ISSN 1407-6160

# TRANSPORT AND TELECOMMUNICATION

Volume 12. No 3

2011

Transporta un sakaru institūts
(Transport and Telecommunication Institute)

# Transport and Telecommunication

**Volume 12, No 3 - 2011**

**ISSN 1407-6160**
**ISSN 1407-6179**
(On-line: www.tsi.lv)

Riga – 2011

05/J80



**Host Organizations:**
Transport and Telecommunication Institute, Latvia – Boriss Misnevs, Rector
Telematics and Logistics Institute, Latvia – Igor Kabashkin, Director

**Supporting Organizations:**
Latvian Transport Development and Education Association
Latvian Academy of Sciences
Latvian Operations Research Society
Telecommunication Association of Latvia
Latvian Academic Park

All articles are reviewed.
Articles can be presented in the journal in English.

**EDITORIAL CORRESPONDENCE**

Transporta un sakaru institūts (Transport and Telecommunication Institute)
Lomonosova iela 1, LV-1019, Riga, Latvia. Phone: (+371)67100594. Fax: (+371)67100535.
E-mail: kiv@tsi.lv, http:// www.tsi.lv

**TRANSPORT and TELECOMMUNICATION**, 2011, Vol. 12, No 3
ISSN 1407-6160
The journal of Transport and Telecommunication Institute (Riga, Latvia).
The journal is being published since 2000.

The papers published in Journal "Transport and Telecommunication" are included in
**SCOPUS** (since 2008, Vol. 9, No 1), **Elsevier Database**
www.info.scopus.com
www.elsevier.com

# CONTENTS

Interoperability Problems of Especially Electronic Toll Collection
*Gabriel Nowacki* ..... 4

Resource Allocation Problems in Mesoscopic Flow Models
*Jurijs Tolujevs* ..... 18

Critical Situations Evaluation of Discrete Transportation Systems
*Jacek Mazurkiewicz, Tomasz Walkowiak* ..... 27

Software-Engineering Measurement for Logistics and Transport Systems
*Sergey Orlov, Andrei Vishnyakov* ..... 41

An Approach to Estimation of the Automatic Vehicle Location Systems Functionality by Comparison of Its Technical Parameters
*Daniil Opolchenov, Valery Kutev* ..... 54

Vehicle Dynamic Localization in Intelligent Transportation Systems Based on Sensor Networks
*Victor Krebss, Boris Tsilker* ..... 63

Authors' index ..... 73

Personalia ..... 74

Cumulative Index ..... 77

Preparation of Publications ..... 81

*Transport and Telecommunication, 2011, Volume 12, No 3, 4–17*
*Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia*

# INTEROPERABILITY PROBLEMS OF ESPECIALLY ELECTRONIC TOLL COLLECTION

***Gabriel Nowacki***

*Motor Transport Institute,*
*Management and Transport Telematics Centre*
*Jagiellońska 80, 03–301 Warsaw, Poland,*
*Phone +48 228113231 ex. 134*
*E-mail: gabriel.nowacki@its.waw.pl*

The paper refers to the implementation problems of Intelligent Transport System (ITS) in Member States of the European Union. The autonomous systems implemented in Member States of EU are not interoperable due to some reasons, especially lack of cooperation capability. European Commission has taken steps in the mentioned issue (directive 2010/40/EU, M/453, decision 2011). Furthermore the paper discussed assumptions and test results of NATCS Pilot Project developed by Motor Transport Institute, Autoguard SA, and Fela Management AG. Legislation steps were taken at the EC level because of interoperability problems of European Electronic Tolling Service (EETS) in the EU. Commission has urged the member states to conduct studies and pilot projects concerning these issues. Motor Transport Institute has taken up a challenge by developing and testing the pilot project – the functional structure of the NATCS. System has some requirements of EC legislation and it is interoperable with other DSRC and GPS/GSM based systems implemented in the member states of the European Union. Test results have shown a high accuracy and efficacy of the system.

**Keywords:** Intelligent Transport Systems (ITS), interoperability, the European Electronic Toll Service (EETS), the National Automatic Toll Collection System (NATCS), eCall

## 1. Introduction

Intelligent Transport Systems or ITS means systems in which information and communication technologies are applied in the field of the road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport. Interoperability means the capacity of systems and the underlying business processes to exchange data and to share information and knowledge.

Interoperability of ITS is the capacity of systems and the underlying business processes to exchange data and to share information and knowledge. ITS application means an operational instrument for the application of ITS. ITS service is the provision of an ITS application through a well-defined organisational and operational framework with the aim of contributing to user's safety, efficiency, comfort and/or to facilitate or support the transport and travel operations. ITS service provider means any provider of and ITS service, whether public or private. ITS user is any user of ITS applications or services including travellers, vulnerable road users, road transport infrastructure users and operators, fleet managers and operators of emergency services.

The European Commission has stressed that autonomous Intelligent Transport Systems implemented in EU Member States are not interoperable, means it is no ability of ITS to:

– Provide information and services to other systems,
– Use exchanged information and services to operate together effectively.

The same situation refers to the European Electronic Tolling Systems (EETS). There are two different types of EETS: Dedicated Short Range Communication (DSRC) and GPS/GSM based systems.

In most EU countries (Austria, France, Spain and Italy) DSRC type systems of electronic tolling are used, that rely on dedicated short range radio (microwave frequency - 5.8 GHz).

The OBU on-board device, operating in the DSRC system is small (size similar to the pack of cigarettes). It is mounted on the windscreen inside the vehicle. However, the device is not very smart, very simple and only performs validation functions (read only), it has no display, and cannot receive or transmit any message. The DSRC system requires a well developed road infrastructure, at every crossroads, and gates must be installed at entrances to and exists from the toll road sections.

In the DSRC system, there are two gates types: communication Toll Gates and control gates, because their number is ten times greater than it is the case in the GPS / GSM.

In addition, data transmission is done using the wired communications, and then it can take place over the Internet. The DSRC system will not be able to be incorporated into an integrated technology platform, as it will not even be able to collaborate with other national transport systems. Even in the case of the DSRC system, which is provided by Kapsch, each country has a different type of OBU device. Another solution is to apply GSM or GPS systems.

In this system, thanks to the GPS satellite positioning virtual control and tolling points established, the system can operate without the use of control gates. Data are transferred to the system directly from the OBU devices, using GSM communications.

According to the European Commission, the electronic tolling systems used in the European Union are not interoperable for the following reasons: differences in the concepts of tolling, technology standards, classifications, rates, discrepancies in the interpretation of laws (Fig. 1).

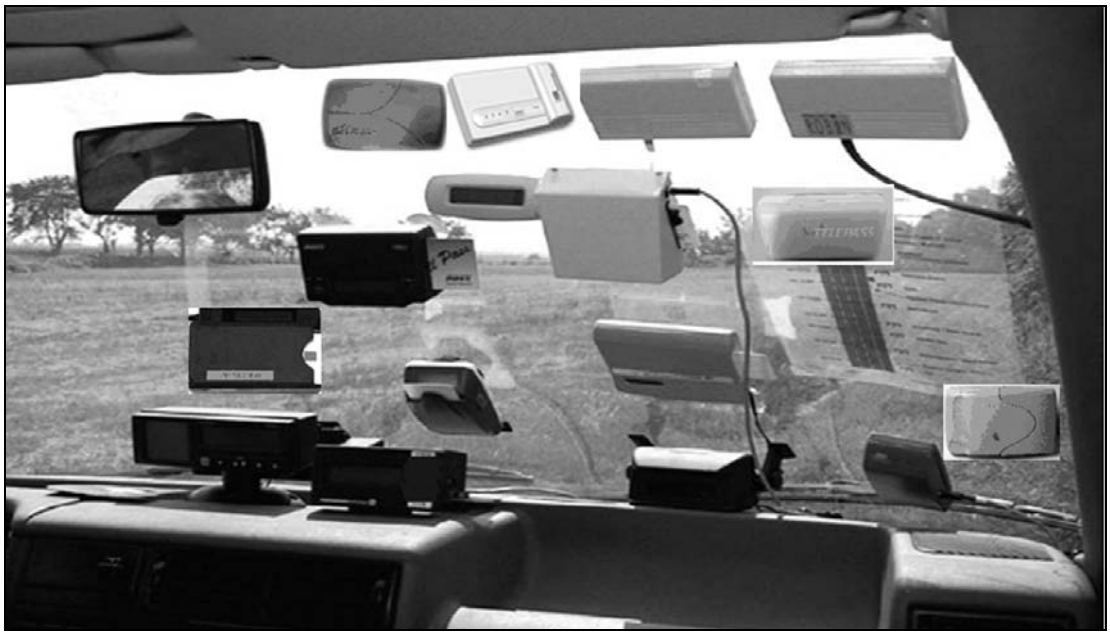


*Figure 1.* Onboard OBU devices currently used on vehicles [5]

The European Commission has taken two mile steps in this regard. The first was Directive 2004/52/EC of 29 April 2004 on the interoperability of electronic road toll systems in the Community [1]. Then there was the decision of the European Commission of 6 October 2009 on definition of the European Electronic Toll Service (EETS), and system architecture [2].

According to the European Commission decision 2009/750/EC, European Electronic Toll Service (EETS) should enable road users to pay tolls easily throughout the whole European Union (EU) thanks to one subscription contract with one Toll Service Provider and one single on-board unit (OBU). The mentioned decision was supported by standard EN ISO 12855 (CEN, Brussels, 05.02.2010) – tolling interoperability aims at enabling a vehicle to driver trough various Toll Domains while having only one OBU operating under contract with Toll Service Provider [8].

Implementation of the interoperability is a long-term and precise action. What comes to the fore in the implementation strategy for interoperability is the need for introduction of the EETS system, consisting of the following systems: DSRC, GSM, GNSS[1].

The best universal solution in complicated situation in UE is implementation of hybrid system (includes: DSRC, GSM, GPS technology), the researches developed in Czech Republic, NATCS is mentioned type of system.

## 2. Problems of Intelligent Transport Systems

### 2.1. General Characterization of ITS

ITS integrate telecommunications, electronics and information technologies with transport engineering in order to plan, design, operate, maintain and manage transport systems. The application of information and communication technologies to the road transport sector and its interfaces with other

[1] GNSS – Global Navigation Satellite System. GNSS-1 is based on existing segments of the orbit Navstar GPS and Russian GLONASS system. An integral part of the GNSS-1 is a system of differential (DGPS - Differential Global Positioning System). Development of GNSS-1 will be the GNSS-2. The constellation of navigation satellites will include the GPS Navstar satellites of II F type GLONASS M and new European satellites wit working name of Galileo.

modes of transport will make a significant contribution to improving the environmental performance, efficiency, including energy efficiency, safety and security of the road transport, including transportation of dangerous goods, public security and passenger and freight mobility, whilst at the same time ensuring the functioning of the internal market as well as increased levels of competitiveness and employment. However, ITS applications should be without prejudice to matters concerning national security or which are necessary in the interest of defense.

The general structure of Intelligent Transportation Systems applications may include: vehicle, airplane & ship operations, crash prevention and safety, electronic payment and pricing, emergency management, freeway management, incident management, information management, intermodal freight, road weather management, roadway operations and maintenance, transit management, traveller information.

These are some areas of ITS which are developed by ISO TC 204 (Tab. 1).

**Table 1.** Category of Intelligent Transportation Systems according to ISO TC 204 [6]

| Category of services | Service No | Service name |
|---|---|---|
| Traveler information | 1 | Pre-trip information |
| | 2 | On-trip driver information |
| | 3 | On-trip public transport information |
| | 4 | Personal information services |
| | 5 | Route Guidance and Navigation |
| Traffic management | 6 | Transportation planning support |
| | 7 | Traffic control |
| | 8 | Incident management |
| | 9 | Demand management |
| | 10 | Policing/Enforcing traffic regulations |
| | 11 | Infrastructure maintenance Management |
| Vehicle | 12 | Vision enhancement |
| | 13 | Automated vehicle operation |
| | 14 | Longitudinal collision avoidance |
| | 15 | Lateral collision avoidance |
| | 16 | Safety readiness |
| | 17 | Pre-crash restrain deployment |
| Commercial vehicle | 18 | Commercial vehicle pre-clearance |
| | 19 | Commercial vehicle administrative process |
| | 20 | Automated roadside safety inspection |
| | 21 | Commercial vehicle on-board safety monitoring |
| | 22 | Commercial vehicle fleet management |
| Public transport | 23 | Public transportation management |
| | 24 | Demand responsive transport management |
| | 25 | Shared transport management |
| Emergency | 26 | Emergency notification and personal security |
| | 27 | Emergency vehicle management |
| | 28 | Hazardous Materials and incident notification |
| Electronic Payment | 29 | Electronic financial transaction |
| Safety | 30 | Public travel safety |
| | 31 | Safety enhancement for vulnerable road users |
| | 32 | Intelligent junctions |

European Intelligent Transport Systems have been fully exploited to maximize the potential of the transport network. European standards will become a key element of the preferred solutions in emerging economies.

Public transport users will have access to up-to-the-minute information, as well as the benefit of smart and seamless ticketing. Freight operators will have real-time information about the entire logistics chain, enabling them to choose the most secure and efficient route for their consignments.

Standardization in transport telematics in Europe is dealt with by the following institutions: CEN, ETSI and CENELEC.

CEN (European Standardization Committee) – is a private technical association of a "non-profit" type, operating within a Belgian legislation, with a seat in Brussels. Officially it was formed in 1974, but the beginning of its activities dated back to Paris, 1961. The primary task of CEN is drafting, acceptance and dissemination of the European standards and other standardizing documents in all the spheres of the economy, except electro-technology, electronics and telecommunication. Currently CEN has 30 state members. Polish Standardization Committee (PKN) gained the status of a full CEN member on January 1, 2004.

ETSI – European Institute for the Telecommunication Standards – was formed on the 29 of March 1988, and is the European equivalent of IEEE. The prime objective of ETSI is drafting standards necessary for creation of the European telecommunication market. In 1995 the work of the organization was made international by admitting also the institutions from outside Europe to participate in it.

CENELEC – European Committee for Electro technical Standardization – was formed in 1973. In Poland the role of the State Committee is performed by Polish Standardization Committee – PKN (it is a CENELEC member since 1 of January 2004).

CENELEC together with CEN and ETSI form the European technical standardizing system, whilst international standards come under the jurisdiction of the International Organization for Standardization (ISO) and International Electro technical Commission (IEC).

In 1991, the Technical Committee for Transport Telematics and Road Traffic – CEN/TC 278 (Road Transport and Traffic Telematics) was established.

Also, a world organization – Telecommunication Industry Association has been established, within which, the Technical Committee ISO/TC 204 is responsible for standardization in Transport Telematics (Intelligent Transport Systems).

In the Committee TC 278, as well as in TC 204, there are working groups, which are responsible for various areas of activities – Tab. 2.

**Table 2.** Areas of activities for TC 278 and TC 204 working groups

| The activity area | TC 278 | TC 204 |
|---|---|---|
| EFC –Electronic fee collection and access control | WG 1 | WG 5 |
| FFMS – Freight and Fleet Management systems | WG 2 | WG 7 |
| PT – Public Transport | WG 3 | WG 8 |
| TTI – Traffic & Traveller Information | WG 4 | WG 10 |
| TC – Traffic Control | WG 5 | WG 9 |
| GRD – Geographic road data | WG 7 | |
| RTD – Road Traffic Data | WG 8 | |
| DSRC – Dedicated Short Range Communication | WG 9 | WG 15 |
| HMI – Human-machine Interfaces | WG 10 | |
| Automatic Vehicle Identification and Automatic Equipment Identification | WG 12 | WG 4 |
| Architecture and terminology | WG 13 | WG 1 |
| After- theft systems for recovery of the stolen vehicles | WG 14 | |
| Safety | WG 15 | |
| Data base technology | | WG3 |
| Navigation systems | | WG 11 |
| Vehicle/road way warning and control systems | | WG 14 |
| Wide area communications/protocols and interfaces | | WG 16 |
| Intermodal aspects using mobile devices for ITS | | WG 17 |

The important thing of ITS is optimization of the traffic management. The traffic management includes controlling the traffic signals depending on the traffic volume by improving the control centres and centralizing traffic signal controls. But other services like the provision of the traffic information or the information service have to be mentioned as well.

ITS can reduce the number of traffic accidents on the expressways and on ordinary roads by supporting the driver's safe driving and improving the pedestrian's safety. Rapid emergency and rescue activities are also included.

### 2.2. Directive 2010/40/UE

ITS standards define how ITS systems, products, and components can interconnect, exchange information and interact to deliver services within a transportation network. ITS standards are open-interface standards that establish communication rules for how ITS devices can perform, how they can connect, and how they can exchange data in order to interoperate. It is important to note that ITS

standards are not design standards: They do not specify specific products or designs to use. Instead, the use of standards gives transportation agencies confidence that components from different manufacturers will work together, without removing the incentive for designers and manufacturers to compete to provide products that are more efficient or offer more features.

The ability of different ITS devices and components to exchange and interpret data directly through a common communication interface, and to use the exchanged data to operate together effectively is called *interoperability*. Interoperability is a key to achieving the full potential of ITS. Seamless data exchange would allow an emergency services vehicle to notify a traffic management centre to trigger the change in timing the traffic signals on the path to a hospital, in order to assist the responding ambulance.

The main aim of Directive 2010/40/UE [3] is ensured coordinated and coherent deployment of interoperable Intelligent Transport Systems throughout the Union cannot be sufficiently achieved by the Member States and/or the private sector and can therefore, by reason of its scale and effects, be better achieved at the Union level, the Union may adopt measures, in accordance with the principle of subsidiary as set out in Article 5 of the Treaty on European Union. In accordance with the principle of proportionality as set out in that Article, this Directive does not go beyond what is necessary in order to achieve that objective.

The mentioned Directive establishes a framework in support of the coordinated and coherent deployment and use of Intelligent Transport Systems (ITS) within the Union, in particular across the borders between the Member States, and sets out the general conditions necessary for that purpose.

For the purpose of this Directive the following shall constitute the priority areas for the development and use of specifications and standards:

- Optimal use of road, traffic and travel data,
- Continuity of traffic and freight management ITS services,
- ITS road safety and security applications,
- Linking the vehicle with the transport infrastructure.

Directive 2010/40/UE stressed the priority areas the following shall constitute the priority actions for the development and use of specifications and standards:

- the provision of EU-wide multimodal travel information services,
- the provision of EU-wide real-time traffic information services,
- data and procedures for the provision, where possible, of road safety related minimum universal traffic information free of charge to users,
- the harmonized provision for an interoperable EU-wide eCall,
- the provision of information services for safe and secure parking places for trucks and commercial vehicles,
- the provision of reservation services for safe and secure parking places for trucks and commercial vehicles.

According to Commission implementing decision of 13.7.2011 adopting guidelines for reporting by the Member States under Directive 2010/40/EU information of a general report on the activities planned in the next five years related to deployment of ITS in the Member State. This report should include at least the relevant information on the following items:

a) a description of the national approach and/or strategy of the development and deployment of ITS, including its main objectives,
b) a description of the technical and legal framework applicable to the development and deployment of ITS,
c) a description of the ITS deployment activities,
d) a description of the national priority areas for actions and related measures, including an indication of how these are related to the priority areas,
e) the implementation of current and planned actions covering:
   – instruments.
   – resources.
   – consultation and active stakeholders.

### 2.3. Mandate 453

The European Commission Mandate M/453 invites the European Standardisation Organisations – ESOs (ETSI, CEN, CENELEC), to prepare a coherent set of standards, technical specifications and technical reports within the timescale required in the Mandate to support European Community wide implementation and deployment of interoperable Co-operative Intelligent Transport Systems

Intelligent Transport Systems (ITS) usage means applying Information and Communication Technologies (ICT) to the transport sector (M/453). ITS can create clear benefits in terms of transport efficiency, sustainability, safety and security, whilst contributing to the EU Internal Market and competitiveness objectives. To take full advantage of the benefits that ICT based systems and applications can bring to the transport sector it is necessary to ensure interoperability among the different systems throughout Europe at least.

CEN and ETSI have formally accepted the Mandate in January 2010 and defined the "minimum set of standards", to be provided in accordance with Mandate M/453, to ensure interoperability of Co-operative ITS – Tab. 3 and 4.

This Mandate supports the development of technical standards and specifications for Intelligent Transport Systems (ITS) within the European Standards Organisations in order to ensure the deployment and interoperability of Co-operative systems, in particular those operating in the 5 GHz frequency band, within the European Community. Standardisation is a priority area for the European Commission in the ITS Action Plan in order to achieve European and global ITS co-operation and coordination.

Standardisation for Cooperative ITS systems has already been initiated both by ETSI and ISO as well as within other international standards organisations. European standardisation activities to provide the standardised solutions for Cooperative ITS services are therefore closely related to the world wide standardisation activities.

Within three months of the date of acceptance of this Mandate ETSI, CEN and CENELEC must present a report to the Commission with the working programme to achieve the goal of completion of the standardization process for Cooperative ITS services.

**Table 3.** CEN WG and ISO WG interoperability [7]

| Proposed Standard | Description | Responsible SDO | Purpose Interoperability cooperation modularity | CEN WG | ISO WG |
|---|---|---|---|---|---|
| Definition and Harmonized Terminology | Common agreement on definitions and terminologies to be used for standardization. Harmonization and cross-check of terminologies among SDOs. | CEN | C | **13**, 1,3,4, 8, 12, 13, 4, 15, 16 | 1, 3, 4, 5, 6, 7, 8, 9, 10, 14, 16, 17, 18 |
| Common agreement on definitions and terminologies to be used for standardization. Harmonization and cross-check of terminologies among SDOs. | Standardized communication architecture for Cooperative ITS systems, the defined architecture accommodates multiple applications and communication means. The architecture is based on OSI model. | ETSI | M | **16**, 13 | 18, 1, 16, 17 |

**Table 4.** CEN and ISO WG dealing with Co-operative Systems standardisation [7]

| The activity area | TC 278 | TC 204 |
|---|---|---|
| EFC –Electronic Fee Collection | WG 1 | WG 5 |
| PT – Public Transport | WG 3 | WG 8 |
| TTI – Traffic & Traveller Information | WG 4 | WG 10 |
| RTD – Road Traffic Data, Integrated Transport Information | WG 8 | WG 9 |
| Automatic Vehicle Identification and Automatic Equipment Identification | WG 12 | WG 4 |
| Architecture | WG 13 | WG 1 |
| After -Theft Systems for Recovery of the Stolen Vehicles | WG 14 | |
| Safety (eSafety, eCall) | WG 15 | |
| Database Technology | | WG 3 |
| General Fleet Management and Commercial/Freight Operations | | WG 7 |
| Traveller Information Systems | | WG 10 |
| Vehicle/Road Way Warning and Control Systems | | WG 14 |
| CALM | | WG 16 |
| Nomadic Devices | | WG 17 |
| Co-operative Systems | WG 16 | WG 18 |

Particular attention must be given to the involvement of all relevant parties, including public authorities, and to the working arrangements between relevant industry forums and consortia.

Within one year of the date of acceptance of this Mandate ETSI, CEN and CENELEC must present a progress report on the achievements in accordance with the working programme. CEN, CENELEC and ETSI must present the annual progress reports to the Commission services.

Twenty months after the acceptance of this mandate a comprehensive report must be presented with the status of the on-going work and the latest available draft of the different standards.

The European Commission mandate on Cooperative Intelligent Transport Systems requires the synchronization among the European Standards Organizations on one hand; on the other hand it recommends collecting feedback from stakeholders affected by that standardization work. This session intends to verify if all the bits and bytes of standardization fit to each other, to identify shortcomings and potential show-stoppers and to find proposals for challenging standardization issues. In addition, the session offers the possibilities to present topics that should be considered by standardization additionally.

Furthermore, within the frame of high level agreements between the European Union, US Department of Transportation and the Japanese communication ministries on global activities to harmonize standardization and cooperative ITS applications as well as a roadmap for deployment, this high level managers round table will provide the latest news on the global activities and discuss the way forward to achieve the global interpretability for cooperative ITS when implemented and deployed in a few years.

## 3. Polisch Researches of Electronic Toll Collection

### 3.1. Functional Structure of NATCS

The research team identified the National Automatic Toll Collection (NATCS) functional structure (Fig. 2).

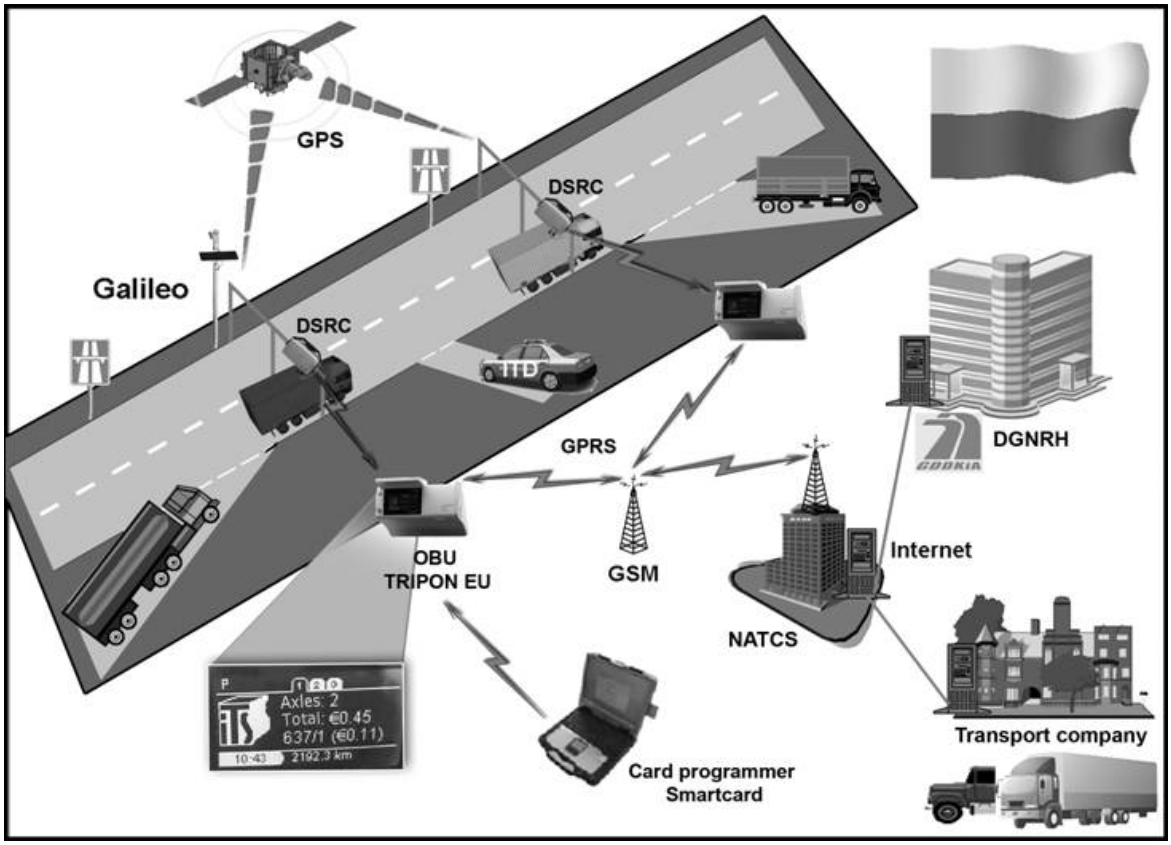



*Figure 2.* Functional structure of NATCS

NATCS structure consists of the following elements:

- Intelligent on-board device called TRIPON-EU, which was installed in test vehicles,
- OBU device installation system using a chip card,
- two control gates (with DSRC modem and a vision tolling system),
- laboratory model of the national Centre for automatic tolling KCAPO,
- a proxy server for data exchange between the headquarters and the OBU system via GPRS,
- control centre to manage the OBU devices allowing the management of OBU and analyses of the data relating to the collection of tolls,
- analytical tools for DSRC, image analysis and classification of vehicles.

The design of the system including the following technologies:

- satellite positioning via GPS, and Galileo in the future,
- wireless communication via GSM (TS 03.60 / 23.060),
- dedicated short range communications – DSRC (5.8 GHz).

The onboard device TRIPON-EU (Fig. 3) is available in two different versions. The test system used the version mounted in a single casing collecting all components, including GPS and GSM antennae. This version is designed for installation on the windscreen of the vehicle.

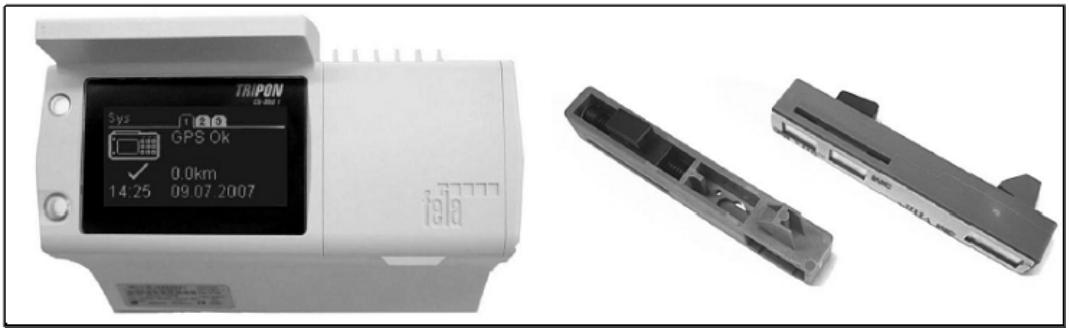



*Figure 3.* An onboard OBU device and its mounting brackets [4]

The OBU device should store the following data: vehicle class, vehicle weight, axles or class of emission, registration numbers and contractual details. Data can be entered into the device using a chip card.

The GPS module used in OBU devices supports the computing navigation *(*DR*, dead reckoning)* to improve the accuracy of positioning.

GPS data (from satellites), supplemented by the results of computing navigation are used as input for detection of on-ground facilities. Detected events are logged in the event file. The European EGNOS system can be enabled or disabled through the configuration file activated at the time of start-up. The device is designed to cooperate with Galileo.

Data recorded by the OBU onboard unit are transmitted to the internal components of the EETS system, using GPRS technology (packet data transmission system used in GSM technology). The data transmission between the mobile onboard units and the internal elements of the system takes place via a proxy server, which operates completely independently of the billing and accounting system. Data is transferred in batches, which means that one does not need to maintain a permanent connection between the onboard devices and the internal components of the system. This is one of the biggest advantages of the concept of smart clients. GPRS allows for even greater reduction of communication costs.

Tripon EU independently analyses the data (GPS location data, vehicle defined data, data on tariffs – fixed schedule of fees and other data) that are remotely transmitted, in real time, to the server. The data about events related to billing, and events relating the control and supervision, are limited to a minimum, which significantly increases the throughput of the system and reduces the operating costs.

Depending on the required precision and an additional control, Tripon EU can operate in two positioning modes: using signals from GPS and assisted by a signal trace from other onboard equipment. In order to verify the system capabilities in both vehicles, OBU devices were checked using only the GPS signal and in conjunction with an additional device, from which signal passage was received. The comparison indicated a small discrepancy between the satellite positioning signal and the passage signal, indicating these by “Delta Tacho +-x%” messages.

On-board equipment TRIPON-EU uses the built-in GSM antennae; there is no need for external antennae. The SIM card installed inside cannot be replaced by the user. For the convenience of testing, using the S button (send) one may activate a GPRS communication session at any time without having to wait for the next automatically initiated session. The onboard device TRIPON-EU can receive short text messages.

Each received message can be: confirmed, denied, confirmed by way of a predetermined message or deleted by the driver.

For this purpose, the appropriate options in the menu are provided. This functionality has been included to demonstrate easily the potentially available value added services that can be implemented on the platform TRIPON-EU.

The device board TRIPON-EU is equipped with a DSRC module (5.8 GHz, IR) DSRC (Dedicated Short-Range Communications). In cross-border traffic OBU device enables collaboration with GPS/GSM tolling systems (Germany, Slovakia) or DSRC systems used in other countries (Austria, Czech Republic, Italy, Spain, France). The basic standard used in these types of systems (DSRC) is the ISO EN 15509 standard (Media Transactions). The onboard unit TRIPON-EU makes use of such transactions in order to illustrate the possibility of tolling in cooperation with the vision system – ANPR.

Transactions can be configured in such a manner, as to support DSRC attributes that are necessary in a specified tolling implementation.

Each onboard unit TRIPON-EU is equipped with a Smart Card interface, which can be used for calibration and initialisation purposes. When configuring the test system Smart Cards will be used for: initiating onboard units with contract data, configuring parameters of onboard equipment, all operations with the use of the cards can also be initiated via the GSM link.

