INTELLIGENT TRANSPORT MEASURES AS A COMPONENT OF CYBER-PHYSICAL SYSTEMS: CASE STUDY FOR ADAZI CITY

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ABSTRACT

Nowadays, the systems developed to integrate real physical processes and virtual computational processes – the cyber-physical systems, are used in multiple areas such as medicine, traffic management and security, automotive engineering, industrial and process control, energy saving, ecological monitoring and management, avionics and space equipment, industrial robots, technical infrastructure management, distributed robotic systems, protection target systems, nanotechnology and biological systems technology. Current paper provides an overview of CPS, their application in different fields of modern business, with main accent to intelligent transport system. Various ITS strategies and its evaluation measures are considered for transport intelligent transport system effective management. Example of transport management solutions realization process (problem definition, data collection, initial model development, verification, validation, ITS strategies developments, testing and evaluation) based on transport modelling is presented. Example is illustrated for one of the Latvian cities – Adazi, where was necessary to improve accessibility level for local drivers to get to and from city center.

Keywords: cyber-physical systems, intelligent transport system, modelling, transport management solutions

1. INTRODUCTION

New competitive approach to the physical and virtual world integration with cyber-physical systems is one of the European Union research priorities. Cyber-physical systems will change the way people interface with systems, the same way as the Internet has transformed the way people interface with information.

Concept of cyber-physical systems, their history and main components and characteristics are considered in this work. Cyber-physical systems can be and is used in different business areas such as commerce, industry, and public health, military and so on. In this paper application of cyber-physical systems in Internet of things, Industry 4.0, healthcare and transport intelligent systems are presented. Main accent is directed to transport intelligent system where physical systems working together with ITS technologies allow developing more sustainable and effective solutions for transport systems management.

To evaluate ITS solution effectiveness, complex mathematical models are used based on transport simulation models. Simulation models allow evaluating complex solutions before realization and selecting the better alternative from existing. Example of transport management solutions realization process and simulation model development and evaluation process are presented in chapter 3.3. One of Latvian cities – Adazi was selected for case study to illustrate transport management solutions realization and simulation model development process for ITS measure evaluations. Case study of Adazi city includes all steps of transport management solutions realization process: definition of case study aims and ITS measure requirements, data collection and initial model development, model verification and validation, development of strategies and evaluation of results for new ITS strategies.

2. CONCEPT OF CYBER-PHYSICAL SYSTEMS

Cyber-physical systems are developed to integrate real physical processes and virtual computational processes. Many objects used in modern daily life are cyber-physical systems. Concept of CPS is complicated (Skorobogatjko 2014), it can be illustrated with a concept map (see Fig. 1), developed in Berkley University (http://cyberphysicalsystems.org/).

The definition of Cyber-physical system from Cyber-Physical Systems Week (www.cpsweek.org): “Cyber-physical systems (CPS) are complex engineering systems that rely on the integration of physical, computation, and communication processes to function.”

Cyber-physical systems have not appeared from nowhere, they have a long history of development, which continues. This chapter is an introduction to cyber-physical systems, their history and overview of the main components and characteristics.

Always growing need for different purpose information management systems leads to optimization of computing tools design techniques. Most of the world’s currently used information management systems are embedded systems and networks. They are closely related to the control or management objects.

