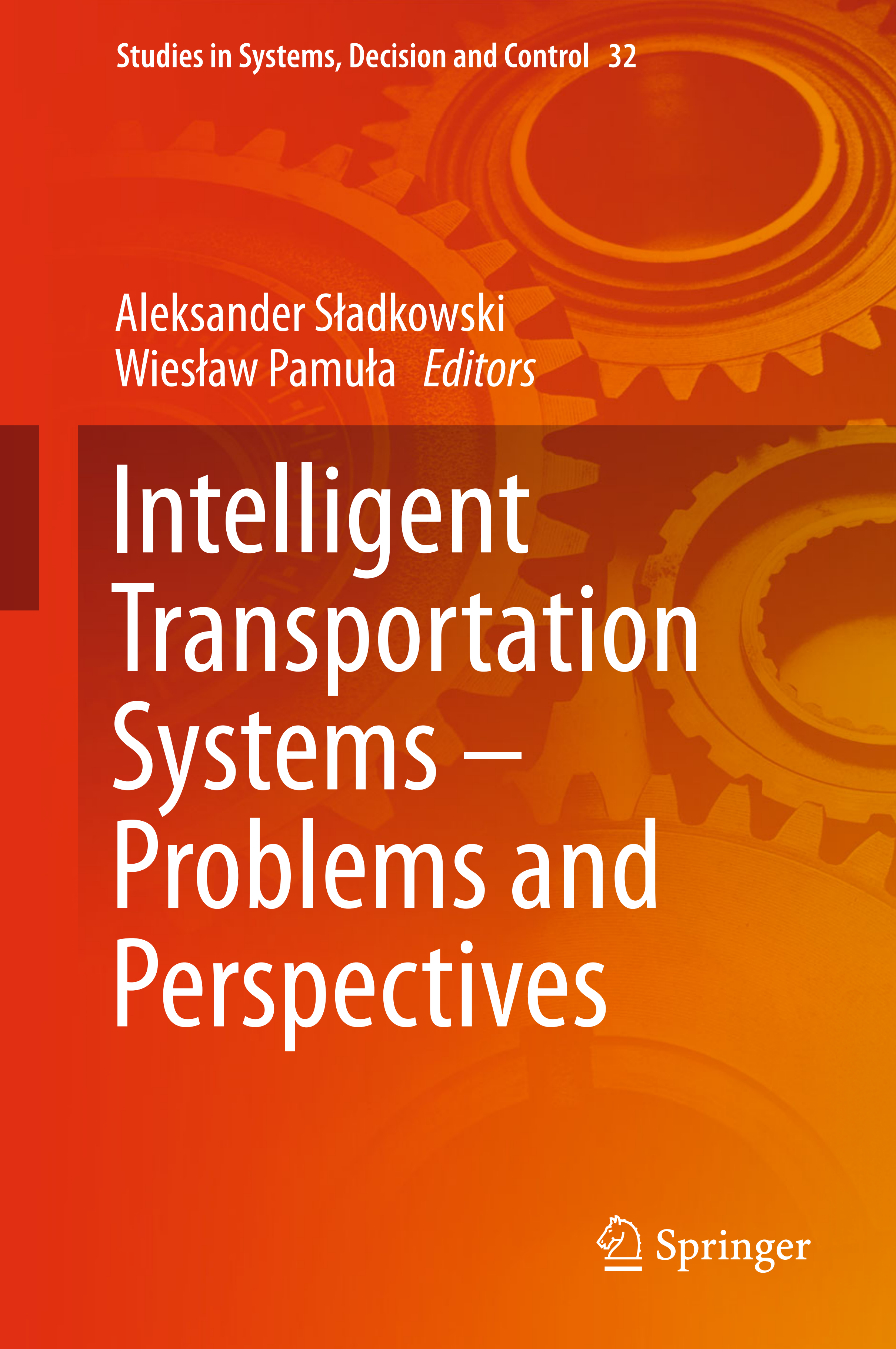

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Aleksander Sładkowski
Wiesław Pamuła *Editors*

Intelligent Transportation Systems – Problems and Perspectives

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Intelligent Transportation Systems – Problems and Perspectives

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Preface

The term “intelligent transport system” is used to name the integration of control, information and communication technologies with transport infrastructure. ITS covers all modes of transport and takes into account the dynamic interaction of all constituents of the transport system. A transport system can be considered effective if it is capable of linking all sources of data in the system to produce valuable information. This information is the basis for control and management decisions which are made by transport users and operators. The potential of Intelligent Transport Systems lies in their wide variety of applications in different modes of transport.

The editors aim was to present the discussion of problems encountered in the deployment of ITS. This discussion places emphasis on the early tasks of designing and proofing the concept of integration of technologies in ITS. The book comprises two parts.

The first part concentrates on the design problems of urban ITS. It is divided into five chapters.

The first chapter reviews the challenges of incorporating ICT for establishing a smart transport system as an autonomic entity and to ensure a high reliability of functioning. Reliability is essential since most other services of the living environment smart city, rely on transport systems. The chapter gives an overview on the state of research based on current literature and recent publications of the authors.

The next chapter emphasizes the problems of designing the ITS for transition to “green” transport. The definition of the environmentally friendly transport is outlined using EU and UN transport policy documents. The term management system is stressed as vital for reaching the goals of such transport. Different aspects of managing the data flow within the system are discussed. Especially the interface between vehicles and infrastructure as the source of data for elaboration of control decisions is presented.

Żochowska and Karoń in Chap. “ITS Services Packages as a Tool for Managing Traffic Congestion in Cities” discuss strategies for managing congestion using packages of ITS services. Congestion management is a vital problem in urban transport systems greatly contributing to the efficiency of ITS. The authors present their concept of combining services to enhance the utilization of collected data in the transport system. This requires a close cooperation and coordination between planners, designers and traffic engineers. The chapter also presents the concept of an integrated approach to this issue in the context of the theory of traffic flow.

The following chapter gives a detailed account of using artificial intelligence methods for determining flow volumes in traffic networks. The aim of the study was to compare the short-term forecasting models based on Bayesian networks (BN) and artificial neural networks (NN), which can be used in traffic control systems especially incorporated into modules of Intelligent Transport Systems.

In the last chapter of the first part the problem of transport line capacities is reviewed. Capacity dimensioning is an important element of resource management in ITS. Mathematical model for optimal capacity sizing of N different transport types (capacity types) is explained, minimizing the total expansion cost. Instead of nonlinear polynomial convex optimization technique, that could be very exhausted, the network optimization method is applied. Using this approach an efficient algorithm for three different capacity types is developed and outlined.

The second part of the book consists of three chapters featuring case studies representative for the different modes of transport. These are freight transport, rail transport and aerospace transport encompassing also space stations.

Freight transport ensures the supply of materials for production and the dispatch of ready products to customers. Just-in-time supply chains, door-to-door transport impose challenges on the design of an efficient transport systems. The introduction of ICT ease the problems and also bring new issues to resolve during deployment. Authors classify the risks of development and deployment of transport systems serving industrial enterprises.

Młyńczak et al. in the following chapter introduce the components of the European Rail Traffic Management System (ERTMS). This system is one of the important components ensuring interoperability of the European rail system. The vital components, their features and functions are discussed. The overall structure of the ERTMS is illustrated.

The last chapter elaborates on the subject of deployment of ITS services in aerospace engineering. Intelligent control must be able to process flying object data under rapidly varying operating conditions, to form conclusions, make decisions, and manage the objects flight. This requires a rigorous interaction between control systems and the transport infrastructure, which can be provided by the integration of ICT. The outline of this integrated system is presented in the chapter.

The content of the book presents the problems of deployment of ITS from a slightly infected perspective. This is the influence of long term State imposed transport policies, which were resistant to the introduction of new technologies for transport control and management. The authors of the book work in Croatia, Germany, Romania, Russia, Saudi Arabia, Ukraine, United Kingdom and Poland. This multi national perspective constitutes a valuable incentive for elaborating common solutions for integration of ICT in transport.

The book provides ideas for deployment which may be developed by scientists and engineers engaged in the design of Intelligent Transport Systems. It can also be used in the training of specialists, students and post-graduate students in universities and transport high schools.

Aleksander Sładkowski
Wiesław Pamuła

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Part I
Deployment of ITS in Road Transport

Autonomic Transport Management Systems—Enabler for Smart Cities, Personalized Medicine, Participation and Industry Grid/Industry 4.0

Jörn Schlingensiepen, Florin Nemtanu, Rashid Mehmood and Lee McCluskey

Abstract Today's societies are facing great challenges in transforming living environments in a way better serving people's demands of the future. A key point in this transformation is reinventing cities as *smart cities*, where the core services are integrated in a way that ensures a high quality of life while minimizing the usage of resources [Smart cities in Europe. Serie Research Memoranda 0048, VU University Amsterdam, Faculty of Economics, Business Administration and Econometrics 1]. Setting up smart cities resp. transforming cities to smart cities includes the development of *smart transport systems* as a main service all other services rely on. Thinking about current mega trends like Individualization of Products (Mass Customization) in so called Industry grid also known as Industry 4.0 [Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0 2] (Industrie 4.0 describes the industry in the 4th industrial revolution to customized mass production after mechanization, mass production, digitalization [Map 'n' tag. Thinking highways 3]), Personalized Medicine or the need of better support for disabled and older people in an aging society, the interconnection of involved bodies is a premise. In virtual world this means integration of data networks and ICTs in the physical world this means establishing individual and personalized transport

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services that cover individual mobility and individual distribution of goods. To ensure the best utilization of infrastructure while having less employable people in an aging society a high grade of automation and information integration is needed. We call this a *smart transport system* as the next step in development of today's *intelligent transport systems* (*ITS*) and propose establishing this ITS of the future as an *autonomic system* to meet all the different requirements and ensure a high reliability of the overall system. Reliability is essential since most other services of the living environment smart city, will rely on transport systems. This chapter gives an overview on state of research based on current literature and recent publications of the authors (see references) and focus on the ICT system needed to manage transportation the *autonomic transport management system*.