The concept of toll control gates in the system tested in Poland is based on experiences Fela Company, collected during the operation of the Swiss system. The following devices are installed on the control gates (Fig. 4):

- DSRC locator to carry out transactions with the traffic lane controller (according to EN 15509 standard),
- vision system ANPR (automatic number plate recognition and photographic documentation (ANPR, only from the front)
- a local driver software for the registration fee collection.


*Figure 4.* Control gate at Motor Transport Institute in Warsaw

The DSRC locator conducts standard DSRC transactions (in accordance with CEN TC278/EN155509) detecting every vehicle passing through the gate.

Essentially the contract data are recorded, including the registration numbers and characteristics of the vehicle. The collected data should include in particular: the registration number and characteristics of the vehicle. These data are essential in the process of collection of fees – i.e. they are compared to the data coming from the ANPR (automatic number plate recognition). The DSRC locator is mounted on the top of the gate, about 5–6 meters above the road. In addition to the beacon a so called "traffic lane driver software" should be installed on the gate, which will process data from the locator and control its operation during the transaction. The data should be periodically sent via Ethernet to the system central unit.

Depending on the location of gates and / or traffic conditions one can apply a variety of other triggering signals. The monochromatic ANPR camera will be equipped with an image converter with a resolution of 1620 x 1220 pixels and Gig-E interface. The controller installed inside the camera casing: transmits triggering signals to the camera/impulse source of infrared radiation, converts the signals from light sensor, based on signals from the light sensor generates the parameter settings of the camera / impulse source, controls the temperature in the camera casing (turn on/turn off the heating/cooling)

A photo of vehicle is transmitted to tolling server from a given traffic lane for further processing and is analysed in order to read the registration numbers. At the same time, it will serve as documentation if it is necessary to start tolling procedures.

To enable fully automatic gate operation, an ambient light sensor is used, whose signal is based on the control of the camera and the impulse infrared radiation source. The sensor is oriented on the detection of vehicles and has a dynamic range from 3 to 30,000 lux.

All data collected at toll control are transmitted to the tolling system servers and are made available in the tolling controlling software.

This software enables viewing all collected images, results/details of ANPR algorithm operations and DSRC results.

The laboratory model of National Centre for Automatic Tolling (KCAPO) comprises the following elements:

- Three PCs – one dedicated as a database server, the second one serves as application software server, while the third one is a user terminal,
- application and system software,
- databases,
- software and physical interfaces (between KCAPO and OBU, between KCAPO and control gates),
- user interface (online WWW service).

In the proposed solution the proxy server is the main element of the service provider's interface. It supports and controls OBU sending and receiving all data. The system operates using Linux and ensures the stable operation.

The task of the proxy server should include communication only, but also including SW updates of OBU devices. Toll tariff tables and geographic objects displayed on OBU screen should be sent from a proxy server to the OBU. Data received from the OBU should be checked for consistency, and then made available for analysis.

Databases in KCAPO are divided into the following groups: data on users, vehicles and tariffs, Physical Inventory, Dynamic Inventory.

The design defines a total of six major interfaces that are included in the proposed test system with OBU on-board device.

1. Installation and maintenance contract for the on-board equipment. OBU is configured using Smartcards.
2. Connecting to the vehicle. OBU is connected to the following points in the installation of vehicle: power, ground, ignition, tachograph.
3. OBU user interface. The screen displays the following information: the symbol of context (collection area) Toll (P for Poland), graphical representation of the Polish context of the toll (for example, outline of the borders of the country) declared number of vehicle axles, the total value of toll charged per vehicle run, amount due for passage of the current segment, the time and the amount of kilometres travelled from the time of installation.
4. DSRC Interface (5.8 GHz, IR) is used to conduct the standard transactions with DSRC devices that are installed at tolling gate.
5. Data interface (from the tolling operator to the provider of the system). This is an "internal" interface because there are no isolated places for toll collectors and suppliers of the system in the test system.
6. The tolling procedure was demonstrated with the use of DSRC antennae and ANPR cameras (Automatic Number Plate Recognition) on a test gate installed on a single lane.

### 3.2. Tests results of NATCS

Tests of the KSAPO system, including the control of OBU devices, tolling segments at selected sections of roads as well as control gates were conducted in July and August, while vehicles passing through the control gates were registered from 1st July to 30th November 2010. The tests of the system were conducted by the following research team:

- Motor Transport Institute (Gabriel Nowacki, Anna Niedzicka, Ewa Smoczyńska),
- FELA Management AG (Thomas Kallweit),
- Autoguard SA (Robert Rozesłaniec, Tomasz Garbacz, Krzysztof Pusłowski).

The architecture of the system is in conformity with Directive 2004/52/EC and decision of the European Commission of 6th November 2009 as well as the CE and ISO standards.

During the test four OBU Tripon EU units were examined, whose task was to detect all events associated with the collection of toll directly in OBU, as well as in the log file and display them on the screen. OBU is also meant to send the log files to the proxy server and to receive data from the server (data, status information and software updates.) For testing purposes four vehicles were added to the database.

Out of the several proposed test route options we chose the Płońsk – Garwolin, Garwolin – Płońsk route, as the most diverse one that allows the greatest number of elements of the system for checking, including the both control gates in the immediate vicinity of the route and allowing the use of as many as three actual segments of expressways:

- two segments of expressway S7, eastern bypass of Płońsk (a section of 4,7 km), western bypass of Nowy Dwór Mazowiecki (a section of 14,6 km, Zakroczym – Ostrzykowizna – Czosnów),
- one segment of expressway S17, bypass of Garwolin of 12,8 km length with two carriageways,
- two segments of the National Roads.

On the basis of the recorded data, transmitted by the vehicle in the form of messages, it was possible to recreate the exact route of the vehicle with the OBU device.

One of the most important parameters determining the accuracy of measurement and transmitted in location messages is PDOP (Position Dilution of Precision) is a defect in determination of position precision. PDOP is a coefficient describing the relationship between the error of user's position and the error of the satellite position.

The value of any of the parameters equal to 0 means that at any given time measurement of position is impossible due to the interference, weak signals from the satellites, too few visible satellites, etc. The smaller the value of this parameter (but greater than zero), the more accurate is the measurement. The following descriptions signal quality depending on the value of PDOP are assumed: 1 (perfect), 2–3 (excellent), 4–6 (good), 7–8 (moderate), 9–20 (poor), > 20 (bad).

The data of the PDOP parameter obtained in the tests was presented in Fig. 5. The horizontal axis (X) depicts the values for PDOP. The vertical axis (Y) depicts the number of measurements (in percentages) during which a given value of PDOP was obtained. The stats were calculated based on 4627 measurements of position.

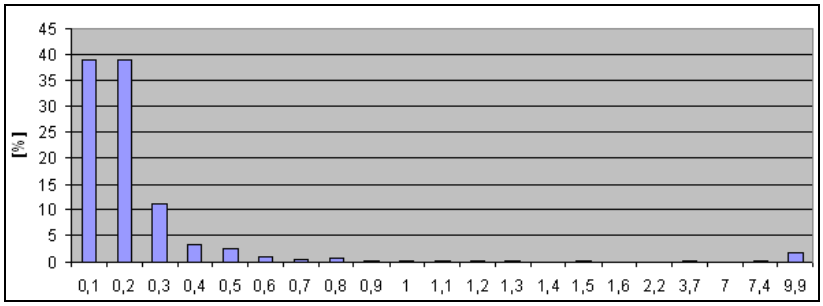



*Figure 5.* Results of PDOP

Average value of PDOP for all OBU was 90% of perfect and 8% excellent values. Analysis of the measurement data of the PDOP parameter and the number of the satellites used during the test showed that 90% of the PDOP measurements were lower than 1, which should provide accuracy of location with error of no more than 6 meters.

The number of the satellites used for measurements of all OBU devices is presented in Fig. 6. For purposes of KSAPO it was assumed that GPS receiver in OBU should track at least 5 satellites, for more accurate calculations and in the event of loss of signal from one of them.

The presented data show that the maximum number of satellites used in for the purpose of location was 11, and in the case of 99% of measurements at least 5 satellites were used (the detailed results of the satellites: (5–10%, 6–17%, 7–25%, 8–22%, 9–16%, 10–7%, 11–2%).

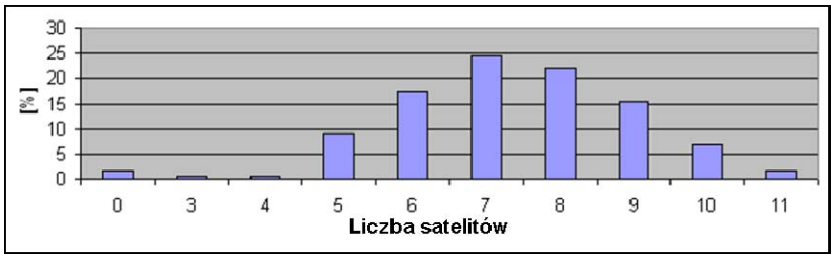



*Figure 6.* Number of used satellites for localization

As part of the project two DSRC gates with tolling system were prepared. This has allowed testing of the following functions:

- operation of DSRC microwave devices
- operation of visual system ANPR system (automatic number plate recognition).

Data obtained from the passage of vehicles through the gates were stored in a separate database. Gates used for testing were described as follows:

- ITS Demo (UID = 1000,2),
- Autoguard Demo (UID = 1001,3).

From 1st July to 30th November 2010, 2964 vehicles passing through the control gates were registered in the database of the system. Not all vehicles were equipped with OBU.

During the tests at the ITS Demo and Autoguard Demo gates, using the DRSC system, passage of 24 test vehicles was recorded. During the tests at the ITS Demo gate as many as 667 photographs of passing vehicles were taken.

During the tests at the Autoguard Demo gate 2297 photographs of passing vehicles were taken. Example of the vehicle photo is presented in Fig. 7.


*Figure 7.* Picture of WWY 07512 vehicle, PTM, 5 Przemysłowa Street, 07-200 Wyszków

Legend: Date (ANPR): 28.09.2010 09:25:53; Reg. no. (ANPR): WWY 07512; Accuracy: 0.980; Gate ID: 3; Gate name: Autoguard Demo; Date (DSRC): 28.09.2010 09:25:54; Country code: F (France), Registration number (DSRC): WWY 07512; Context data: WWY 07512; OB ID: 1103467888; Vehicle ID: 2147483647; Emission class: 1; Vehicle class: 1; Vehicle weight: 18000; Total weight: 40000; Number of axles: 5; Means of payment: 2147483647.

The registered vehicle was equipped with a French made OBU device – Passango (DSRC). It was fully identified in the system as a user, which means that the KSAPO system is interoperable and can work with both, systems of DSRC type as well as GPS / GSM systems.

During each and every passage the operation of control gates as well as the conformity of the DSRC data with the ANPR (automatic number plate recognition) reading was verified. For the purpose of the second stage the onboard OBU devices were replaced with the new ones. Due to a mistake the devices were wrongly installed, however the system immediately discovered the error.

Also the operation of the control gates was tested – mainly with respect to the detection of various vehicle speeds. Thanks to this, it was possible to adjust the software and then to check the newly replaced onboard OBU devices with respect to the correctness of detection of vehicles coming up to the control gate at especially small selected speeds. The system detects vehicles travelling at speeds of 1 to 200 km/h.

In addition to test the drives and the checking of the functionality of them, the efficacy of the gates was checked, recording all vehicles passing at the premises of Motor Transport Institute and at the premises of the AutoGuard company in various weather conditions and at various times of day. The efficacy of automatic detection of number plates was 99,9%. All the segments were identified by the onboard devices correctly, and there were no problems in this respect. Each segment consisted of three points, and in order for each one of them to count, all three segments had to be detected by the OBU device. As a result of this drivers who will cut through toll roads, or only pass through them, will not be registered in the system.

The tests were successful and confirmed the efficacy of the selected solutions in accordance with the assumptions of the project.

## 4. Conclusions

Intelligent Transport Systems are integral part of European Transport Policy. ITS Directive is the legal instrument for the deployment of ITS in Europe. Standardization has a major role in the development of interoperable ITS. Interoperability and building ITS architecture brings about the necessity to develop the standards concerning, among the others, technical safety solutions as well as data transmission protocols between the system elements and the environment solutions. These applications may provide quick and precise information in the future and allow the safely managing transport. In the forthcoming years they will be further improved by using Galileo system, whose localizing precision will be better than that of GPS. Integration of tools by using standards would allow: reducing times and errors (preventing re-typing), facilitating engineering & trading, improving data recording, improving survey, maintenance and repair (life cycle).

One of the key benefits of ITS is the exchange of information and completion of transactions directly between computers, eliminating the need for processing purchase orders, bills of lading or invoices. Clear, constructive, harmonised, and easy applicable legal rules affect differently the economic parameters of maritime transport than vague and contradictory legal rules or even more the absence of legal provisions. Community legislation now exists for all modes of transport creating new open market conditions.

The European Commission Mandate M/453 on Cooperative Intelligent Transport Systems was approved by CEN and ETSI.

Furthermore, within the frame of high level agreements between the European Union, US Department of Transportation and the Japanese communication ministries on global activities to harmonize standardization and cooperative ITS applications as well as a roadmap for deployment, this high level managers round table will provide the latest news on the global activities and discuss the way forward to achieve the global interpretability for cooperative ITS when implemented and deployed in a few years.

Motor Transport Institute in cooperation with Autoguard SA and Fela Management AG has developed the functional structure of NATCS according to directive 2004/52/EC, decision of European Commission from 6$^{th}$ October 2009 and CEN standards.

During the test of NATCS phase, from 1$^{st}$ July till 30$^{th}$ November 2010, 2964 vehicles passing through the control gates were registered in the database of the system. In addition to testing the drives and checking the functionality, the efficacy of the gates was checked, recording all vehicles passing at the premises of Motor Transport Institute and at the premises of the AutoGuard company in various weather conditions and at various times of day.

The efficacy of automatic detection of number plates was 98%, and thanks to proceeding data by analyze stand, the efficacy of the system increases to 99.9%.

Analysis of the measurement data of the PDOP parameter and the number of satellites used during the test showed that 90% of the PDOP measurements were lower than 1, and 8% had value from 1 to 3.

For the purposes of NATCS it was assumed that GPS receiver in OBU should track at least 5 satellites, for more accurate calculations and in the event of the loss of signal from one of them. Tests results showed that in the case of 99% of measurements at least 5 satellites were used for the purpose of location.

The NATCS turned out to be flexible when it comes to extending toll collection to every road category, every category of vehicle and, what is more, in terms of cost efficiency in implementation and operation. Another advantage is an absence of the need for the new road infrastructure (gantries), while the operators can keep using the existing infrastructure. System works without toll booths, extra lanes, speed restrictions or complex structures along toll roads. Furthermore, the system is able to support other value-added services on the same technology platform.

Tests of NATCS project has been a complete success. The system uses GPS/GSM technologies, but also recognises devices such as DSRC and OBU. During tests, the system recognised four Tripon – EU OBU, French made DSRC Passango device and a German made Toll Collect device of the GPS/GSM type, installed in a vehicle which did not participate in the test, but accidentally ran through the control gate. This implies that the NATCS system is interoperable and can cooperate with both GPS/GSM systems as well as with DSRC types of systems existing in other EU Member States.

**Acknowledgement**: The paper has been prepared with framework of NATCS Pilot Project, N R10 0001 04.

## References

1. Commission Decision of 6 October 2009 on the definition of the European Electronic Toll Service and its technical elements. *Official Journal of the European Union* L 268/11, 13.10.2009.
2. Directive 2004/52/EC of the European Parliament and of the Council of 29 April 2004 on the interoperability of electronic road toll systems in the Community. *OJ of the EU*, L 166/132, 30.04.2004.
3. Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of intelligent transport systems in the field of road transport and for interfaces with other modes of transport. *Official Journal of the European Union* L 207/1.
4. Kallweit, T. *Technical Trial of ETC in Poland. Fela Management AG*. Diessenhofen. 03/09/2010.
5. Kossak, A. Implemented and Envisaged Road Toll Policies in the Central-Eastern-European Countries. *Seminary – PIARC TC A.3*. Budapest, 6–7 May, 2009.
6. McQueen, B. & McQueen, J. *Intelligent Transportation Systems Architectures*. Artech House, 1999.
7. Schade, H. J. The Mandate on Co-operative ITS and the ITS Directive. *CEN. 3rd ETSI TC ITS Workshop*, Venice, 09–11 February 2011.
8. Standard EN ISO 12855. ETC. Information Exchange between Toll Provider and Toll Operator. 2010.

*Transport and Telecommunication, 2011, Volume 12, No 3, 18–26*
*Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia*

# RESOURCE ALLOCATION PROBLEMS IN MESOSCOPIC FLOW MODELS

***Jurijs Tolujevs***

*Transport and Telecommunication Institute*
*Lomonosova str. 1, LV-1019, Riga, Latvia*
*E-mail: juri.tolujew@iff.fraunhofer.de*

This paper presents the standard rules formulated for the allocation of resources in mesoscopic flow models. In terms of level of detail, the underlying mesoscopic simulation approach is situated between the prevalent approaches to continuous and discrete event simulation. Mesoscopic models use piecewise constant flow rates to represent the logistics flow processes. The resulting linearity of the cumulative flows facilitates event scheduling and the use of mathematical formulae to recalculate the system state variables at every simulation time step. Multichannel funnels are a mesoscopic model main component because they represent properly the processes of parallel or sequential processing and storage of several product types and product portions in a real area of operations. The identical types of resources that are arbitrarily allocable among the funnel different channels are labelled homogenous resources. The paper describes a mesoscopic simulation model of the passenger check-in processes on an airport. Resource allocation strategies based on mathematical formulae are an important part of the model.

**Keywords:** simulation, material flow, logistics systems, mesoscopic models

## 1. Introduction

Two classes of simulation models exist, namely continuous and discrete. Continuous models are based on differential equations and most frequently applied as system dynamics models to reproduce manufacturing and logistics processes [1], [2], [3]. Their level of aggregation renders them incapable of accurate representing the numerous logistics objects (products, resources, etc.) and control strategies, which demand consideration when resolving tactical or operational problems.

The principles and tools of discrete event simulation [4], [5], [6] are utilized to implement the discrete models. Models in this class tend to be very complicated and slow and their creation and implementation very time- and labour-consuming [1], [7].

The approach to mesoscopic simulation proposed by these authors is situated between continuous and discrete event approaches in terms of the level of modelling detail. It facilitates the quick and effective analysis and planning in manufacturing and logistics networks. This mesoscopic approach is consistent with the principles of the discrete rate simulation paradigm implemented in the simulation software ExtendSim [8], [9] and resembles the principles of hybrid simulation [10]. Piecewise constant flow rates and the resulting linear cumulative flows support event scheduling and boost computational performance.

This paper examines briefly the processes in mesoscopic flow models and proposes standard rules for resource allocation in such models. The example of a mesoscopic model of passenger check-in processes on an airport illustrates the possibilities of application of the analytical methods for dynamic resource allocation in mesoscopic models.

## 2. Mesoscopic Approach to Modelling of Flow Systems

In terms of applied modelling of manufacturing and logistics systems, continuous system dynamics models can be called macroscopic, since these models are usually developed in the form of abstract generic models that do not support the analysis of concrete material flows but the analysis of business processes on an aggregated level. Common discrete event models can be called microscopic, since they represent changes in the conditions of many separate material (informational and financial) objects. In [11, 12, 13] the authors define a class of the mesoscopic models, which are situated between two model classes described above in terms of the level of modelling detail. In Figure 1 the processes in a single stock are shown, which can be applied to the models of all three classes described above. Stock input and output flows are set, based on which dynamics of changes in contents is measured.

Orientation of the mesoscopic models on piecewise constant flow rates is of major importance since the changes of cumulative flows and contents levels under these conditions correspond solely to the piecewise linear functions. In the same way as in piecewise linear aggregates [14], the points of time can be forecast

when the model state variables represented by such piecewise linear functions reach the set “critical values”. In other words, mesoscopic models enable to plan the events (in the same way as in discrete event models) for continuous processes, characteristics of which do not change between these events.

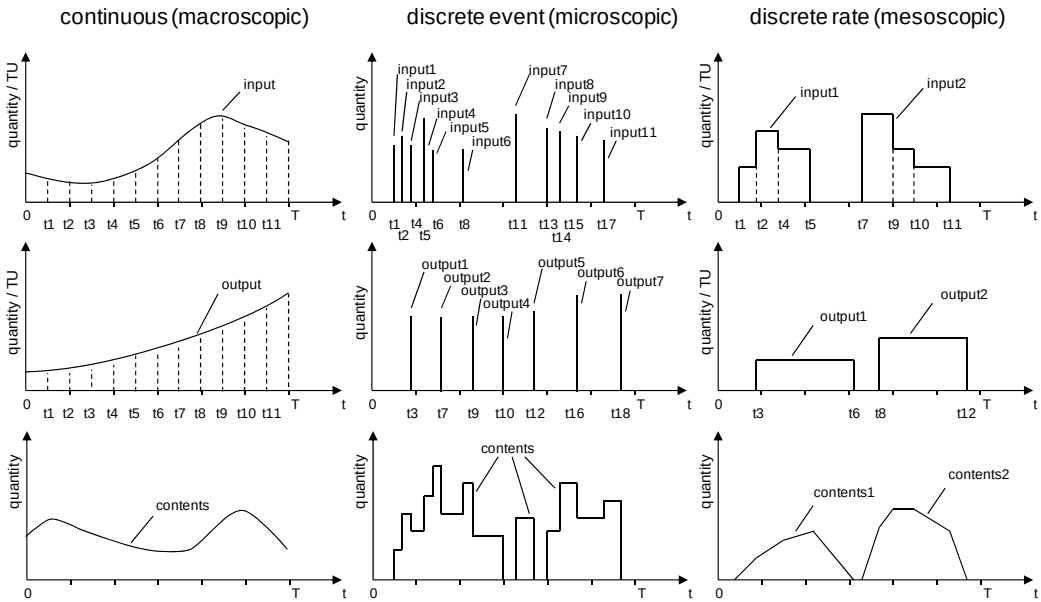



*Figure 1*. Processes in a single stock in different types of modelling

Figure 2 presents a mesoscopic model with multi-channel funnels instead of the simple ones. Exactly the application of parallel channels in a funnel enables to treat separately the product portions simultaneously stored in a funnel. Funnel channels (see funnels *stock 1* and *stock 2* in Figure 2) are given numbers, which correspond to the numbers of parallel product flows (see products *Pr1* and *Pr2* in Figure 2). Products in mesoscopic model can be represented by all types of a substratum transported in flows.

Multi-channel funnel can be regarded as a main structural component of a given mesoscopic model. Figure 3 depicts the performance principle of a multi-channel funnel and the main components of its mathematical model. The channel input flow $\lambda_i^{in}(t)$, its maximum throughput $\mu_i(t)$, and the level of contents $S_i(t)$ are assumed to be given. Figure 3 shows that the channel output flow $\lambda_i^{out}(t)$ at each point of time can be determined in one of three possible ways, depending on the given conditions.

A multi-channel funnel in a model can represent a workstation, manufacturing area, warehouse or even an entire manufacturing or logistics enterprise. A transport element (see element *transport 1* on Figure 2) is used in a model to represent all the planned delays, which arise, for instance, during the product transportation or storage processes and are important for modelling. A delay in a funnel can be caused solely by formation of jam, which leads to accumulation of contents. No additional time is needed to for the funnel output flows. (The process can be pictured as a free passage of bulk products through the funnel, with zero contents in a funnel). The situation when the check-in capacity on an airport is 500 passengers per hour, whereas only 300 arrive during a certain hour, can be an example. These passengers leave the check-in area with the same speed, what they arrive with. A several minute delay in serving a single passenger can be omitted in mesoscopic modelling.

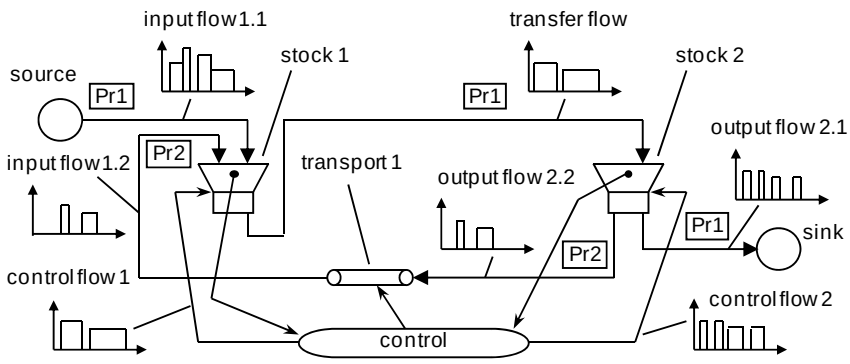



*Figure 2*. Example of a mesoscopic model structure

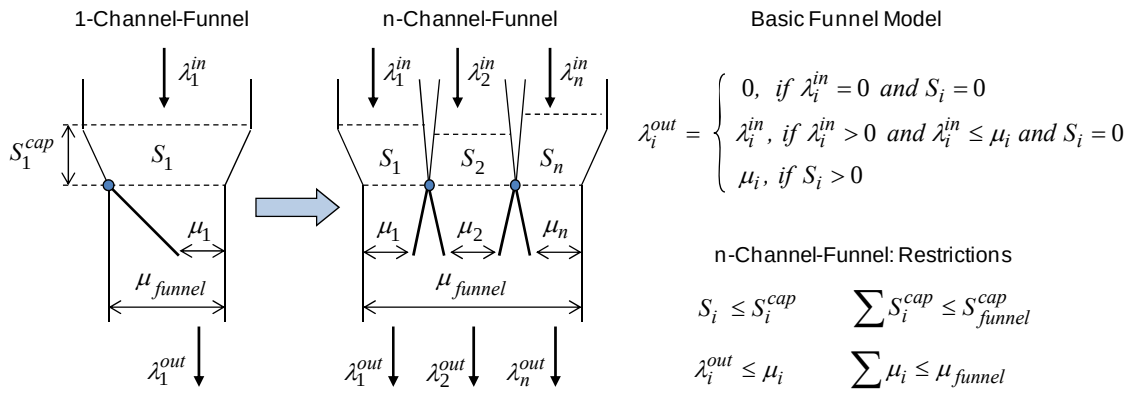



*Figure 3.* Model of the multi-channel funnel

Throughout the capacity of each funnel directly depends on the resources used in processing the product portions. Resources are divided into consumable (fuel, water etc.) and reusable ones (staff, technical tools etc.). Both consumable and reusable resources can be limited and unlimited.

Resource allocation strategies in mesoscopic modelling can be described in the form of plain algorithms. A special interest, however, is aroused by a possibility to apply directly the analytical methods, one of which will be analysed in this paper further.

## 3. Standard Resource Allocation Rules at a Funnel

A multichannel funnel represents a homogenous resource of the modeled system and has *m* resource holders at its disposal. The identical types of resources that are arbitrarily allocable among a funnel different channels are labeled homogenous resources. Each resource holder *k* (*k* = 1,…,*m*) has a potential performance $pl_k$.

Three standard potential performances $pl_k$ are distinguished in terms of the units of measurement:

Case 1: $pl_k$ [unit of quantity/unit of time];

Case 2: $pl_k$ [operating time/unit of time];

Case 3: $pl_k$ [operations/unit of time].

The total potential performance *PL* is the sum of all resource holders' potential performances:

$$PL = \sum_{k=1}^{m} pl_k \ . \tag{1}$$

The coefficient of consumption $vk_i$ converts fluxes and maximum throughputs measured in [unit of quantity/unit of time] into the variables of resource consumption and back. In Case 1, the coefficient of consumption is obviously not necessary: $vk_i = 1$. In Case 2, the coefficient of consumption $vk_i$ [operating time/unit of quantity] specifies the operating time required to generate one unit of quantity for the output flow $\lambda_i^{out}$ of a funnel channel. In Case 3, the coefficient of consumption $vk_i$ [operations/unit of quantity] specifies the number of operations required to generate one unit of quantity for the output flow $\lambda_i^{out}$ of a funnel channel.

The demand for resources $bd_i$ [unit of resource/unit of time] for all types of products is calculated with the coefficient of consumption $vk_i$ :

$$bd_i = vk_i \cdot \lambda_i^{in} \ . \tag{2}$$

The total demand *BD* is the sum of the demands for all product types:

$$BD = \sum_{i=1}^{n} bd_i \ . \tag{3}$$

The maximum throughput $\mu_i$ [unit of quantity/unit of time] of every channel determines the allocated resources $r_i$ [unit of resource/unit of time] for every channel:

$$r_i = \mu_i \cdot vk_i . \tag{4}$$

The total amount of the allocated resources *R* is the sum of the allocated resources for every channel:

$$R = \sum_{i=1}^{n} r_i = \sum_{i=1}^{n} (\mu_i \cdot vk_i) . \tag{5}$$

The maximum throughput $\mu_i$ of a channel may be calculated when $r_i$ is known:

$$\mu_i = \frac{ri}{vki} . \tag{6}$$

The following presents the formulae for calculating $\mu_i$ at every time step for eight different resource allocation rules. A complete calculation is only presented for rule 1; only the results are presented for other rules.

**Resource allocation rule 1**

The maximum throughput is identical for every product type: $\mu_i = \mu$ .

The total potential performance is distributed among the channels. Therefore, $R = PL$ applies.

$$R = \sum_{i=1}^{n} r_i = \sum_{i=1}^{n} (\mu \cdot vk_i) = \mu \cdot \sum_{i=1}^{n} vk_i = PL . \tag{7}$$

$$\mu_i = \mu = \frac{PL}{\sum_{i=1}^{n} vk_i} . \tag{8}$$

**Resource allocation rule 2**

The maximum throughput is proportional to the input flow: $\mu_i \sim \lambda_i^{in}$ .

$$\mu_i = \frac{PL}{BD} \lambda_i^{in} . \tag{9}$$

**Resource allocation rule 3**

The maximum throughput is proportional to the content of the channel: $\mu_i \sim S_i$ .

$$\mu_i = \frac{PL}{\sum_{i=1}^{n} (S_i \cdot vk_i)} S_i . \tag{10}$$

**Resource allocation rule 4**

The maximum throughput is proportional to the demand: $\mu_i \sim bd_i$ .

$$\mu_i = \frac{PL}{\sum_{i=1}^{n} (bd_i \cdot vk_i)} bd_i . \tag{11}$$

**Resource allocation rule 5**

The rates of change of the contents of all the channels are identical: $\lambda_i^{in} - \mu_i = const$ .

$$\mu_i = \lambda_i^{in} - \frac{BD - PL}{\sum_{i=1}^{n} vk_i} . \tag{12}$$

**Resource allocation rule 6**

The content for all product types may not change: $S_i = const$ .

$$\mu_i = \lambda_i^{in} . \tag{13}$$

This rule is applicable only when the total potential performance is at least as great as the total demand for resources: $PL \geq BD$ .

**Resource allocation rule 7**

The maximum throughput is proportional to the priorities of the product types: $\mu_i \sim pr_i$ .

$$\mu_i = \frac{PL}{\sum_{i=1}^{n} (pr_i \cdot vk_i)} pr_i . \tag{14}$$

**Resource allocation rule 8**

Top priority is assigned to one product type *p*. Demand will be completely satisfied when $bd_p \leq PL$ such that

$$\mu_p = \frac{bd_p}{vk_p} . \tag{15}$$

with the remaining resources being allocated in accordance with one of the aforementioned allocation rules.

The demand for the product with top priority cannot be completely satisfied when $bd_p \geq PL$ such that

$$\mu_p = \frac{PL}{vk_p} . \tag{16}$$

with the other product types not receiving any resources.

## 4. Modelling Task

The check-in process is being modelled. The modelled time is 240 minutes (4 hours), within which the check-in of passengers for 3 flights is completed. The model represents a group of passengers of one flight as a flow. Table 1 shows the parameters of three modelled passenger flows.

**Table 1**. Parameters of the modelled flows

| Parameter | Flow 1 (Pax 1) | Flow 2 (Pax 2) | Flow 3 (Pax 3) |
|---|---|---|---|
| Quantity of passengers in the flow | 600 | 300 | 150 |
| Starting time of incoming the passenger flow [min] | 0 | 30 | 60 |
| Duration of incoming the passenger flow [min] | 180 | 180 | 180 |
| End time of incoming the passenger flow [min] | 180 | 210 | 240 |
| Starting time of check-in [min] | 90 | 120 | 150 |
| Duration of check-in [min] | 90 | 90 | 90 |
| End time of check-in [min] | 180 | 210 | 240 |
| Average check-in duration of 1 passenger [min] | 1,0 | 0,75 | 0,5 |
| Working time for check-in [man-min] | 600 | 225 | 75 |

For modelling the dynamics of three incoming passenger flows the same scheme for distribution of passengers in the time shown in Figure 4, is applied. It is assumed that the real statistical data of the passenger arrival process at a check-in can be presented in this mesoscopic form. Every step of the *differential* function refers to 10 minute interval of the passenger arrival process and shows the percentage of total number of passengers of a flow that is expected to arrive within the 10 minutes. The piecewise linear *cumulative* function shows the result of the integration of the differential function. The result of application of the *differential* function for the generation of three passenger flows in Table 1 is the overall passenger arrival process at the check-in with duration of 240 minutes as shown in Figure 5.

