IP address, and provide new kinds of service (Fig.26).

8. Conclusion

Taking in consideration methodology of adaptive traffic management with priority allocation to public transport vehicles where such management has great influence on whole traffic, through simulation model (present state and with implemented adaptive management algorithms with emergency vehicles priority) it is expected to lower times of travel for emergency vehicles, therefore shorter time to respond on traffic incident. Given solution can be improved because emergency vehicles can get additional information through vehicle to infrastructure and vehicle to vehicle information system (alternative route, waiting time on traffic lights).

Through simulation it is proven that travel time of emergency vehicles becomes shorter with optimization of traffic signals. Designed algorithms and vehicle to vehicle and vehicle to infrastructure communication brings new era of adaptive traffic control. This analysis of current state and technology that is already implemented in current traffic brings summary of possibilities.

Infrastructure in Croatia is outdated but with big efforts of traffic specialists it is possible to bring improvements that can give opportunity for implementing new technology. Combining technology and knowledge of Faculty of traffic and transport science can produce new applications, algorithms and infrastructure that will in future interact on new level. Improvements are needed and necessary to rise level of service and safety in traffic.

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