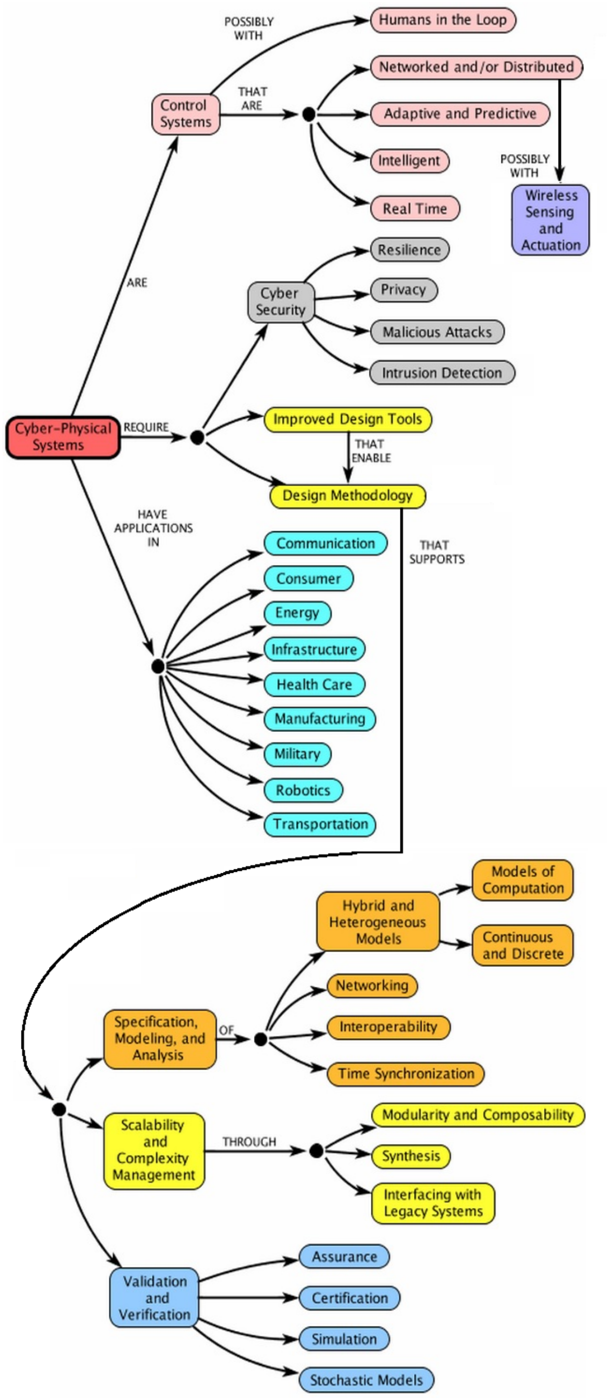

Figure 1: A concept map of Cyber-physical systems

From certain common computing systems' classifications best suited to the modern situation is classification proposed by David Patterson and John Hennesy (Patterson 2013). Their classification was guided by the use of the system. They divided computing system into 3 categories: desktop computers, servers and embedded systems. Embedded systems by the area of use are separated into:

- Automatic control systems;
- Measuring systems and systems that read information from sensors;
- Real-time "question – answer" type information systems;
- Digital data transmission systems;
- Complex real-time systems;
- Moving objects management systems;
- A general purpose computer system subsystems;
- multimedia systems.

The concept of embedded systems appeared in the early 50's and it is in rapid development even today. It is interesting to view the evolution of embedded systems:

- Information management systems, 60's;
- Embedded computing systems, 70's;
- Embedded distributed systems, 90's;
- Cyber-physical systems, from 2006.

Information management system is a computing system designed for management purposes, but it is the most alienated from the control object. Integrated micro-scheme and microprocessors development led to information management system bringing directly to the management object. World had entered the era of embedded systems. System elements are gradually becoming cheaper and their integration increases, as well as the security level and the opportunity to combine them in controlled networks.

Downturn in embedded systems' elements prices and increasing connection with physical management objects led to appearance of cyber-physical systems.

Cyber-physical systems are specialized computing systems that interact with control or management objects. Cyber-physical systems integrate computing, communication, data storage with real world's objects and physical processes. All above said processes must occur in real-time, in safe, secure and efficient manner. Cyber-physical systems must be scalable, cost-effective and adaptive. Cyber-physical systems are in use in various areas such as smart medical technologies, environmental monitoring and traffic management.

Wireless sensor networks can become an important part of cyber-physical systems, because of high sensitivity capability it is one of the main driving factors of cyber-physical systems application distribution. The rapid development of WSN, medical sensors and cloud computing systems makes cyber-physical systems impressive candidates for use in inpatient and outpatient health care improvement (Milenkovic 2006). Cloud computing maturity is a direct result of few technologies such as distributed computing, internet technology, system management and hardware development (Buyya 2011).