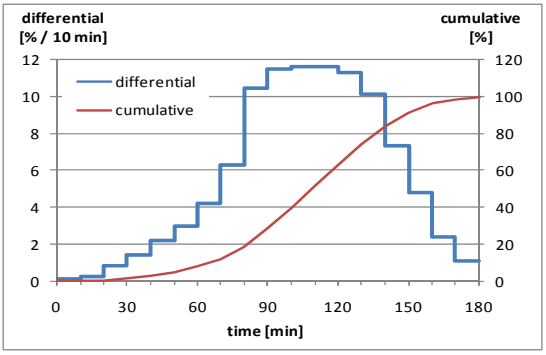



*Figure 4.* The basic model of the incoming passenger flow

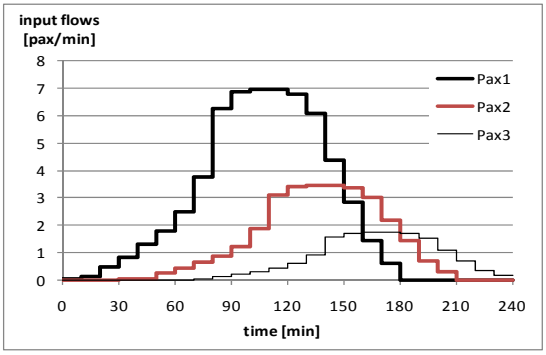



*Figure 5.* The rates of three passenger flows

The first characteristic of organizing the check-in process is the assumption that every passenger group forms an own queue. The check-in desks working at the same time can serve passengers from all three queues in the defined proportions (see queuing system structure in Figure 6). The second characteristic lies in the fact that the number of check-in desks working at the same time *m* is variable, representing the total amount of the resources allocated for serving the passengers. Thus, the task of assessing the required amount of resources consists in determining *m*. The resource allocation task consists in determining the passenger serving rules for the *m* check-in desks working at the same time. Regardless of its characteristics, every concrete resource allocation algorithm combining these two tasks, should be oriented on completing the check-in of the passengers of every flow $i(i=1,2,3)$ by the point of time $t_i^{end}$, shown in Table 1. The mesoscopic approach assumes that the resource allocation algorithm is activated only at the so-called decision points. The given model suggests that these decision points occur in correspondence with the schedule, i.e. regularly with a 10 minutes interval.

## 5. Solution of the Modelling Task

The main target of the presented model is the illustration of application of the mesoscopic modelling principles, in particular, in terms of resource allocation of the analysed system. The given model can be implemented using the simulation software for both continuous simulation (e.g. Vensim) and discrete-event simulation (e.g. AnyLogic or ExtendSim). It can also be created on the basis of a universal programming language, e.g. in MS Excel-VBA. The principle of flexible distribution of passengers between *m* concurrently operating check-in desks is considerably easier to implement with continuous simulation tools. A "real" mesoscopic model (i.e. a model with dynamic event planning for piecewise continuous processes) is best implemented with the Discrete Rate paradigm in the ExtendSim package or with the special mesoscopic simulation package MesoSim (Figure 7).

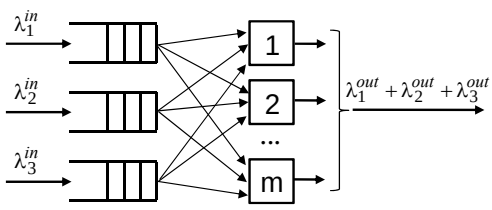



*Figure 6.* Conceptual model of the passenger check-in process

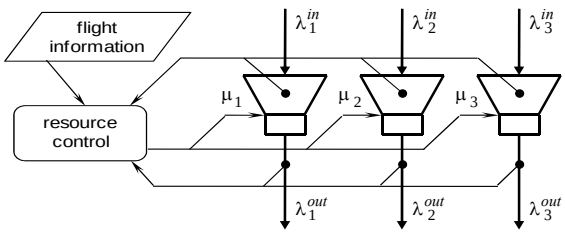



*Figure 7.* Executable mesoscopic model in MesoSim notation

In the following part of this paper two variants of the model, which are based on the principle of "allocating a resource proportional to a requirement for it" (see Resource allocation rule 4) will be shown, but they differ in method of determining this requirement at the decision point, i.e. in the method of determining the variable *m* (see Table 2). When modelling variant 1 the resource allocation strategy is based on the measured value: current length of queue $S_i$ (see position of measuring points in the model, shown in Figure 7). While modelling variant 2 the total planned quantity of passengers in the flow $s_i^*$ is known and another measured value is considered: the number of served passengers $s_i$ at the current moment *t*.

**Table 2.** Calculation formulae for two resource control strategies

| Description of the variables | Strategy 1 | Strategy 2 |
|---|---|---|
| Remaining time till the end of the check-in process ($t$ – current time) | $\tau_i^{rest} = t_i^{end} - t$ | |
| Number of passengers which still have to be checked-in ($s_i^*$ – total planned number of passengers in the flow; $s_i$ – number of checked-in passengers at time $t$) | | $S_i^{rest} = s_i^* - s_i$ |
| Required average check-in rate ($S_i$ – length of the queue at time $t$) | $\mu_i^* = \frac{S_i}{\tau_i^{rest}}$ | $\mu_i^* = \frac{S_i^{rest}}{\tau_i^{rest}}$ |
| Resource needs of a flow $i$ ($\tau_i$ – average check-in time of a passenger) | $m_i^* = \tau_i \cdot \mu_i^*$ | |
| Total calculated demand (number of check-in desks before rounding) | $m^* = \sum_{i=1}^{3} m_i^*$ | |
| Real amount of resources (number of check-in desks after rounding) | $m = Int(m^* + 1)$ | |
| Auxiliary sum | $Q = \sum_{i=1}^{3} \left( m_i^* \cdot \tau_i \right)$ | |
| Real check-in rate (throughput of a funnel channel $i$) | $\mu_i = \frac{m_i^* \cdot m}{Q} = \mu_i^* \cdot \frac{m \cdot \tau_i}{Q}$ | |

The results of modelling two resource allocation strategies are very different from each other, nevertheless the basic condition, i.e. completing the check-in till $t_i^{end}$, is satisfied in both strategies (see Figure 8). Obviously, strategy 2 appears to be more efficient: the maximum length of every passenger queue is 40% lower than in strategy 1, while the maximum number of simultaneously operating check-in desks is reduced from 14 to 10.

## 6. Conclusions

The presented model has characteristics that are typical for the mesoscopic approach to modelling flow systems:

- the input flows of the system are not given with the help of distribution of time intervals between events, but numerically (graphically) in form of piecewise continuous intensity graphs;
- for the representation of heterogeneous flows the concept of “portions” is used (e.g. a group of passengers departing with the same flight), which is not defined in other modelling concepts;
- the service time of objects of the input flow is not given as a random variable, but as a constant equal to the average service time;
- the resource control (thus the flow control) is not done continuously, but only at the decision points;
- the resource allocation strategy is described not only with algorithms but to a great extend in form of analytical models (calculation formulae).

The time interval of 10 minutes was chosen only for the simplification of the model and results description. In mesoscopic models, any external and internal conditions for the occurrence of decision situations can be formulated. For example, a critical value for the length of one queue or for the total number of waiting passengers can be given. When reaching these thresholds immediate actions can be undertaken to increase the maximum throughput of the check-in process.

The advantages of a mesoscopic approach reveal themselves already at the stage of development of a conceptual model, since the developer has to operate with considerably more aggregated characteristics of resources and processed flows, compared to those of discrete event models. Mesoscopic models are not only more compact and clear than discrete event ones, they are also considerably faster processed on a computer, due to the fact that the number of modelled events can be reduced by several times. As a rule, they are quicker and more precise than continuous models, since they eliminate the known negative effects connected with the use of the fixed time interval $\Delta t$ for the reproduction of the processes in a model.

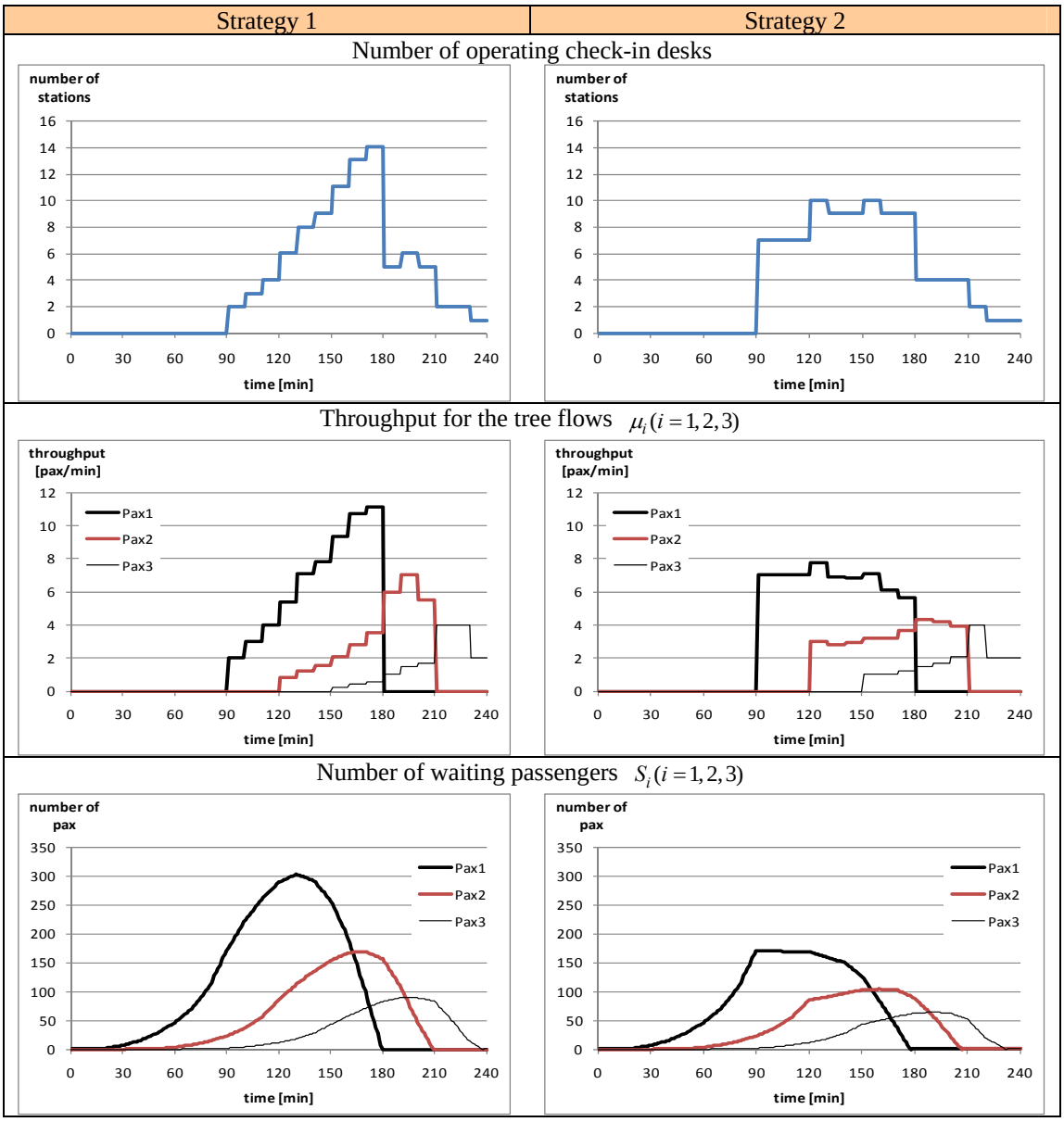



*Figure 8*. Mesoscopic modelling results

## References


1. Pierreval, H., Bruniaux, R., Caux, C. A Continuous Simulation Approach for Supply Chains in the Automotive Industry. In: *Simulation Modelling Practice and Theory*, vol. 15, No. 2, Elsevier B.V., Amsterdam, 2007, pp. 185–198.
2. Scholz-Reiter, B., Delhoum, S., Zschintzsch, M., Jagalski, T., Freitag, M. Inventory Control in Shop Floors, Production Networks and Supply Chains Using System Dynamics. In: *Tagungsband zur 12. ASIM-Fachtagung „Simulation in Produktion und Logistik", Wenzel, S. (ed.)*, SCS, Erlangen, 2006, pp. 273–282.
3. Angerhofer, B. J., Angelides, M. C. System Dynamic Modeling in Supply Chain Management: A Research Review. In: *Proceedings of the 2000 Winter Simulation Conference, Joines, J. A., Barton, R. R., Kang, K., Fishwick, P. A. (eds.)*, IEEE, Inc., Piscataway, NY, 2000, pp. 342–351.
4. Schriber, T. J., Brunner, D. T. Inside Discrete-Event Simulation Software: How it Works and Why it Matters. In: *Proceedings of the 2008 Winter Simulation Conference, Mason, S. J., Hill, R. R., Mönch, L., Rose, O., Jefferson, T., Fowler, J. W. (eds.)*, IEEE, Inc., Piscataway, NY, 2008, pp. 182–192.
5. Banks, J. *Discrete-Event System Simulation.* Pearson, Prentice Hall, Upper Saddle River, NY, 2005.

6. Law, A. M. *Simulation Modelling and Analysis*. McGraw-Hill, New York, 2007.
7. Huber, D., Dangelmaier, W. Controlled Simplification of Material Flow Simulation Models. In: *Proceedings of the 2009 Winter Simulation Conference*, *Rossetti, M. D., Hill, R. R., Johansson, B., Dunkin, A., Ingalls, R .G. (eds.)*, IEEE, Inc., Piscataway, NY, 2009, pp. 839–850.
8. Krahl, D. ExtendSim Advanced Technology: Discrete Rate Simulation. In: *Proceedings of the 2009 Winter Simulation Conference*, *Rossetti, M. D., Hill, R. R., Johansson, B., Dunkin, A., Ingalls, R .G. (eds.)*, IEEE, Inc., Piscataway, NY, 2009, pp. 333–338.
9. Damiron, C., Nastasi, A. Discrete Rate Simulation Using Linear Programming. In: *Proceedings of the 2008 Winter Simulation Conference*, *Mason, S. J., Hill, R. R., Mönch, L., Rose, O., Jefferson, T., Fowler, J. W. (eds.)*, IEEE, Inc., Piscataway, NY, 2008, pp. 740–749.
10. Kouikoglou, V. S., Phillis, Y. A. Hybrid Simulation Models of Production Networks. *Kluwer Academic, Plenum Publishers,* New York, 2001.
11. Schenk, M., Tolujew, J., Reggelin, T. A Mesoscopic Approach to Modeling and Simulation of Logistics Networks. In: *Logistics and Supply Chain Management: Trends in Germany and Russia / Ivanov et al. (Eds.).* Publishing House of the Saint Petersburg State Polytechnic Institute, 2008, pp. 58–67.
12. Schenk, M., Tolujew, J., Reggelin, T. Mesoscopic Modeling and Simulation of Logistics Networks. In: *Preprints of the 13th IFAC Symposium on Information Control Problems in Manufacturing*, Moscow, Russia, June 3–5, 2009, pp. 586–591.
13. Schenk, M., Tolujew, J., Reggelin, T. A Mesoscopic Approach to the Simulation of Logistics Systems. In: *Advanced Manufacturing and Sustainable Logistics / W. Dangelmaier et al. (Eds.).* Springer Berlin Heidelberg, 2010, pp. 15–25.
14. Buslenko, N. P., Kalashnikov, V. V., Kovalenko, I. N. *Lectures on the Theory of Complex Systems.* M.: Sov. Radio, 1973. (In Russian)

`Transport and Telecommunication, 2011, Volume 12, No 3, 27–40
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

# CRITICAL SITUATIONS EVALUATION OF DISCRETE TRANSPORTATION SYSTEMS

***Jacek Mazurkiewicz, Tomasz Walkowiak***

*Institute of Computer Engineering, Control and Robotics*
*Wroclaw University of Technology*
*ul. Janiszewskiego 11/17, 50-372 Wroclaw, Poland*
*E-mails: Jacek.Mazurkiewicz@pwr.wroc.pl, Tomasz.Walkowiak@pwr.wroc.pl*

The paper presents the formal model of discrete transportation systems (*DTS*). The modelling methodology is based on the system functional behaviour. Monte Carlo approach is used as a simulation tool. The actual *DTS* situation is measured by the global metric called availability. The proposed solution is very useful for the system owner and manager. The critical situations are caused by reliability, functional and human origin. Absence of restrictions on the system structure and on the kind of distribution describing the system functional and reliability parameters is the main advantage of the approach. The exemplar *DTS* driven into critical situation is presented in the final part. The results show and discuss different ways to restore the normal operating point. The proposed solution seems to be essential for the owner and administrator of the transportation systems.

**Keywords:** reliability, discrete transportation system, Monte-Carlo simulation, critical sets

## 1. Introduction

The transportation systems are characterized by a very complex structure. The performance of the system can be impaired by various types of faults related to the transportation vehicles, communication infrastructure or even by traffic congestion or human resource [1]. Each part of the system is characterised by absolutely unique set of features and can cause the critical situation of the whole system if it starts to work in unusual way or the fault or error of it is noticed. It is hard for an administrator, manager or an owner to understand the system behaviour and to combine the large scale of variant states of it in single – easily observable and controlled global metric as a pointer to make the proper decision in a short time period. To overcome this problem we propose a functional approach.

The transportation system is analysed from the functional point of view, focusing on business service implemented by a system [16]. The analysis is following a classical one [4]: modelling and simulation approach. It allows calculating different system measures which can be a base for the decisions related to administration of the transportation systems.

The metric are calculated using Monte Carlo techniques [7]. Absence of the restrictions on the system structure and on a kind of distribution is the main advantage of the method. Such approach allows – forgetting about the classical reliability analysis based on Markov or Semi-Markov processes [2] idealised and hard for reconciliation in practice. The results of the system observation is understand the set of data collected during the simulation process; they are the basis to define the critical situations and they allow providing the probably proper solution to lift-up the systems in effective way if the critical situation occurs. This is the only sensible way, because the critical situations are the real and not removable part of the system life.

Section 2 presents a brief environmental transport systems discussion. The real system – a source and motivation for the work is described in section 3. The developed discrete transportation system model is presented in section 4. The main service given by the post system is the delivery of mails. From the client point of view the quality of the system can be measured by the time of transporting the mail from the source to the destination. A driver is a new element of the system description. We pointed the set of states to characterise the actual driver position including formal law-origin aspects: number of hours he or she can work daily for example. We offer the heuristic approach to the system management (section 5). In our opinion it seems to be the most adequate to the level of detail to provide the well-established description of the critical situation. Next we show the idea, logic and implementation aspects of the prepared and used simulator (section 6).

The quality of the analysed system is measured by the availability defined as an ability to realize the transportation task at a required time (described in section 7). The section defines the critical situation matter and the most important features. Next (section 8), we give an example of using the presented model for the analysis of the Dolny Slask Polish Post regional transportation system.

## 2. Environmental Transport Systems Discussion

### 2.1. Traffic Problem

Modelling traffic flow for design, planning and management of transportation systems in urban and highway area has been addressed to since the 1950s mostly by the civil engineering community. The following definitions and concepts of traffic simulation modelling can be found in works such as Gartner et al. [8]. Depending on the level of detail in modelling the granularity of traffic flow, traffic models are broadly divided into two categories: macroscopic and microscopic models. According to Gartner et al. [8], a macroscopic model describes the traffic flow as a fluid process with aggregate variables, such as flow and density. The state of the system is then simulated using the analytical relationships between average variables such as traffic density, traffic volume, and average speed.

On the other hand, a microscopic model reproduces interaction of punctual elements (vehicles, road segments, intersections, etc) in the traffic network. Each vehicle in the system is emulated according to its individual characteristics (length, speed, acceleration, etc.). Traffic is then simulated, using processing logic and models describing vehicle driving behaviour, such as car-following and lane-changing models. These models reproduce the driver-driver and driver-road interactions. Despite its great accuracy level, for many years this highly detailed modelling has been considered a computationally intensive approach. For the last twenty years, with the improvements in processing speed, this microscopic approach has become more attractive. In fact, Ben-Akiva et al. [3], Barcelo et al. [1] and Liu et al. [12] claim that using microscopic approach is essential to track the real-time traffic state and then, to define strategy to decrease congestion in urban transportation networks. For the control of congestion, they explain that the models must accurately capture the full dynamics of time dependant traffic phenomena and must also track vehicles reactions when exposed to Intelligent Transportation Systems (ITS).

From the latter assertions, in order to control the traffic congestion in internal transportation networks it appears that the microscopic modelling will be more appropriate. A common definition of congestion is the apparition of a delay above the minimum travel time needed to traverse a transportation network. As stated in Taylor et al. [14], this notion is context-specific and complex because a delay may always appear in the dynamic transport system, but this delay must exceed a threshold value in order to be considered.

### 2.2. Microscopic Discussion

Few works have considered the traffic behaviour when studying outdoors vehicle-based internal transport operational problems. In the surface mining environment, pickup and delivery operations involve a fleet of trucks transporting materials from excavation stations to dumping stations, through a designed shared road network. At pickup stations, shovels are continuously digging during a shift according to a pre-assigned mining production plan. Trucks are moving in a cyclical manner between shovels (pickup stations), and dumping areas (delivery stations). A truck cycle time is defined as the time spent by a truck to accomplish an affected mission that consists of travelling to a specific shovel, being serviced by the shovel and hauling material to a specific dumping area. Burt and Caccetta [5] state that mine productivity is very sensitive to truck dispatching decisions which are closely related to the truck cycle time. Thus several papers have studied and proposed algorithms and software to resolve this problematic issue. In fact, this critical decision consists of finding, according to the real environment, to which the best shovel truck must be affected. Such decision has to be generated continuously during a shift, whenever the truck finishes dumping at a delivery station.

Despite the several proposed dispatching software, the recent articles by Krzyzanowska [11] formally criticize the simplistic assumption behind those software which tend to provide dispatching decisions with the objective to optimise a truck cycle times previously calculated. Generally speaking, those software systems based on the optimisation process of the past period collected data of trucks cycle

times and assume that for the next period trucks will spend on average the same time to accomplish missions. But in the reality of mining operation, the duration of truck travel time appears to be very sensitive to the variable traffic state and road conditions. Burt and Caccetta [5] and Krzyzanowska [11], point out the unresolved problematic of truck bunching and platoon formation in mining road network which apparently induce lower productivity.

### 2.3. Container Operations

Similarly to the material transportation in mining operation, several papers (Ioannou [10], Vis [15]) have provided the methods for improving the container terminal complex operations. In such applications, three types of handling operations are defined: vessel operations, receiving/delivery operations and container handling and storage operations in the stack yards. As we are interested by internal transportation systems, our review concerns the papers dealing with the container handling and storage operations in the stack yards. Generally speaking, vessels bring inbound containers to be picked up by internal trucks and distributed to the respective stocks in the yard.

Once discharged, vessels have to leave with on board outbound containers which also are delivered by internal trucks from the storage yard. For this purpose, trucks are moving through a terminal internal road network. In order to decrease the vessel turnaround time, which is the most important performance measure of the container terminals, it is important to perform those operations as quickly as possible. In fact according to [3], this movement of containers between quay sides and storage yards appears to affect the productivity of containership journey greatly. Vis and Koster [15] gives an extended review of the numerous research papers, providing algorithms to solve this complex routing and scheduling problem. They criticize the lack of consistency of the simplistic assumptions made to solve the proposed models within the real-world highly stochastic environment. The ignored traffic situation in the complex seaport internal transportation network is strongly criticized in recent papers [4], [10].

For example, in [3], a travel time of a container internal truck is modelled as a static mean time of travel, based on the distance and the truck average speed. Duinkerken et al. [6], put a uniform distribution between zero and 30% of the nominal travel time formulation, aiming to assimilate the complexity of traffic. More accurate work to solve this issue is the one provided recently by Liu, Chu and Recker [12]. They integrate a traffic model to the internal service model and reported the effectiveness of this integration which allows analysing the tractor traffic flow in a port container terminal.

Conscious about the critical problem of congestion in the road network inside a terminal, a quantitative measure of congestion to be added as a controllable decision variable have been developed. For this purpose, they considered the road system inside the terminal as a directed network and they measured flows on arcs in units of trucks travelling per unit time.

Those two last works appear as providing the leader approach in term of consideration of congestion and traffic in container terminals; however, their approach is ultimately macroscopic. As we have lately discussed, even if this macroscopic approach allows analysing the traffic behaviour, the highly detailed microscopic model is more efficient for an effective real-time traffic monitoring and control.

## 3. Real Transportation System

The analysed transportation system is a simplified case of the Polish Post (Fig. 1). The business service provided the Polish Post is delivery of mails. The system consists of a set of nodes placed in different geographical locations. Two kinds of nodes can be distinguished: central nodes (*CR*) and ordinary nodes (*PK*). There are bidirectional routes between the nodes. Mails are distributed among ordinary nodes by trucks, whereas between the central nodes by trucks, railway or by plane.

The mail distribution can be understood by tracing the delivery of some mail from point *A* to point *B*. At first the mail is transported to the nearest A ordinary node. Different mails are collected in ordinary nodes, packed in larger units called containers and then transported by trucks to the nearest central node. In central node containers are repacked and delivered to the appropriate (according to the delivery address of each mail) central node.

In the Polish Post there are 14 central nodes and more than 300 ordinary nodes. There are more than one million mails going through one central node within 24 hours. It gives a very large system to be modelled and simulated. Therefore, we have decided to model only a part of the Polish Post transportation system – one central node with a set of ordinary nodes.

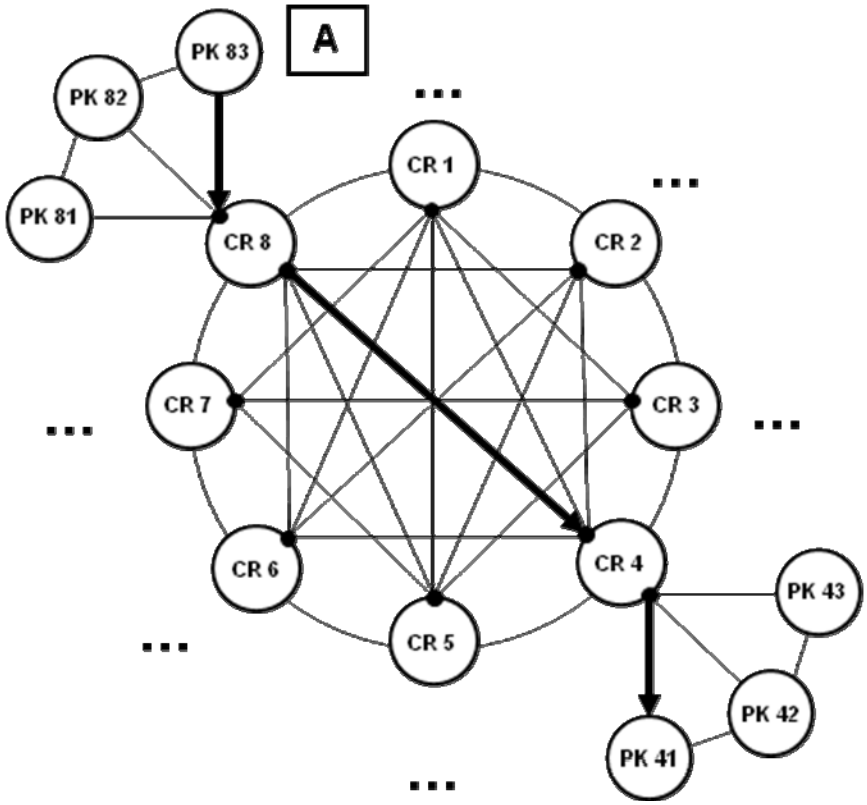



*Figure 1*. General idea of the analysed *DTS*

The income of mails to the system, or rather addressed containers of mails as it has been discussed above, is modelled by a stochastic process. Each container has a source and destination address. The generation of containers is described by some random process. In case of the central node, there are separate processes for each ordinary node. The containers are transported by vehicles. Each vehicle has a given capacity – maximum number of containers it can haul. The central node is a base place for all vehicles. They start from the central node and the central node is the destination of their travel. The vehicle hauling a commodity is always fully loaded or taking the last part of the commodity if it is less than its capacity. When a vehicle approaches the ordinary node it is waiting in an input queue if there are any other vehicles being loaded/unloaded at the same time. There is only one handling point in each ordinary node. The time of loading/unloading vehicle is described by a random distribution.

The containers addressed to the given node are unloaded and empty space in the vehicle is filled by containers addressed to a central node. Next, the vehicle waits till the time of leaving the node (set in the time-table) is left and starts its journey to the next node. The operation is repeated in each node on the route and finally the vehicle is approaching the central node when it is fully unloaded and then it is available for the next route. The process of vehicle operation can be stopped at any moment due to a failure. After the failure, the vehicle waits for a maintenance crew, it is repaired (random time) and then it continues its journey [3].

## 4. Formal Model

We decided to model formally a part of the Polish Post transportation system, one regional section which consists of one central node and a set of ordinary nodes.

An implementation of the system service needs a defined set of technical resources. Moreover, the operating of vehicles transporting mails between system nodes is done according to some rules – some management system. Therefore, we can model the discrete transportation system as a 4-tuple:

$$DTS = \langle Client, BS, TI, MS \rangle, \tag{1}$$

where: *Client* – client model, *BS* – business service, a finite set of service components, *TI* – technical infrastructure, *MS* – management system.

### 4.1. Technical Aspects

The technical infrastructure of *DTS* can be described by three elements:

$$TI = \langle No, V, MM \rangle, \tag{2}$$

where: *No* – the set of nodes; *V* – the set of vehicles; *MM* – the maintenance model.

The set of nodes (*No*) consists of a single central node (*CR*), a given number of ordinary nodes ($PK_i$). The distance between each two nodes is defined by the function:

$$distance : No \times No \rightarrow R_+ . \tag{3}$$

Each node has one functional parameter – the mean (normal distribution) time of loading a vehicle:

$$loading : No \rightarrow R_+ . \tag{4}$$

Moreover, the central node (*CR*) has additional functional parameter: the number of service points (in each ordinary node there is only one service point):

$$servicepoi\,nts : CN \rightarrow N_+ . \tag{5}$$

Each vehicle is described by the following functional and reliability parameters:

- mean speed of a journey
  $$meanspeed : V \rightarrow R_+ , \tag{6}$$
- capacity – number of containers which can be loaded
  $$capacity : V \rightarrow R_+ , \tag{7}$$
- mean time to failure
  $$MTTF : V \rightarrow R_+ , \tag{8}$$
  a time when failure occurs is given by exponential distribution with mean equal to a value of *MTTF* function,
- mean repair time
  $$MRT : V \rightarrow R_+ , \tag{9}$$

it is modelled by a truncated Gaussian distribution.

The traffic is modelled by a random value of vehicle speed and therefore the time of vehicle (*v*) going from one node ($n_1$) to another ($n_2$) is given by a formula:

$$time(v, n_1, n_2) = \frac{distance(n_1, n_2)}{Normal(meanspeed(v), 0.1 \cdot meanspeed(v))}, \tag{10}$$

where *Normal* denotes a random value with the truncated Gaussian distribution [17].

The maintenance model (*MM*) consists of a set of maintenance crews which are identical and unrecognized. The crews are not combined to any node, are not combined to any route, they operate in the whole system and are described only by the number of them.

The time when a vehicle is repaired is equal to the time of waiting for a free maintains crew (if all crews are involved into maintenance procedures) and the time of a vehicle repair which is a random value with the truncated Gaussian distribution: ($Normal(MRT(v), 0{,}1 \cdot MRT(v))$).

### 4.2. Human Factor

The human infrastructure is composed by the set of drivers. So the description of this part of system infrastructure requires the analysis of the drivers' state and the algorithms, which model the rules of their work. Each driver can be in one of the following states ($s_d$): rest (not at work), unavailable (illness, vacation, etc.), available (at work – ready to start driving), break (during driving), driving.

The number of driver working hours is limited by the labour law. For analysed Post Transportation System the daily limit for each driver equals to 8 hours and a single driver operates with one truck. It gives a simple algorithm:

- if $w_h > limit$ then *state* = "rest" & $w_h = 0$,
- where $w_h$ – working hours, *limit* = 8 hours

Drivers in Polish Post work in two shifts, morning or afternoon one. So twice a day a driver state and shift type is analysed:

- at 6am for each driver:
  - if *shift* == morning & $s_d$ == rest then $s_d$ = available,
- at 1pm for each driver:
  - if *shift* == afternoon & $s_d$ == rest then $s_d$ = available,

The next problem ought to be modelled is the driver's illness state. We propose the following approach:

- for every driver at 4am:
  - if $s_d$ == rest and $rand() < d_i$ then during $x$ days (according to a given distribution) the driver is in $s_d$ = unavailable,
    where $d_i$ – driver's illness parameter.