Keywords Personalized mobility · Logistics for industry grid/industry 4.0 · Smart cities · Individual/personalized transport · Personalized medicine · Individual products/mass customization · Networked information systems · Sensors as a service autonomic computing · Participation of disabled

1 Current State—Need for Action

Mobility of people and goods is a key challenge for the future. Transport is one of the world's largest industrial sectors, but today's road transport system are already fully loaded. The cost of congestion alone estimated at Euro 100 billion per year in the EU [4].

Following the Communication from the Commission Europe 2020—*A strategy for smart, sustainable and inclusive growth* [5] European Union has set three priorities:

- **Smart growth**: developing an economy based on knowledge and innovation.
- **Sustainable growth**: promoting a more resource efficient, greener and more competitive economy.
- **Inclusive growth**: fostering a high-employment economy delivering social and territorial cohesion.

Following this agenda causes some socio-technological issues. *Smartness* will cause a higher grade of automation like autonomous systems and the question of liability for these systems is not clear (and there is not much public discussion about this)—today the UN-Convention on Road Traffic Vienna [6] permits autonomous vehicles in general—and of course the question of privacy in a world all systems serving us are highly integrated has to be discussed.

Beside this legal and sociological issues we need to think about new ways in providing infrastructure, not only in case of transportation, but since this is the main underlying service it is the enabler for all other services or function and therefore we focus on how transport systems can help optimizing the overall system.

Since mass transportation does not fulfill the demands in personal transport and individual good distribution future transport systems will be multi-modal, combined transport systems including cars, vans and trucks as well as buses, trains and other public transport vehicles.

Today’s systems of road traffic flow are affected by the outcome of individual driving decisions, often assisted by personalized navigation and information-providing devices. Even in future actors in those systems will make their own local decisions by human passengers or local decision engines. Therefore vehicles and passengers need to be integrated in those systems by mobile devices/controllers (so called *on board units*) and new requirements on vehicles and traffic management systems are coming up. The spreading of incorporated units doing local decisions causes using distributed software system architecture and the main purpose for this distributed system resp. its backbone is providing current data to the local decision engines in a fast and reliable way.

Autonomic Transport Management Systems (ATMS) face those problems and provide a new approach for establishing transportation networks.

2 Expectations on Smart Transport

According to [7] the core function of a Smart City is an open, inter-operable and scalable platform that provides intelligent infrastructure functionality as a service and allows for optimal resource management. Figure 1 shows the main aspects of open inter-operable infrastructure for a smart city.

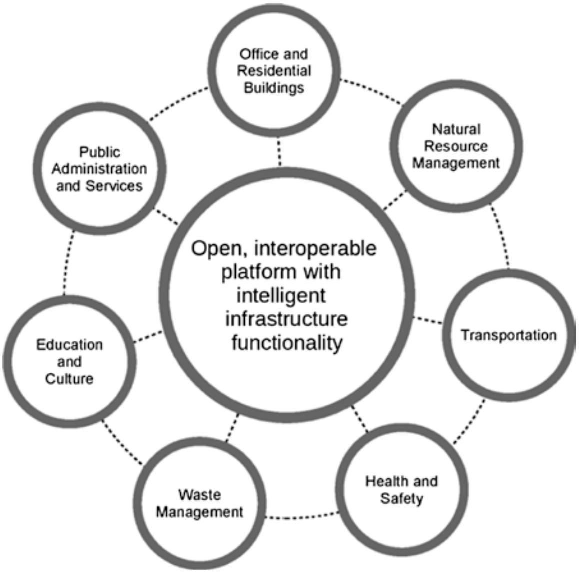

Fig. 1 Main aspects of open interoperable infrastructure for a smart city (*source* [7])

The concept of Smart Cities needs a flexible partnership between public and private sectors as well as diverse industries such as telecommunication, energy providers, manufacturers and suppliers to ensure improvements in mobility, energy consumption, governance and social cohesion in European cities [8, 9]. At present the modal split of transport in Europe is dominated by passenger cars (73.4 % compared to just 1.4 % for tram and metro combined). According to the World Health Organisation, some 40 million people in the 115 largest cities in the EU are exposed to air exceeding WHO air quality guideline values for at least one pollutant [10].

Expectation on Smart Transport is to reduce this pollution and the related health risks in order to improve quality of life in urban areas while providing a better service to the inhabitants by fulfilling personal demands in an easy to use, flexible and cost-efficient way.

3 Requirements on Smart Transport

The user experience while using smart city service has to be designed in a way user gets a better service respective his needs are fulfilled with less effort/time consumption and a minimum of interaction needed. Industrial users will require a high reliability and adherence to schedules to integrate general transport system in their supply chain and production lines.

This leads to the main issues to be addressed:

- Resources need to be allocated predictively
- Allocation of resource has to follow the overall benefit
- Peaks in needs have to be eliminated
- To ensure reliability the overall system need to be fault tolerant, it has to work even if there are dysfunctions in some areas.

Beside this general requirements there are requirements cause by changes in different areas show up in the following subsections.

3.1 Emerging Requirements Caused by Changes in Industry

Beside this needs for more efficient use of energy, land and other resources in execution of transport the fundamental changes in industry related to the concept of *industry 4.0* [11] and the *internet of things* cause new requirements on transport.

Different initiatives like Smart *Manufacturing Leadership Coalition* [12] or *Zukunftsprojekt Industrie 4.0* [13] propagate different but similar scenarios for future development in production, the common characteristic are the strong customization of products under the conditions of high flexibilized (mass-) production. This means products are tailored for specific costumers. As a result traditional distribution and supply chains using stock house storing standard products or just-in-time production with long order time are obsolete. A popular example from Germany for this is *myMüsli* [14] an online shop to order customized cereals fitting personal liking. Their product is a personalized granola that is mixed to the order. There is no way to use classic stock and of course the costumer expect his granola for the breakfast next morning. If we take this sample as a first step on a way to an industry providing built to order products only like stated in [2, 15, 16] we can assume a high rate of growth in the field of personalized just in time transport in the next few years.

3.2 Emerging Requirements Caused by Personalization of Medic Care

Beside industrial products the so called personalized medicine is going to provide personalized drugs or health programs based on person's genome or personalized care taker applications [17, 18]. This will cause a new class of time critical transport goods with undefined transport targets, since they are not needed at a person's home address but a person's whereabouts. Another aspect of personalized medicine is taking tele-medicine to the next level. The miniaturization of machines for diagnosis and the so called health monitoring gadgets (e.g. Apple Health [19], Microsoft HealthVault [20], Samsung S Health [21]) will allow earlier detection of health problems and will cause new kind of emergency protocols that has to be considered while planning a future transportation system.

3.3 Emerging Requirements Caused by Changes in Users Demands

Beside the transportation of good the personalized travel planning and assistance dictates additional requirements to the system. Today's public transport is not accepted because of a lack of comfort, reliability and time efficiency. Following [3, 22] this can be done by implementing a *Adaptive Travel Planning and Monitoring system* that provides travel planning and support during the travel by giving advice based on the current traffic situation. Today *TrafficCheck.at* (a project funded by the Austrian ministry responsible for traffic, innovation and technology) [23] has implemented some of this aspects by using crowd intelligence. Inhabitants can access this data via a central web portal using their smartphones and post back their rating to this central data base.

Future smart transport systems shall gain this data directly from the field like it is done in project *mobile* [24] (funded by the German Ministry of Education and research). This project focus on the problem that today's public transport is not easy to use by people having mental problems, are disabled or infirm. Traffic planning today is powered by online time tables calculating the optimal way to use public transport in terms of time and costs.

3.4 Emerging Requirements Caused by Ensuring Better Participation of Disabled and Elderly

Focusing on optimizing only one aspect of traveling, like described in the section above, is not suitable for a group of travelers having constraints in using vehicles, vehicle types or particular stations for health reasons. Since most of those people are not able to drive a car on their own, making public transport available opens them a way to get more personal independence. The political agenda is very clear, the UN-Convention on the Rights of Persons with Disabilities [25] and its national implementations clearly states the goal allowing this persons to take part in social and cultural life and in the sample described in Sect. 6 shows, and this means implementing planning algorithms that are personalized.

3.5 Requirement Sustainability

As already stated in [26] the sustainability of transport systems has four main issues to be addressed: the (i) *energy efficiency* (for the same transport activity a smaller quantity of energy should be consumed), (ii) *saving time* (the time allocated for transport activity has to be minimized), (iii) *saving money* (the cost of transport is reflected in the price of goods not in the quality of them) and (iv) *environmental aspects* (the transport should protect the environment not to destruct it). The fourth priority area of *European ITS Directive* [27] is focused on linking the vehicles with the infrastructure based, especially, on open in-vehicle platform as well as cooperative systems. That means integration between the vehicles and the infrastructure. Urban ITS is an important domain of ITS applications and ITS and Autonomic Road Transport Systems (ARTS [28]) could be tools of solving traffic and mobility problems in cities (*Urban ITS Expert Group* has already elaborated a set of guidelines oriented on ITS for urban areas—i.e. *Guidelines for ITS Deployment in Urban Areas—Multimodal Information* [29]).