Cyber-physical systems integrate computing and physical processes. Compared with embedded systems much more physical components are involved in CPS. In embedded systems, the key focus is on the computing element, but in cyber-physical systems, it is on the link between computational and physical elements. Cyber-physical system parts exchange information with each other that is why the third component - communication is added there. For this reason, cyber-physical system is denoted by the symbol

C3 (Computation, Communication and Control). Links improvement between computational and physical elements, extends cyber-physical systems usage possibilities.

3. CYBER-PHYSICAL SYSTEMS APPLICATION

Cyber-physical systems are used in multiple areas such as medicine, traffic management and security, automotive engineering, industrial and process control, energy saving, ecological monitoring and management, avionics and space equipment, industrial robots, technical infrastructure management, distributed robotic systems, protection target systems, nanotechnology and biological systems technology.

3.1. Internet of Things and Industry 4.0

In several sources (Buyya 2011; AENEAS 2014; Koubaa 2009) it is predicted that within ten years almost half of the electronic devices will be connected to the World Wide Web. This network is termed as Internet of Things. It connects not only household appliances such as refrigerators, thermostats, but also sophisticated production equipment.

Industry 4.0 concept aims a comprehensive cyber-physical systems use in manufacturing, customer relationship management and supply chain management processes, combining it all into one system. Smart manufacturing lines communicate with each other in order to optimize the production process.

Modern construction technology enables the creation of intelligent building designed with minimum energy consumption or even without it. However, they need constant monitoring. Engineers must attach smart buildings to smart grids, and add control mechanism – cyber-physical systems (CyPhERS, 2014).

Comprehensive use of cyber-physical systems for commerce, industry and public health, military and civilian purposes, makes the protection of these systems a matter of national significance. That is why embedded systems security systems, mainly anomaly detection system that enables resist spoofing and service failure type attacks, are currently actively developed (Amin 2013).

3.2. Healthcare Cyber-Physical Systems

There are hospitals, where robots already bring dishes to patients, sort mail, change bed linen and collect waste. Robotic beds transport patients to the surgery room. However, fully automated healthcare system has not been implemented yet. Currently, a number of hospitals in the world remote operations are carried out by the help of a robotic hand and high-resolution cameras (NITRDP 2009), however, there is still a long way to autonomous surgery when cyber-physical system itself, without human management, performs the operation.

Human-in-the-Loop Cyber-Physical Systems can greatly improve lives of people with special needs. Human-in-the-Loop Cyber-Physical Systems formulate opinions about the user's intentions based on his cognitive performance by analysing data from sensors attached to the body or head. Embedded system convert these findings to robot control signals, which, thanks to robotic management mechanisms, allow users to interact with the surrounding natural environment. Example of Human-in-the-Loop CPS is robotic assistance systems and intelligent prosthesis (Schirner 2013).

Existing healthcare cyber-physical systems were mapped to this taxonomy and number of healthcare CPS groups (with several examples) were allocated: notable CPS applications (Electronic Medical Records, Medical CPS and Big Data Platform, Smart Checklist), daily living applications (LiveNet, Fall-Detecting System, HipGuard), medical status monitoring applications (MobiHealth, CodeBlue, AlarmNet), medication intake applications (iCabiNET, iPackage.).

3.3. Intelligent transport system

Intelligent transport system (ITS) provides realization of complex functions that can process of high dimension information and development of optimal and efficient decisions. ITS various strategies, guides, technologies are directed to existing transport system improvements without major reconstructions and investments with aim to provide more information, safety for all transport system operators, better coordinated transport network, congestion reduction, sustainable transport development and increase accessibility.

ITS technologies (wireless, radio, optics etc.) together with physical systems (traffic cameras, sensors, processors, variable message signs, ramp metering, data collectors etc.) help to manage transport systems and provide control of these systems. As result of such cooperation various ITS technologies are developed for more sustainable economic and social growth (Ezell 2010):

- Highway, freeway, road management system. Examples of application: ramp metering, traffic control, parking management, traffic signal control system, demand management, variable message signs.
- Transit management system. Examples of application: fleet management, lane preemption, signal priority, demand management.
- Freight transport management. Examples of application: system that can execute control of vehicle height and load limits.
- Accident and emergency management system. Examples of application: automatic accident detection, re-routing of traffic in case of accidents, detections of dangerous transport situations at roads, identifying driver's level of alcohol, drugs.
- Multimodal management system
- Traveler information system. Examples of application: pre-trip, route information.