Moreover we propose to categorise the driver's illnesses as follows: short sick: 1 to 3 days, typical illness: 7 to 10 days, long-term illness: 10 to 300 days [21]. We prepare the daily record of the driver. The algorithm to fix the driver to the vehicle is the last part of the driver model:

- if no driver – the vehicle does not start,
- driver can be chosen if: $s_d$ = available
  and $w_h$ + *estimated time of journey* < *limit* * 1.1,
- the driver is chosen randomly or by least value approach:
  *abs*(limit – $w_h$ – *estimated time of journey*).

### 4.3. Business Service

Business service [19] ($BS$) is a set of services based on a business logic, that can be loaded and repeatedly used for concrete business handling process. Business service can be seen as a set of service components and tasks that are used to provide the service in accordance with the business logic for this process. Therefore, $BS$ is modelled by a set of business service components (*sc*):

$$BS = \{sc_1, ..., sc_n\}, n = length(BS) > 0 , \tag{11}$$

the function *length*($X$) denotes the size of any set or any sequence $X$.

### 4.4. Client Description

The service implemented by the clients of the transportation system, sending the mails from a source node to a destination one. Client model consist of a set of clients ($C$).

Each client is allocated in one of nodes of the transportation system:

$$allocation : C \rightarrow No . \tag{12}$$

A client allocated in an ordinary node is generating containers (since we have decided to monitor the containers but not the separate mails during the simulation) according to the Poisson process with destination address set to ordinary nodes. In the central node, there is a set of clients, one for each ordinary node. Each client generates the containers by a separate Poisson process and is described by the intensity of container generation:

$$intensity : C \rightarrow R_+ . \tag{13}$$

The central node is the destination address for all containers generated in ordinary nodes.

## 5. Dispatching Problem

### 5.1. Legacy Solution

The management system controls the operation of vehicle. It consists of a sequence of routes:

$$MS = \langle r_1, r_2, ..., r_{nr} \rangle . \tag{14}$$

Each route is a sequence of nodes starting and ending in the central node, times of leaving each node in the route ($t_i$) and the recommended size of a vehicle (*size*):

$$r = \langle CR, t_0, n_1, t_1, ..., n_m, t_m, CR, size \rangle \quad v_i \in No - \{CR\} \quad 0 \le t_0 < t_1 < ... < t_m < 24h \,. \tag{15}$$

The routes are defined for one day and are repeated each day. The management system selects vehicles to realise each route in a random way, first of all vehicles (among vehicles available in the central node) with capacity equal to recommended size are taken into consideration. If there is no such vehicle, vehicles with larger capacity are taken into consideration. If still there is no vehicle fulfilling requirements the vehicle of smaller size is randomly selected. If there is no available vehicle a given route is not realised [18]

### 5.2. Heuristic Approach

The decisions (to send a truck to a given destination node) are taken in the moments when a container arrives to the central node. The truck is send to a trip if:

- the number of containers waiting in for delivery in the central node of the same destination address as that just arrived is larger than a given number,
- there is at least one available vehicle,
- the simulated time is between 6 am and 22 pm minus the average time of going to and returning from the destination node.

The truck is send to a node defined by a destination address of just arrived container. If there is more than one vehicle available in the central node, the vehicle with size that fits best to the number of available containers is selected, i.e. the largest vehicle that can be fully loaded. If there are several trucks with the same capacity available the selection is done randomly. The restriction for the time of truck scheduling (the last point in the above algorithm) are set to model the fact that drivers are working on two 8-hours shifts.

### 5.3. Soft Computing Idea

The system consists of a multilayer perceptron to decide if and where to send trucks. The input to the neural network consists of:

$$in = \langle pkc_1, pkc_2, ..., pkc_{npk}, crc_1, crc_2, ..., crc_{npk}, nfv \rangle, \tag{16}$$

$npk$ – number of ordinary nodes,
$pkc_i$ – number of containers waiting for delivery in the central node with destination address set to $i$-th ordinary node,
$nfv$ – number of free vehicles in the central node.

Each output of the network corresponds to each ordinary node:

$$nnout = \langle out_1, out_2, ..., out_{npk} \rangle \,. \tag{17}$$

The output of the network is interpreted as follows (for sigmoid function used in output layer):

$$j = \arg\max_{i=1...npk} \{out_i\} \,. \tag{18}$$

If $out_j$ is greater than 0.5 send a vehicle to node $j$ do nothing. If there are more vehicles available in the central node, the largest vehicle that can be fully loaded is selected. If there are available several trucks with the same capacity selection is done randomly. The neural network decision (send a truck or not and where the truck should be sent) are taken in the given moments in time. These moments are defined by the following states of the system:

- the vehicle comes back to the central node and is ready for the next trip,
- if there is at least one available vehicle in central node and the number of containers of the same destination address is larger than the size of the smallest available vehicle.

The neural network used in the management system requires a learning process that will set up the values of its weights. The most typical learning in the case of multilayer perceptron is the back propagation algorithm. However, it cannot be used here since it is impossible to state what should be the proper output values of the neural network. Since it is hard to reconcile what are the results of a single decision made by the management system. The results of the set of decisions are important. Since the business service implemented by transportation system is to move commodities without delays, the neural network should take such decisions that allow reducing delays as much as possible.

To train neural network to perform such task we propose to use genetic algorithm [18, 21]. Similar approach to training neural network is applied in case of computer games. The most important in case of genetic algorithm is a definition of the fitness function. To follow the business service requirements of transportation system we propose the following definition of the fitness function calculated for a given neural network after some time ($T$) (therefore after a set of decisions taken by the neural network) [17]:

$$fitness(T) = \frac{N_{ontime}(0,T) + N_{ontimeinsystem}(T)}{N_{delivered}(0,T) + N_{insystem}(T)} . \tag{19}$$

It is a ratio of on-time containers (delivered with 24h and being in the system but not longer then 24h) to all containers (that already delivered $N_{delivered}(0,T)$ and still being presented in the system $N_{insystem}(T)$).

## 6. DTS Simulator

### 6.1. Event-Driven Simulation

Once a model has been developed, it is executed on a computer. It is done by a computer program which steps through time. One way of doing it is so called event-driven simulation. It is based on the idea of event, which can be described by the time of event occurring and the type of event.

The simulation is done by analyzing the queue of event (sorted by time of event occurring) while updating the states of system elements according to the rules related to a proper type of event. Due to a presence of randomness in the *DTS* model the analysis of it has to be done basing on Monte-Carlo approach [21]. It requires a large number of repeated simulation.

Summarising, the event-driven simulator repeats $N$-times the following loop:

- beginning state of a *DTS* initialization,
- event state initialization, set time $t = 0$,
- repeat until $t < T$,
- take first event from event list,
- set time equals time of event,
- implement the event – change state of the *DTS* according to the rules related to the proper type of event: change objects attributes describing system state, generate new events and put them into event list, write data into output file.

### 6.2. Events and Elements of DTS

In case of *DTS* the following events (mainly connected with vehicles) have been defined:

- vehicle failure,
- vehicle starts repair,
- vehicle repaired,
- vehicle reached the node,
- vehicle starts from the node,
- vehicle is ready for the next route,
- time-table (starting the route in the central node).

Processing the events is done in objects representing *DTS* elements. The objects are working in parallel. The following types of system elements have been distinguished: vehicle, ordinary node, central node, time table.

The life cycle of each object consists of waiting for an event directed to this object and then execution of tasks required to perform the event. These tasks include the changes of the internal state of the object (for example when vehicle approaches the node it is unloaded, i.e. the number of hauled containers decreases) and sometimes creating a new event (for example the event “vehicle starts from the node” generates the new event “vehicle reaches the node” – next node in the trip).

The random number generator is used to deal with random events, i.e. failures. It is worth noticing that the currently analysed event not only generates a new event but also can change the time of some future events (i.e. time of approaching the node is changed when failure happens before). The time of a new event is defined by the sum of current time (moment of execution of the current event) and the duration of a given task (for example vehicle repair). Only time of starting a given route (event “vehicle starts from the central node”) is predefined (according to the time table). Duration of all other tasks is defined by the system elements states:

- time when vehicle waits in a queue for loading/unloading,
- time when vehicle waits in a queue for maintains crew,

or is given by the random processes:

- time of vehicle going between two nodes,
- time of loading/unloading,
- time to failure,
- repair time.

Moreover, each object representing a node has additional process (working in parallel) which is responsible for generating containers. The life cycle of this process is very simple: waiting a random time, generating a container with a given destination address (central node for all ordinary nodes, and each ordinary nodes for processing in the central node) and storing a container in the store house (implemented as a queue) of a given node.

### 6.3. Implementation

The event-simulation program can be written in a general purpose programming language (like C++), in a fast prototyping environment (like Matlab) or a special purpose discrete-event simulation kernel. One of such kernels, is the Scalable Simulation Framework (*SSF*) [17] which is a used for *SSFNet* [17, 18] computer network simulator. *SSF* is an object-oriented *API* – a collection of class interfaces with prototype implementations. It is available in C++ and Java. *SSFAPI* defines just five base classes: Entity, inChannel, outChannel, Process, and Event. The communication between entities and delivery of events is done by channels (channel mappings connects entities).

For the purpose of simulating *DTS* we have used Parallel Real-Time Immersive Modelling Environment (*PRIME*) [17] implementation of *SSF* due to a much better documentation then available for the original *SSF*. We have developed a generic class derived from *SSF* Entity which is a base of classes modelling.

*DTS* objects which model the behaviour of the discrete transport system presented in section 2 and 4.

As it was mentioned, due to a presence of randomness in the *DTS* model, the Monte-Carlo approach is used. The original *SSF* was not designed for this purpose so some changes in *SSF* core have been done to allow restarting the simulation for several times from time zero within one run of simulation programme.

The statistical analysis of the system behaviour requires a very large number of simulation repetition, therefore the time of performance of the developed simulator is very important.

### 6.4. Performance

Next, we have tested the DTS simulator performance and scalability. We calculated the time of running one batch of simulation of the exemplar DTS presented above for 100 days on a 2.80 GHz Intel Core Duo machine on Linux system (Tab. 1). The CYGWIN base Windows implementation of PRIME SSF was around 10 times slower then Linux one. Next, we have enlarged the number of containers transported each day 10, 50, 100 and 500 times and proportionally enlarged the transport system (number of trucks, routes and service points). As it can be seen in Table 1 and Figure 2 the memory usage is linearly proportional to a number of containers transported each day. Whereas the simulation time is polynomially proportional (see Fig. 2).

We think that the time and memory effectiveness of simulation done in PRIME environment is very promising. Of course, the time needed to perform one simulation depends on the number of events presented in the system, which is a result DTS configuration.

**Table 1.** DTS simulator performance

| | Reference DTS | 10 x larger | 50 x larger | 100 x larger | 500 x larger |
|---|---|---|---|---|---|
| **Number of trucks** | 52 | 520 | 2 600 | 5 200 | 26 000 |
| **Number of router per day** | 184 | 1 840 | 9 200 | 18 400 | 92 000 |
| **Number of containers per day** | 4 400 | 44 000 | 220 000 | 440 000 | 2 200 000 |
| **Simulation time** | 0,21s | 2,60 s | 31,91 s | 154,5 s | 1910,0 s |
| **Memory usage** | 2 MB | 12 MB | 63 MB | 125 MB | 600 MB |

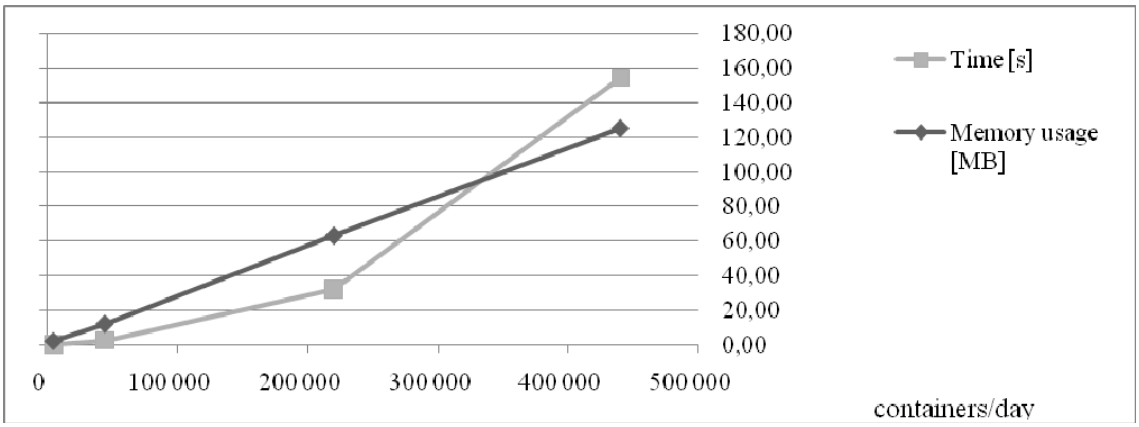



*Figure 2*. Simualtaion time and memory usage in a function of number of containers per day generated in DTS

## 7. Critical Situation

### 7.1. Problem Description

The *DTS* works correctly if there are no problems related to reliability and functional parameters. On the other hand the number and the volume of tasks loaded into the system cannot be above the system possibilities. The sentences sound very trivial, but – in general – it is not so trivial to find the global measure to check if the system is not overloaded.

Of course the correctly tuned system ought to be characterised by the set of fault tolerant features. It means the system is able to realise the loaded tasks even if the different faults occur because of reliability or functional insufficiencies. The problem pointed above needs a multi-criteria solution. In other words it is possible to find a kind of pareto set (Fig. 3.) to guarantee the system as functionally ready for the defined tasks.

The critical situation occurs if an actual operating point of the system is located outside the pareto set. The main goal if the critical situation is noticed is to drive the system to the pareto set as soon as possible. The proper management reaction is the first option to rescue the system situation. We propose the metric called the acceptance ratio to check if the operating point of the system is located at the pareto set [2].

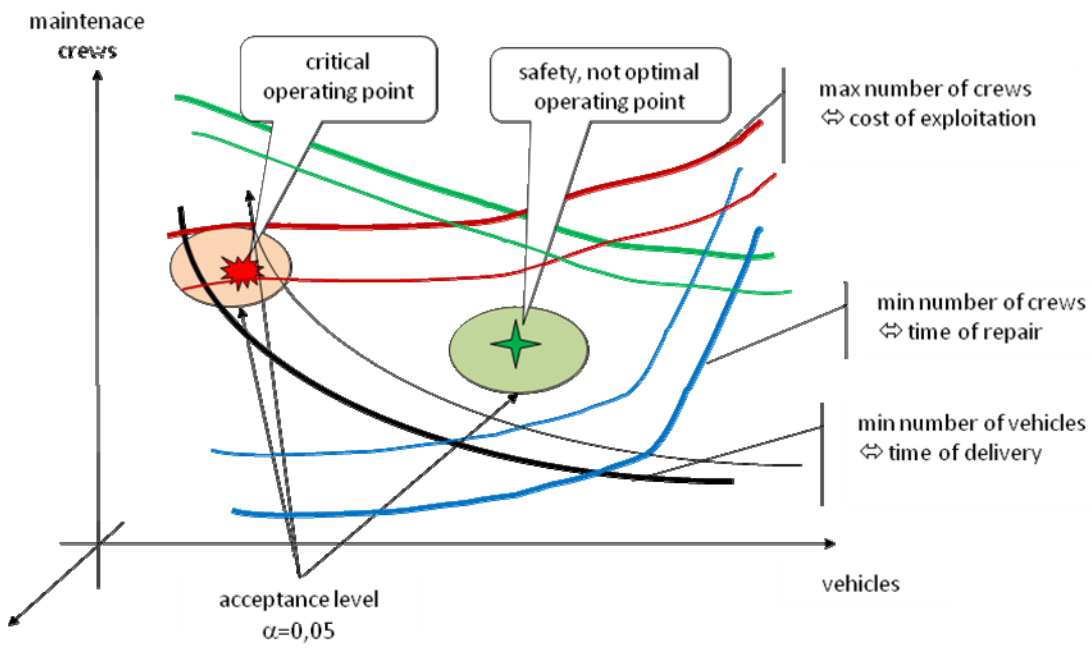



*Figure 3*. General idea of the pareto set

### 7.2. Availability – Definition

One can define the availability in different ways, but the value of an availability can always be easyly transformed into economic or functional parameters perfectly understood by owner of the system. The availability is mostly understood as a probability that the system is up and is defined as a ratio of the expected value of the uptime of a system to the observation time. It is a simple definition but it requires defining what it means that the transportation system is working.

The similar metric is the acceptance ratio defined by information as a number of accepted requests to the total number of requests.

In paper [20] we have proposed the definition of up time as a time when the number of delayed containers does not exceed a given threshold. Let us introduce the following notation:

- $T$ – a time measured from the moment when the container has been introduced to the system to the moment when the container has been transferred to the destination (random value);
- $T_g$ – a guaranteed time of delivery, if exceeded the container is delayed;
- $N_{deleyed}(t)$ – a stochastic process describing the number of delayed containers at time $t$, i.e. the number of containers for which T > $T_g$.

Therefore, the functional availability $A_k(t)$ can be defined as a probability that the number of delayed containers at time $t$ does not exceed $k$, the value $k$ is the level of acceptable delay:

$$FA_k(t) = \Pr\{N_{deleyed}(t) \le k\}. \tag{20}$$

### 7.3. Average Functional Availability

The defined in the previous section functional availability describes a state of an analyzed system at a given point of time. In case if somebody wants to analyze the state of the system in a time interval we have proposed in [7] the other metric: average functional availability $AFA_k(t)$. It is defined as an average probability that a system in the time interval from 0 to $t$ is in up-time state (i.e. the number of delayed containers does not exceed threshold $k$):

$$AFA_k(t) = \frac{1}{t}\int_0^t \Pr\{N_{deleyed}(\tau) \le k\} d\tau . \tag{21}$$

### 7.4. Acceptance Ratio

A very often used estimation of the availability, which uses its asymptotic property and is based on an assumption of a uniform rate of the clients' requests, is the acceptance ratio. For *DTS*, we have defined it [16] as the ratio of on-time containers (containers for which $T < T_g$) to all containers within a given time of observation (0, $\tau$). Within the time period a given number of containers are delivered ($N_{delivered}(\tau)$), a part of them or all delivered on time ($N_{ontime}(\tau)$), but in the end of analysed time period there can be some containers not delivered yet (waiting in the source node or being transported) ($N_{insystem}(\tau)$) and all or part of them being not late yet ($N_{ontimeinsystem}(\tau)$). Taking into consideration the introduced symbols the availability can be calculated as the expected value (Monte-Carlo approach) of ratio of on-time containers to all containers:

$$AR_\tau = E\left(\frac{N_{ontime}(\tau) + N_{ontimeinsystem}(\tau)}{N_{delivered}(\tau) + N_{insystem}(\tau)}\right). \tag{22}$$

## 8. Critical Situation Evaluation

### 8.1. Exemplar *DTS*

We propose for the case study analysis an exemplar *DTS* based on Polish Post regional centre in Wroclaw. We have modelled a system consisting of one central node (Wroclaw regional centre) and twenty two other nodes – cities where there are local post distribution points in Dolny Slask Province. The length of the roads has been set according to the real road distances between cities used in the analyzed case study. The intensity of generation of containers for all destinations has been set to 4.16 per hour in each direction giving in average 4400 containers to be transported each day.

The vehicles speed has been modelled by Gaussian distribution with 50 km/h of mean value and 5 km/h of standard deviation. The average loading time has been equal to 5 minutes. There have been two

types of vehicles: with capacity of 10 and 15 containers. The MTF of each vehicle has been set to 20000. The average repair time has been set to 5h (Gaussian distribution). We also have tried to model the drivers' availability parameters. We have fulfilled this challenge by using the following probability of a given type of sickness: short sick: 0.003, typical illness: 0.001, long-term illness: 0.00025.

### 8.2. Results – Discussion

We entered the above defined system into critical situation: first of all to observe the actual value of the acceptance ratio – to find how deep degradation we can notice. The second goal was to compare the effectiveness of three possible management systems in case of driving the operating point of the system to the pareto set as soon as possible (Fig. 4). Finally we tried to find the real pareto set for the defined set of task loaded into the system, the adjusted number of vehicles and the adjusted number of drivers (Fig. 6).

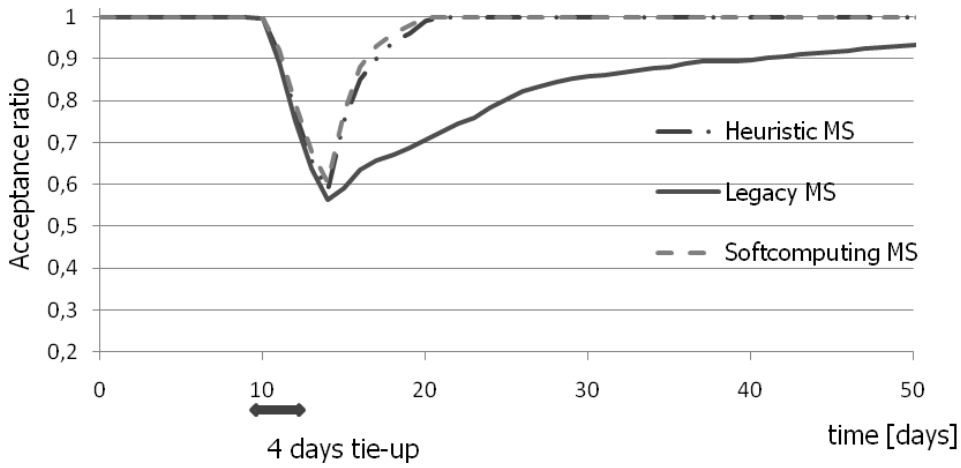
Let us assume that for some days the system is working at 50% level. The tie-up of the system can be caused for example by a driver strike or some contagious diseases resulting in situation that only 50% of vehicles are available. After a given number of days the system is again working fully.

The achieved results (acceptance ratio calculated according to (22)) for 4 and 14 days tie-up are presented in Figure 4. As it can be expected the acceptance ratio in day 10 (when critical situation starts) is starting to drop down and when drivers come back is enlarging.

However, the system with heuristic management as well as the soft computing one is coming back to normal operation much faster than the legacy one. The soft computing one is slightly outperforming the heuristic one.

The Figure 5 presents how many days are needed for the transportation system to achieve the required level (0.9, 0.95 and 0.98) after a tie-up of the different length. The system is driven by the soft computing management system.

a)




b)

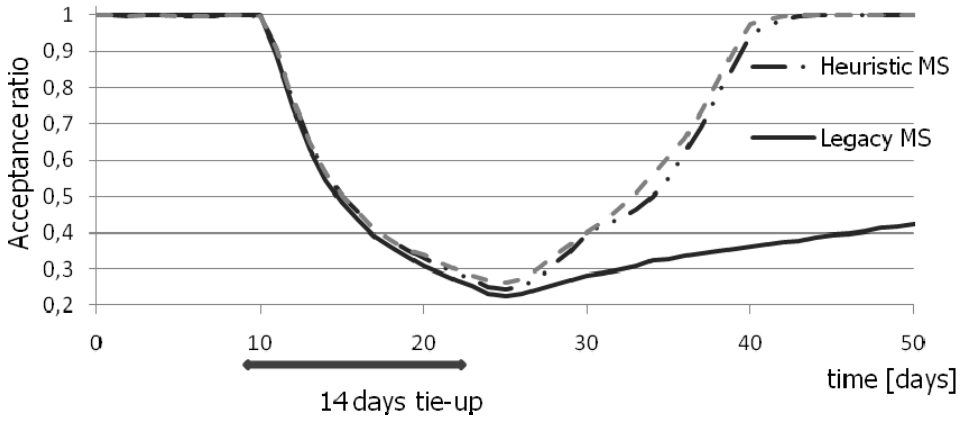



*Figure 4*. Acceptance ratio for 4 days (a) and 14 days (b) tie-up vehicles for different management system

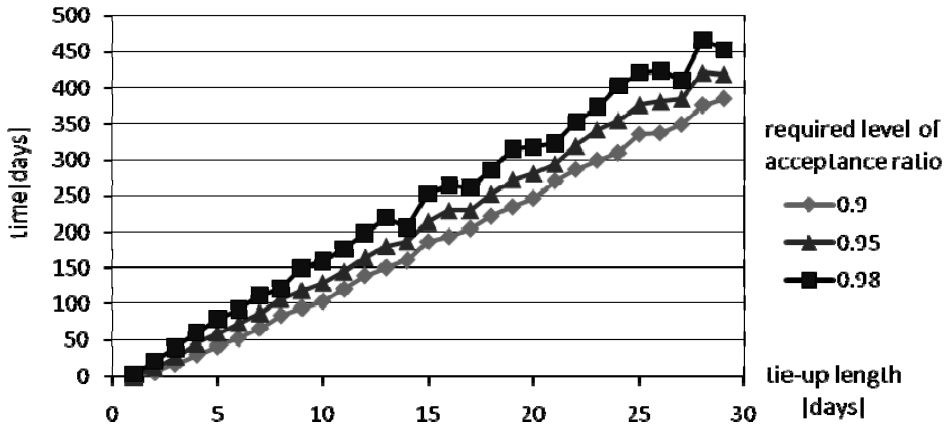



*Figure 5*. Time required to achieve a given level of acceptance ratio after a tie-up of different length for the exemplar *DTS* driven by the soft computing management system

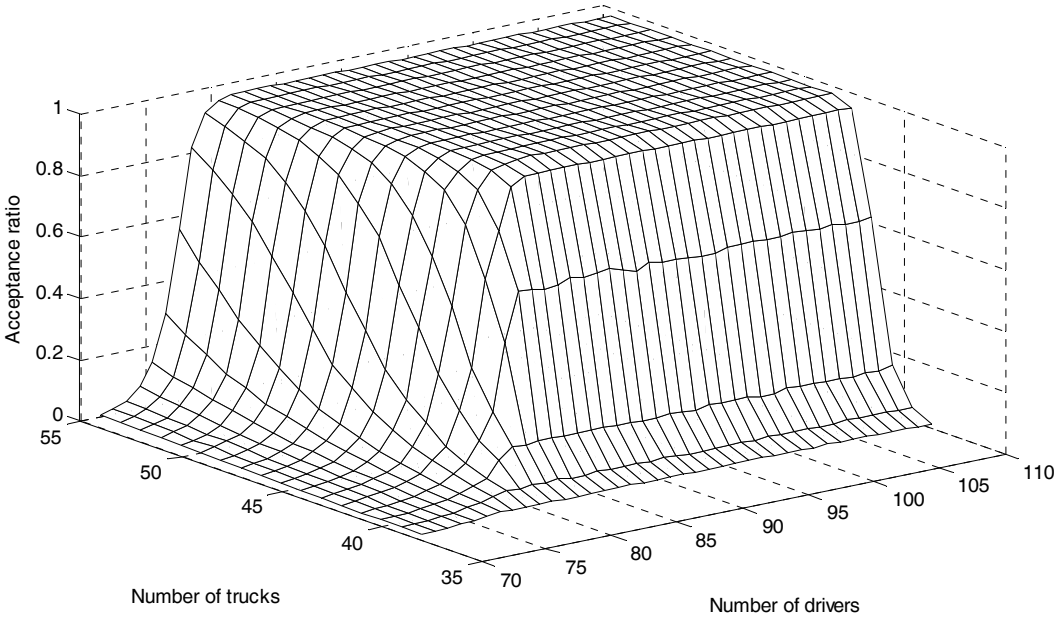



*Figure 6*. Pareto set in a function of number of trucks and number of drivers for tested *DTS*

## 9. Conclusion

We have presented a formal model of discrete transportation system (*DTS*) including reliability, functional parameters as well as the human factor component. The *DTS* model is based on the Polish Post regional transportation system. We proposed three different management approaches for the defined system. The critical situation is described and the availability of metric to create the pareto set guarantees the possible safety operating points for actual *DTS*.

The proposed approach allows performing reliability and functional analysis of the *DTS*, for example:

- determine what will cause a ”local” change in the system,
- make experiments in case of increasing the number of containers per day incoming to system,
- identify the weak points of the system by comparing a few of its configuration,
- understand better how the system behaves.

We have introduced the exemplar *DTS* into critical situation to discuss how deep breakdown it causes and to test which management approach can drive the system operating point into pareto set as soon as possible. The *DTS* described as the case study is based on the real Polish Post Wroclaw area. The presented solution can be used as a practical tool for defining an organization of the vehicle maintenance and transportation system logistics.

## Acknowledgment

Work reported in this paper was sponsored by a grant No. N N509 496238, (years: 2010–2013) from the Polish Ministry of Science and Higher Education.

## References

1. Barcelo, J., Codina, E., Casas, J., Ferrer, J.L. and D. Garcia. Microscopic Traffic Simulation: a Tool for the Design, Analysis and Evaluation of Intelligent Transportation Systems, *Journal of Intelligent and Robotic Systems: Theory and Applications*, Vol. 41, 2005, pp. 173–203.
2. Barlow, R., Proschan F . *Mathematical Theory of Reliability*. Philadelphia: Society for Industrial and Applied Mathematics, 1996. 345 p.
3. Ben-Akiva, M., Cuneo, D., Hasan, M., Jha, M. and Q. Yang. Evaluation of Freeway Control Using a Microscopic Simulation Laboratory, *Transportation Research,* Part C (Emerging Technologies), 11C, 2003, pp. 29–50.
4. Birta, L., Arbez G. *Modelling and Simulation: Exploring Dynamic System Behaviour*. London: Springer, 2007. 246 p.
5. Burt, C.N. and L. Caccetta. Match Factor for Heterogeneous Truck and Loader Fleets, *International Journal of Mining, Reclamation and Environment*, Vol. 21, 2007, pp. 262–270.
6. Duinkerken, M.B., Dekker, R., Kurstjens, S.T.G.L., Ottjes, J.A., and N.P. Dellaert. Comparing Transportation Systems for Inter-Terminal Transportation at the Maasvlakte Container Terminals, *OR Spectrum*, Vol. 28, 2006, pp. 469–493.
7. Fishman, G. *Monte Carlo: Concepts, Algorithms, and Applications*. Springer-Verlag, 1996. 129 p.
8. Gartner, N., Messer, C.J. and A.K. Rathi. *Traffic Flow Theory and Characteristics / T.R. Board, ed.* Texas: University of Texas at Austin, 1998. 125 p.
9. Gold, N., Knight, C., Mohan, A., Munro, M. Understanding service-oriented software, *IEEE Software*, Vol. 21, 2004, pp. 71–77.
10. Ioannou, P.A. *Intelligent Freight Transportation.* Carolina: Taylor and Francis Group, 2008. 245 p.
11. Krzyzanowska, J. The Impact of Mixed Fleet Hauling on Mining Operations at Venetia Mine, *Journal of The South African Institute of Mining and Metallurgy*, Vol. 107, 2007, pp. 215–224.
12. Liu, H., Chu, L, Recker W. Performance Evaluation of ITS Strategies Using Microscopic Simulation, *Proceedings of the 7th International IEEE Conference on Intelligent Transportation Systems*, 2004, pp. 255–270.
13. Sanso, B. and L. Milot. Performability of a Congested Urban-Transportation Network when Accident Information is Available, *Transportation Science*, Vol. 33, No 1, 1999, pp. 10–21.
14. Taylor, M.A.P., Woolley, J.E., Zito, R. Integration of the Global Positioning System and Geographical Information Systems for Traffic Congestion Studies, *Transportation Research* Part C (Emerging Technologies) 8C, 2000, pp. 257–285.
15. Vis, I.F.A. Survey of Research in the Design and Control of Automated Guided Vehicle Systems, *European Journal of Operational Research*, Vol. 170, 2006, pp. 677–709.
16. Walkowiak, T., Mazurkiewicz, J. Analysis of Critical Situations in Discrete Transportation Systems. In : *Proceedings of International Conference on Dependability of Computer Systems*, *Brunow*, *Poland, June 30-July 2, 2009*. Los Alamitos: IEEE Computer Society Press, 2009, pp. 364–371.
17. Walkowiak, T., Mazurkiewicz, J. Availability of Discrete Transportation System Simulated by SSF Tool. In: *Proceedings of International Conference on Dependability of Computer Systems*, *Szklarska Poreba*, *Poland, June, 2008*. Los Alamitos: IEEE Computer Society Press, 2008, pp. 430–437.
18. Walkowiak, T., Mazurkiewicz, J. Functional Availability Analysis of Discrete Transportation System Realized by SSF Simulator. In: *Computational Science – ICCS 2008, 8th International Conference*, *Krakow, Poland, June 2008*. Springer-Verlag, LNCS 5101, 2008. Part I, pp. 671–678.
19. Walkowiak, T., Mazurkiewicz, J. Algorithmic Approach to Vehicle Dispatching in Discrete Transportation Systems. In: *Technical approach to dependability / Eds. Jarosław Sugier [at al].* Wroclaw: Oficyna Wydawnicza Politechniki Wroclawskiej, 2010. pp. 173–188.
20. Walkowiak, T. and J. Mazurkiewicz. Functional Availability Analysis of Discrete Transportation System Simulated by SSF Tool, *International Journal of Critical Computer-Based Systems*, Vol. 1, No 1–3, 2010, pp. 255–266.
21. Walkowiak, T. and J. Mazurkiewicz. Soft Computing Approach to Discrete Transportation System Management. In: *Lecture Notes in Computer Science. Lecture Notes in Artificial Intelligence*. Springer-Verlag, 2010. Vol. 6114, pp. 675–682.