One of the keys to increase energy efficiency is avoiding traffic jam or other interferences of traffic flow. These also will decrease the amount of CO_2 emitted by traffic as these numbers show: On the one hand in 2007 the CO_2 emissions caused by traffic jams (not including inappropriate periods of traffic lights or additional break usage on heavy loaded roads) in Germany only was 714,000 to (288 million liters of fuel) or approximately 7 % of the CO_2 emissions by passenger cars. On the other hand the recent study *Understanding Road Usage Patterns in Urban Areas* [30] shows that, even during peak hours 98 % of the road segments are underutilized. Therefore, the approach to better utilize existing infrastructure through better planning of utilization appears promising.

Beside better usage of infrastructure the EU FP7 funded project SARTRE (Safe Road Trains for the Environment) [31] shows up another approach to minimize fuel usage. The project aims to encourage a step change in personal transport usage by developing of road trains called platoons. Platoon members shall benefit from a better aerodynamic of the overall road train [32]. The planned systems will facilitating the safe adoption of road trains on unmodified public highways with interaction with other traffic. A scheme will be developed whereby a lead vehicle with a professional driver will take responsibility for a platoon. Following vehicles will enter a semi-autonomous control mode that allows the driver of the following vehicle to do other things that would normally be prohibited for reasons of safety; for example, operate a phone, reading a book or watching a movie. As shown in [33] this approach needs a very reliable vehicle to infrastructure communication that will be provided by the corporative ICT described in Sect. 7.4 and a flexible scalable system of sensor integration that will be provided by the overlay network described in Sects. 7.1–7.3.

3.6 Influencing Traffic Requirements

To allow an effective traffic management the current traffic situation and operating grade has to be captured to allow predictions on future situations to hedge decisions made by users, operators and decision engines.

All described aspects a *Smart Transport Systems* requires a good understanding about the mechanisms traffic of independent and controlled vehicles is organized and can be influenced by managed infrastructure and service elements like traffic lights, special trains etc. A pre-condition for *Smart Transport System* is an automated decision system to control these influencing element. This means the system has to incorporate knowledge gained from traffic simulations done during set up or changing infrastructure or while optimizing the current system as well as knowledge gained from real-time in-line simulation that is fed with current state of the overall system and allows prediction on the near time behavior in terms of road load, congestions, speed and resulting travel time. An overview on current state in these different kind of simulations can be found in Sect. 6.

The main issue while implementing those kind of systems is providing a good basis for decision to the decision engines and in-line simulations. The best basis for decisions is knowing about the current state of the overall system. That is why the data acquisition and the networks transporting the information about the current situation in the field are an important aspect of ATMS.

Figure 7 shows that decisions in the vehicle are made by the on board support decision engine or the driver. Today and in the near future for legal reasons and reasons of user acceptance all decisions at all levels will be made by the driver, so the information of ITS are incorporated in the decision-making process as suggestions, provided to the driver by a mobile device called adviser. Studies of University of Twente have shown that the drivers' trust in the advice of the system is an essential requirement and this confidence is often absent [34]. Drivers make decisions (e.g. choosing lanes, speed adjustment) on the basis of personal experiences. Therefore the effect of not trusting the advice is boosted, because in road traffic systems the results of decisions that are inauspicious for the overall system are not hurting the decision maker but other road users.

Figure 8 derived from [26] shows some examples for actions respectively decisions made at the different levels, details on this can be found in [26].

4 Approach for ATMS

At this point it is obvious that reliability of data is essential and the most important requirement to the ATMS. Therefore the COST ARTS group propose usage of the principles of autonomic systems. Establishing an autonomic system gives some great advantages in increasing reliability of the overall systems. Autonomic Computing was launched by IBM [35] and can be viewed as a challenge to embed desirable self-managing intelligent properties into large systems to cope with the problems of their inherent complexity. Autonomic systems will help solving today's core problems in engineering new transport systems: their costly configuration and maintenance, high operating complexity, suboptimal operation, and the problem of embedding and maintaining safety and environmental conditions within the operational parameters of the controlling system. Autonomic Computing integrates ideas from several areas of AI including automated reasoning, machine learning and automated planning, and implementations often draw on distributed AI technologies such as intelligent agents.

Before proposing autonomic systems as a holistic approach there was already research into the many challenges of implementing autonomic behavior in transportation systems, and what has been done has been carried out in a range of fragmented research areas. Some pilot studies concerning road transport systems technologies use agent-based technology [36–39]. Utilizing a more centralized notion of self-maintenance, theory refinement algorithms for automatically evolving a requirements model of air traffic control criteria was developed in work sponsored by the UK NATS [40]. Concentrating on self-organization is the focus of *Organic Computing*, a large cooperative research effort sponsored by the DFG [41]. Its goals are the development and control of emergent and self-organizing technical systems. In the area of Organic Computing several projects have investigated the feasibility of adaptive, intelligent traffic light controllers and their ability to self-organise, e.g. to form progressive signal systems [42]. Systems with autonomic capabilities will help alleviate many of today's problems associated with life cycle management of complex systems. Autonomic systems embody self-assessment and self-management abilities that enable the system to assess its own state, then adapt or heal itself in response to that assessment.

The interface between system and owner is set at a very high level: the owner sets out goals, policies or service levels that the system must follow, and the system translates these into its system functions resulting in a change of behavior. IBM defines four areas of autonomic functions: (i) *self-configuration* through automatic configuration of components; (ii) *self-healing* through automatic discovery, and correction of faults; (iii) *self-optimization* through automatic monitoring and control of resources to ensure the optimal functioning with respect to the defined requirements; and (iv) *self-protection* through proactive identification and protection from arbitrary attacks. We define autonomification as the process of transforming an entity (a service, system or infrastructure) into an autonomic entity such that the process infuses autonomic properties into an entity causing the entity to become an autonomic entity. In terms of an ITS this influence two aspects of the system: Components design and architecture of the system. Components needs to be implemented in a way that includes not only posting and consuming data but also self-assessing and giving additional data about own state and the trustability of measured data which can be combined with networks of trust and service levels. Today's systems process only measured data with high trustability, in case of harvesting several data from many different measuring entities like it is done in an ATMS processing of unsure data will lead to a more valid picture of current system state. On top of current network infrastructure a p2p-Layer (overlay network) shall be established. Where users can join the network using their personal device and infrastructure elements are plugged in as service providers (see Sect. 7.3). The architecture of an autonomic ITS has to respect the fact, that the different component in the system are owned, run and configured by different stakeholders with different interest. To fulfill the described requirements we need to define two main aspects of the overall system. 1st is the architecture of the overlay network that is used to gather all information to provide a valid picture of the field (in our case the traffic situation in a given area). This overlay network provides the base of the ATS. 2nd is the overall architecture of the back-end that is used to receive, store, process and provide incorporated information resp. data.

The described approach calls for integration of existing technologies and research approaches, the following sections gives an overview on promising approaches that needs to be incorporated into an ATMS.

5 Overlay Descriptions for Personalized Travel Planning

The project *mobile* funded by The *German Federal Ministry of economy and energy*[1] in order to reach the goals of the UN-Convention on the Rights of Persons with Disabilities [44] aims to develop a system to support disabled and elderly people while using public transports. Within this project and approach for personalized travel planning was developed and introduced to public in [22]. This kind of planning systems seems to be interesting being included in an ATMS. Details about the project at all can be found in [45].

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[1] Project mobile is part of initiative *from door to door* [43] funded by BMWi, as a mobility initiative for the public passenger transport of the future. Within this initiative, a set of projects were started that address different aspects of public transportation.

Today's public transport is not easy to use by people having mental problems or are disabled. Traffic planning today is powered by online time tables calculating the optimal way to use public transport in terms of time and costs. Therefore usually a graph or petri net representing the public transport network is set up and algorithms taken from graph theory or operations research are used to find optimal routes [46]. An implicit assumption in this is that *optimal* has the same meaning for all stakeholders, e.g. minimizing travel time. So the travel planer can use a common graph for all requests and generate look up tables to guaranty short answering times.

This is not suitable for a group of travelers having constraints in using vehicles, vehicle types or particular stations for health reasons. Since most of those people are not able to drive a car on their own, making public transport available opens them a way to get more personal independence. Therefore in *mobile* a system was developed that allows undertaking personal constraints in route planning. Therefore a system that describes vehicles, stations and personal attributes of mentioned travelers was developed. This allows generation of a second graph representing the public transport network not in dimension of time and costs but in preferences and dislike of a given traveler. This second graph is overlayed the standard graph to get a personalized graph that allows finding a suitable route respecting the constraints of the user.

5.1 Investigation Area

About 28 million people use the public passenger transport in Germany daily, this shows the good acceptance of a well meshed traffic system. The Verkehrsverbund Rhein-Ruhr (abbreviated VRR) is the public transport association covering the area of the Rhine-Ruhr conurbation in Germany. It was founded on 1 January 1980, and is Europe's largest body of such kind, covering an area of some 5,000 km^2 with more than seven million inhabitants, spanning as far as Dorsten in the north, Dortmund in the east, Langenfeld in the south, and Mönchengladbach and the Dutch border in the west [47]. Since this infrastructure is already established this area is a good place to justify investment to open this service for people which are not able to use it today. And the dense mesh provided by the companies running VRR is the perfect area to introduce a system that provide support for disabled people with means that support them during traveling in public transport systems [45, 48]. Especially, the local transportation system is addressed where a mixture of different transportation means (e.g., bus or tram) are used. As a result, the major problem is to support people while changing vehicles.

During the first assessments within the project, it came out that a major problem of the people is lack of information and a proper handling of uncertainty. As a result, a major goal of the project is to…

- …provide the traveler with routes that meet their individual capabilities, restrictions, needs and preferences; this covers a wide range of issues like avoiding overcrowded buses, inability to uses stairs, inabilities to use complex bus stations etc.