- Traffic control systems. Examples of application: traffic signals, traffic monitoring, vehicle and pedestrians detectors.
- Automatic fare payment systems. Examples of application: electronic tolls, transit fare payment, parking fare payment.

Smart transport systems equipped with various computerized and integrated management systems at different levels provide data collection from different sources and assign it between vehicles group or separate vehicles, for example Vehicle-to-Vehicle and Vehicle-to-Infrastructure interaction technologies that provide communication between vehicles; and vehicle and surrounding infrastructure. Such technologies allow improve road network capacity, transport operator safety, drivers' interaction on roads, decrease traffic delays, and number of car accidents. (Hashimoto 2009).
An example of cyber-physical systems known to the general public is Google car, which does not require a driver.
Example of transport management solutions realization process in order to propose the most effective solution from developed is presented in Fig 2.

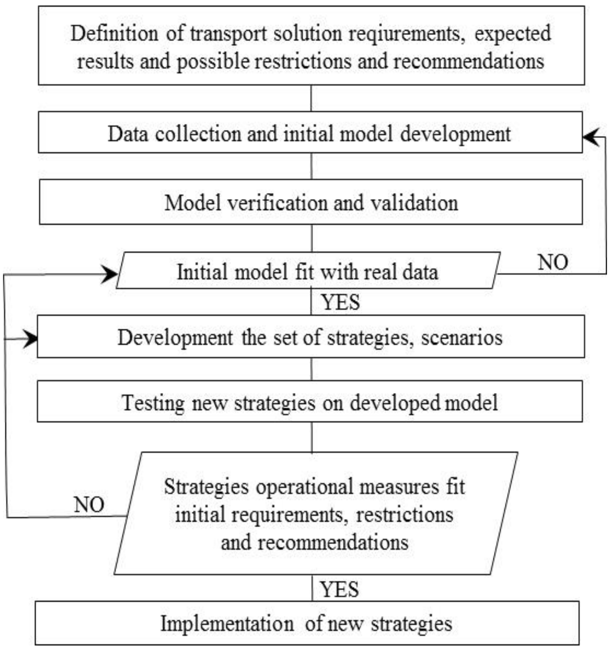

Figure 2: Example of transport management solutions realization process with transport modelling

Effective use of ITS can reduce delays, congestion time, accident counts, fuel consumption and improve traveler travel time, traffic flow, traveler mobility. Various types of measures can be used to evaluate ITS benefits (Koonce 2005):

- Capacity. To evaluate the capacity and/or level of service maximum number of vehicles or persons in peak hour can be used.
- Mobility. Mobility can be expressed as delay time and travel time per time unit.
- Safety. Safety usually is measured as number of accidents at roads, number of injury, fatalities.
- Productivity. Productivity is measured as cost saving, level of service analyzed unit (roads, lanes, pedestrians, public transport).
- Energy and environmental. Energy and environmental changes is measured by emission level, fuel use.

To evaluate ITS measures the good understanding of the dynamics of traffic at micro and macro levels, bottlenecks effects on the network, driver's behaviors, elements that influence on congestion initiation are essential. Simplified mathematical models are not enough for such complex dynamical problems and the better way how to evaluate and control various complex transport management systems strategies and solutions are to use traffic simulation models (Papageorgiou 2012). Example of simulation model development and evaluation process is presented in Fig. 3.