*Transport and Telecommunication, 2011, Volume 12, No 3, 41–53*
*Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia*

# SOFTWARE-ENGINEERING MEASUREMENT FOR LOGISTICS AND TRANSPORT SYSTEMS

***Sergey Orlov, Andrei Vishnyakov***

*Transport and Telecommunication Institute*
*Lomonosova str.1, Riga, LV-1019, Latvia*
*E-mails: sorlov@tsi.lv, andrei.vishnyakov@gmail.com*

Today logistics and transport systems are complex and expensive, so it is necessary to use modern metric suits for their development process, which takes into account the characteristics of such systems. It is very important to choose a metric suite on the early development stages and the choice should be based on objective facts and experience.

To choose the optimal metric suite it is necessary to use a technique that contains a number of steps. At each step, a specific criterion should be used to make a selection from the available metric suites. As long as the metric suite is chosen it is necessary to perform its improvement. To do so each metric in the suite should be considered separately and replaced if the analogous metrics provides a better criteria matching. In the end we obtain the modified metric suite, which is optimal according to the requirements.

**Keywords:** metric suite, object oriented design metrics, metrics selection algorithm, logistics and transport software, Chidamber & Kemerer's metrics suite, software package metrics, metrics for object oriented design, LCOM

## 1. Introduction

Modern logistics and transportation systems are complex and expensive, so it's necessary to use modern metric suits for their development process, which takes into account the characteristics of such kind of systems.

Among different groups of software metrics the suites of metrics for software design stage takes the essential part, including object-oriented and post-object-oriented design metrics. The total number of different metrics is extremely large, and they have different characteristics, as well as offer different approaches to measuring the quality of the systems. Metrics which are used to evaluate complex characteristics of systems and integrated into the groups called metric suites. As an example, one of the most commonly used metrics suite is Chidamber & Kemerer's metrics suite [1].

During the initial stage of development, it's necessary to have a technique that allows selecting a metric suite among of different suites. Also such technique should help to optimise the selected metric suite. In addition, such a choice should take into account the specific requirements for the logistics and transport systems.

## 2. Selection of a Metric Suite

To choose the optimal metric suite it's necessary to use a technique that contains a number of steps and based on some criteria. The criterion can be expressed as scalar or vector value and can vary in accordance with the required characteristics of logistics and transportation systems.

The algorithm for this technique consists of the following steps (see Figure 1):

1. Determination of metric suites;
2. Determination of criteria;
3. Obtaining values of the criteria;
4. Choice of the metric suite with the optimal values of the criteria.

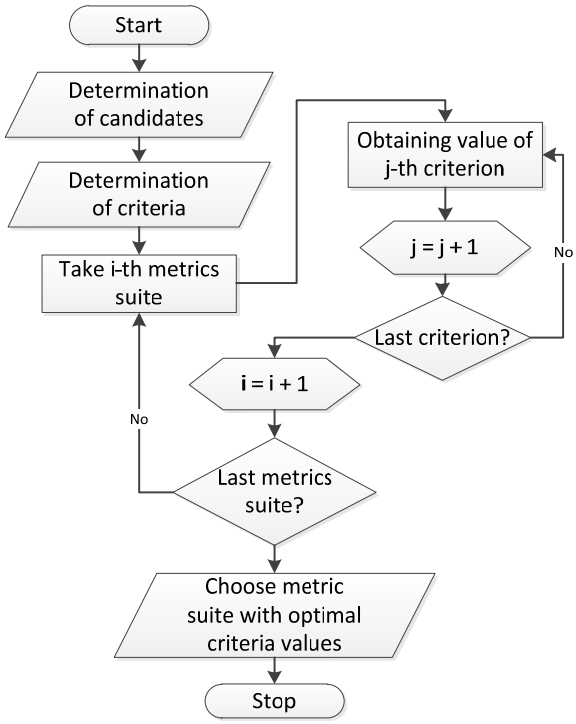



*Figure 1.* Flowchart representation of metric suite selection algorithm

### 2.1. Determination of metric suites

There are available several metric suites, which could be used at the software design stage:

- Chidamber & Kemerer's metrics suite [1, 2];
- Lorenz and Kidd metrics suite [1];
- Software Package Metrics proposed by Robert Cecil Martin [3];
- Metrics for Object Oriented Design proposed by Fernando Brito e Abreu [1, 4].

Let us take a close consideration of the Chidamber & Kemerer's metrics suite and the metrics suites proposed by Robert Cecil Martin and Fernando Brito e Abreu. These metrics suites are considered in many publications, and the calculations of values for their metrics are implemented in several commercial products.

#### *2.1.1. Chidamber & Kemerer's metrics suite*

This metric suite was proposed by Chidamber & Kemerer in 1994 [2]. The suite uses the class as a fundamental element of object-oriented system. The long usage experience of the suite has proved its efficiency and showed that it's performed well. Its widespread use just confirms it.

There are a number of works which examine and evaluate the proposed metric suite [1]. The results of such research have proved the relations between the metrics and such quality indicators as a project cost, reusability, maintenance complexity, etc. On the other hand, some of the metric in the suite are criticized and there are proposed various alternatives and modifications [5, 6, 7].

Chidamber & Kemerer proposed the following metrics [2]:

- Weighted Methods Per Class (WMC) – number of methods defined in class;
- Depth of Inheritance Tree (DIT) – maximum inheritance path from the class to the root class;
- Number of Children (NOC) – number of immediate sub-classes of a class;
- Coupling between Object Classes (CBO) – number of classes to which a class is coupled;
- Response for a Class (RFC) – set of all methods that can be invoked in response to a message to an object of the class;
- Lack of Cohesion of Methods (LCOM) – number of not connected method pairs in a class representing independent parts having no cohesion.

### *2.1.2. Software Package Metrics*

This metric suite was proposed by Robert Cecil Martin for object-oriented software evaluation which is based on subsystem's relationship analysis [3]. Project which contains strong dependencies between the subsystems require more effort in developing and maintaining. On the other hand, it's impossible to avoid all dependencies. Robert Cecil Martin suggested the characteristics which can help to make system reusable, fault-tolerant and easy modifiable.

To measure these characteristics he proposed a number of easily applicable metrics:

- Afferent Couplings (Ca) – number of other packages that depend upon classes within the package;
- Efferent Couplings (Ce) – number of other packages that the classes in the package depend on;
- Abstractness (A) – ratio of the number of abstract classes in the analysed package to the total number of classes in the analysed package;
- Instability (I)– ratio of efferent coupling to total coupling;
- Distance from the Main Sequence (D) – perpendicular distance of a package from the idealized line A + I = 1;
- Package Dependency Cycles – packages participating in package dependency cycles.

These metrics measure the project correspondence to the ideal models of dependency and abstraction. Such measures are based on certain standards which might not be applicable for every system and as a result can only degrade the quality of the system.

The examination of this metric suite is important, since the suite is widely used for agile development, which is becoming more and more popular.

### *2.1.3. Metrics for Object Oriented Design*

Metrics for Object Oriented Design was proposed by Fernando Brito e Abreu in 1994 [4]. The main objectives of the metric are: coverage of the basic structural mechanisms of the object-oriented paradigm, formal definition, size and language independence. All metrics are considering only the methods and attributes in the system. The results represent the average value for the entire system.

There are a number of papers devotes to this metric suite, though much smaller than for Chidamber & Kemerer's metrics suite. It is also used less frequently in practice than the previous two metric suites.

Fernando Brito e Abreu proposed the following metrics:

- Method Hiding Factor (MHF) – ratio of the sum of the invisibilities of all methods defined in all classes to the total number of methods defined in the system;
- Attribute Hiding Factor (AHF) – ratio of the sum of the invisibilities of all attributes defined in all classes to the total number of attributes defined in the system;
- Method Inheritance Factor (MIF) – ratio of the sum of inherited methods in all classes of the system to the total number of available methods for all classes;
- Attribute Inheritance Factor (AIF) – ratio of the sum of inherited attributes in all classes of the system to the total number of available attributes for all classes;
- Polymorphism Factor (POF) – ratio of the actual number of possible different polymorphic situations to the maximum number of possible distinct polymorphic situations;
- Coupling Factor (COF) – ratio of the maximum possible number of couplings in a system to the actual number of couplings not imputable to inheritance.

Each metrics in the suite reflects some basic structural mechanism of the object-oriented paradigm as encapsulation (MHF, AHF), inheritance (MIF, AIF), polymorphism (POF) and message passing (COF).

## 2.2. Determination of criteria

The evaluation and comparison of several metric suites isn't an easy task. Therefore the criteria, which take into consideration the requirements for the metric suite, should simplify the problem. The selection of the criteria depends on many factors, and every solution might have different criteria. In general, such criteria selection is made by software engineers and should be based on some expert evaluations.

For a criterion preference rule the maximization is used, where each criterion includes a combination of indicators. As long as not every indicator can be quantified or it might have different scales, we use a scale of correspondence for its evaluation. This scale has a range from 0 to 2, where 0 – no correspondence, 1 – average level of correspondence, 2 – full correspondence. The value of every indicator is chosen empirically.

The weighting coefficients could be used in addition to preference rule. Weight coefficients should be chosen according to the specified requirements for the system.

According to the preceding, our criterion preference rule is defined as:

$$K = \sum_{i=1}^{n} \alpha_i \cdot C_i \to \max ,$$

where:

- $\alpha_1, \alpha_2, \ldots, \alpha_n$, – weigh coefficient of preference indicators which usually meets the following conditions:

$$0 \le \alpha_i < 1, \sum_{i=1}^{n} \alpha_i = 1;$$

- $C_i$ ($i$ = 1, 2, …, $n$) – preference indicators which meet the conditions presented below:

$$\forall C_i \in R,\ R = \{0,\ \ 1,\ \ 2\}.$$

*2.2.1. Determination of Indicators and Weight Coefficients*

For the metric suits evaluation we use the following indicators:

- $C_1$ – Theory base and validation;
- $C_2$ – Usability;
- $C_3$ – Availability of tools;
- $C_4$ – Completeness;
- $C_5$ – Redundancy.

Such indicators are chosen based on the requirements for logistics and transport systems as well as metric suite requirements for such systems.

Weight coefficients are determined using the expert evaluation. Below there are listed the values of weight coefficients for our indicators:

- $\alpha_1 = 0.25$;
- $\alpha_2 = 0.20$;
- $\alpha_3 = 0.18$;
- $\alpha_4 = 0.22$;
- $\alpha_5 = 0.15$.

So, it's obvious that theory base and metric suite completeness have the greatest impact on the criterion. On the other hand, the redundancy has the smallest weight coefficient.

### 2.3. Obtaining values of the indicators

It's required to obtain values of the listed indicators for Chidamber & Kemerer's metrics suite and Software Package Metrics.

*2.3.1. Theory base and validation*

Theoretical base, empirical validation and analysis of metric suites characteristics allow us to make a decision regarding the metric suite quality.

***Chidamber & Kemerer's metrics suite***

In publication [2] Chidamber & Kemerer used the formal process of metric suite validation based on Weyuker's properties. The Weyuker proposed properties for metric suite evaluation which includes: noncoarseness, nonuniquencess, design details are important, monotony, non-equivalence of interaction,

interaction increases complexity. Chidamber & Kemerer conclude that all the metrics satisfy the majority of the properties prescribed by Weyuker. Only DIT and LCOM doesn't fully comply with it.

Since this metric suit almost completely corresponds to the indicator, the value of indicator $C1_{CK} = 2$.

***Software Package Metrics***

At the moment this metric suite hasn't any theoretical base, however, there are still a number of works devoted to the empirical validation of this metric suite [3, 8, 9].

Since there is a lack of sufficient research, the value of indicator $C1_{SPM} = 1$.

***Metrics for Object Oriented Design***

There are a number of works devoted to MOOD validation. For instance, in publications [4, 10] there are shown practical and theoretical validations of this metric suite. Also, this metric suite fulfills the following criteria: metrics determination should be formally defined, non-size metrics should be system size independent, metrics should be dimensionless or expressed in some consistent unit system, metrics should be obtainable early in the life-cycle, metrics should be down-scalable, metrics should be easily computable, metrics should be language independent.

As long as this metric suit has a reasonable amount of works denoted to its theoretical and practical validation, the value of indicator $C1_{MOOD} = 2$.

*2.3.2. Usability*

By usability we mean the convenience of metric usage, i.e. the simplicity of their calculations. It's obvious that the metrics that are easy to calculate could be understood easily. As a result they are used much wider.

***Chidamber & Kemerer's metrics suite***

The calculation of the metrics WMC, DIT, NOC and CBO are quite simple, so such calculations can be performed based on static models of a system. RFC calculating requires slightly bigger effort and could be done based on dynamic model of software system. LCOM metric is the most complex in the suite. This is because there are available a number of different modifications of the metric. Also the calculation requires some knowledge regarding the private data and some internal dependencies which may not be available at the design stage.

As long as there are no any significant weaknesses from the usability point of view, the value of indicator $C2_{C\&K} = 2$.

***Software Package Metrics***

The calculating of metrics Afferent Couplings, Efferent Couplings, Abstractness can be done using static models of a system. Such calculations aren't complex. Instability and Distance from the Main Sequence are kind of derivatives from the first three metrics. Such values obtaining shouldn't cause any difficulties as well. Package Dependency Cycles may require additional details in the static model of the system.

Since the calculation of metrics for a given suite doesn't cause major difficulties, the value of indicator $C2_{SPM} = 2$.

***Metrics for Object Oriented Design***

All the metrics in the given metric suite are relatively simple, so they do not require some complicated calculations. For their calculation we need to know the number of methods and attributes for every class, as well as the number of inherited methods and attributes. The problem of such calculation lies in the fact that they require to have some information regarding private methods and attributes. Such information might not be available at the design stage; hence you might need a reasonable effort to obtain them.

Since this metric suite requires additional data at the design stage, the value of indicator $C2_{MOOD} = 1$.

### *2.3.3. Availability of tools*

Automated tools could significantly simplify the usage of metrics. This is especially useful for large projects where manual computation requires huge effort.

There are a number of tools available that allow obtaining the values of metrics automatically. In the Table 1 are listed the most popular metric tools and the level of coverage for each metrics suite.

**Table 1.** Metrics suite coverage level by the metric tools

| Tool | Vendor | Languages | Chidamber & Kemerer's metrics suite coverage | Software Package Metrics coverage | Metrics for Object Oriented Design |
|---|---|---|---|---|---|
| Essintial Metrics | Power Software | C++, Java | Full suite | - | MHF, AHF, MIF, AIF, PF |
| SDMetrics | SDMetrics | C++, Java | WMC, DIT, NOC, CBO, RFC | Ca, Ce, A, I, D | - |
| Understand | Scientific Toolworks | C++, Java, C#, etc. | Full suite | Ce | - |
| JDepend | - | Java | - | Full suite | - |
| Ndepend | Ndepend | C# | LCOM | Ca, Ce, A, I, D | - |
| Eclipse metrics | - | Java | Full suite | Ca, Ce, A, I, D | - |

***Chidamber & Kemerer's metrics suite***

Although the metric suite is supported by a large number of tools, there are some issues in the obtained results. In the publication [9] are listed the values obtained by different tools. These results indicate that different tools have a different interpretation for some of metrics, so the values are different. Based on that, the value of indicator $C3_{CK} = 1$.

***Software Package Metrics***

As long as there are enough tools which allow to obtain the metric suite's values, the value of indicator $C3_{SPM} = 2$.

***Metrics for Object Oriented Design***

Since this metrics suite is supported by a limited set of the metric tools, the value of indicator $C3_{MOOD} = 1$.

### *2.3.4. Completeness*

This indicator evaluates how well a metric suite cover the characteristics of the system. We are interested mostly in evaluation of object-oriented systems, so completeness evaluation should be based on the characteristics of object-oriented systems.

Different researches show that the metric suites should cover the following features of the static UML models:

- Interfaces;
- Attributes;
- Methods;
- Generalization;
- Aggregation, Association, Dependencies.

The details regarding UML characteristic coverage by each metric suite are provided in table 2.

**Table 2.** UML features coverage by the metric suites

| Scope / Suite | Interfaces | Attributes | Methods | Relationships | |
|---|---|---|---|---|---|
| | | | | **Generalization** | **Aggregation, Association, Dependencies** |
| Chidamber & Kemerer's metrics suite | - | LCOM | WMC, LCOM | NOC, DIT | CBO, RFC |
| Software Package Metrics | A | - | - | - | Ca, Ce |
| Metrics for Object Oriented Design | - | AFH, AIF | MFH, MIF | POF, MIF, AIF | - |

***Chidamber & Kemerer's metrics suite***

Chidamber & Kemerer's metrics suite reflects well the characteristics of object-oriented systems. The metric suite contains metrics which evaluate the number of methods (WMC), inheritance (NOC, DIT), external relations (CBO, RFC). In addition, the metric LCOM indirectly consider attributes and methods.

Since the most of UML features are covered by the suite, the value of indicator $C4_{CK} = 2$.

***Software Package Metrics***

Metrics from this suite have a fairly narrow focus. They evaluate mainly the relationships between objects/packages and the stability of the package by evaluating the number of abstract classes and interfaces.

As long as only few UML features are covered, the value of indicator $C4_{SPM} = 1$.

***Metrics for Object Oriented Design***

This metric suite reflects very well the characteristics of the object-oriented systems, since it was made for such types of system design evaluation. Each metric in this suite is related to one of object-oriented paradigm fundamental feature: encapsulation (MNF, ANF), inheritance (MIF, AIF), polymorphism (POF) or message passing (COF).

Based on the fact that most of the UML features are covered by this metric suite, the value of indicator $C4_{MOOD} = 2$.

*2.3.5. Redundancy*

In our case, the redundancy is the existence of several metrics which measure the same or similar characteristics of the system. Let's use the correlation coefficient to determine the redundancy, which determines the closeness of the linear relationship between variables (metrics).

The empirical data of cargo transport fleet management system were used to obtain correlation values.

***Chidamber & Kemerer's metrics suite***

Table 3 shows the correlation values for the metrics in the system.

**Table 3.** Correlation coefficient values for the metrics

| | **CBO** | **NOC** | **WMC** | **RFC** | **DIT** | **LCOM** |
|---|---|---|---|---|---|---|
| CBO | 1 | -0.02144 | **0.570007** | 0.237647 | 0.126227 | 0.364266 |
| NOC | -0.02144 | 1 | 0.155889 | -0.03971 | -0.16163 | -0.05677 |
| WMC | **0.570007** | 0.155889 | 1 | 0.236418 | 0.091223 | 0.249562 |
| RFC | 0.237647 | -0.03971 | 0.236418 | 1 | **0.910849** | -0.19671 |
| DIT | 0.126227 | -0.16163 | 0.091223 | **0.910849** | 1 | -0.28036 |
| LCOM | 0.364266 | -0.05677 | 0.249562 | -0.19671 | -0.28036 | 1 |

The values of correlation coefficient indicate that for this system there is a significant relation between CBO and WMC. Also there is a very close relation between the metrics RFC and DIT.

Since most of the metrics in the suite do not correlate with each other, the value of indicator $C5_{CK} = 2$.

### *Software Package Metrics*

Table 4 shows the correlation values for the metrics in the system.

**Table 4.** Correlation coefficient values for the metrics

| | Ca | Ce | A | I | D |
|---|---|---|---|---|---|
| Ca | 1 | -0.15545 | **-0.80704** | 0.370458 | **0.767875** |
| Ce | -0.15545 | 1 | 0.285002 | -0.18804 | -0.22956 |
| A | **-0.80704** | 0.285002 | 1 | **-0.65272** | **-0.87742** |
| I | 0.370458 | -0.18804 | **-0.65272** | 1 | **0.652026** |
| D | **0.767875** | -0.22956 | **-0.87742** | **0.652026** | 1 |

The values of correlation coefficient show that the system has a significant number of metrics related to each other. For instance, metrics Ca and A, Ca and D, as well as A and D have a high correlation. Metrics A and I, as well as I and D have a significant relation. Part of such relations can be explained by the fact that couple of the metrics in this suite is derived from others.

As long as the correlation between the metrics are more noticeable, the value of indicator $C5_{SPM} = 1$.

### *Metrics for Object Oriented Design*

Table 5 shows the correlation values for the metrics in the system.

**Table 5.** Correlation coefficient values for the metrics

| | MHF | AHF | MIF | AIF | COF | POF |
|---|---|---|---|---|---|---|
| MHF | 1 | 0.40704 | -0.25262 | -0.31742 | 0.04075 | 0.16284 |
| AHF | 0.40704 | 1 | **-0.92571** | -0.27889 | 0.17063 | **0.59182** |
| MIF | -0.25262 | **-0.92571** | 1 | 0.29818 | -0.13308 | **-0.52922** |
| AIF | -0.31742 | -0.27889 | 0.29818 | 1 | -0.46749 | **-0.74875** |
| COF | 0.04075 | 0.17063 | -0.13308 | -0.46749 | 1 | **0.821254** |
| POF | 0.16284 | **0.59182** | **0.52922** | **-0.74875** | **0.821254** | 1 |

The values of correlation coefficient shows that the system has a significant number of related metrics, especially almost every metric has significant or high correlation with POF. Partially such relations can be explained by the fact that most of the metrics take into account the inherited attributes and methods.

Since the correlation between the metrics is noticeable, the value of indicator $C5_{MOOD} = 1$.

## 2.4. Summary

The above described metric suites aimed of measuring the quality of the product. The main idea of all three metric suites is in evaluation of the individual classes or packages and the relationships between them. The difference is in the way how they make such evaluation. Software Package Metrics provides some generalized assessment. Chidamber & Kemerer's metrics suite provides statistics that help to a developer to make a decision regarding the product quality. Similar approach is used for Metrics for Object Oriented Design; however, instead of considering individual classes the metric suite obtains the values for whole system or package.

The total values of the indicators for the metric suites are presented in table 6.

**Table 6.** The values of the indicators for the metric suites

| Indicator | Weight coefficients | Chidamber & Kemerer's metrics suite | Software Package Metrics | Metrics for Object Oriented Design |
|---|---|---|---|---|
| Theory base and validation | 0.25 | 2 | 1 | 2 |
| Usability | 0.20 | 2 | 2 | 1 |
| Availability of tools | 0.18 | 1 | 2 | 1 |
| Completeness | 0.22 | 2 | 1 | 2 |
| Redundancy | 0.15 | 2 | 1 | 1 |

Hence the criteria for the considered metric suites are defined as follows:

$$K_{CK} = \sum_{i=1}^{n} \alpha_i \cdot C_{CKi} = 0.25 \cdot 2 + 0.2 \cdot 2 + 0.18 \cdot 1 + 0.22 \cdot 2 + 0.15 \cdot 2 = 1.82 .$$

$$K_{SPM} = \sum_{i=1}^{n} \alpha_i \cdot C_{SPMi} = 0.25 \cdot 1 + 0.2 \cdot 2 + 0.18 \cdot 2 + 0.22 \cdot 1 + 0.15 \cdot 1 = 1.38 .$$

$$K_{MOOD} = \sum_{i=1}^{n} \alpha_i \cdot C_{SPMi} = 0.25 \cdot 2 + 0.2 \cdot 1 + 0.18 \cdot 1 + 0.22 \cdot 2 + 0.15 \cdot 1 = 1.47 .$$

The values of the criteria for the metric suites lead us to the conclusion that Chidamber & Kemerer's metrics suite is more appropriate according to the requirements.

## 3. Metric Suite Optimisation

After the metric suite is chosen it's necessary to perform its improvement. To do so each metric in the suite should be considered separately, analogous metrics should be determined and compared against the original metric. After such comparisons, the decision should be made regarding the original metric replacement with the analogous one. After these steps we obtain the modified metric suite which is optimal according to the requirements.

The algorithm for this technique consists of the following steps (see Figure 2):

1. Determination of criteria;
2. Take *i*-th metric;
3. Determination of metric alternatives;
4. Obtaining criteria values for every alternative;
5. Replacing the metric with the alternative if alternative's criteria values are more optimal;
6. If it isn't the last metric in the suite then take the next metric (return to step 2).

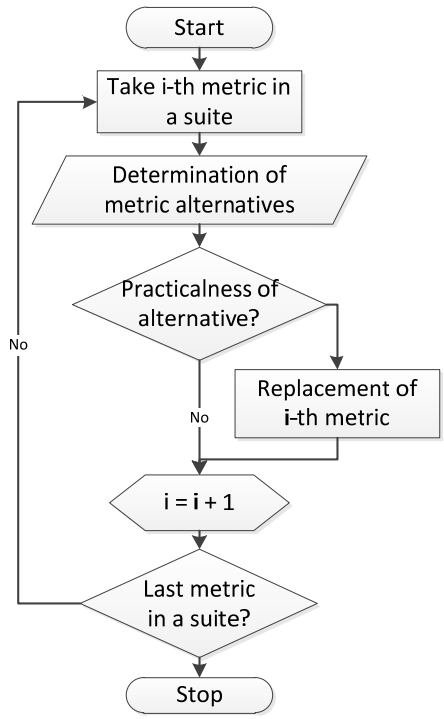



*Figure 2.* Flowchart representation of metric suite optimisation algorithm

### 3.1. LCOM metric

Let's make an improvement for one of the metric from Chidamber & Kemerer's metrics suite. Perhaps the most criticism in this suite was subjected to LCOM metric. Various studies have shown a lot of it weaknesses, so it should be used carefully. For instance, completely different classes can have the same value and often this metric very poorly reflects the cohesiveness of the class [7].

For these reasons there were proposed different variations and alternatives of this metric. In [1, 5, 6, 7, 11] are presented the following LCOM alternatives:

- LCOM1, LCOM2, LCOM3, LCOM4, LCOM5;
- Connectivity (Co);
- Unified Cohesion (Coh);
- Tight class cohesion (TCC);
- Loose class cohesion (LCC);
- Information-flow-based cohesion (ICH).

As long as there are so many alternatives, it's reasonable to determine the most appropriate metric which satisfy well the requirement of the system.

### 3.2. Determination of LCOM alternatives

Due to the fact that many of these metrics are computed in a similar way, let's select the most characteristic of them which are listed below:

LCOM1 – this metric was introduced by Chidamber & Kemerer in 1991 [12];

LCOM2 – this metric also known as LCOM and was introduced by Chidamber & Kemerer in 1994 [2];

LCOM4 – LCOM modification where value calculated as the number of connected vertices in undirected graph [6];

LCOM-HS – LCOM modification proposed by Henderson-Sellers [5, 11];

LCOM% – LCOM modification used in Understand Metrics tool and expressed in per cent.

### 3.3. Determination of Criteria

The criterion preference rule for metric suite optimization is similar to the criterion for metric suite selection and is defined as:

$$K = \sum_{i=1}^{n} \alpha_i \cdot C_i \to \max,$$

where:

- $\alpha_1, \alpha_2, \ldots, \alpha_n$, – weigh coefficient of preference indicators;
- $C_i$ ($i$ = 1, 2, …, $n$) – preference indicators.

For a metric suite optimization indicators should be chosen basing on the requirements for logistics and transport systems as well as the metric requirements for such systems. We are also using the same scale of correspondence for its evaluation.

#### *3.3.1. Determination of Indicators and Weight Coefficients*

According to our requirements for the considered systems, we use the following indicators for the metrics evaluation:

- $C_1$ – Usability;
- $C_2$ – Availability of tools;
- $C_3$ – Correlation with the cluster.

Weight coefficients are determined using the expert evaluation. Below are listed the values of weight coefficients for our indicators:

- $\alpha_1 = 0.35$;
- $\alpha_2 = 0.25$;
- $\alpha_3 = 0.4$.

We can see that indicator $C_3$ has the greatest impact on the criterion and $C_2$ – the lowest one.

### 3.4. Obtaining values of the indicators

It's required to obtain values of the listed above indicators for each metric.

#### *3.4.1. Usability*

Similarly as for metric suite selection, by usability we mean the convenience of metric usage, i.e. the simplicity of their calculations. Let's examine a calculation algorithm for each metric.

***LCOM1***

The initial metric defined by Chidamber & Kemerer, later it was replaced by LCOM2. The value of the metric is the number of pairs of methods in the class using no attribute in common.

***LCOM2***

Classical metric from Chidamber & Kemerer's metrics suite, it is also known as LCOM and has the following formula:

$$LCOM = \begin{Bmatrix} |P| - |Q|, if\,(P > Q) \\ 0, otherwise \end{Bmatrix},$$

where:

- $P$ – number of pairs of methods without shared instance variables;
- $Q$ – number of pairs of methods with shared instance variables.

***LCOM4***

For this metric calculation an undirected graph should be constructed, where the vertices are the methods of a class, and there is an edge between two vertices if the corresponding methods share at least one instance variable or one method explicitly uses another one. The result of the metric equals to the total number of edges between vertices.

***LCOM-HS***

Henderson-Sellers revise the LCOM metric to normalize it for the number of methods and variables that represent in the class, so they proposed the following definition [5]:

$$LCOM = \frac{\left(\frac{1}{a}\sum_{j=1}^{a}\mu(A_j)\right) - m}{1-m},$$

where:

- $m$ – the number of methods in the class;
- $a$ – the number of variables;
- $\mu(A_j)$ – the number of methods of the class accessing a particular variable.

This metrics takes its values in the range [0–2].

***LCOM%***

It's a variation of LCOM metric where the value is expressed as a percentage. At first stage the metrics calculates what percentage of class methods use a given class instance variable. Next the average percentages for all of that class's instance variables is calculated and subtracted from 100%.

***Results***

Since the computational cost for all the metrics are similar (it is necessary to determine the relations between the methods or method and attributes) the indicators have the following values:

$C1_{LCOM1} = C1_{LCOM2} = C1_{LCOM4} = C1_{LCOM\ HS} = C1_{LCOM\%} = 1$.

*3.4.2. Availability of tools*

In the Table 7 are listed the information regarding the tools that provide the calculation of different LCOM variations.

**Table 7.** LCOM variations support by different tools

| Tool | Vendor | Supported LCOM type |
|---|---|---|
| Essintial Metrics | Power Software | LCOM2 |
| Understand | Scientific Toolworks | LCOM% |
| Ndepend | Ndepend | LCOM HS |
| Eclipse metrics | - | LCOM2, LCOM HS |

We can see that there are no automated tools that calculate the metrics LCOM1 and LCOM4.

Thus, the values of indicator are the following:

- $C2_{LCOM1} = C2_{LCOM4} = 0$;
- $C2_{LCOM2} = C2_{LCOM\ HS} = C2_{LCOM\%} = 2$.

*3.4.3. Correlation with the cluster*

To determine this indicator the set of objects of the considered transport system was split into the three following clusters:

- Classes with low cohesion;
- Classes with mean cohesion;
- Classes with high cohesion.

Table 8 shows the correlation between the LCOM variations and the clusters variable for the considered system.

**Table 8.** The values of the correlation between the LCOM variations and the cluster variable

| | **Cluster** |
|---|---|
| LCOM1 | **0.5878015009** |
| LCOM2 | **0.6375499653** |
| LCOM4 | 0.251728185 |
| LCOM HS | **0.7276782418** |
| LCOM% | **0.558340097** |

LCOM-HS has close relation with the cluster variable, thus $C4_{LCOM\ HS} = 2$.

Metrics LCOM1, LCOM2, LCOM% has significant relation with the cluster variable, so the value of indicators $C4_{LCOM1} = C4_{LCOM2} = C4_{LCOM\%} = 2$.

LCOM4 doesn't have a significant relation with the cluster variable, so $C4_{LCOM4} = 0$.

### 3.5. Summary

In table 9 are listed all values of the indicators for the metrics.