- …provide travelers with timely information about their current schedule (what happens next, when to leave the vehicle, how much time is left until the connecting vehicle arrives, etc.)
- …help people locating themselves, especially with respect to bus stations or other locations important for the current journey; this especially addresses identifying the right bus station on the appropriate side of the street or within a complex bus terminal station
- …identifying transportation vehicles in order to decide whether or not to enter a vehicle; this must be done in a way so that the traveler is sure that he enters the right bus or tram
- …inform people when to prepare and when to leave vehicle during a trip
- …identifying stressful situations to the traveler and calming down people when needed

This findings lead to three problems to solve: (i) The actual advice generated by the system must be customizable to match the individual needs of the traveler and (ii) presentation and interaction with the system must be adaptable to user's capabilities and to ensure this (iii) system needs to know very precisely where the user is. All problems are addressed in project *mobile* e.g. by indoor-navigation [49, 50] or personalized user interface design [51, 52]. For the functions that needs to be incorporated into an ATMS we focus on how the back-end system can generate personalized advices based on the current traffic situation and road maps.

The people within the target groups that are addressed in this projects differ significantly with respect to their capabilities and needs. In general two major groups are addressed: people with mental problems and people with physical disabilities.

The group of mentally restricted people suffer from a wide range of problems that start from intellectual restrictions like illiteracy or in-capabilities of dealing with concepts of time. These people need a strong support and a user interface that especially addresses their deficiencies. For example, speech output or simple graphical symbols must be used if the traveler cannot read. On the other hand, there are also people that e.g. are capable of using a smart-phone without any problems but may be easily distracted. As a result, special means are needed to draw their attention towards the current travel related issues.

For the group of physically disabled people, we especially address temporary restrictions (e.g., caused by the surgery). For these cases, people that usually travel by their own car are temporarily forced to use public transport and often suffer from a lack of knowledge and training how to use public transportation. As a result, information about where to reach the next bus station, which vehicle to enter and when to leave are the major aspects that are to be addressed.

5.2 Personas and Characteristics

To allow describing the characteristics of infrastructure and users an attribution system was developed. There are five kind of entities that can be described by attributes, while the attribute value may vary depending on the time of day, the day of week or holidays:

1. **Users** have different needs and preferences that can be expressed by attributes assigned to this user. To allow dealing with different type of users so called *personas* where defined. This method taken from User Experience Design allows description of typical users an their behaviors in order to have a better understanding of the needs during development without referring to real persons [54]. Users have Tolerance settings describing the user's tolerance to *route changes*, *idle time along the trip*, *crowded areas*, *noisy surroundings* and *visual contact with other people*. *Movement* settings describing the user's motoric capabilities which includes the *walking speed* and *endurance* as well as the ability to take *steps*, use *escalators* or *elevators*. This includes also the demand of the user to get a *free seat* or *special places* at stations or within transport vehicles.
2. **Vehicle types** have different attributes describing the way a special type of vehicle can be used, e.g. a low floor bus can be used by wheelchair users, while a common bus cannot be used. So the most important attribute of vehicle type are *height*, *width*, *steps* and *existence of special places*.
3. **Vehicles** have different attributes describing the way a particular vehicle can be used. Some buses may have identification support, while other don't. In this case users that are reliant on vehicle identification support are not able to use this vehicle.
4. **Stations** are the nodes in the network having different attributes describing the way they can be used for start and end of travel or during changing vehicles. In terms of personalized route planning the most important attributes describing a station are *steps*, *daylight*, *security* and *load*. The existence of steps without an elevator makes a station unusable for wheel chair users. *Daylight* and *load* has to be added to cover needs of users having mental problems and may panic in crowded stations or vehicles or on using an under-bridge. *Load* attribute dependents on time of use. Since most of the users in our target group are defenseless the attribute *security* became very important during travel planning.
5. **Links** between the nodes are the traffic lines used by the user during traveling a calculated route. In terms of personalized route planning the most important attributes describing a link are the *load*, *security*, *costs* and *speed*. While *costs* and *speed* are usual attributes in route planning, the *load* and *security* has to be added to meet user's requirements (see above).

To allow easier management of attribution of entities a class system was developed it consists of:

- **Persona** describing a stereotypical user which is similar to real passengers [54] and are constructed with different behaviors, profiles and objectives. A persona does not correspond to a real person, but represents a typical user, which is composed of different features and behavior. Inside the system every user is composed of the different behaviors of persona, where specific needs overwrite the attributes of the assigned persona.
- **Infrastructure Elements** are all elements in the public transport system, like Vehicles, Vehicle Type, Lines, Links, and Stations etc. Those element provide facility for given needs, therefore the Infrastructure Elements are designed as a complement to Persona.

- **Classes** of Persona or Infrastructure Elements incorporate entities with similar attributes, this allows easy management of descriptions by implementing classes of stations (main station, hub, terminal, etc.) or disease patterns.

5.3 Dimensions and Penalty

To allow comparison of routes and find a suitable route for a user a penalty system was developed to overlay the speed and cost optimal routes with the needs of the user. To calculate this weighted route efforts each infrastructure element used in a route is loaded by a user specific penalty summand (e.g. stations) or a user specific penalty factor (e.g. links, vehicle use). In reality not all attributes for stations and users are available since some of them may not be suitable or not gathered. Therefore a system that allows flexible calculation based on the available information was developed. All attributes are normalized and ordered in dimensions. E.g. the need of a user for an elevator instead of stairs and the existence of an elevator in a station are the same dimension. Inside a dimension the attribute values are normalized, like shown in Table 1.

The system to calculate this weights works in four steps:

- Determine the specific descriptions of user's needs from Persona, Class of Persona and personal settings.
- Determine the specific description of possibly used infrastructure element.
- Calculate a penalty factor on usage of each possibly used infrastructure element.
- Calculate the route efforts while using weighted speed and costs.

Determination of the specific attributes and values for a user is done by collecting values for each dimension from the class system, by the following algorithm: Starting with personal record, if dimension attribute is set take it, go to next dimension, if attribute is not set go on with the record of the class this record is based on. Reaching the root class without getting an attribute means this dimension is not described for this user. Figure 2 show determination of attribute values.

Table 1 Normalized values for attributes

Value	User	Infrastructure element
−8	Try to avoid	Very hard to use
−4	Strong do not like	Hard to use
−2	Do not like	Inconvenient to use
0	No special need	No special service
2	Nice to have	Provide service
4	Recommended	Special facilities to provide
8	Strongly recommended	Perfect
1000	Hard need	–/–

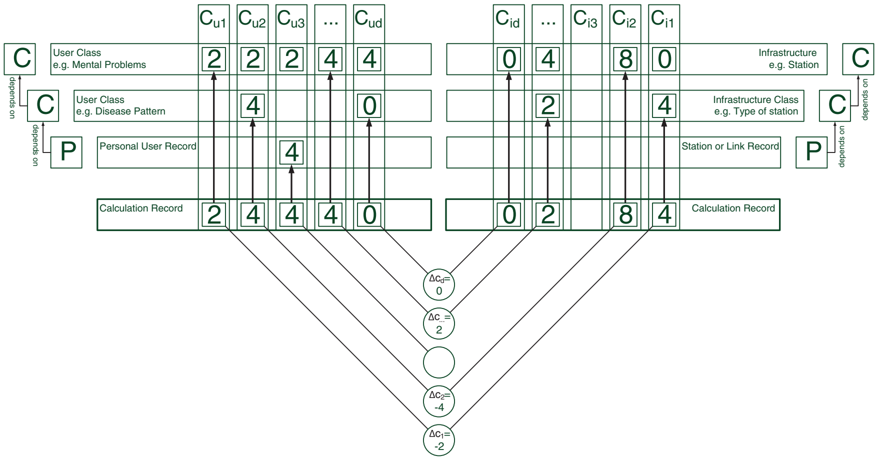

Fig. 2 Using class system to determine user and infrastructure element specific attributes

Determination of the specific description of an infrastructure element follows the same algorithm using the records of infrastructure description.

Calculation of penalty factor p_{ui} (User u uses infrastructure element i) for n determined dimensions is done by calculation of the normalized distance in $\mathbb{R}^n$, as shown in Eq. 1 the distance in dimension d (Δc_d) is calculated by the difference of the user attribute in dimension d c_{ud} and the infrastructure attribute in this dimension c_{id}. The normalized weight factor is calculated by Pythagoras and normalized by division by maximal distance in the given dimension (see Eq. 2).

$$\Delta c_d = c_{ud} - c_{id} \tag{1}$$

$$p_{ui} = \frac{|\Delta \vec{c}|}{\left|\Delta \vec{c}_{\max}\right|} = \frac{\sqrt{\sum_{d=1}^{n} \Delta c_d^2}}{4\sqrt{n}} \tag{2}$$

Calculation of the route efforts usually is done by minimizing two aspects speed (time consumption) and costs, where most route planers use travel time as a target dimension and add the cost as an informational aspect. This use case travel time use used as a target dimension as well. This lead to the need to convert the penalty in time to get a have a value to minimize. Since getting penalty factors from the steps above, a weighted travel time can be calculated. Therefore all time consuming usages of transport vehicles are multiplied with the specific penalty factor for this user and vehicle and the usage of static infrastructure elements like stations is considered by adding a summand that is calculated by multiplying the penalty factor with a user specific constant.

$$t_R = \sum_{x=1}^{m} t_{vx} + \sum_{x=1}^{0} t_{sx} \tag{3}$$

$$t_{uR} = \sum_{x=1}^{m} p_{ux} t_{vx} + \sum_{x=1}^{0} (t_{sx} + p_{ux} w_u) \qquad (4)$$

Equation 3 shows the calculation of time consumption for a route (t_R) as a sum of time using m vehicles (t_{vx}) and waiting/change vehicles at o stations (t_{sx}). Equation 4 shows the calculation of user specific weighted time consumptions (t_{uR}) using calculated penalties (p_{ux}) and personal (user specific) weight factor (w_u). During route planning both has to be used since the planning of change vehicles has to be done with real travel time and not the weighted travel time.