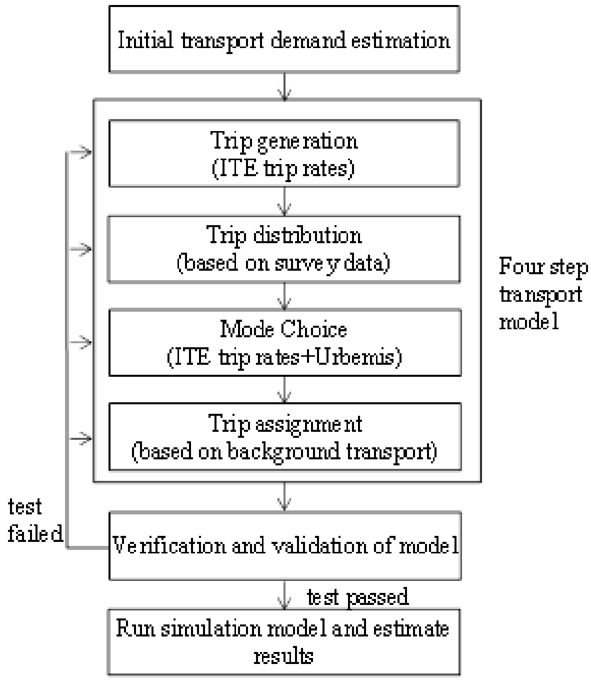

Fig. 3. Simulation model development and evaluation process

When simulation model is developed, verified and validated then different transport management scenarios, strategies, solutions can be developed and tested on simulation model in order to propose the most effective solution from developed.

4. CASE STUDY

The case study has been divided into group as it is showed in Fig. 2 in order to illustrate transport management solutions realization process and transport model development process with modelling for Adazi city.

4.1. Definition of case study aims and ITS measure requirements

The primary objective of the case study is to manage the bypass vehicles at Adazi city Local Street (Fig. 4 – yellow line) in the moments when Main road (Fig. 4 – blue line) is overloaded with heavy transports and drivers choose Local Street to overpass the congested road section. In such situation Local Street becomes over congested too and local drivers cannot with accessible level of service get to home (Adazi city center) or from home.

Figure 4: Research area. Yellow line - main road; blue one – bypass road

The aim of the study to improve transport accessibility for local drivers, to provide the efficient way for them to get to / from city center in case of Main Street peak hours by developing ITS measures. It was decided that for this study the following measures will be considered and analyzed based on local capacity and available land space:

- Improvements of transport infrastructure (changes in specific intersection geometry),
- Improvements in traffic lights signalization,
- Implementation of Variable message signs (VMS). VMS is devices that display messages of special events, time, road congestion and so on.
- Implementation of incident management system at Main road that allows detecting traffic accident and quick clear road from accident event participants to reduce the traffic blocking time.

Research area with Main and bypass (Local) streets is showed in Fig 4. In peak hour's Main road is loaded preliminary with the heavy transport that by transit is going to Estonia and non-truck drivers try to bypass Main road section by using Local Street despite the fact that travel time is approximately the same at Main and Local Street. Analyzed Local street section contains two roundabouts and 4 additions minor accesses to Adazi city.

4.2. Data collection and initial model development

To develop initial simulation model two modelling software Aimsun 8.0 developed by Trafficware Corporation and Synhro/Simtraffic 6.0 developed by Traffic Simulation Systems were selected based on literature comparison. Aimsun 8.0 is integrated transport analysis tool that can be used for transport planning, microscopic modelling, and demand and transport data analysis. Aimsun simulation tool provides integrated platform for statistical and dynamical modelling. Synchro simulation tool provides transport flow capacity analysis and signal timing optimization. Trafficware simulation tool provides Synhro 2d animation.

In the case study Aimsun simulation tool is used to create four step transport demand model: trip generation, trip distribution, mode choice and trip assignment. And Synhro tool is used for specific access traffic signal timing optimization. For analyzed alternatives with signal timing, signals optimization was done with Synhro to select best alternative and then this signal timing is used in transport demand model developed in Aimsun.

Initial model for existing situation was developed based on the following steps:

- Road geometry creation (lines, signs, pedestrian crossings, road types, free-flow speed etc.).
- Initial matrix and matrix adjustment creation with traffic data for different vehicles types: cars, trucks, buses, pedestrians.
- Public transport lanes with stops, transit schedules and set time spent for passenger departing and arriving.
- Signal timing definition for each intersection.
- Matrices, public transport, signal timing addition to travel transport demand model.
- Model initiated parameters configuration (warmup time, lane changing, modelling periods, number of runs etc.)