**Table 9.** The values of the indicators for the metrics

| **Indicator** | **Weight coefficients** | **LCOM1** | **LCOM2** | **LCOM4** | **LCOM-HS** | **LCOM%** |
|---|---|---|---|---|---|---|
| Usability | 0.35 | 1 | 1 | 1 | 1 | 1 |
| Availability of tools | 0.25 | 0 | 2 | 0 | 2 | 2 |
| Correlation with the cluster | 0.4 | 1 | 1 | 0 | 2 | 1 |

Hence the criteria for the considered metrics are defined as follows:

$$K_{LCOM1} = \sum_{i=1}^{n} \alpha_i \cdot C_{LCOM1i} = 0.35 \cdot 1 + 0.25 \cdot 0 + 0.4 \cdot 1 = 0.75.$$

$$K_{LCOM2} = \sum_{i=1}^{n} \alpha_i \cdot C_{LCOM2i} = 0.35 \cdot 1 + 0.25 \cdot 2 + 0.4 \cdot 1 = 1.25.$$

$$K_{LCOM4} = \sum_{i=1}^{n} \alpha_i \cdot C_{LCOM4i} = 0.35 \cdot 1 + 0.25 \cdot 0 + 0.4 \cdot 0 = 0.35.$$

$$K_{LCOM-HS} = \sum_{i=1}^{n} \alpha_i \cdot C_{LCOM-HSi} = 0.35 \cdot 1 + 0.25 \cdot 2 + 0.4 \cdot 2 = 1.65.$$

$$K_{LCOM\%} = \sum_{i=1}^{n} \alpha_i \cdot C_{LCOM\%i} = 0.35 \cdot 1 + 0.25 \cdot 2 + 0.4 \cdot 1 = 1.25.$$

The values of the criteria for the metrics lead us to the conclusion that metric LCOM-HS is the most appropriate according to the requirements.

## 4. Conclusions

In this paper the technique that allows making a decision regarding metric suite selection for logistics and transportation software is proposed. The technique consists of several steps where at each step a specific criterion should be used to make a selection from the available metric suites. There may be used several different criteria indicators for a metric suite like completeness, usability, availability of tools, etc. Such indicators should be changed in accordance with the required characteristics of logistics and transport systems.

As long as the metric suite is chosen it's necessary to perform its improvement. To do so each metric in the suite should be considered separately, analogous metrics should be determined and compared against the original metric. After the comparisons, the decision should be made regarding the original metric replacement with the analogous one. In the end we obtain the modified metric suite which is optimal according to the requirements.

For efficiency and usability evaluation of the proposed technique a series of experiments and empirical research were performed. During the experiments Chidamber & Kemerer's metrics suite, Software Package Metrics and Metrics for Object Oriented Design were used. The experiment showed that Chidamber & Kemerer's metrics suite is more suitable according to the defined requirements.

During metric suite improvement step LCOM metric were analysed, and several alternatives were proposed. The results of this experiment showed that LCOM-HS has the best fit according to the requirements.

The results indicate that the proposed technique is applicable for metric suite selection for logistics and transport systems development process.

## References


1. Orlov, S. A. *Software Engineering: A Textbook for Universities, 3rd ed*. SPb.: Piter, 2004. 527 p. (In Russian)
2. Chidamber, S. R., Kemerer, C. F. A Metrics Suite for Object Oriented Design, *IEEE Transactions on Software Engineering,* Vol. 20, No 6, 1994, pp. 476–493.
3. Martin, R. C. *Agile Software Development: Principles, Patterns and Practices.* Pearson, 2003. 552 p.
4. Abreu, F. B., Carapuca, R. Object-Oriented Software Engineering: Measuring and Controlling the Development Process. *Proceedings of the 4th International Conference on Software Quality, McLean, Virginia, USA, Oct. 3–5, 1994*.
5. Henderson-Sellers, B., Constantine, L., Graham, I. Coupling and Cohesion: towards a valid metrics suite for object-oriented analysis and design, *Object-oriented Systems,* Vol. 3(3), 1996, pp. 143–158.
6. Hitz, M., Montazeri, B. Measuring Coupling and Cohesion in Object-Oriented Systems. *Proc. Int'l Symp. Applied Corporate Computing (ISACC '95), Monterrey, Mexico, Oct. 25–27, 1995*.
7. Gupta, B. S. *A Critique of Cohesion Measures in the Object-Oriented Paradigm: Master of Science Thesis.* Michigan Technological University, Department of Computer Science. 1997. 49 p.
8. Briand, L., Wüst, J., Lounis, H. Replicated Case Studies for Investigating Quality Factors in Object-Oriented Designs, *Empirical Software Engineering: An International Journal*, Vol. 6, No 1, 2001, pp. 11–58.
9. Lincke, R., Lundberg, J., and Löwe, W. Comparing Software Metrics Tools, *ISSTA'08, July 20–24, 2008, Seattle, Washington, USA,* 11 p.
10. Harrison, R., Counsell, S. J., Nithi, R. V. An Evaluation of the MOOD Set of Object-Oriented Software Metrics, *IEEE Transactions on Software Engineering, vol. 24, pp. 491–496,* June 1998.
11. Henderson-Sellers, B. *Object-oriented metrics: measures of complexity.* Prentice-Hall, 1996, pp. 142–147.
12. Chidamber, S. R., Kemerer, C. F. *Towards a Metrics Suite for Object Oriented Design.* OOPSLA'91, pp. 192–211.

*Transport and Telecommunication, 2011, Volume 12, No 3, 54–62*
*Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia*

# APPROACH TO ESTIMATION OF THE AUTOMATIC VENICLE LOCATION SYSTEMS FUNCTIONALITY BY COMPARISION ITS TECHNICAL PARAMETERS

***Daniil Opolchenov, Valery Kutev***

*Transport and Telecommunications Institute*
*Lomonosova str. 1, Riga, LV-1019, Latvia*
*Ph.: +371 67100634. Fax: +371 67100660.*
*E-mails: Daniil.Opolchenov@tsi.lv, Valerijs.Kutevs@tsi.lv*

This work has focused on the development of approach to estimation of the automatic vehicle location system functionality which is determined by system technical parameters. The work examines the main elements of the automatic vehicle location systems and options for their implementation on the basis of modern technical means. To estimate system functionality it is necessary to choose correctly the set of the main parameters able to provide the possibility of the system comparison with other ones. We propose to use "weigh" estimation of system functionality for performing such comparison.

Some results of the comparative analysis for the "on-line" as well as "off-line" automatic vehicle location systems are presented. On this basis a new approach to the estimation of its functionality is proposed.

**Keywords:** transportation, transport monitoring systems, automatic vehicle location system, system architecture, efficiency, functionality

## 1. Introduction

Transport monitoring systems (TMS) provide reliable and flexible solutions for many applications within the transportation industry [1]. A modern system of transport monitoring provides the following possibilities [2]:

- Ensure a two-way communication between a vehicle and a control station;
- Define the technical and security state of the vehicle (locks sensors, diagnostic system on board the vehicle);
- Determine the location of the vehicle and parameters of its motion;
- Provide remote control of the systems installed in the vehicle (electronic locks, stop engine function);
- Inform manager about compliance with the route and traffic schedule;
- Automatic Manager Notification of the force major situation on board the vehicle;
- Store all the information received by the controller for a long time, for further analysis of the data received;
- Draw up different reporting documents, using filters, and with varying degrees of detail on the basis of monitoring results.

The above-mentioned features of the transport monitoring systems can be successfully applied in various transportation areas. Capabilities of such systems range from monitoring the state of transported goods, to monitoring transportation infrastructure and the vehicle itself, to providing real-time information to warn or inform the public [3].

Currently, for many companies that have its own fleet of vehicles the following tasks are at the top of the priority list:

- Ensure the safety and security of the vehicle;
- Provide safety of the transported goods in transportation;
- Reduce fuel consumption and maintenance costs;
- Increase efficiency of vehicle use and control of the intended use of the vehicle use purposefulness;
- Optimise transport routes.

To some extent, Automatic Vehicle Location (AVL) systems could help to solve the tasks mentioned above.

The dominant use of AVL systems is to perform real-time tracking of a vehicle's position. For transit, the most established AVL application is tracking buses. By tracking their bus fleet with real-time AVL, operators can improve schedule adherence, improve service efficiency, and provide better operations support, reduce the number of street supervisors, simplify operation of the vehicle for the driver, and provide customers with real-time service information [4].

The effectiveness of any technical means is determined by their function, as well as the results of their appointment and the cost of their creation and operation. In this context, indicators to be used as criteria for estimation of the effectiveness, in general, should contain parameters or characteristics describing the purpose, the results of application, as well as the cost of creation and operation of technical means. It is clear that the effectiveness must be higher than the result of more and less than the cost of it construction and operation. Criterion that meets these requirements is as follows [4]:

$$E = (W - C) / W_i, \tag{1}$$

where $W$ – result of the tools use for its purposes; $C$ – the cost of development and operation of equipment; $W_i$ – the result of the tools applying in case when its tasks are executed in full.

Analysis of practical problems shows the possibility of using as criteria of effectiveness indicators, more intuitive and simple in comparison with (1). This opportunity stems from fact that many practical problems may be addressed through separate estimation of the investigated tools technical and economic efficiency.

Criteria of technical efficiency are the comparison of $W$ – the tools use for its purposes and $W_i$ – results of the tools use in case when its tasks are executed in full, i.e.,

$$E_t = E_t(W, W_i), \tag{2}$$

and criteria of economic efficiency are the comparison results of $W$ – the tools use for its purposes and $C$ cost of the tools development and operation, i.e.,

$$E_e = E_e(W, C). \tag{3}$$

In this work for estimation of the transport monitoring system technical efficiency we shall be use criterion (2) in following form:

$$E_t = W / W_i, \tag{4}$$

where $W$ and $W_i$ are determinates through technical data of the TMS.

Let each $j$-th of compared devices has a combination of $n_j$ parameters $\lambda_{i,j}$ that determine the result W of use the device for its technical purposes. If for use of $j$-th device in case when its tasks are executed in full we may introduce combination of $n_j$ parameters $\lambda_{i,0}$ then we shall say about "ideal" device which result in use is $W_i$.

Carrying out a valuation of parameters $\lambda_{i,j}$ with respect to the corresponding parameters $\lambda_{i,0}$ in accordance with the expression

$$\xi_{i,j} = \lambda_{i,j} / \lambda_{i,0}, \quad if \quad \lambda_{i,j} < \lambda_{i,0}$$

or (5)

$$\xi_{i,j} = \lambda_{i,0} / \lambda_{i,j}, \quad if \quad \lambda_{i,j} > \lambda_{i,0},$$

it is possible to make determination of technical efficiency (functionality) of compared devices in form:

$$E_{ij} = \frac{1}{n_j} \sum_i \alpha_i \xi_{i,j}, \tag{6}$$

where $\alpha_i \leq 1$ – weight coefficients for device technical parameters in accordance of customer requirements.

## 2. Automatic Vehicle Location Systems

Automatic Vehicle Location systems as well as any information systems may be described by its architecture, which defines: the functions that are required for TMS, the physical entities or subsystems where these functions reside, and the information flows and data flows that connect these functions and physical subsystems together into a system. The logical architecture of AVL systems defines a set of functions (or processes) and information flows (or data flows) that respond to the selected user service requirements. Processes and data flows are grouped to form particular transportation management functions (i.e., manage traffic) and are represented graphically by data flow diagrams, which can be broken down into several levels of detail. A physical architecture is the physical view of a system which provides agencies with a physical representation, though not a detailed design of how the system should provide the required functionality. A physical architecture takes the processes identified in the logical architecture and assigns them to physical entities called subsystems. In addition, the data flows from the logical architecture that originate from one subsystem and end at another are grouped together into physical architecture flows.

A common AVL system set-up is shown on Figure 1. Global Navigation System (GNS) technology is used to determine position information of the vehicle. A simple GNS receiver can be installed on any vehicle and position information can readily be determined.

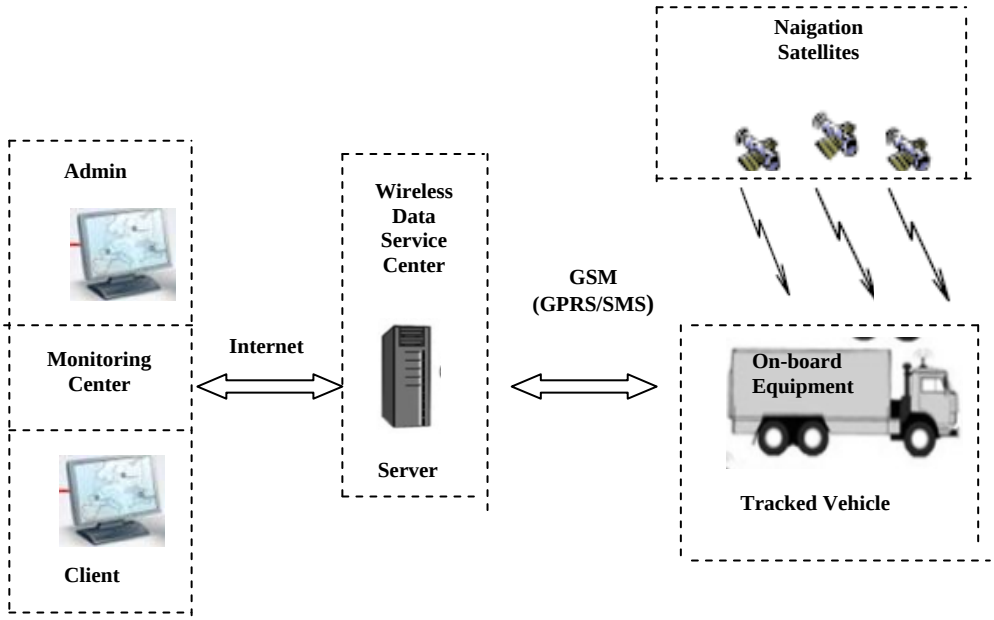



*Figure 1.* Common Automatic Vehicle Location system set-up

The position data are then transmitted via means of wireless communication to a centralized communication centre, which then passes the information onto the management centre via the Internet. The wireless communications may use a wide-area communication technique such as General Packet Radio Service (GPRS, part of the cellular telephone system) or use vehicle to roadside communication.

Position data can be stored on the vehicle for a period of time prior to transmission, or instantly transmitted once the information is available. The frequency that the information is sent out can also vary considerably, depending on the application.

The task of the Monitoring Centre is to obtain information from the board of the vehicle and keep it in the database; then data from the database may be transferred to the end-user or directly to the dispatcher and the company customers. Dispatcher holds the operational monitoring of the location, movement parameters and the safety state of vehicle and cargo.

Dispatch system consists of hardware and software. The hardware includes different interfaces for transmission and reception of information both to the vehicle and to/from the customers, and also server applications for the storage of the information received. The software part provides a user interface for working with databases.

On-board equipment of transport monitoring system can be connected to the existing vehicle diagnostic system, as it is shown on Figure 2.

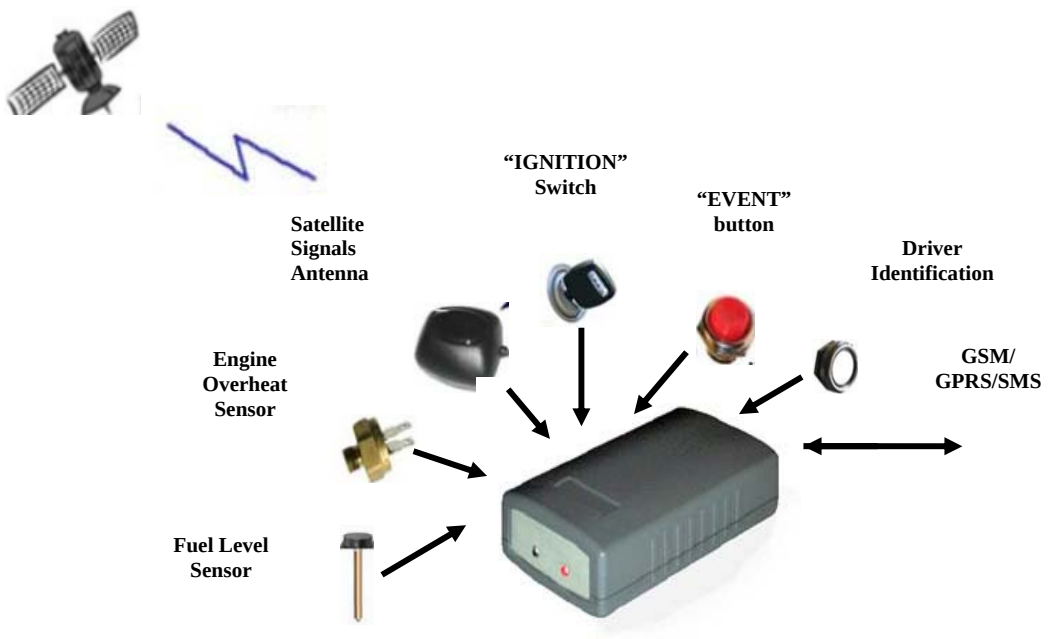



*Figure 2.* On-board sensors of Transport Monitoring Systems (example)

Some necessary additional sensors could be added, for example such as: Fuel Level Sensor; Engine Overheat Sensor; "IGNITION" Switch; Vehicle safety sensors ( "EVENT" button, Driver Identification).

Typical on-board AVL device hardware architecture is shown on Figure 3. The on-board AVL device is installed in the vehicle and performs most of the initial data processing on the movement of the vehicle and events on board.

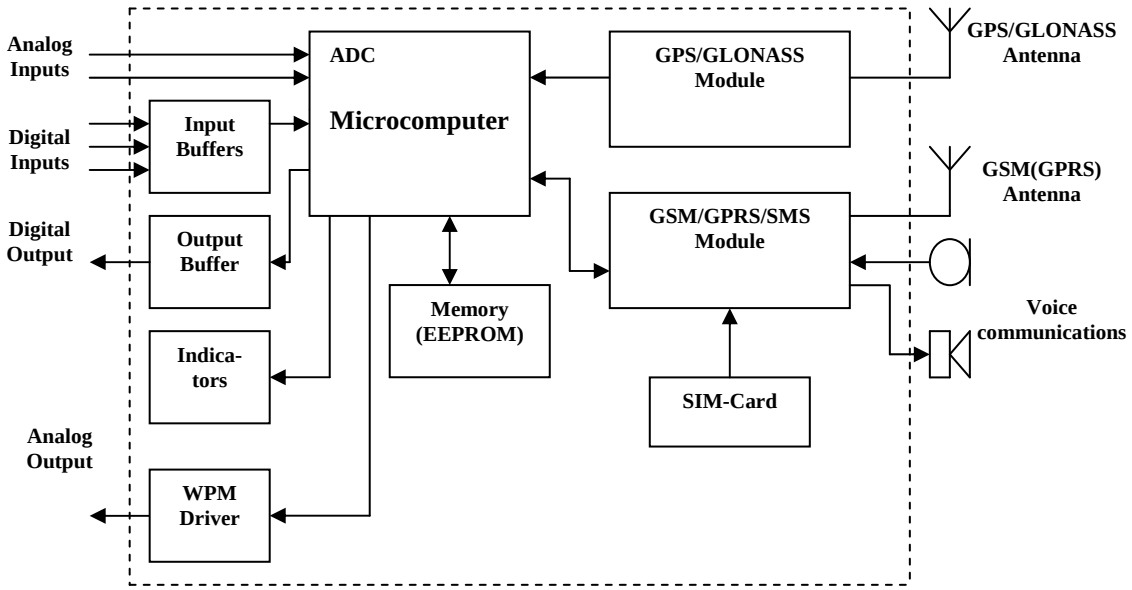



*Figure 3.* Typical on-board AVL device hardware architecture

There are two Global Navigation Systems (GNS) may be used in AVL systems today. These are NAVSTAR GPS (U.S.A.) and GLONASS (Russia). Systems which are under development now and may be used in future are Galileo (European GNS) and Beidou/Compass (Chinese GNS); full deployment and commissioning of all services of those systems is scheduled for 2015/2016 year.

Main characteristics of used today GNS GLONASS and NAVSTAR GPS are presented in Table 1.

**Table 1.** Main characteristics of GNS, which may be used in AVL systems

| GNS Characteristics | GLONASS | NAVSTAR GPS |
|---|---|---|
| Projected total number of satellites in system (operational/in space spares) | 24 (21/3) | 24 (21/3) |
| Number of orbital planes | 3 | 6 |
| Number of satellites in each orbital plane | 8 | 4 |
| Type of satellite orbits | Circular | Circular |
| Height of satellites, km | 19100 | 20180 |
| Orbital inclination, grad | 64,8 | 55 |
| Orbital period, hours | 11,25 | 12 |
| Satellite signal selection | Frequency selection | Code selection |
| Frequencies of navigation signals:<br>L1, Mhz<br>L2, Mhz | <br>1602,56-1615,50<br>1246,44-1256,5 | <br>1575,42<br>1227,60 |
| Used model of the Earth | PZ90 | WGS84 |

The modern on-board AVL device includes three main components: a GLONASS/GPS module (satellite navigation receiver), GSM /GPRS/SMS Module (GSM cellular modem), and a microcomputer. In addition to the coordinates, direction, and speed of the vehicle, the on-board AVL device also records a large number of other parameters and events: acceleration, activation of switches (raising/lowering of cargo hold, opening of doors, etc.), readings of analogue sensors (cargo hold temperature, amount of fuel in tank, etc.), and many more.

The fact that on-board AVL device has its own computer and the principle of distributed data processing are the main features that set it apart from other similar systems The system automatically selects the most economical means of communication available (data, GRPS, or SMS) and controls the reception of messages, which guarantees reliable operation even when communication is intermittent.

The AVL system, which has been examined above, is known as "On-line monitoring system". Many AVL applications use "Off-line monitoring systems" as it is shown on Figure 4. The principal difference of an off-line monitoring system is that information from the on-board equipment to the Monitoring Station is transmitted not in real time but only when the vehicle returns to the parking lot.


*Figure 4.* Common "Off-line" Automatic Vehicle Location system set-up

The off-line Automatic vehicle location system is the most inexpensive and the most cost effective solution for vehicle and special machinery monitoring. The off-line AVL system advantages are as follows:

- Monitoring after vehicle is driven;
- Has not any operation fees;
- Not needed any wireless communication network;
- Data removing to PC by standard USB Flash Drive;
- Download data in any convenient place;
- Easy installation and easy operation.

## 3. Transport Monitoring System Functionality

In Table 2 technical data of some modern transport monitoring system are presented, which are working in on-line as well as off-line modes [5].

**Table 2.** Technical data on-board equipment of some modern transport monitoring systems AVL type

| N | On-board equipment / Technical data | GLONASS On-line (j=1) | GPS On-line (j=2) | GLO-NASS/GPS On-line (j=3) | GLONASS Off-line (j=4) | GPS Off-line (j=5) | GLONASS/ /GPS Off-line (j=6) |
|---|---|---|---|---|---|---|---|
| **1.** | Error of determination for:<br>-vehicle position, m<br>-vehicle speed, m/s | 30<br>0,5 | 10<br>0,2 | 15<br>0,3 | 30<br>0,5 | 10<br>0,2 | 15<br>0,3 |
| **2.** | Delay of the time scale synchronization, s | 0,2 | 0,1 | 0,2 | 0,2 | 0,1 | 0,2 |
| **3.** | Number of the writing to system memory | 100 000 | 130 000 | 100 000 | 300 000 | 300 000 | 300 000 |
| **4.** | Cycle of data write to memory (programmable) | 1s...18 h | 1s...18 h | 1s...18 h | 1s...18 h | 1s...18 h | 1s...18 h |
| **5.** | Communication channels | Data call, GPRS, SMS | Data call, GPRS, SMS | Data call, GPRS, SMS | USB 1.0 / 2.0 | USB 1.0 / 2.0 | USB 1.0 / 2.0 |
| **6.** | Data rate (max.), bps | 19200 | 19200 | 19200 | - | - | - |
| **7.** | Voltage of power supply, V | 12...24 (option up 110 V) | 12...24 (option up 110 V) | 12...24 (option up 110 V) | 12...24 (option up 60 V) | 12...24 (option up 60 V) | 12...24 (option up 60 V) |
| **8.** | Number of inputs:<br>- analogue<br>- digital | <br>2<br>2 | <br>2<br>2 | <br>2<br>2 | <br>1<br>1 | <br>1<br>1 | <br>1<br>1 |
| **9.** | Number of control outputs | 2 | 2 | 2 | 2 | 2 | 2 |
| **10.** | Overall dimensions, mm | 100x82x32 | 100x82x32 | 100x82x32 | 100x82x32 | 100x82x32 | 100x82x32 |
| **11.** | Operational temperature,°C | -40...+85 | -40...+85 | -40...+85 | -20...+65 | -40...+80 | -20...+65 |
| **12.** | Massa, kg | 0,35 | 0,2 | 0,3 | 0,1 | 0,06 | 0,12 |

In order to illustrate a proposed quantitative estimation of the functionality for the transport monitoring systems we introduce an "ideal" system, which is characterized by the following essential parameters:

- Error of a vehicle position determination ($\lambda_{1,0}$) – 5,0 m ;
- Error of a vehicle speed determination ($\lambda_{2,0}$) – 0,1 m/s;
- Number of the writing to system memory ($\lambda_{3,0}$) – 50000 ;
- Delay of time scale synchronization ($\lambda_{4,0}$) – 0,05 s;
- Number of analogue inputs ($\lambda_{5,0}$) – 5;
- Number of digital inputs ($\lambda_{6,0}$) – 5;
- Number of control inputs ($\lambda_{7,0}$) – 5;
- Mass ($\lambda_{8,0}$) – 0,05 kg;
- Number of communication channels ($\lambda_{9,0}$) – 5.

Then it is possible to calculate the parameters $\zeta_{i,j}$ in according to (5) as it is shown in Table 3. For estimation of the functionality we choose nine essential technical characteristics ($\lambda_{1,j}$..... $\lambda_{9,j}$) for on-line systems ($j$ = 1, 2, 3) and only eight parameters ($\lambda_{1,j}$..... $\lambda_{8,j}$) for off-line systems ($j$ = 4, 5, 6).Therefore all systems, which are presented in Table 2, will be divided in two groups (on-line and off-line systems).

**Table 3.** The parameters $\zeta_{i,j}$ for technical data of compared monitoring systems

| Index i | On-line systems | | | Off-line systems | | |
|---|---|---|---|---|---|---|
| | $j = 1$ | $j = 2$ | $j = 3$ | $j = 4$ | $j = 5$ | $j = 6$ |
| 1 | $\xi_{1,1} = 0{,}166$ | $\zeta_{1,2} = 0{,}5$ | $\zeta_{1,3} = 0{,}333$ | $\zeta_{1,4} = 0{,}166$ | $\zeta_{1,5} = 0{,}5$ | $\zeta_{1,6} = 0{,}333$ |
| 2 | $\xi_{2,1} = 0{,}2$ | $\xi_{2,2} = 0{,}5$ | $\xi_{2,3} = 0{,}333$ | $\xi_{2,4} = 0{,}2$ | $\xi_{2,5} = 0{,}5$ | $\xi_{2,6} = 0{,}333$ |
| 3 | $\xi_{3,1} = 0{,}2$ | $\xi_{3,2} = 0{,}26$ | $\xi_{3,3} = 0{,}2$ | $\xi_{3,4} = 0{,}6$ | $\xi_{3,5} = 0{,}6$ | $\xi_{3,6} = 0{,}6$ |
| 4 | $\xi_{4,1} = 0{,}25$ | $\xi_{4,2} = 0{,}5$ | $\xi_{4,3} = 0{,}25$ | $\xi_{4,4} = 0{,}25$ | $\xi_{4,5} = 0{,}5$ | $\xi_{4,6} = 0{,}25$ |
| 5 | $\xi_{5,1} = 0{,}4$ | $\xi_{5,2} = 0{,}4$ | $\xi_{5,3} = 0{,}4$ | $\xi_{5,4} = 0{,}2$ | $\xi_{5,5} = 0{,}2$ | $\xi_{5,6} = 0{,}2$ |
| 6 | $\xi_{6,1} = 0{,}4$ | $\xi_{6,2} = 0{,}4$ | $\xi_{6,3} = 0{,}4$ | $\xi_{6,4} = 0{,}2$ | $\xi_{6,5} = 0{,}2$ | $\xi_{6,6} = 0{,}2$ |
| 7 | $\xi_{7,1} = 0{,}4$ | $\xi_{7,2} = 0{,}4$ | $\xi_{7,3} = 0{,}4$ | $\xi_{7,4} = 0{,}4$ | $\xi_{7,5} = 0{,}4$ | $\xi_{7,6} = 0{,}4$ |
| 8 | $\xi_{8,1} = 0{,}143$ | $\xi_{8,2} = 0{,}25$ | $\xi_{8,3} = 0{,}167$ | $\xi_{8,4} = 0{,}5$ | $\xi_{8,5} = 0{,}83$ | $\xi_{8,6} = 0{,}417$ |
| 9 | $\xi_{9,1} = 0{,}6$ | $\xi_{9,2} = 0{,}6$ | $\xi_{9,3} = 0{,}6$ | - | - | - |

In order to perform the estimation of technical functionality according to (6) it is necessary to introduce the weight coefficients $\alpha_{i,j}$ and divide each sum of parameters $\zeta_{i,j}$ on number of used technical data.

The results of functionality calculations according to (6) for transport monitoring systems on-line and off-line system types are presented on Figure 5. The weight coefficients $\alpha_{i,j} = 1$ were used in (6) for both events.

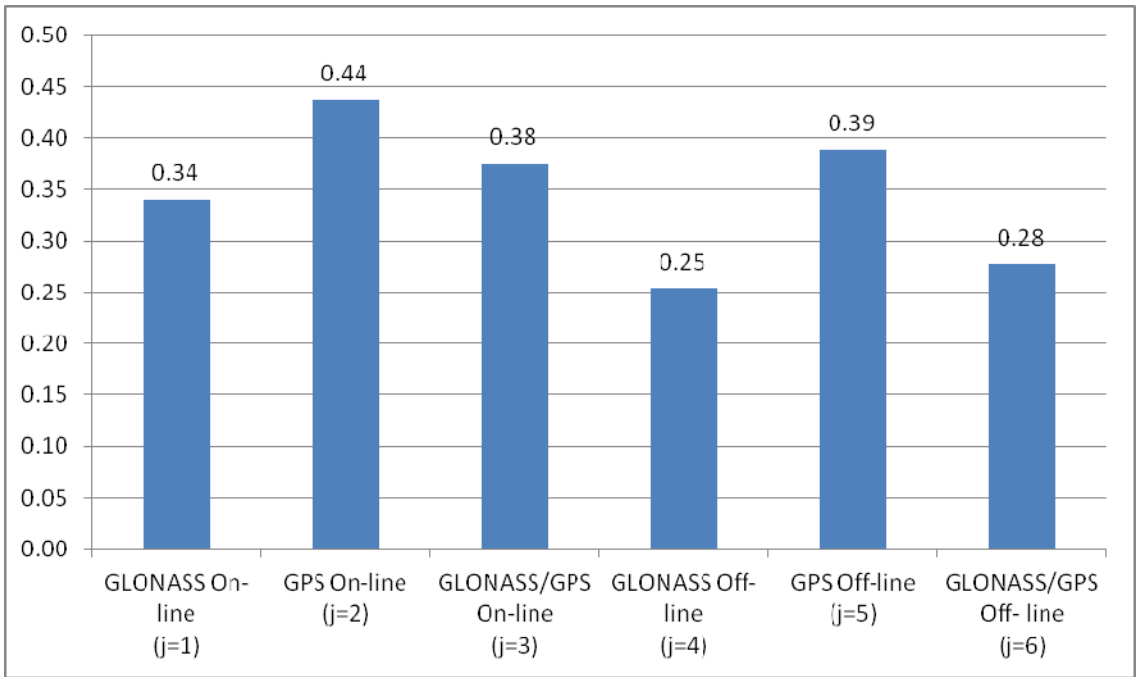



*Figure 5.* The results of the functionality estimations (case $\alpha_{i,j} = 1$)for AVL systems, which technical data are presented in Table 2: on-line systems – $j$ = 1, 2, 3; off-line systems – $j$ = 4, 5, 6

Variant of using different weight coefficients is presented in Fig.6 for on-line AVL systems. The used weight coefficients are: $\alpha_{1,j} = 0{,}3$; $\alpha_{2,j} = 0{,}2$; $\alpha_{3,j} = \alpha_{4,j} = \alpha_{5,j} = 0{,}1$; $\alpha_{6,j} = \alpha_{7,j} = \alpha_{8,j} = \alpha_{9,j} = 0{,}05$.