5.4 *Challenges in Bringing Overlays to ATMS*

Adding additional scales to route planning causes generation of user specific graph. Therefore a new algorithms to calculate optimal routes needs to be developed. Today's algorithms assumes travel planning data is common for all users and the target in being time efficient is the same for all users. So in terms of minimizing data storage and computational time a common graph is kept for all request. New algorithms has to consider that travel planning is finding an optimal route respecting personal circumstances.

6 Using Simulations in Prediction of Traffic State

One of the most important steps in delivering mobility is to predict the state of the traffic as well as the prediction of the state of transport system in urban area. Based on these predictions a decision making process is set as a main process having the role of providing the mobility services for citizens and freights. ATMS as an autonomic system has to focus on this type of prediction for internal decision making model and a simulation environment has to be defined internally.

6.1 *Model and Simulation Environment*

At this moment the decision making process related to traffic and transport systems has an important component based on various software platforms which permit to model the traffic state as well as the state of transport systems. The chain of using models as tools for prediction is shown in Fig. 3.

The elaboration of a model is an activity which is based on two categories of inputs: the existing models and experiences, as a reference for a model, and information from traffic a transport systems, this category forms the nucleon of

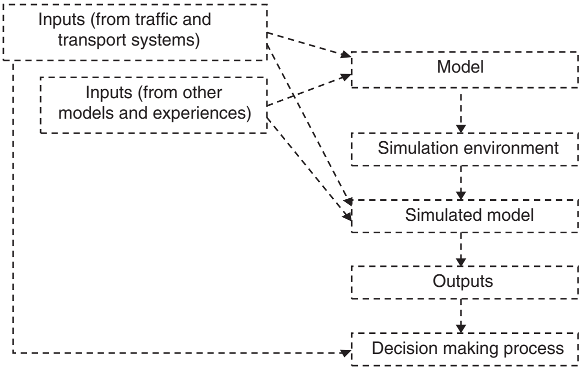

Fig. 3 Simulated models as tool for decision making process

the model (based on this information a model is elaborated). After the elaboration of a model the elaboration of a simulated model in a simulation environment is needed. This simulated model is created based on software platform which is able to facilitate the usage of the model to create various scenarios based on traffic and transport inputs. These scenarios could support in an efficient manner the decision making process.

6.2 Simulation Environments

A simulation environment is a set of tools and simple models which is able to support the construction of complex models [55]. The majority of existing simulation environments are developed based on software platforms.

Today's software platforms[2] are able to create an environment for traffic and transport models and the following functionalities are built in:

- **Analysis of transport demand**—based on the 4 step model [60] (trip generation, trip distribution, mode choice, route choice) this analysis is the first step in providing mobility services, and the system has to respond to this demand. The 4 step model is shown in Fig. 4.
- **Network modelling**—modelling of various transport systems, modes of transport, user classes in the context of transport network as well as sub-network generation.
- **Public transport assignment procedures and operations**—several examples of functionalities are: timetable-based assignment, headway-based assignment, line blocking, modeling complex fare systems in one model, line costing calculation.

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[2] Examples of today's software platforms for creation of models in simulation environments are: Visum/Vissim [56], TransCAD [57], CUBE [58] and Aimsun [59].

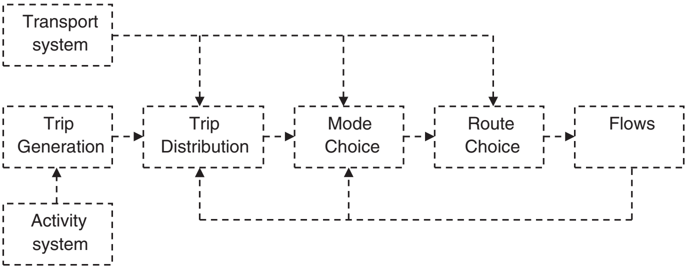


Fig. 4 Four step model for analysis of transport demand

- **Private transport assignment procedures**—convergent and fast assignment procedures, simultaneous assignment of several user classes, as well as static and dynamic assignment procedures.
- **Traffic engineering**—node impedance calculation, coding of various signal control, signal optimization for green time, cycle time, and offset time.
- **Analyses, reports and interfaces**—scenario comparison, matrix histograms, flow bundle calculation, interactive shortest path search, isochrones, environmental analyses (noise, emissions), analysis of accident data.

6.3 Integration of Simulation in ATMS

All decisions are made based on models and the decisions in ATMS has to be taken in a self made manner (the operator as decision maker is replaced by the subsystems of the system).

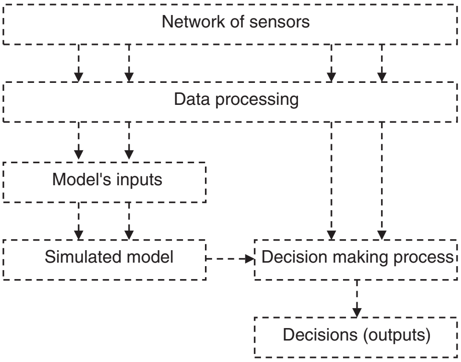
The autonomic system has to use the simulation environments in its internal decision making process and to model the traffic and transport system to do the self-* properties without any external intervention. The functionalities of a software platform could be integrated as main part of decision making *"brain"* of the system.

In an autonomic traffic management system a hybrid simulation is able to be implemented as a combination from a classical simulation approach and some real components of the system [61, 62]. The system is able to self configure the model for simulation using real or simulated components depends of the level of hybrid simulation selected:

- **level 1**—one simulated component and multi real components;
- **level 2**—multi simulated components and multi real components;
- **level 3**—multi simulated components and one real component;
- **level 4**—only simulated components are taken into consideration in the simulated model.

The integration of simulation of models in ATMS is shown in Fig. 5.

Fig. 5 Integration of simulation in ATMS



The ATMS system collects autonomous data from sensors, processes this data and provides information/inputs to a model and creates a simulated model based on internal software platform. Information/outputs from the simulated model are transmitted to decision making process and ATMS is able to emit decision inside of the system.

7 Architecture of ATMS

A high level architecture of the autonomic transportation management system (ATMS) is given in Fig. 6. The system includes the overlay network that connects all service providers and sensors in the field and a backbone build on this network. There are different type of back-end components providing simple or more complex services to the system resp. the users.

In detail the system incorporates the following components:

- **Sensors** providing the data from the field as a base for all decisions made in the system (Sect. 7.1)
- **The overlay network** collects and transports the required data from the sensors and between the other component in the back-end (Sects. 7.2 and 7.3)
- **Broker components** to find services in the network and orchestrate them to get higher level services (Sect. 7.7)
- **Data providers** providing access to data stored in data bases or made by forecast (Sect. 7.7)

Using this general approach allows later implementation of services that are not known today to fulfill future requirements without re-implementing the infrastructure by simply including new types of components to the system.

Today's common approach to reduce complexity while implementing a distributed ICT is splitting up functions to different components providing this functions to other component in a defined environment. This means the functions provided

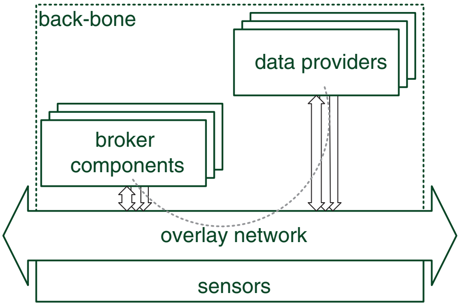


Fig. 6 System Architecture: service providing components connected by overlay-network

to and consumed from the system are seen as services, where the infrastructure has to ensure that services can be found in the system and can be called by other components. Usually this is done by implementing different components in a way they meet a contract/service description resp. implementing an interface and so can be replaced by alternative implementations. To allow service consumers finding a suitable service provider services and their instance are listed in directories called service registry and can be found using a lookup function provided by a service broker [63, 64].

The most common understanding of services in this so called *service oriented architecture* (*SOA*) is treating the service layer as a set of functions callable from different systems. These calls are e.g. handing over a process to another system, using a software component to do some calculations, get information from a database etc. On implementation level this lead to the limitation, services do provide functions a service consumer can call and get some result. Today's very popular implementations of SOA using web services shows this concept. In fact most people use web service and SOA as synonymous.