At this step initial model is developed and are ready for running the simulation. After model is finished simulation, verification and validation of model should be done to receive reliable model.

4.3. Model verification and validation

To verify and validate initial simulation model the following technics were used: Root mean square error (1), correlation coefficient (R), Theil's Inequality Coefficient (2).

$$RMS_i = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(w_{ij} - v_{ij})^2} \quad (1)$$

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$$U = \frac{\sqrt{\frac{1}{n}\sum_{j=1}^{n}(w_{ij} - v_{ij})^2}}{\sqrt{\frac{1}{n}\sum_{j=1}^{n}w_{ij}^{\;2}} + \sqrt{\frac{1}{n}\sum_{j=1}^{n}v_{ij}^{\;2}}} \quad (2)$$

The root mean square error between estimated and observed results was 11%, correlation coefficient was 0.92 and and Theil's Inequality Coefficient was 0.11. The results of initial model verification and validation were showed appropriate results and simulation model can be used to test new strategies.

4.4. Development of strategies

To fit projects objectives six different scenario were considered to improve accessibility for local Adazi city drivers:

1) Scenario without changes. Local Street has two roundabouts (Fig. 5). This scenario will be used to compare results with other scenario.
2) Scenario 1. Local Street geometry is not changed. At Local Street entrance Variable message sign (VMS) is placed that in real-time shows travel time necessary to cross Main and Local Streets sections for transit drivers.

Figure 5: Scenario 1. Local Street has two roundabouts

3) Scenario 2. One of roundabouts at Local Street is changed to signalized intersection (Fig. 6) and without VMS.

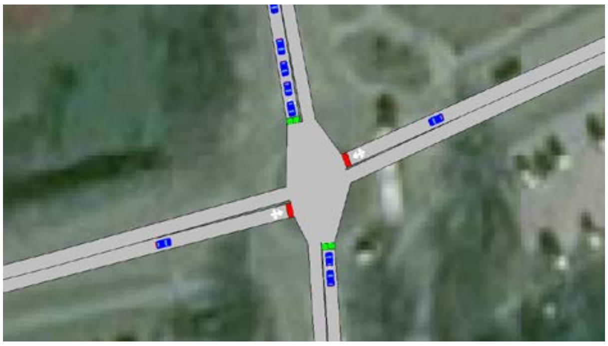

Figure 6: Scenario 2. One of roundabouts is changed to signalized intersection

4) Scenario 3. One of roundabouts at Local Street is changed to signalized intersection with protected left turns (Fig. 7) and with VMS.

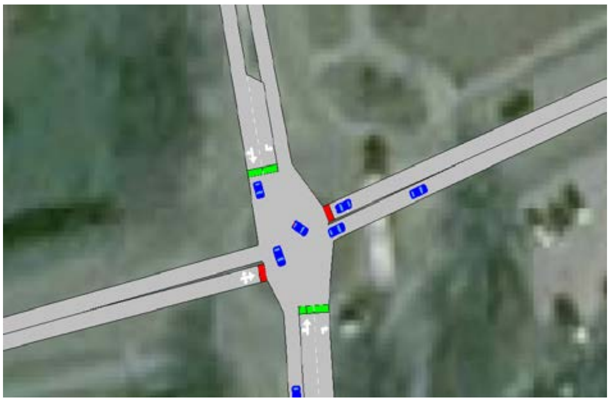

Figure 7: Scenario 3. One of roundabouts is changed to signalized intersection with protected left turns

5) Scenario 4. Both roundabouts geometry at Local Street is changed to signalized intersections with protected left turns (Fig. 8) and with VMS.

Figure 8: Scenario 4. Both roundabouts geometry is changed to signalized intersections with protected left turns

6) Scenario 5. Both roundabouts geometry at Local Street is changed to signalized

intersections with protected left turns (Fig. 8), Variable message sign is placed at Local Street entrance and accident management system will be implemented at Main road section.