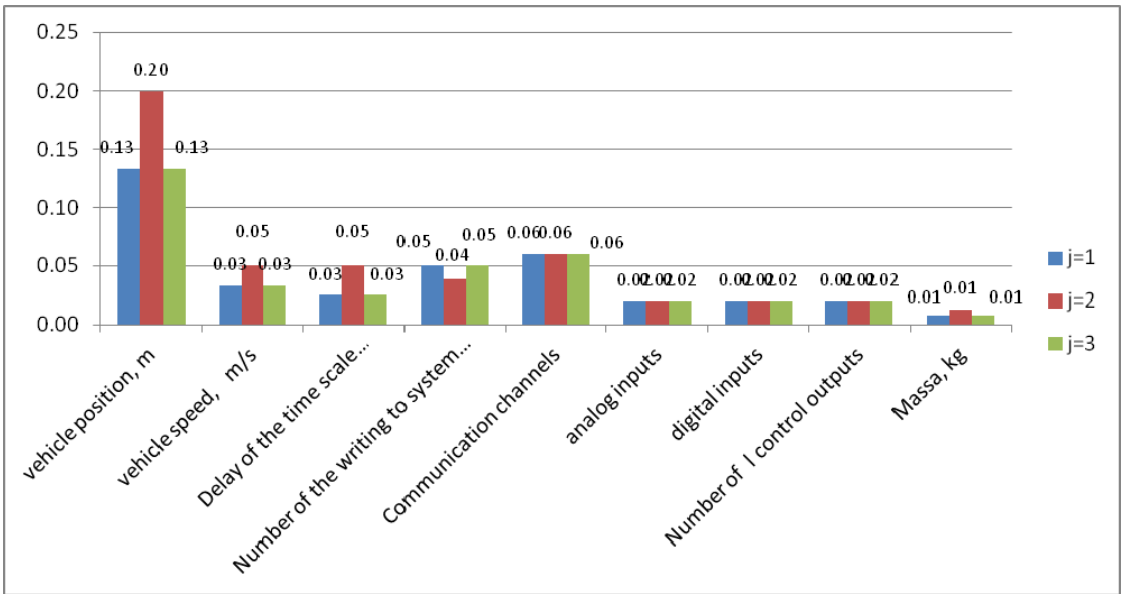



*Figure 6.* Distribution of the weight sums $\Sigma\alpha_j\zeta_{i,j}$ for on-line AVL systems

The results of functionality calculations for transport monitoring systems both on-line and off-line system types are presented in Fig. 7.

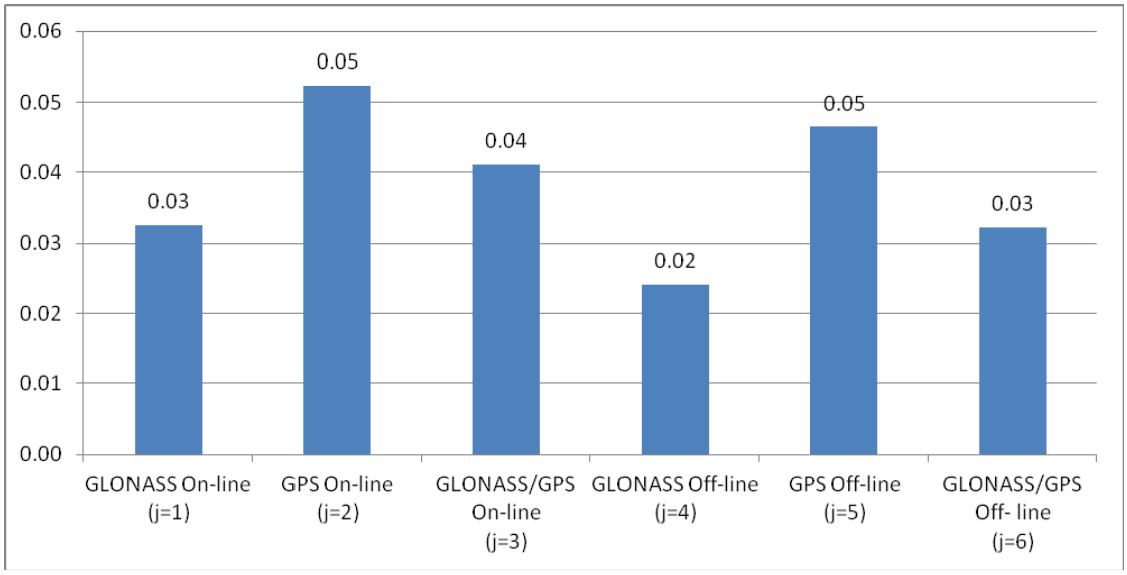



*Figure 7.* The results of the functionality estimations for AVL systems, which technical data are presented in Table 2 (case of different $\alpha_{i,j}$)

As it is shown from the presented data maximal functionality has GPS AVL systems working both on-line and off-line modes. GLONASS as well as GLONASS/GPS AVL systems are characterized by more low values of the functionality estimations.

If the functionality of transport monitoring system is known then one may easy to determine its efficiency as:

$$E = E_{ij}/C$$

in accordance to criterion "functionality/cost".

## 4. Conclusions

The main results of this work are the following:

- It is shown that as there exists a large number of monitoring systems which ensure their functioning, the actual problem is to estimate both technical and economic efficiency of transport monitoring systems;
- Most modern automatic vehicle location (AVL) technologies are using GLONASS and GPS global navigation systems for determination of vehicle position as well as the means of mobile communication for data transmission to monitoring centre for vehicle tracking;
- Many additional sensors may be used in transport monitoring systems in order to company owners, directors, transport managers always have a real information of vehicles, vehicles fleet and its utilization;
- It is proposed to perform estimation of the transport monitoring system functionality on base of its technical data and the system efficiency to determine in accordance to criterion "functionality/cost".

## References

1. *EU Energy and Transport in figures.* Luxembourg: Publications Office of the European Union, 2010.
2. Solodovnichenko, M., Thompson, V. Evaluating the effectiveness of systems for monitoring vehicles, *Operation of maritime transport,* No 2, 2006, pp. 13-16. (In Russian)
3. Atkinson, Robert D. and Daniel D. Castro. Digital Quality of Life: Understanding the Personal and Social Benefits of the 9th Information Technology Revolution, *Information Technology and Innovation Foundation*, October 1, 2008, p. 106.
4. Cvetkov, A. *Principles of quantitative estimation of radio electronic equipment*. M.: Sov. Radio, 1971. 200 p. (In Russian)
5. *Systems of transport monitoring* – http://locatrans.ru /opport.htm (In Russian)

*Transport and Telecommunication, 2011, Volume 12, No 3, 63–72*
*Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia*

# VEHICLE DYNAMIC LOCALIZATION IN INTELLIGENT TRANSPORTATION SYSTEMS BASED ON SENSOR NETWORKS

***Victor Krebss*[1], *Boris Tsilker*[2]**

[1]*CPS Ltd, Skanstes 13, Riga, LV 1013, Latvia*
*Ph: +371 29243923, e-mail: victor@cps.lvl*

[2]*Transport and Telecommunication Institute*
*Lomonosova str.1, Riga, LV 1019, Latvia*
*Ph: +371 67100604, fax: +371 67100560, e-mail: tsilker@tsi.lv*

Most of modern vehicle navigation and safety applications suppose availability of precise vehicle coordinates. Occasionally the only way for getting of these coordinates is vehicle self-localization. The ability of a vehicle to determine its own location, is vital for many aspects of Intelligent Transportation Systems (ITS) and telematics. Localization might be realized in two ways, geometric methods (trilateration, triangulation, hyperbolic methods) and fingerprinting methods (signal mapping). The accuracy localization based on distance measurements may be degraded by noise. The impact of the ranging error usually depends on the estimation algorithm, the bandwidth of pulses, application scenarios, etc. Additionly the position information provided by some anchor nodes may be inaccurate.. It is clear that a single localization technique is not enough to meet requirements of critical applications at the same time, such as being available anywhere and anytime, with highly accurate and reliable position computations. As a result, Data-fusion techniques to combine different localization methods and protocols in a single localization system are required, such as moving average, least squares, Kalman, particle filters Bayesian inference and Dempster-Shafer methods. In order to improve the localization precision several statistical based approaches have been proposed in [1, 2]. However, the statistical methods may not be able to provide enough accuracy if the data quantity is not sufficient. There is also the probabilistic approach considered in order to improve the localization precision. The inaccuracies are characterized by modeling the range measurements as a set of probability density functions. These functions can be used to compute the probabilistic constraints that reduce the uncertainties of the nodes positions. This approach can lead to significant enhancements in the localization accuracy compared to the least squares estimate.

**Keywords**: Intelligent Transportation System, sensor network, localization, cooperative positioning, data fusion

## 1. Introduction

Among the wide range of transportation problems, more or less successfully solvable by means of the intellectual transportation systems (ITS), the road safety problem undoubtedly is the most significant. Such kind ITS, due to the real time processing of information, incoming both from onboard and road infrastructure sensors, give a chance to ensure the on-time response on the vehicle movement within the traffic stream.

One of the most promising vehicular safety applications is the development of an advanced cooperative collision warning system [1]. It is envisioned that the system will use vehicle-to-vehicle radio communications to create a cooperative collision warning system, where vehicles cooperatively share information (i.e. location, speed, heading, acceleration, etc.) for collision anticipation.

In most of today vehicular safety applications location there is the most essential context. Location knowledge of nodes in a network is essential for many tasks such as routing, cooperative sensing, or service delivery in ad hoc, mobile, or sensor networks.

Almost all existing localization approaches basically consist of two stages: 1 measuring geographic information from the ground truth of network deployment and 2 computing node locations according to the measured data.

Perhaps the simplest method of providing localization is to equip every sensor node with a GPS receiver. However, a GPS receiver is expensive in terms of money, size and energy. Moreover, their accurate measure is not always available because of GPS signal losses or multipath. Important problem with the GPS is that it cannot receive signals inside buildings, underground or in tunnels. Also, vehicles are not necessarily equipped with GPS and even they cannot obtain availability of line of sight access to the satellites, particularly when they enter tunnels.

The most common alternative for localizing the nodes involves using a limited number of nodes (perhaps the base stations) equipped with GPS receivers (called beacon or anchor nodes) to localize all of the other nodes (commonly called unknown nodes).

Wireless sensor network localization techniques are used to estimate the locations of the sensors with unknown positions in a network using the a priori available knowledge of positions of, typically, a few specific sensors in the network and inter-sensor measurements such as distance, time difference of arrival, angle of arrival and connectivity. Sensor network localization techniques involve further challenges in several aspects: (1) a variety of measurements may be used in sensor network localization; (2) the environments in which sensor networks are deployed are often complicated, involving urban environments, indoor environments and non-line-of-sight conditions; (3) wireless sensors are often small and low-cost sensors with limited computational capabilities; (4) sensor network localization techniques are often required to be implemented using the available measurements and with minimal hardware investment; (5) sensor network localization techniques are often required to be suitable for deployment in the large scale multi-hop networks; and (6) the choice of sensor network localization techniques to be used often involves consideration of the trade-off among cost, size and localization accuracy to suit the requirements of a variety of applications [2].

This paper investigates the different aspects of the error induced by measurement error component in multi-hop localization setups. In particular, we will discuss the techniques for estimating the range between wireless sensor nodes using radio frequency (RF) measurements and ranging accuracy is limited by noise, multipath channel effects, clock synchronization, clock frequency accuracy, and sampling artifacts. Then we characterize and discuss the error components typical to the localization algorithms.

## 2. Problem Formulation

At localization of vehicle with unknown coordinates when GPS or other device assisted the location technology is not available we must have at least 3 anchor nodes or nodes with a prior knowledge of their location (vehicles equipped with GPS or infrastructure nodes). The vehicle localize itself by means of trilateration based on the measured range of measurements with respect to these anchor nodes and their known location. Later vehicles being localized become the new anchors for other vehicles.

Three or more independent range measurements with respect to anchor nodes can then be used to solve a 2D trilateration problem.

In general, the trilateration problem can be formulated as follows: given set of references $X_i$, $Y_i$, and a set of range measurements $R_i$, a system of linear equations needs to be solved for unknown $U_i$.

$$\begin{bmatrix} (X_1-U_x)^2+(Y_1-U_y)^2 \\ (X_2-U_x)^2+(Y_2-U_y)^2 \\ . \\ . \\ . \\ (X_n-U_x)^2+(Y_n-U_y)^2 \end{bmatrix} = \begin{bmatrix} R_1^2 \\ R_2^2 \\ . \\ . \\ . \\ R_n^2 \end{bmatrix}.$$

The accuracy derived through trilateration depends heavily on great number of different factors, such as the geometry of the position references, accuracy of anchor coordinates the accuracy of the range measurements, and so on.

Taking into account only accuracy of the anchor position and the measurement accuracy, we can transform the previous expression by introducing corresponding errors

$$\begin{bmatrix} (X_1+e^v_{X_1}-U_x)^2+(Y_1+e^v_{Y_1}-U_y)^2 \\ (X_2+e^v_{X_2}-U_x)^2+(Y_2+e^v_{Y_2}-U_y)^2 \\ . \\ . \\ . \\ (X_n+e^v_{X_n}-U_x)^2+(Y_n+e^v_{Y_n}-U_y)^2 \end{bmatrix} = \begin{bmatrix} (R_1+e^e_1)^2 \\ (R_2+e^e_2)^2 \\ . \\ . \\ . \\ (R_n+e^e_n)^2 \end{bmatrix},$$

where $e^v_{X_i}, e^v_{Y_i}$ are vertex error (explained later) components for anchor node *i*, $e^e_i$ – edge (distance measurement) error for i anchor node and examined vehicle.

The focus of this work is in evaluating of measurement and vertex errors from the viewpoint of their influence on the accuracy of vehicle localizations. No other factors will be examined. It will be the subject of next investigations.

## 3. Classification of Error Components

The localization error comes from two sources:

- Vertex errors $\{e^v\}$ (for all node $\in N$): this is the error in neighboring nodes, since their location information may contain error, especially for non-anchor neighbors. For anchor nodes, the vertex error is simply zero.
- Edge error $\{e^e\}$ (for all edges between *t* and node $\in N$): this is the error in distance measurements. For regular distances, a Gaussian white noise is assumed.
- The error $\hat{e}_t$ in the location estimate is a function of both vertex and edge errors:

$$\hat{e}_t = g\left(\left\{e^v_i\right\} i \in N, \left\{e^e_i\right\} i \in N\right).$$

This allows not only compute a location estimate $\hat{x}_t$, but also document the "quality" of the estimate using $\hat{e}_t$.

## 4. Measurement Error Characterization

The most of sensor measurements, both with respect to localization and relative distances, but also with respect to a general sensor observation, need to be associated with a common time reference in order to be properly fused together. If the time synchronization in the wireless sensor network is acceptable, then node-pairs can exchange information and measurements and readily use the information for localization. Network time synchronization protocols used over the fixed network are not applicable, due to the volatile and possibly time varying connectivity and the clock drift of the low complexity sensor devices.

Node *i* can have known or unknown position $p^i_t$ at each time instant. Depending on measurement type and whether one, two or more nodes have to collaborate to form an observation, the following notation can be used:

$$x^i_t = h_{type}\left(p^i_t\right) + e^i_t,$$

$$x^{ij}_t = h_{type}\left(p^i_t, p^j_t\right) + e^{ij}_t,$$

$$x^{ijk}_t = h_{type}\left(p^i_t, p^j_t\, p^k_t\right) + e^{ijk}_t,$$

where $x^i_t$ is location estimate, $e^i_t$ corresponding estimation error and $h_{type}$ stands for localization type mentioned further in the article.

In all specific measurement models, the measurement noise is additive. The first and convenient approximation is that the measurement is unbiased and the noise is white and Gaussian with a standard deviation $\sigma_e$. Appropriate accuracy levels depend on both the type of measurement and the network architecture. The generally applicable assumption is that the measurement error is Gaussian with a probability density function

$$p_E\left(e_t\right) = N\left(0, \sigma\right).$$

Depending on sensor capabilities and the nodes synchronization and communication capabilities, three different types of observations can be distinguished:

- *Waveform observations.* A highly capable sensor node is able to operate on the signal waveform and this observation can be shared with other nodes if bandwidth allows. Sensors which are very close to each other (in the order of half a wavelength) can form a sensor array and correlate the phase of the emitted signal to get a direction of arrival estimates. For sensors being further separated, there will be an integer problem in the ambiguity of the number of periods that may be resolved by merging other information.
- *Timing observations.* If a known or easily distinguished signature is embedded in the signal, the sensor can correlate the signal with the signature to accurately estimate time of arrival. The timing estimation accuracy depends on the signature as well as the sensor capability.
- *Power observations.* Another possibility is that the sensor estimates the received signal power (received signal strength – RSS). In essence, this means integrating the received signal power within a certain frequency band during an integration interval to estimate the received signal energy during the time interval. If the emitted power is known, RSS provides a coarse range information.

Table 1 summarizes the discussed sensor observations.

**Table 1.** Mathematical notation of available sensor observations in the wireless sensor networks

| **Measurement Type** | **Nonlinear Measurements** | **Accuracy** |
|---|---|---|
| Direction of arrival | $h_{DOA} = angle\left(p_t^i - p_t^j\right)$ | 5º - 10º |
| Time of arrival | $h_{TOA} = \left\|p_t^i - p_t^j\right\|$ | 5 – 100 m |
| Time difference of arrival | $h_{TDOA} = \left\|p_t^i - p_t^j\right\| - \left\|p_t^i - p_t^k\right\|$ | 10 – 60 m |
| Interferometrics | $h_{TDOA} = \left\|p_t^A - p_t^D\right\| - \left\|p_t^B - p_t^D\right\| + \left\|p_t^B - p_t^C\right\| - \left\|p_t^A - p_t^C\right\|$ | 0.1 – 1 m |
| Received signal strength | $h_{RSS,\log} = P_0^i - n_{i,j}\left(\left\|p_t^i - p_t^j\right\|\right)$<br>$h_{RSS,lin} = \overline{P}_0^i \left\|p_t^i - p_t^j\right\|^{-n_{i,j}}$ | 4 – 12 dB |
| Digital map information | $h_{MAP}^j\left(p_t^i, p_t^j\right)$ | (RSS MAP 3dB) |
| Position estimates Inertial sensors | $h_{POS} = p_t^i$<br>$h_{INS}\left(p_t^i, p_t^j\right)$ | 5 – 20 m (GPS) |

## 5. Accuracy Limits

The achievable accuracy of ranging systems is limited by four primary factors which are noise, time synchronization, sampling artifacts, and multipath channel effects. These factors introduce random, time and spatially varying errors into the estimate resulting in reduced accuracy. Frequency accuracy between the devices involved in the measurement can also impact ranging system accuracy significantly. Each effect can dominate the error under the different circumstances, and a system must be designed so that the combination of these effects does not degrade accuracy beyond useful limits. Because the introduced errors are stochastic, the errors can never be eliminated, but it is possible that measurement techniques can be used to mitigate these effects.

### 5.1. Noise

Noise and interference introduce unknown errors into measurements. The effect of white noise processes such as thermal and electronic noise is well understood and can be quantified. A range measurement degraded only by noise is limited in accuracy by the signal energy to noise ratio at the receiver and the occupied bandwidth.

A ranging system suffers in low signal to noise ratio (SNR) environments because the exact time of an event cannot be resolved precisely. In a simple example “edge detection” ranging system, the ranging signal is a step function sent by the transmitter at t = 0 and the receiver measures the time of the rising edge it observes. When this signal is received, the edge time may be detected slightly early or slightly late due to the noise added to the signal.

The mathematical expression that links SNR and bandwidth together to give a bound on ranging performance can be derived from the Cramér-Rao lower bound (CRB). The CRB can be calculated for any unbiased estimate of an unknown parameter. The CRB can be used to calculate a lower bound for the variance of the estimate for the range, $\hat{r}$, as

$$\sigma_{\hat{r}}^2 \geq \frac{c^2}{(2\pi B)^2 \frac{E_s}{N_0}} \left( 1 + \frac{1}{\frac{E_s}{N_0}} \right) m ,$$

where $\sigma_{\hat{r}}^2$ ˆr is the variance of the range estimate, $c$ is the speed of light, $B$ is the occupied signal and width in Hertz, and $E_s / N_0$ is the signal energy to noise density ratio. The SNR is related to $E_s / N_0$ that

$$SNR = \frac{P_s}{P_n} = \frac{E_s}{N_0 t_s B} ,$$

where $P_s$ is the signal power, $P_n$ is the noise power, $t_s$ is the signal duration during which the bandwidth $B$, is occupied. In many common signals, the bandwidth and duration are tied together such that $t_s B \approx 1$. Therefore, the $E_s / N_0$ ratio is approximately equal to the SNR. By exchanging the locations of the factors

$$\frac{E_s}{N_0} = t_s B \cdot SNR .$$

For a fixed signal energy and noise density, increasing the bandwidth provides significant improvements in noise performance. This fact is one argument for increasing the bandwidth of RF based ranging systems.

### 5.2. Time Synchronization

RF time of flight measurement systems must be able to estimate the time of transmission and arrival using a common time base for the accurate measurements. When two wireless devices, $A$ and $B$ perform the range estimation, the most straightforward method is for $A$ to send a signal at $t = 0$ and for $B$ to start a timer at $t = 0$ and stop it when it receives the signal sent by $A$. The value of the timer at $B$ is equal to the time of flight (TOF). If the clocks are not perfectly time synchronized, however, and $B$ notion of $t = 0$ is offset in time from $A$, then this offset, $\Delta t$, directly adds a bias to the measurement. Time synchronized wireless networks are typically synchronized to on the order of 1 μs resulting in errors of up to 300 m, but high power and expensive systems can achieve the time synchronization of better than 10 ns or 3 m.

If $A$ and $B$ have full duplex radios, that is, they can transmit and receive at the same time, then a two way or a round trip measurement can be made. $A$ sends a signal to $B$ at a carrier frequency $f_{c1}$ and $B$ translates this signal to a different carrier frequency $f_{c2}$ and retransmits that signal in real time. The signal is received back at $A$ at $f_{c2}$ such that $A$ can compare the signal it is receiving from $B$ to the signal it is sending to $B$. By measuring the delay between these two signals, the round trip TOF, $\hat{\tau}_{RT}$, is estimated, and the range estimate is $c \cdot \frac{\hat{\tau}_{RT}}{2}$.

### 5.3. Sampling Artifacts

Ranging systems estimate the time of arrival of a signal and compare that time with the time the signal was transmitted to calculate the time of flight and thus the range. It is commonly assumed that the ranging accuracy is limited to $c / f_s^2$ where $f_s$ is the receiver sampling rate. This limit is known as a range binning, and it can impact the resolution if steps are not taken to mitigate its impact. A common implementation is to estimate the time of arrival using a matched filter that is sampled at the signal

bandwidth resulting in time resolution of 1/*B*. This sampling adds error to the estimate because the estimate space is divided up into range bins that are *c*/*B* wide. The error associated with this process is uniformly distributed inside the range bin. By using the variance of the uniform distribution, the impact of sampling can be found

$$\sigma_{sample}^2 = \frac{1}{12 \cdot f_s^2}.$$

### 5.4. Multipath Channel Effects

When a ranging system has been well designed, it often still fails to achieve the expected performance because the measurement is not taken in free space. In real environments the RF signals bounce off objects in the environment causing the signal to arrive at the receiving antenna through the multiple paths as shown in Figure 1. In this figure, the direct path is obstructed by walls, but the other paths are not.

This is common indoors, and it is likely that the non-direct paths have the higher power than the direct path. The communication environment is called the channel, and multipath channels.

They not only vary by the type of environment (office building, residential or outdoors) but also they are specific to the geometry of the transmitter and receiver in that environment. The channel is often time varying resulting in a multipath environment that changes from one time to another.

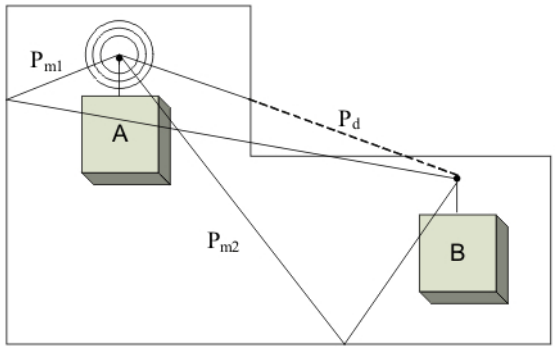



*Figure 1.* A multipath environment

The bandwidth required to achieve a very fine resolution in a Gaussian white noise environment is far smaller than that required to achieve the equivalent resolution in a typical indoor multipath environment, and the techniques to improve the multipath performance are far more computationally intensive than those to combat noise. Many measurements in indoor environments will not have a resolvable direct path using any method or bandwidth, and the resulting range estimate will be highly inaccurate.

## 6. Vertex Error Characterization

Different sources of errors in multi-hop localization systems can be categorized in three broad classes [3] setup error, channel error and algorithmic error. Setup error is induced by intrinsic measurement error and it is reflected in the network configuration parameters such as network density, concentration of beacons (or other landmarks), network size and measurement error characteristics known prior to deployment and certainty of beacon locations.

Channel error is a result of the extrinsic measurement error and represents the physical channel effects on sensor measurements. Multipath and shadowing, multiple access interference, the presence of obstructions that results in unpredictable non-line of sight components, and fluctuations in the signal propagation speeds are just a few of these effects that can introduce error into the computation of locations. The magnitude of these effects on the distance measurement process is typically specific to the particular measurement technology and the environment in which they operate; hence, different considerations should be applied for each technology.

Finally, the multi-hop nature of the problem and the different operational requirements introduce another level of complexity and subsequently more errors. The results of a multi-hop localization process are based on a series of single hop multilaterations in an iterative manner. At each step localized vehicle becomes the anchor, which can be used at next steps. In such a process, errors, coming from each step of multilateration, propagate and accumulate.

To control the error propagation, [4] proposes a mechanism to keep the track of estimation error and determines which neighbors have the reliable location information and which don't.

This mechanism filters out outliers ("the bad seeds"), preventing them from propagating further. To keep the track of estimation error, first is considered the simplified problem of localizing a node *t* given *N*, the set of neighbors in distance constraint graph (DCG) with known locations. For the shortest path approximation, *N* includes those 3~5 closest anchors to the node.

Taking trilateration as a representative of multilateration, [5] focuses on the accuracy issue of localization under noisy ranging measurement. In order to address the above challenges, as a "quality" measure concept of Quality of Trilateration (QoT) is considered, which is inspired by the key observation that different geometric forms of trilaterations providing different levels of localization accuracy.

The metric QoT quantitatively describes such differences and, more importantly, helps to compare and make choices of trilaterations. This mechanism enables the ability of distinguishing and avoiding poor trilaterations with much uncertainty or potential flip ambiguity.

The based fact that the geometric relation of reference nodes affects the localization effect significantly, a fine grained method is necessary. QoT is beyond a binary output function, providing a quantitative evaluation of different forms of trilaterations. Indeed, QoT can be extended to multilateration straightforwardly.

Let $t = Tri\left(s, \{i = 1,2,3\}\right)$ denote a trilateration for *s* based on three reference nodes $s_i$. Let *p(s)* be the real location of sensor node *s* and let *pt(s)* be the estimated location of *s* by trilateration *t*. Let $d(s_i, s_j)$ denote the real distance between two neighbor nodes $s_i$ and $s_j$. We assume it possesses some probability distribution denoted by $f_{s_i,s_j}(x)$, where $x \in [0,+\infty)$ denotes the distance value. Any point *p* in a 2D plane, the probability density of *p* is given by

$$f_t(p) = \prod_{i=1}^{3} f_{s_i,s_j}\left(d\left(p, p(s_i)\right)\right).$$

Then, *Disk(p, R)* is defined as a disk area centered at *p* with radius *R*. The parameter *R* is an application specified for the different requirements of localization accuracy. The quality of trilateration t is defined as:

$$Q(t) = \int_p f_t(p)dp, p \in Disk\left(p(s), R\right).$$

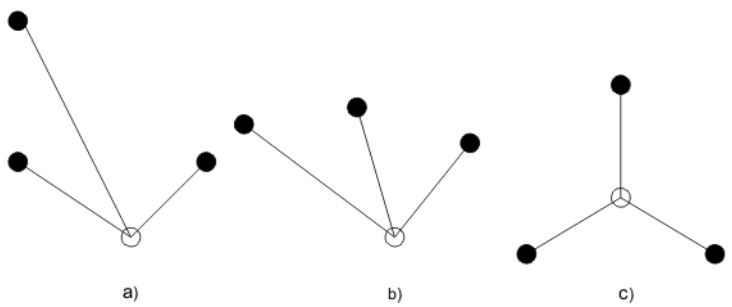



*Figure 2.* Three cases of trilaterations

Figure 2(a), (b), and (c) shows three cases of trilaterations. Assuming normal noises in ranging measurement in the first case, Figure 2(a) displays the probability distribution of a general case. In the second case, Figure 2(b) indicates a high probability of the flip ambiguity as three reference nodes almost lie in a line. In the third case, Figure 2(c) plots a concentrated probability distribution which is accord with the fact that three references are well separated around the node to be localized.

Some other researchers [6] have considered error distribution based probabilistic approach to further improve localization accuracy for the wireless sensor networks.

Scenario is depicted in Fig. 3(a), where four anchor nodes have known or pre-deployed positions. We use these four anchors to locate any event occurred in the region, which is represented by point *B* in the figure. The anchors are initially assumed to be on the unit grid. Assume the actual distance and the measurement error between anchors $A_i$ and *B* are $d_i$ and $\lambda_i$, respectively, where $\lambda_i << d_i$ and $i \in [1,2,3,4]$, the measured distance is then given by $d_i + \lambda_i$. For the following analytical modeling, error in measured distance, $\lambda_i$, is proportional to the distance. The uncertainty ratio $\rho$ is assumed to be uniformly distributed and is within the range $[-\delta, \delta]$. Thus, $m_i = d_i + \lambda = d_i(1+\rho)$ where $\rho \in [-\delta, \delta]$.

With the measured distances, any two anchors may produce a position estimate using methods such as a circle-based method [7] or a hyperbola-based method [8]. For example, using anchors $A_1$ and $A_2$, the resulting estimation is $B_1$, shown in Fig. 3(b) (with the other estimate dropped out).

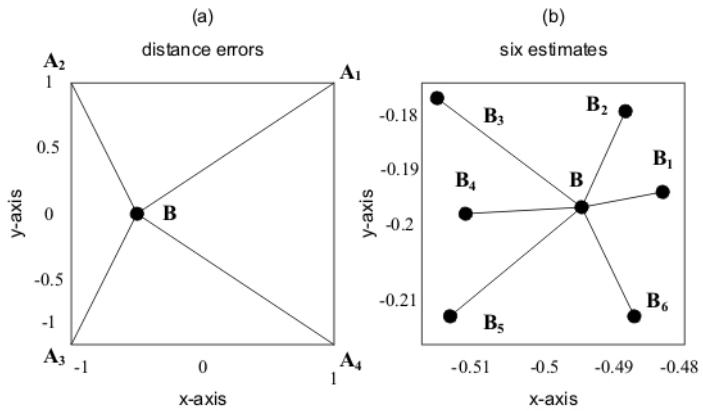



*Figure 3.* Localization with measurement errors

Four anchors will yield a total of six estimates, as shown in Fig. 3(b). If the measurements contain no errors, then all the position estimates will coincide to the exact event location. However, in practice, these estimates will be distributed in a region due to the measurement noise; the size of the region depends on the intensity of the noise. This method identifies the final location using the error probability distribution.

Probabilistic based localization method, first, utilizes two anchors to obtain the position of an event. Then probability density distribution of the estimate is developed basing on the measurement error distribution. Then with four anchor nodes, the combination of any two anchors will give a probability density distribution. By combining these distributions, a probability density function for final location estimation can be obtained. The location with the highest probability density will be chosen as a final result. Each pair of anchors is used instead of three or more anchors to obtain the initial locations because the methods using three or more anchors normally base localization process on the least squares, whereas the least squares add in errors to localization.

## 7. Modeling Ranging Error

In most of the papers [9], simplified models such as deterministic or Gaussian distribution models are utilized. Though this method is convenient, nevertheless, it can hardly describe the real NLOS (non-line of sight) error. The major error sources in the mobile location include both Gaussian measurement noise and NLOS propagation error, the latter being the dominant factor.

The challenge is ranging in indoor NLOS conditions, which can be characterized as dense multipath environments. In these conditions, depending on the presence or absence of the direct path (DP), the ranging errors can significantly vary. Specifically, in the presence of the DP, the dominant sources of error are multipath and propagation delay. Multipath error corrupts the distance estimates due to the multipath components (MPC), which are delayed and attenuated replicas of the original signal, arriving and combining at the receiver shifting the estimate. Propagation delay caused by the signal traveling through obstacles can further add a positive bias to the estimates. Although ultra wide band can

mitigate multipath with the availability of excess bandwidth, its ability to perform in the absence of the DP needs to be investigated further.