We extend our earlier work [26] and propose an ATMS architecture as depicted in Fig. 7. The figure shows that the ATMS back-bone has the general structure of a distributed system. The separation between vehicles as moving parts and infrastructure as the fixed parts is common. On both sites different information like data about the current state (mainly collected by sensors) and plans (input by users and operators) are collected. Based on this information it is possible to derive control factors for the overall system. Therefore, this information must be brought together and evaluated. Therefore a general subdivision of communication in vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) is commonly used. The main goal of the overall system is fulfilling the plans of the users (road users, public transport users and traffic system operators) while minimizing the number of resources. Based on the aggregated data both the infrastructure and the vehicle make predictions on the future state of the road and make local or global decisions. Figures 7 and 8 gives some examples of modules that interact through the ATMS Backbone. The number of direct interactions between components is minimized since interaction shall be done using data aggregation provided by the backbone. As seen in the figure the plans of infrastructure provider are to optimize the utilization grade of the

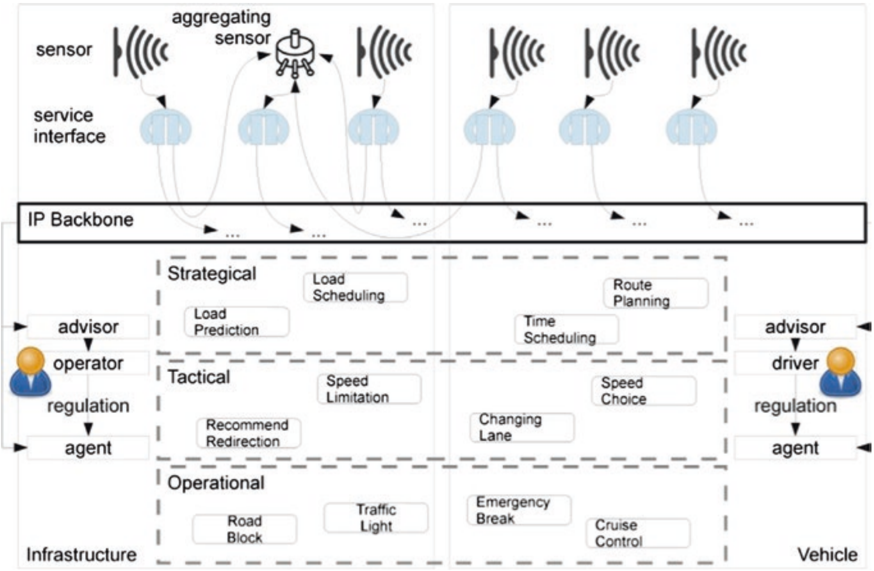


Fig. 7 Skeleton of the network including two sites (infrastructure and vehicle) a backbone and a set of data providers/sensors implementing the same interface

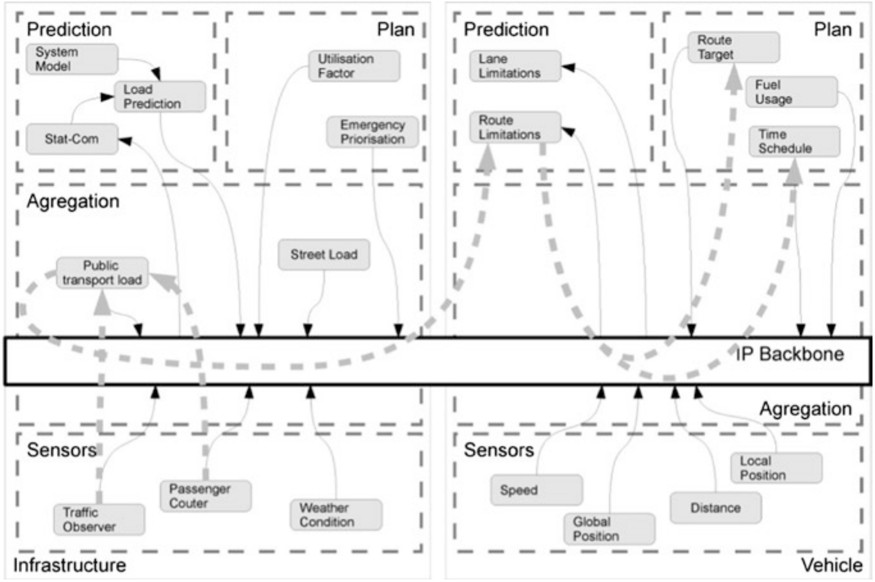


Fig. 8 Aggregation of data provides higher level information to allow better predictions (derived from [26])

infrastructure and allow emergency prioritization on demand. Therefore simulation models of the overall system (including vehicle behavior, see Sect. 6) and a statistical component using (e.g.) simulation or machine learning (Stat-Com) are used to generate a load prediction for all street sections. This prediction engine has learned from the past and is fed by the current state of the overall system provided by the sensors plugged into the network. The load prediction is provided to other users of the system and is used by the components on the vehicle site to derive local decisions. All information providers (sensors, aggregating sensors, prediction components, etc.) implement the same service interface, so every stakeholder can get this information to optimize local decisions.

On vehicle site we have individual plans like reaching a route target, saving fuel and time. Those plans influence local decisions. By providing this plans to the ATMS the prediction of the infrastructure gets more precise. As an example for local decisions on vehicle site the choice of speed, lane and route can be named. Those decisions will be made on the basis of the local prediction of Lane Limitations and Route Limitations. For example reducing/increasing speed might be reasonable if the best route has limitations that will be gone/arisen sometimes later and an alternative route is not suitable.

In order to allow all these predictions, information about the current state has to be collected from the field. On the infrastructure site these information are collected by internal sources like traffic observers but also external sources like weather conditions (including forecast) or passenger counter from public transport systems. On the vehicle site information about the current state like speed and global position and information about environment like local position (lane, direction) and distance to other vehicles are collected to allow having a proper model of current situation, e.g. traffic load.

7.1 Incorporation of Sensors

The 1st important aspect in establishing an ATMS is establishing a system gathering information about the field in this case the load of roads or other transport systems. We propose to establish this as a corporative ICT system [65]. The corporative ICT architecture was introduced in [66] and this section shows how adapting the principles of this architecture could be used to establish a base of an ATMS.

7.2 Requirements on Overlay Network

The first requirement for incorporation of sensors is on the communication network level. Technologies chosen has to allow exchange of traffic information between system components from different vendors in a kind of open peer-to-peer (P2P)-system. Users can join and leave the network at any time. The components of infrastructure assume different roles than those of vehicles. Such kind of asymmetrical P2P systems are already sufficiently investigated (compare [66]), therefore the challenges to the system design can be easily derived. Following already known problems from peer-to-peer-systems must be considered in our use case named in [26]:

- **V2V trust:** In P2P-Systems information is provided by every peer. Therefore the peers need an internal model of evaluating the trustability of the provided information.
- **V2I trust:** Infrastructure provided by local authorities may help solving the problems of trust by providing mechanisms for collecting and verifying information and prognosis.
- **V2V pollution:** A common problem in open P2P-Systems is so called pollution [53, 67], where malicious peers may send manipulated data to affect the overall system and change its behavior to earn a benefit or just to create confusion.
- **V2V/V2I anonymity:** In contrast to the requirements on trust the road user requires a level of anonymity that ensures individuals are not tracked by authorities or other parties. Especially in case of transmitting the user's plans via the system to prediction engines privacy is a recommended function.

Main problems of trust and pollution within an urban system with dense infrastructure can be solved, at the cost of increased communication latency, by allowing only direct communication between vehicles and infrastructure and establish a pseudo V2V communication via infrastructure covered by state of the art mechanisms from cryptography like local, user and manufacturer certificates and derived signing protocols. As a result a structured P2P-Overlaynetwork is formed. The problem of anonymity cannot be solved easily in those kinds of networks. In principle confidence in transmitted data respectively information depends on the sender's credibility and therefore an authentication is required or in other words: *If I should trust you, I need to know who you are.* From that follows that motion profiles of vehicles and hence people are possible. Within urban system with high amount of traffic, those problems may be solved by temporary identities and a net of trust, like proposed in [53]. While the information of different road users are matched to get a confident picture but in general all structured P2P Networks are vulnerable to trojan behavior and sybil attacks [68]. Therefore a deep analysis of the system is strongly recommended before an industrial application.

Further requirements and problems arise while considering the more detailed architecture shown in Fig. 8. Decisions made by road users and operators can be assigned to strategic, tactical and operational level. The decisions refer to different time horizons between long-term planning (strategic), medium-term behavior (tactical) and direct action/reaction (operational).

Figure 8 shows some examples for actions respectively decisions made at three different levels:

- **Load Scheduling and Load Prediction** are methods on strategic level allowing the operators to predict the traffic flow and optimize it using scheduling mechanisms.

- **Speed Limitation and Recommend Redirection** are functions on tactical level allowing the operator regulating the behavior of road users by or defining rules like temporary speed limits or giving advice to selected users to avoid overloads.
- **Block Road and affecting Traffic Lights** are functions on operational level allowing operators to control traffic flow directly. This can be used to ensure emergency privileges or prioritize selected lanes or roads to ensure traffic flow.
- **Time Scheduling and Route Planning** are methods on strategic level allowing road users to find optimal way fulfilling their traffic requirements. Time scheduling describes choosing time slots outboard the rush hour if possible. Route planning describes planning the route to minimize the time or distance. During the ride this is related to the operational level where adaptive route planning may use the recommended redirection to change planned routes.
- **Speed Choice and Changing Lane** are methods on tactical level, where drivers chose an adequate speed to avoid being at known traffic hot spots on the route during rush hour or choose the lane they expect to have less incidents in traffic flow.
- **Emergency Break and Cruise Control** are functions on operational level that describes reaction on the surrounding traffic. Emergency break is a reaction on suddenly appearing episodes. Cruise control describes adapting suitable speed from other road users respectively their personal speed limit to reach an optimal traffic flow. Today's approaches on this are described by the term Connected Cruise Control (CCC) [34].

In longer perspective vehicles will have more autonomous functions and more decisions will be made by local or centralized decision engines. As in every situation all decisions on longer term issues have to be made on the basis of insecure data and a look at the list of functions and decision listed above shows most of them are safety critical. Therefore the main objective of an overall system must be to provide and verify necessary information as early as possible and to provide appropriate methods of prediction on future conditions. Personalized mobility includes many other actions which are not illustrated in Fig. 8; for example multimodal journey planning, personalized mobility for disabled etc.