4.5. Evaluation of results for new ITS strategies

For each considered scenario transport simulation model was build based on initial transport model. Each scenario was modelled during one hour. To evaluate results of each scenario the evaluation measures (Table 1) were divided in two groups: measures for Local drivers and for transit drivers that used Local Street.

Measures for local drivers consist:

- Travel time for local driver to get to city center.
- Level of service for intersections.
- Delay time for signalized intersections (for scenarios 2 - 5).
- Capacity for roundabout (base scenario without changes and scenarios 1, 2).
- Emission level calculated according to simulation software Aimsun.

Measures for transit driver consist:

- Travel time for transit driver to pass Local Street.
- Travel time at Main road.
- Number of trucks at Main road.
- Emission level calculated according to simulation software Aimsun.

Table 1: Evaluation results of scenarios

Measures for local drivers:						
	Base	Sc 1	Sc 2	Sc3	Sc4	Sc5
Travel time for local driver to get to city center, sec	214.6	208.1	205	208.3	206	207.4
Level of service	-	-	C	B/C	B/C	B
Delay time, sec	-	-				
Capacity for roundabout	0.75	0.76	-	-	-	-
Measures for transit driver:						
Travel time for transit drivers to pass Local Street, sec	253.9	253.1	260.9	259	258.9	254.9
Travel time at main road, sec	267.1	269.9	268.8	270	267.3	271.4

Level of service and delay time were calculated according to Highway capacity manual 2010 (HCM 2010). Level of service and delay time estimation methodology according to HCM2010 is presented in Fig. 9.

The evaluation results of new ITS strategies (scenarios) showed then better strategy from level of service, travel time and capacity point of view is the fifth scenario in which both roundabouts geometry at Local Street were changed to signalized intersections with protected left turns (Fig. 8), Variable message sign was placed at Local Street entrance and showed time necessary to pass Local street and Main street; and with implemented accident management system at Main road section.

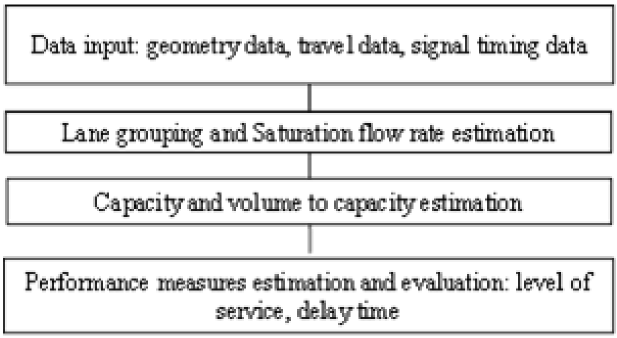

Fig. 9: Level of service and delay time estimation methodology

The second result showed scenario 1 in which Local Street geometry was not changed, but at Local Street entrance Variable message sign (VMS) was placed that in real-time showed travel time necessary to cross Main and Local Streets section for transit drivers.

5. CONCLUSIONS

An overview of CPS, their application in Internet of Things and Industry 4.0, healthcare and intelligent transport system is presented. The main aspect of research was devoted to intelligent transport system. Various ITS technologies that combine intelligent transport solutions and physical systems are listed. Example of transport management solutions realization process (definition of requirements, data collection and initial simulation model development, model verification and validation, development of scenarios, testing new scenarios and implementation) for Adazi city is considered. Six different development strategies were analyzed for Adazi city to improve accessibility for local drivers to get to city center: 1) strategy without changes in transport network geometry at Local street; 2) strategy without changes in transport network geometry at Local street and with implemented Variable message sign that will redirect transit transport from Local Street to main Street; 3) strategy with changes at one of road intersection at Local Street and without VMS; 4) strategy with changes at one of road intersection at Local Street and with VMS; 5) strategy with geometry changes at two road intersections at Local Street and with VMS; 6) strategy with changes at two road intersections at Local Street, with VMS and with implemented accident management system at Main road section. Performance measures (travel time, delay time, level of service, capacity) were used to evaluate each development strategy for Adazi city. Strategy evaluation results have shown that from all considered strategies, the sixth strategy showed the smallest travel time for local drivers to get to city center and travel time for transit drivers at Main road increased only for 2%.

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