Ranging errors have been modeled using different approaches. In [10], they were modeled as a combination of Gaussian and exponential distributions using ray-tracing simulation software and through measurements, respectively. The latter refined the technique of the former and added an additional classification of extreme NLOS. The main problem with this approach is that it is not based on any system model; therefore, it lacks physical significance. Alternatively, [11] modeling approach can focus on the behavior of errors in the presence and absence of the DP.

The spatial characteristics of the ranging errors are determined by the behavior of the biases, which are random due to the unknown structure of the indoor environment and the relative location of the user to them. Furthermore, to model and compare the behavior in different building environments and scenarios, the normalized ranging error will be modeled instead. This is given by:

$$\psi = \frac{\varepsilon}{d} = \frac{\left(\hat{d} - d\right)}{d}.$$

The range error experienced in an indoor environment can then be modeled by combining the conditions in (6) and (7) through the following expression:

$$\psi = \psi_m + G\left(\psi_{pd} + X\psi_B\right),$$

where $\psi_m$ is a normalized multipath error that exists in both the presence and absence of the DP. $\psi_{pd}$ is a normalized propagation-delay-induced error. $\psi_B$ is a normalized error due to DP blockage. To distinguish between the error behavior in LOS and NLOS, Bernoulli random variable $G$ is used.
That is:

$$G = \begin{cases} 0, & LOS \\ 1, & NLOS \end{cases},$$

where $p\,(G = 0) = p$ (LOS) is the probability of being in LOS, and $p\,(G = 1) = p$ (NLOS) is the probability of being in NLOS. Similarly, $X$ is a Bernoulli random variable that models the occurrence of DP blockage given by:

$$X = \begin{cases} 0, & \zeta_1 \\ 1, & \zeta_2 \end{cases},$$

where $p\,(X = 1) = p\,(\zeta_2)$ denotes the probability of the occurrence of blockage, and $p\,(X = 0) = p\,(\zeta_1)$ denotes the probability of detecting a DP.

## 8. Conclusion

Two main types of errors influencing the common accuracy of the vehicle localization were examined. The results of evaluation may be useful at selection of the most effective method of trilateration, giving the highest precision of the vehicle position estimation. It is clear that these two factors are sufficient, but not sole in ensuring the precise vehicle localization. The other factors and their effect as well as the selection of the most appropriate method of lateration will be the subject of further investigations.

## References

1. Parker, R., Valaee, S. Vehicle Localization in Vehicular Networks, *Vehicular Technology Conference*, 2006. VTC-2006 fall. IEEE 64th, pp. 1–5.
2. Mao, G., Fidan, B. *Localization Algorithms and Strategies for Wireless Sensor Networks.* Porttland: Book News Inc, 2009. 510 p.

3. Savides, A., Garber, W., Adlakha, S., Moses, R., Srivastava, B. On the Error Characteristics of Multihop Node Localization in Ad-Hoc Sensor Networks. In: *IPSN'03 Proceedings of the 2nd international conference on Information processing in sensor networks*. Springer, 2003, pp. 317–332.
4. Juan, Liu, Ying Zhang, and Feng Zhao. Robust distributed node localization with error management. In: *MobiHoc '06: Proceedings of the seventh ACM international symposium on Mobile ad hoc networking and computing*, ,New York, ACM Press, 2006, pp. 250–261.
5. Zheng Yang; Liu, Y. Quality of Trilateration: Confidence based Iterative Localization. In: *IEEE Transactions on Parallel and Distributed Systems,* Vol. 21, No 5, May 2010, pp. 631–640.
6. Bian, T. Venkatesan, R. Li, C. An improved localization method using error probability distribution for underwater sensors. In: *Communications (ICC), 2010 IEEE International Conference,* 23–27 May 2010, pp. 1–6.
7. Dong, S., Agrawal, P., and Sivalingam, K. Localization error evaluation in heterogeneous sensor networks. In *Proc. of the 2008 IEEE Global Telecommunications Conference (GLOBECOM'08)*, New Orleans, USA, November 2008. pp. 1–5.
8. Fan, R., Jiang, H., Wu, S., and Zhang, N. Ranging error-tolerable localization in wireless sensor networks with inaccurately positioned anchor nodes, *Wireless Communications and Mobile Computing*, Vol. 9, No. 5, May 2009, pp. 705–717.

*Transport and Telecommunication, 2011, Volume 12, No 3*
*Transport and Telecommunication Institute, Lomonosov 1, Riga, LV-1019, Latvia*

# Authors' index

Krebss, V. 63
Kutev, V. 54
Mazurkiewicz, J. 27
Nowacki, G. 4
Opolchenov, D. 54
Orlov, S. 41
Tolujevs, J. 18
Tsilker, B. 63
Vishnyakov, A. 41
Walkowiak, T. 27

**Igor V. Kabashkin** (born in Riga, August 6, 1954)

- Vice-rector for Research and Development Affairs of Transport and Telecommunication Institute, Professor, Director of Telematics and Logistics Institute
- Ph.D in Aviation (1981, Moscow Institute of Civil Aviation Engineering), Dr.sc.habil. in Aviation (1992, Riga Aviation University), Member of the International Telecommunication Academy, Member of IEEE, Corresponding Member of Latvian Academy of Sciences (1998)
- **Publications:** 390 scientific papers and 67 patents
- **Fields of research:** information technology applications, operations research, electronics and telecommunication, analysis and modelling of complex systems, transport telematics and logistics

**Irina V. Yatskiv** (born in Krasnoyarsk, Russia)

- Vice-Rector of Transport and Telecommunication Institute, Professor of Computer Science Department
- **Education:** Riga Civil Aviation Engineering Institute, studied computer science and obtained an engineer diploma in 1982.
- **Scientific and university degrees:** Candidate of Technical Science Degree (1990), Riga Aviation University, Dr.sc.ing. (1992).
- **Scientific activities:** Member of Classification Society of North America, Member of Latvian Simulation Modelling Society, Director of Latvian Operation Research Society, the leader of project BSR INTERREG III B Programme InLoC, and projects connected with transport system simulation in Latvia.
- **Publications:** more than 70 scientific papers and teaching books
- **Fields of research:** multivariate statistical analysis, modelling and simulation, decision support system..

**Sergey A. Orlov** (born in Belaja Tcerkov, Ukraine)

- Head of the Chair of Software Engineering, Professor of Computer Science Department
- **Education:** the Perm High Engineering School, Kharkov Aviation Institute, Faculty of Control Systems of Flying Devices, Diploma of Electrical Engineer: control systems of flying devices and an electric equipment to them, 1970
- **Scientific and university degrees:** Candidate of Technical Science Degree (1984), Riga Aviation University, Dr.sc.ing. (1992)
- **Publications:** more than 100 scientific papers and teaching books
- **Fields of research:** software engineering, visual modelling, theory of programming languages, information technology applications, architecture of computer systems, theory of control systems

**Andrei Vishnyakov** (born in Rezekne, Latvia, February 12, 1982)

- Mg.sc.comp., Transport and Telecommunication Institute
- **University study**: Bachelor degree in computer science, Transport and Telecommunication Institute (2004); Master degree in computer science, Transport and Telecommunication Institute (2006)
- **Publications:** 3 scientific papers

**Jacek Mazurkiewicz** (born in Wroclaw, Poland, October 7, 1968)

- Assistant Professor at the Institute of Computer Engineering, Control and Robotics, Faculty of Electronics, Wroclaw University of Technology, Poland
- **Scientific and university degrees:** MSc and PhD degrees in Computer Science from the Faculty of Electronics Wroclaw University of Technology, respectively, in 1992 and 2001
- **Scientific activities:** Program and Organising Committee member of International Conference on Dependability of Computer Systems (DepCoS-RELCOMEX), a member of the Polish Neural Network Society from 1995, member of the Polish Safety and Reliability Association from 2005, was involved in 7 programs granted from the Polish Committee for Scientific Research and Polish Ministry of Higher Education, participant of 16 projects realised at Wroclaw University of Technology
- **Publications:** author and co-author over 100 papers printed in: international journals, books chapters, Springer LNCS/LNAI series, proceedings of conferences
- **Fields of research:** soft-computing methods, computer architecture, wireless telecommunication systems, dependability and functional analysis as well as modelling of systems

**Tomasz Walkowiak** (born in Wroclaw, Poland, November 18, 1969)

- Assistant Professor at the Institute of Computer Engineering, Control and Robotics, Faculty of Electronics, Wroclaw University of Technology, Poland
- **Scientific and university degrees:** MSc and PhD degrees in Computer Science from the Faculty of Electronics Wroclaw University of Technology, respectively, in 1993 and 1999
- **Scientific activities:** Program and Organising Committee member of International Conference on Dependability of Computer Systems (DepCoS-RELCOMEX), was involved in: 2 European Framework research projects, 7 projects granted from the Polish Committee for Scientific Research and Polish Ministry of Higher Education, participant of 15 projects realised at Wroclaw University of Technology
- **Publications:** author and co-author over 120 papers printed in: international journals, books chapters and proceedings of conferences
- **Fields of research:** dependability and functional analysis and modelling of transportation and information systems, Digital Signal Processing, object recognition, e-learning

**Valery A. Kutev** (born in Leningrad, January 20,1945)

- Professor of Transport and Telecommunication Institute, a Head of Electronics Department
- Director of Academic Programme "Bachelor of Engineering Sciences in Electronics" and Professional Programme "Electronics" (Transport and Telecommunication Institute)
- **University study**: Riga Civil Aviation Engineering Institute (1963–1968); Candidate of Technical science degree in Radiolocation and Radio navigation (1973), Riga Civil Aviation Engineering Institute; Dr.sc.ing.(1992) and Dr.habil.sc.ing. (1993), Riga Aviation University
- **Publications**: 126 publications, 8 certificates of inventions
- **Scientific activities**: electronics, digital technology, radar subsurface probing, radar data processing

**Daniil A. Opolchenov** (born in Ventspils, March 24, 1984)

- Mg.sc.ing., assistant at Transport and Telecommunication Institute
- **University study**: Bachelor of engineering sciences in electronics (2007); Master of engineering sciences in electronics and electrical engineering science (2010).
- **Publications**: 3 publications
- **Scientific activities**: electronics, hardware programming, computer modelling

**Boris Y. Tsilker** (born in Riga, November 19, 1948)

- Associate Professor, Dr.sc.ing., Ass. Professor of Telecommunication Department
- **University study**: Riga Institute of Civil Aviation Engineers (1966–1971)
- Ph.D in Radiolocation and Radio-navigation (1980, Moscow Institute of Civil Aviation Engineers), Dr.sc.ing. (1992, Riga Aviation University)
- **Publications:** 73 scientific papers, 17 teaching books, 4 patents
- **Fields of research:** computer architecture, software engineering, aviation simulators, sensor networks, intelligent transportation systems

**Victor Krebss** (born in Riga, Latvia, October 1968)

- IT Director Complete Payment Systems Ltd. Riga, Latvia
- **Education:** Master of natural science in computer science.
- Doctorate student of Telematics and Logistics (Transport and Telecommunication Institute)
- **Fields of research:** Intelligent Transportation Systems, information technology applications, statistical data computer processing methods, sensor networks.

# CUMULATIVE INDEX

## *TRANSPORT and TELECOMMUNICATION, Volume 12, No 3, 2011 (Abstracts)*

**Nowacki, G.** Interoperability Problems of Especially Electronic Toll Collection, *Transport and Telecommunication*, Vol. 12, No 3, 2011, pp. 4–17.

The paper refers to the implementation problems of Intelligent Transport System (ITS) in Member States of the European Union. The autonomous systems implemented in Member States of EU are not interoperable due to some reasons, especially lack of cooperation capability. European Commission has taken steps in the mentioned issue (directive 2010/40/EU, M/453, decision 2011). Furthermore the paper discussed assumptions and test results of NATCS Pilot Project developed by Motor Transport Institute, Autoguard SA, and Fela Management AG. Legislation steps were taken at the EC level because of interoperability problems of European Electronic Tolling Service (EETS) in the EU. Commission has urged the member states to conduct studies and pilot projects concerning these issues. Motor Transport Institute has taken up a challenge by developing and testing the pilot project – the functional structure of the NATCS. System has some requirements of EC legislation and it is interoperable with other DSRC and GPS/GSM based systems implemented in the member states of the European Union. Test results have shown a high accuracy and efficacy of the system.

**Keywords:** Intelligent Transport Systems (ITS), interoperability, the European Electronic Toll Service (EETS), the National Automatic Toll Collection System (NATCS), eCall

**Tolujevs, J.** Resource Allocation Problems in Mesoscopic Flow Models, *Transport and Telecommunication*, Vol. 12, No 3, 2011, pp. 18–26.

This paper presents the standard rules formulated for the allocation of resources in mesoscopic flow models. In terms of level of detail, the underlying mesoscopic simulation approach is situated between the prevalent approaches to continuous and discrete event simulation. Mesoscopic models use piecewise constant flow rates to represent the logistics flow processes. The resulting linearity of the cumulative flows facilitates event scheduling and the use of mathematical formulae to recalculate the system state variables at every simulation time step. Multichannel funnels are a mesoscopic model main component because they represent properly the processes of parallel or sequential processing and storage of several product types and product portions in a real area of operations. The identical types of resources that are arbitrarily allocable among the funnel different channels are labelled homogenous resources. The paper describes a mesoscopic simulation model of the passenger check-in processes on an airport. Resource allocation strategies based on mathematical formulae are an important part of the model.

**Keywords:** simulation, material flow, logistics systems, mesoscopic models

**Mazurkiewicz, J., Walkowiak, T.** Critical Situations Evaluation of Discrete Transportation Systems, *Transport and Telecommunication*, Vol. 12, No 3, 2011, pp. 27–40.

The paper presents the formal model of discrete transportation systems (*DTS*). The modelling methodology is based on the system functional behaviour. Monte Carlo approach is used as a simulation tool. The actual *DTS* situation is measured by the global metric called availability. The proposed solution is very useful for the system owner and manager. The critical situations are caused by reliability, functional and human origin. Absence of restrictions on the system structure and on the kind of distribution describing the system functional and reliability parameters is the main advantage of the approach. The exemplar *DTS* driven into critical situation is presented in the final part. The results show and discuss different ways to restore the normal operating point. The proposed solution seems to be essential for the owner and administrator of the transportation systems.

**Keywords:** reliability, discrete transportation system, Monte-Carlo simulation, critical sets

**Orlov, S., Vishnyakov, A.** Software-Engineering Measurement for Logistics and Transport Systems, *Transport and Telecommunication*, Vol. 12, No 3, 2011, pp. 41–53.

Today logistics and transport systems are complex and expensive, so it is necessary to use modern metric suits for their development process, which takes into account the characteristics of such systems. It is very important to choose a metric suite on the early development stages and the choice should be based on objective facts and experience.

To choose the optimal metric suite it is necessary to use a technique that contains a number of steps. At each step, a specific criterion should be used to make a selection from the available metric suites. As long as the metric suite is chosen it is necessary to perform its improvement. To do so each metric in the suite should be considered separately and replaced if the analogous metrics provides a better criteria matching. In the end we obtain the modified metric suite, which is optimal according to the requirements.

**Keywords:** metric suite, object oriented design metrics, metrics selection algorithm, logistics and transport software, Chidamber & Kemerer's metrics suite, software package metrics, metrics for object oriented design, LCOM

**Opolchenov, D., Kutev, V.** An Approach to Estimation of the Automatic Vehicle Location Systems Functionality by Comparison of Its Technical Parameters, *Transport and Telecommunication*, Vol. 12, No 3, 2011, pp. 54–62.

This work has focused on the development of approach to estimation of the automatic vehicle location system functionality which is determined by system technical parameters. The work examines the main elements of the automatic vehicle location systems and options for their implementation on the basis of modern technical means. To estimate system functionality it is necessary to choose correctly the set of the main parameters able to provide the possibility of the system comparison with other ones. We propose to use “weigh” estimation of system functionality for performing such comparison.

Some results of the comparative analysis for the “on-line” as well as “off-line” automatic vehicle location systems are presented. On this basis a new approach to the estimation of its functionality is proposed.

**Keywords:** transportation, transport monitoring systems, automatic vehicle location system, system architecture, efficiency, functionality

**Krebss, V., Tsilker, B.** Vehicle Dynamic Localization in Intelligent Transportation Systems Based on Sensor Networks, *Transport and Telecommunication*, Vol. 12, No 3, 2011, pp. 63–72.

Most of modern vehicle navigation and safety applications suppose availability of precise vehicle coordinates. Occasionally the only way for getting of these coordinates is vehicle self-localization. The ability of a vehicle to determine its own location is vital for many aspects of Intelligent Transportation Systems (ITS) and telematics. Localization might be realized in two ways, geometric methods (trilateration, triangulation, hyperbolic methods) and fingerprinting methods (signal mapping). The accuracy localization based on distance measurements may be degraded by noise. The impact of the ranging error usually depends on the estimation algorithm, the bandwidth of pulses, application scenarios, etc. Additionally the position information provided by some anchor nodes may be inaccurate. It is clear that a single localization technique is not enough to meet requirements of critical applications at the same time, such as being available anywhere and anytime, with highly accurate and reliable position computations. As a result, Data-fusion techniques to combine different localization methods and protocols in a single localization system are required, such as moving average, least squares, Kalman, particle filters Bayesian inference and Dempster-Shafer methods. In order to improve the localization precision several statistical based approaches have been proposed in [1, 2]. However, the statistical methods may not be able to provide enough accuracy if the data quantity is not sufficient. There is also the probabilistic approach considered in order to improve the localization precision. The inaccuracies are characterized by modelling the range measurements as a set of probability density functions. These functions can be used to compute the probabilistic constraints that reduce the uncertainties of the nodes positions. This approach can lead to significant enhancements in the localization accuracy compared to the least squares estimate.

**Keywords**: Intelligent Transportation System, sensor network, localization, cooperative positioning, data fusion

## *TRANSPORT and TELECOMMUNICATION, 12.sējums, Nr.3, 2011 (Anotācijas)*

**Novackis, G.** Īpašo elektronisko nodevu iekasēšanas sadarbspējas problēmas, *Transport and Telecommunication,* 12.sēj., Nr.3, 2011, 4.–17. lpp.

Raksts attiecas uz Inteliģento transporta sistēmu ieviešanas problēmām Eiropas Savienības dalībvalstīs. Autonomās sistēmas, kas ir ieviestas ES dalībvalstīs nav sadarbspējīgas dažu iemeslu pēc, t.i., īpaši sadarbības iespēju trūkums. Eiropas Komisija ir pieņēmusi mērus šajā direktīvā (direktīva 2010/40/EU, M/453, lēmums 2011). Rakstā autori iztirzā pieņēmumus un testa rezultātus, kas veikti *NATCS* (Nacionālā automātiskā nodevu iekasēšanas sistēma) Pilotprojektā un kas norisinājās Transporta institūtā u.c.

Pārbaužu rezultāti uzrāda augstu precizitāti un sistēmas efektivitāti.

**Atslēgvārdi:** Inteliģentās transporta sistēmas, sadarbspēja, Eiropas elektronisko nodevu iekasēšana, Nacionālā automātiskā nodevu iekasēšanas sistēma (*NATCS*), e-zvans

**Tolujevs, J.** Resursu piešķiršanas problēmas mezoskopisku plūsmu modeļos, *Transport and Telecommunication,* 12.sēj., Nr.3, 2011, 18.–26. lpp.

Šajā rakstā ir izmantoti standarta noteikumi, kas formulēti resursu piešķiršanai mezoskopisku plūsmu modeļiem. Attiecībā uz detalizācijas pakāpi, pamatā esoša mezoskopiska simulācijas pieeja atrodas starp izplatītām pieejām uz nepārtrauktu un diskrētu notikumu imitāciju. Mezoskopiski modeļi izmanto konstantu plūsmu ātrumu, lai pārstāvētu loģistikas plūsmas procesus. Kumulatīvo plūsmu rezultējoša linearitāte atvieglo pasākumu plānošanu un matemātisku formulu izmantošanu, lai pārrēķinātu sistēmas stāvokļa mainīgo lielumu katrā simulācijas laika posmā. Daudzkanālu piltuves ir mezoskopiska modeļa galvenā sastāvdaļa, jo tie pienācīgi veido paralēlas un secīgas apstrādes procesus un vairāku produktu veidu un produktu daļu uzglabāšanu reālā darbību laukā. Rakstā tiek parādīts mezoskopiskas imitācijas modelis pasažieru reģistrācijas procesiem lidostā. Resursu piešķiršanas stratēģijas, balstītas uz matemātisku formulu, ir modeļa svarīga daļa.

**Atslēgvārdi:** simulācija, materiālu plūsma, loģistikas sistēmas, mezoskopiski modeļi

**Mazurkevičs, J., Valkovjaks, T.** Kritisku situāciju izvērtēšana diskrētās transportēšanas sistēmās, *Transport and Telecommunication,* 12.sēj., Nr.3, 2011, 27.–40. lpp.

Raksts parāda diskrētās transportēšanas sistēmas (*DTS*) formālu modeli. Modelēšanas metodoloģija ir balstīta uz sistēmas funkcionālo uzvedību. Monte Karlo pieeja tiek pielietota kā simulācijas līdzeklis. Faktiskā DTS situācija tiek mērīta ar globālās metrikas palīdzību, sauktu par pieejamību. Piedāvātais risinājums ir ļoti noderīgs sistēmas īpašniekam un vadītājam.

Rezultāti parāda un diskutē dažādus veidus kā atjaunot normālu darbības punktu. Piedāvātais risinājums izskatās kā būtisks transportēšanas sistēmas īpašniekam un administratoram .

**Atslēgvārdi:** paļāvība, diskrētā transportēšanas sistēma, Monte Karlo simulācija, kritiskie komplekti

**Orlovs, S., Višņakovs, A.** Programmatūras inženierijas mērījumi loģistikas un transporta sistēmām, *Transport and Telecommunication,* 12.sēj., Nr.3, 2011, 41.–53. lpp.

Mūsdienās loģistikas un transporta sistēmas ir sarežģītas un dārgas, līdz ar to ir nepieciešams lietot modernas metrikas komplektus to attīstības procesam, kas ņem vērā šādu sistēmu raksturojumus. Ir ļoti svarīgi izvēlēties metrisko komplektu jau agrīnās attīstības stadijās, un izvēlei jābalstās uz objektīviem faktiem un pieredzi.

Lai izvēlētos optimālo metrisko komplektu ir nepieciešams pielietot tehniku, kas ietver vairākus soļus Katrā posmā ir jāizmanto īpašs kritērijs, lai izdarītu izvēli no pieejamajiem metriskajiem komplektiem. Galu galā mēs iegūstam modificēto metrisko komplektu, kas ir optimāls saskaņā ar prasībām.

**Atslēgvārdi:** metrikas komplekts, objektorientētā dizaina metrika, metrikas izvēles algoritms, loģistikas un transporta programmatūra, Čidambera un Kemerera metriskais komplekts, programmatūras paketes metrikas, metrikas objektorientētam dizainam

**Opolčenovs, D., Kutevs, V.** Pieeja automātiskās transporta līdzekļa lokācijas sistēmas funkcionalitātes novērtēšanai salīdzinājumā ar tās tehniskajiem parametriem, *Transport and Telecommunication,* 12.sēj., Nr.3, 2011, 54.–62. lpp.

Darbs tiek fokusēts uz pieejas attīstību, lai novērtētu automātiskās transporta līdzekļa lokācijas sistēmas funkcionalitāti, kas ir noteikta ar sistēmas tehniskajiem parametriem. Darbā tiek izskatīti automātiskās transporta līdzekļa lokācijas sistēmas galvenie elementi un iespējas to ieviešanai, balstoties uz modernajiem tehniskajiem līdzekļiem. Lai novērtētu sistēmas funkcionalitāti, ir nepieciešams pareizi izvēlēties galveno parametru rindu, kas spēj nodrošināt sistēmas salīdzināšanu ar citām. Autori piedāvā pielietot sistēmas funkcionalitātes 'izsvēršanas' novērtēšanu, lai veiktu šādu salīdzināšanu. "On-line" , kā arī "off-line" tiek parādīti daži rezultāti salīdzināmās analīzes automātiskām transporta līdzekļa lokācijas sistēmām.

**Atslēgvārdi:** transportēšana, transporta monitoringa sistēmas, automātiskās transporta līdzekļa lokācijas sistēmas, efektivitāte, funkcionalitāte

**Krebss, V., Ciļkers, B.** Transporta līdzekļa dinamiska lokalizācija inteliģentās transportēšanas sistēmās, balstīta uz sensoru tīkliem, *Transport and Telecommunication,* 12.sēj., Nr.3, 2011, 63.–72. lpp.

Lielākā daļa no mūsdienu transporta līdzekļu navigācijas pieņem precīzu transporta līdzekļu koordinātu pieejamību. Reizēm vienīgais veids šādu koordinātu iegūšanā ir transporta līdzekļu pašlokalizācija. Transporta līdzekļa spēja noteikt paša atrašanās vietu ir vitāli svarīgi inteliģentām jeb viedām transportēšanas sistēmām un telemātikai no daudziem aspektiem. Lokalizāciju var realizēt divos veidos: ģeometriskās metodes un pirkstu nospiedumu metodes (signālu kartēšana). Lokalizācijas precizitāte, balstīta uz distances mērījumiem, var tikt noārdīta trokšņa dēļ. Ranžēšanas kļūdu ietekme parasti ir atkarīga no novērtēšanas algoritma, pielietota scenārija, etc. Papildu informācija par atrašanās vietu, ko dod daži enkuru mezgli, var būt neprecīza. Ir skaidrs, ka ar vienīgo lokalizācijas metodi ir nepietiekami, lai vienlaicīgi ievērotu kritiska rakstura prasības, tādas kā esot pieejamam jebkur un jebkad ar ļoti precīziem un ticamiem aprēķiniem. Tā rezultātā ir vajadzīgas Datu saplūšanas metodes, lai apvienotu dažādas lokalizācijas metodes un protokolus vienīgā lokalizācijas sistēmā. Tās ir – piemēram, mainīgais vidējais rādītājs, mazākais kvadrāts, *Kalman, Bayesian* izveduma daļiņu filtri un *Dempster-Shafer* metodes.

Rakstā parādītā pieeja var dot svarīgus uzlabojumus lokalizācijas precizitātē salīdzinājumā ar mazāko kvadrātu aprēķinu.

**Atslēgvārdi:** Inteliģentās jeb viedās transportēšanas sistēmas, sensoru tīkls, lokalizācija, datu saplūšana

# TRANSPORT
# &
# TELECOMMUNICATION

**ISSN 1407-6160 & ISSN 1407-6179 (on-line)**



**Host Organizations:**
Transport and Telecommunication Institute, Latvia – Boriss Misnevs, Rector
Telematics and Logistics Institute, Latvia – Igor Kabashkin, Director

**Supporting Organizations:**
Latvian Transport Development and Education Association
Latvian Academy of Sciences
Latvian Operations Research Society
Telecommunication Association of Latvia
Latvian Academic Park

All articles are reviewed.
Articles can be presented in the journal in English.

**EDITORIAL CORRESPONDENCE**

Transporta un sakaru institūts (Transport and Telecommunication Institute)
Lomonosova iela 1, LV-1019, Riga, Latvia. Phone: (+371)67100594. Fax: (+371)67100535.
E-mail: kiv@tsi.lv, http:// www.tsi.lv

**TRANSPORT and TELECOMMUNICATION**, 2011, Vol. 12, No 3
ISSN 1407-6160
The journal of Transport and Telecommunication Institute (Riga, Latvia).
The journal is being published since 2000.

The papers published in Journal "Transport and Telecommunication" are included in **SCOPUS** (since 2008, Vol. 9, No 1), **Elsevier Database**
www.info.scopus.com
www.elsevier.com

# PREPARATION OF CAMERA-READY TYPESCRIPT: COMPUTER MODELLING AND NEW TECHNOLOGIES

1. In order to format your manuscript correctly, see the Page Layout Guideline for A4 (21 cm x 29,7 cm) paper size. Page Layout should be as follows: Top – 3 cm, Bottom – 3 cm, Left – 3 cm, Right – 3 cm.
2. Maximum length for the article is **10 pages**.
3. **Using of other Styles with the exception of Normal is not to be allowed!**
4. ***Articles*** should be Times New Roman typeface, single-spaced.
5. The article should include:
   - title;
   - author's name(s) and information (institution, city, country, the present address, phones, and e-mail addresses);
   - abstract (100-150 words);
   - keywords (max. 6);
   - introduction – clear explanation of the essence of the problem, previous work, purpose of the research and contribution;
   - description of the research;
   - conclusion section (this is mandatory) – should clearly indicate on the advantages, limitations and possible applications;
   - references.

   **Attention!** First name, last name, the title of the article, abstract and keywords must be submitted in the English and Latvian languages (in Latvian it is only for Latvian authors) as well as in the language of the original (when an article is written in different language).
6. The text should be in clear, concise English (or other declared language). Please be consistent in punctuation, abbreviations, spelling (***British English***), headings and the style of referencing.
7. ***The title of the article*** – 14 point, UPPERCASE, style Bold and centred.
8. ***Author's names*** – centred, type size 12 point, Upper and lower case, style Bold Italic.
9. ***Author's information*** – 10 point, Upper and lower case, style Italic, centred.
10. ***Abstract and keywords*** – 8 point size, style Normal, alignment Justify.
11. ***The first level Headings*** – 11 point, Upper and lower case, style Bold, alignment Left. Use one line space before the first level Heading and one line space after the first level Heading.
12. ***The second level Headings*** – 10 point, Upper and lower case, style Bold, alignment Left. One line space should be used before the second level Heading and 1/2 line space after the second level Heading.
13. ***The third level Headings*** – 10 point, Upper and lower case, style Italic, alignment Left. One line space should be used before the second level Heading and 1/2 line space after the third level Heading.
14. ***Text*** of the article – 10 point, single-spaced, alignment Justify.
15. The set of ***formulas*** on application of fonts, signs and a way of design should be uniform throughout the text. The set of formulas is carried out with use of editors of formulas MS Equation 3.0 or MathType. The formula with a number – the formula itself should be located on the left edge of the text, but a number – on the right one. Font sizes for equations are the following: 11pt – full, 7pt – subscripts/superscripts, 5pt – sub- subscripts/superscripts, 16pt – symbols, 11pt – subsymbols.
16. All ***Figures*** – must be centred. Figure number and caption always appear below the Figure, type size 8 point.

*Figure 1.* This is figure caption

***Diagrams, Figures and Photographs*** – must be of high quality, in format *.TIFF, *.JPG, *.BMP with resolution not less than 300 dpi. Also formats *.CDR, *.PSD are possible. Combination of Figures in format, for instance, *.TIFF with elements of the in-built Figure Editor in MS Word is prohibited.

17. ***Table Number and Title*** – always appear above the Table. Alignment Left. Type size 8 point. Use one line space before the Table Title, one line space after the Table Title and 1/2 line space after the Table.

**Table 1.** This is an example of a Table

| **Heading** | **Heading** | **Heading** |
|---|---|---|
| Text | Text | Text |
| Text | Text | Text |

18. ***References*** in the text should be indicated by a number in square brackets, e.g. [1].
References should be numbered in the order cited in the manuscript. The correct format for references is the following:

*Article***:** author, title, journal (in italics), volume and issue number, year, inclusive pages
Example: 1. Amrahamsson M., Wandel S. A Model of Tearing in Third – Party Logistics with a Service Parts Distribution Case Study, *Transport Logistics*, Vol. 1, No 3, 1998, pp. 181-194.

*Book***:** author, title (in Italics), location of publishers, publishers, year, whole pages
Example: 2. Kayston M. and Fried W. R. *Avionic Navigation Systems.* New York: John Wiley and Sons Inc, 1969. 356 p.

*Conference Proceedings:* author; title of an article; proceedings (in italics); title of a conference, date and place of a conference; publishing house, year, concrete pages
Example: 3. Canales Romero J. A First Step to Consolidate the European Association of Aerospace Students in Latvia (Presented by the Munich Local Group). In: *Research and Technology – Step into the Future: Programme and Abstracts. Research and Academic Conference, Riga, Latvia, April 7–11, 2003, Transport and Telecommunication Institute.* Riga: TTI, 2003, p. 20.

19. ***Authors Index***
Editors form the author's index of a whole Volume. Thus, all contributors are expected to present personal colour photos with the short information on the education, scientific titles and activities.
20. ***Acknowledgements***
Acknowledgements (if present) mention some specialists, grants and foundations connected with the presented paper. The first page of the contribution should start on page 1 (right-hand, upper, without computer page numbering). Please paginate the contributions, in the order they are to be published. Use simple pencil only.
21. **Articles poorly produced or incorrectly formatted may not be included in the proceedings**.