7.3 Setup of Overlay Network

On the basis of existing research approaches like [66], a general architecture for ITS to derive requirements for future vehicles and to identify issues can be developed, a detailed description of this architecture can be found in [26]. In general ITS backbones has to be considered as distributed ICT systems following the principles of p2p system, dealing with all benefits and problems of these systems emerging from heterogeneous user group, heterogeneous devices and the leak of confidence and reliability resulting from the fact everybody can join and leave the system at any time. As mentioned above today's understanding of developing distributed ICT is developing service providing components following the so called service oriented architecture (SOA). In this concept every component like data storage, computing facilities, and algorithms is seen as a service. So different software vendors and hosting providers are able to offer their various products in a common run time environment or as a software product. Users benefit from this, because of having a choice to find a product fitting their needs.

Usually the different components are implemented as services meeting a contract or service description by implementing an interface and so can be replaced by alternative implementations. To allow service consumers finding a suitable service provider services descriptions and service instances are listed in directories called service registry and can be found using a lookup function provided by a service broker [63, 64].

To allow integration of traffic sensors and other data providers (see above) in a SOA environment and providing capabilities of continuous data processing we prefer using a pristine definition of service orientation that allows understanding **data providers as a service**, allows definition of data processing chains and so allows providing current data to decision engines in almost real-time way. These services and the network need to follow these principles:

- Consumers shall be able to subscribe/unsubscribe to data collected by a sensor or any other data provider
- The sensor or data provider as a service shall emit collected data on registration or a level of change
- The network infrastructure shall transport collected data to subscribers in a fast and reliable way.

Based on this principles we propose the definition of a service interface for a general data provider. That has to be implemented by sensors, data bases and forecast modules. In the field we can classified basic data providers (e.g. sensors to provide traffic characteristics, mobile phone sensors, environmental sensors for GHG/ CO_2), context data providers (e.g. to detect a user context, location etc.), and information and knowledge providers (e.g. to detect relevant information from the environment for the user personalized mobility, to gather/search specific and relevant information, through participatory sensing, crowdsourcing etc.). On this base we define a new sensor type the aggregating sensor, these sensors collect information from other sensors locally and provide a higher level of information, e.g. combination of several axle counters generate information about the load of a street section.

Other components like prediction engines also implement this interface and provide their results as data to the network. Figure 8 shows how this aggregation work on different levels of data acquisition and consumption. Since sensors and any data providing component are encapsulated as services this components can be changed easily without effecting the overall system. There is also no need to implement different kind of data consumers since basic sensors, aggregation sensors and all other components provide the same interface (see. Fig. 7 upper half).

7.4 Corporative ICT System

Since all data is available in the network this setup allows implementation of local decision engines, but since every stake holder or network member may provide data and the members join and leave the network continuously we found to the following requirements to the backbone

- Local decision engines has to be enabled to find the data they need respective the providing component
- Local decision engines has to be enabled to judge the received data as reliable.

These requirements and the main problems of trust and pollution within an P2P system can be solved, by using the concepts of corporative ICT system [66] that are fulfilling these requirements: the *service self-description*, the *service discovery*, the *service assessment* and the *asynchronous routable function call* with its extension *subscription call* allows to build up a system meeting the described requirements. We can give only a short description here for further details refer [66].

7.4.1 Asynchronous Routable Function Call

Asynchronous Routable Function Call in the sense of corporative ICT architecture means calling a service without getting the answer as a response. Figure 9 illustrates the difference in calling concepts. The *direct call concept* says the service provider sends the answer as a reply to the request immediately. In practices the lower layer data connection is kept to carry the answer. The *polling call concept* says if the service provider need more time to provide an answer it replies a Nop (Not operated). In this case the client try to get the answer by sending poll requests. If request is not processed it returns a Nop otherwise the answer is delivered. The *asynchronous function call* means the client sends the request without expecting the result immediately and the service provider send the answer to the client after processing the request without

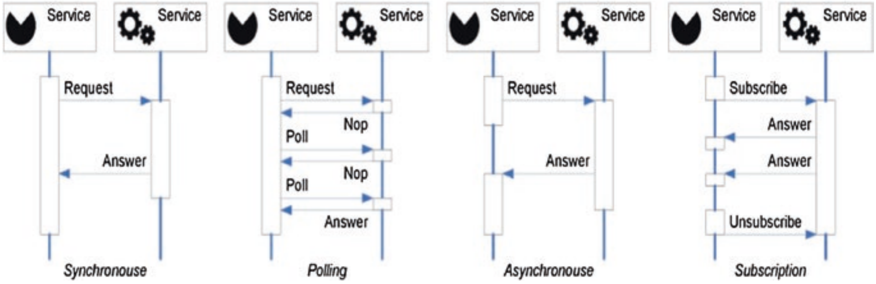


Fig. 9 Illustration of direct call concept, polling call concept, asynchronous routable function call and subscription call concept

any further polling. This concept presupposes an end to end connection and this concept allows also sending an answer from a service provider that was not called. Thus a routing of requests can be established.

7.4.2 Subscription Call

The *discovery of services* in corporative ICT is done by an overlay network established on top of the physical network. Combining the described routing of calls and the capability to send 'answers' to any client lead to the concept of *Subscription Call*. This call allows clients to subscribe to needed information. So the data provider can send the current data in given time intervals or on any change. In case the data provider has to leave the network. The subscription is handed over to the next suitable node given by the protocol of the underlying DHT.

7.4.3 Service Discovery

The *discovery of services* in corporative ICT is done by an overlay network established using a distributed Hash Table (DHT). On accessing a service the Service Discovery component identifies nodes offering this service. The client creates a message defining the required information and subscribes to this node. If this node is not able to fulfill the requirements the request for subscription is passed to another node that is selected by the protocol of the underlying DHT (see Fig. 10 steps 1. to 5.).

7.4.4 Service Assessment

Since data providers are made available by different stakeholders the data may be not trustable. Corporative ICT systems use the concept of *service assessment* to solve this problem. Therefore each node provides a *service self-description* and each node is assigned to different trust zones. Based on this the client can calculate a level of trustworthiness, details on this can be found in [66]. Since infrastructure will be provided by public authority the corporative ITS will be a hybrid-P2P, where so called super-Peers will have a higher credibility and provide core functionality.

7.5 Fault Tolerance by Local Intelligence

Fault tolerance can be reached by implementing local intelligence. This means placing decision engines for operational and tactical decisions close to the actor [26], because this allows actors in the system being autonomous, so they are able to act, even if parts of the overall system are gone.

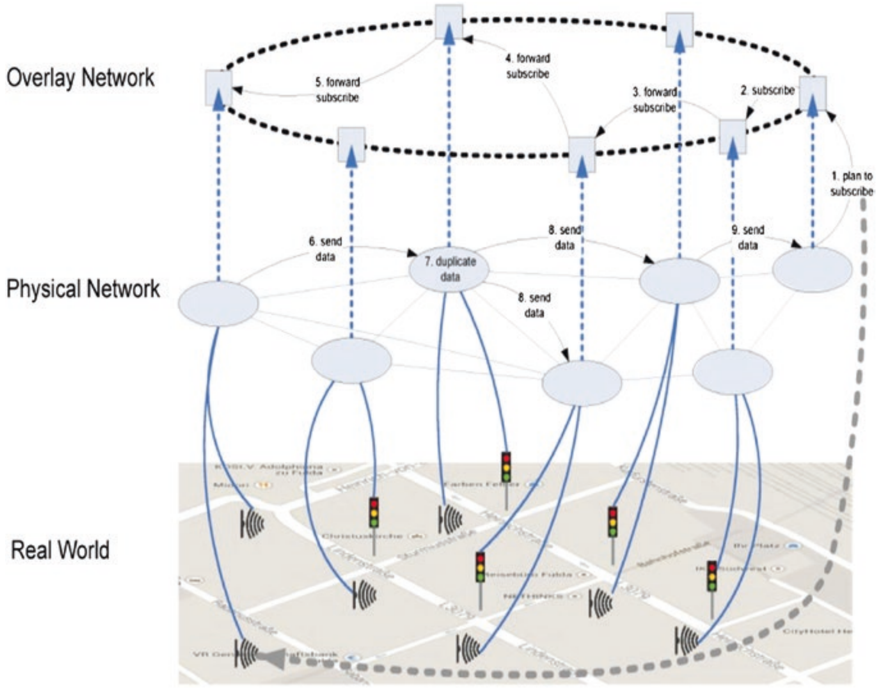


Fig. 10 Service discovery by routing subscription request through overlay network, data distribution by using multicast of the IPv6 network

In our scenario this means vehicles, traffic lights etc. should be able to gain all information they need to make proper decisions. To ensure the function of the overall system some supervising nodes may overrule this local decisions but in case these are not longer available or in case of danger the local decision engine takes over. Since the different components of the system will be produced by different vendors the data transport has to be done in a standardized way (see Sect. 7.6).

7.6 Network Layer

To ensure a simple and fault tolerant transport and distribution of information and easy integration of components from different vendors. We propose a network based on IPv6, this protocol has three features ensuring a simple, safe and lightweight way of data transmission meeting the described demand:

- **First** of all IP is designed to establish networks between components from different vendors, it is a well accepted standard and allows integration of new transmission technology without need to change software stack.

- **Second** IP is designed to ensure data transmission using different routes at runtime, this allows using IP in an environment where the network topology is changing. Today's IP-network components are able to reconfigure routing if a network link is gone or a node is offline.
- **Third** feature of IPv6 allowing data transmission for our purpose is *Multicast*. Multicast allows sending information to many receivers. These receivers need to subscribe in a reserved address range. Infrastructure is able to route and duplicate data packages to ensure multicast without wasting bandwidth.

Using IPv6-Multicast allows using several functions that are helping establishing a reliable communication backbone for distributing data in the system. Figure 10 steps 6. to 9. shows data distribution using multicast in combination with the concept of *asynchronous routable function call*. In fact only using multicast allows scaling the concept of *Subscription Call* in a way that does not overload the physical network.

To ensure reliability on physical layer we propose the installation of a physical backbone that connects all components of infrastructure, this fallback network should be connected to the public internet via several gateways to allow transparent routing. Using this setup allows other stakeholders like logisticians, individual drivers, autonomous vehicles, pedestrians etc. to subscribe the sensor data to feed their local decision engines.

Using IPv6 multicast allows integration of different components from different vendors. Since current standards in networking in public transport and traffic management are based on IP (e.g. [69]) this will be a good approach to reuse current infrastructure.

7.7 *Data Broker and Data Provider*

Based on this setup the data brokers just provide the entry points to a DHT routing on a given service resp. information. These entry points shall be placed in thephysical fallback network, owned and operated by public authorities to have thehighest credibility. For the data providers we can determine two different typesusing the same technical base but having different levels of credibility. The dataproviders owned by the system users or company will provide detailed information about small sector of the field. Data providers owned and operated by localauthority may implement the concept of aggregating data provider and provideinformation about a wider sector or the whole system.

8 Conclusions and Future Work

Using the described methods and concept allows establishing a P2P-Overlay Network on the current networks. The chosen approach using industry standard IPv6 with transparent routing and multicast allows easy extension of this network to public to allow users joining the network using their personal device, like a smart phone or a satellite navigation system of a vehicle or future personal devices that be carried by the user or will be fixed at a place or vehicle. Beside the personal devices the components of infrastructure like traffic management systems, traffic light systems, trains and the data management systems of service providers like public transport provider, taxi associations and others can be integrated in the overlay network easily.

8.1 Further Steps to Establish a Corporative ATMS Network

Since ATMS are very heterogeneous future system will be asymmetric and follow the described approach of corporative IT-Systems [66], which allows using the service oriented architecture on basis of a P2P Overlay-Network. To define and standardize the architecture of future system the following tasks will be needed:

- **Standardization of sensor profiles** that allow choosing proper sensor for current demand
- **Standardization of data provider profiles** that allow choosing proper sensor for current demand
- **Standardization of the overlay network** including protocols to enter and leave the network, provide and consume data/information by subscribing sensors/data providers that respects privacy
- **Standardization of the services in network** including definitions how to exchange location data and types of information.
- **Standardization of the quality of service levels** to ensure a common understanding of the trustworthiness of processed data. This includes definition of services, service levels, zones of trust to allow calculation of trustworthiness while component from different vendors are used.
- **Standardization of *on board units*** that establish network connectivity and implement the mentioned protocols.
- **Integration of *on board units*** with the current assisting systems and definition of a common accepted user interface to advice drivers.

Beside this the functions and interaction mode of current infrastructure need to be enhanced, the prediction systems and their runtime environment needs to be developed and standardized and the legal aspects has to be considered related to the current law and its advancements.

Following this track ATMS can make a contribution in making car traffic more efficient and sustainable and take a step to develop smart cities.

8.2 Conclusions

The upcoming mega trends smart cities, personalized medicine and personalized production by industry grids/industry 4.0 cause a wide range of new requirements on transport that can be solved by establishing smart transportation using autonomic traffic management systems to provide personalized mobility and goods transportation. Beside this these kind of systems will help to utilize public transport for disabled people allowing them to get more self-determination and help supporting elder people which will become important considering the demographic change and may be the next step towards so called Smart Cities that provide smart and personalized services to inhabitants [50, 52].

This is the key to social and economic sustainability in smart cities. Smart cities will be driven through advanced complex ICT systems that harness the power of data collected from distributed network of sensors in order to provide personalized information and services to its consumers under sustainability and other constraints. In this contribution we gave an overview on how to set up an autonomic transport management system (ATMS) that provides personalized mobility services to its users in a smart city setting. Next steps are forcing standardization of sensor networks as described in Sect. 7.2 and create a common understanding which parts of the system shall be provided by public as a smart cities infrastructure and which parts has to be provided by private stakeholders establishing business cases on top of this. Beside this the functions and interaction mode of current infrastructure need to be enhanced, the prediction systems and their runtime environment needs to be developed and standardized and the legal aspects has to be considered related to the current law and its advancements. Following this track ATMS can make a contribution in making transportation and travel more efficient and sustainable and take a step to autonomous traffic that allows even more efficient traffic management, and personalized mobility services. Beside standardization there is a need for further research, e.g. in developing computing algorithms that are personalizable as well as scalable. The current approach needs one overlayed graph per user, which is not feasible, since the amount of data for the time table is very huge. So the next step is optimizing the algorithm to allow separation of route planning and route evaluation to allow implementation for a wider user group.

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Increase of City Transport System Management Efficiency with Application of Modeling Methods and Data Intellectual Analysis

Irina Makarova, Rifat Khabibullin, Eduard Belyaev and Vadim Mavrin

Abstract To provide transition to "green economy," it is necessary to increase the safety and reliability of transport system using Intelligent Transportation Systems. The modern intelligent transportation systems implementation requires communications, command, and control designed originally in vehicles and infrastructure. This paper makes the decision by perfecting vehicle and infrastructure of the transport system. A different way is to use rational management decisions based on the received real-time information. The paper also offers methods to improve the efficiency of the urban transport system.

1 Introduction

Positive changes in shape of world transport in 21 eyelids are accompanied by a number of negative consequences to which number growth of power consumption and negative influence on the environment, constantly growing delays of people and freights on all means of transport which are connected not so much with an objective lack of transport infrastructure capacities, how many with low level of transport streams organization and management belong. Scales and the importance of these problems are estimated as strategic calls national and even continental scale.

All these negative consequences contradict the principles of a sustainable development which the commission of the UN on a sustainable development defined as the society development, allowing to satisfy requirements of present generations, without causing thus damage to the opportunities left in inheritance to future generations for satisfaction of their own requirements [1]. The commission of the UN also defined various aspects of a sustainable development ensuring principles, among which major—the principles of territories sustainable development as the urbanization is one of the key factors influencing development of the modern world.

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The decision found today World transport community, consists any more in creation of control systems by transport, and in design and realization of such transport systems in which means of communication, management and control are built initially in vehicles and objects of infrastructure. In such systems of management (decision-making) possibility, on the basis of information received in real time, have to be available not only to the operators controlling transport, but also all participants of traffic. Problem of such system—integration of traffic all participants interaction: people—transport infrastructure—vehicles, with the maximum use of the latest management information technologies.

In the last decade the phrase "Intelligent Transportation Systems" and the corresponding abbreviations—ITS—became usual in strategic, political and program and target documents of the developed countries. Because the control of such systems is based on the analysis of data large amounts, and decisions must be made often in real time, it is important to provide the opportunity for professionals involved in developing strategies for the development of transport systems and operational planning processes.

While the processes of "intellectualization" affect all the objects of the transportation system: automotive, transport infrastructure such as traffic control, road network), and the object movement control (monitoring parameters of traffic flows, means of movement informing participants, and others). Development and improvement of these tools are aimed at increase of the transportation system functioning efficiency and the safety of all road users.

2 Strategy of UNECE in the Field of Intelligent Transport Systems Development

2.1 Role of Intelligent Transport Systems in a Sustainable Development of Territories

The rapid development of technologies that is a characteristic feature of the world economy in the new millennium requires significant amounts of resources and causes the appearance of an increasing number of sources of negative impact on the environment. In addition, the globalization of industrial production, the growth in the number and size of megacities, causing the necessity of organization of the movement of passengers and cargo, increase the volume of emissions of harmful substances into the environment as well. At the same time, an increasing number of adherents of transition to a green economy is growing, initiating the development of strategies and policy documents on sustainable development (SD) in all spheres of human activity.

The publication of the report "Our common future" of the world commission on environment and development in 1987 is considered to be the beginning of international discussions on SD [2]. In the new millennium a number of documents was adopted that identified new targets, the need to achieve which was caused by negative impacts of urbanization, development of the real sector of the economy and often unjustified harmful human impact on the environment. The most significant of these documents are the following: the report of the UNEP Global green new deal (2009) [3, 4], and the Declaration of the summit Rio +20 "The Future we want" (2012) [2]. The major criterion of a sustainable development in the world is achievement of strategic balance between activity of the person and maintenance of reproducing possibilities of biosphere [6]. It is especially important for regional development since the region is the open difficult dynamic social ecological and economic system functioning under the influence of internal factors, realized through local governments, and external, caused by state economic and social policy [7].

Migratory activity of the population sharply increased in the XX century in connection with improvement of vehicles, time reduction in a way between settlements and the actual removal of distances problem when the globe became possible to be crossed in two 12-hour flights, worldwide.

The migrating population actively participates in economic and social life of the countries, and development of transport system directly determined economic recovery. So, after World War I Germany left crisis, including, at the expense of serious capital investments in development of a transport network, having solved, thus, a problem of unemployment and having provided economy development. In the advanced industrial countries the increase in transport mobility of the population was a direct consequence of its business activity growth.

Speed of construction automobile and tracks in the world since 1996 remains at a stable level—the gain of roads makes to the extent about 1.3–1.4 % a year.

In parallel time which the person spends on the way grows. By the XX century end for the city person there is actual a problem of jams—in 1990 time in a way to work one way in industrialized countries exceeded 20 min. In the most loaded megalopolises of 90 % of daily migration participants reach the downtown, creating jams and multikilometer traffic jams in rush hours.

The key question for the modern megalopolises of Russia consists in compliance of movement implementation requirements and opportunities. From the scientific point of view mobility is defined as mobility and ability to fast movement, opportunities for what on streets of big cities of our country every year becomes less. In this regard, the scientific community is anxious with the solution of questions: what it is possible to make for elimination of periodic collapses in the Russian cities and what already becomes of them for this purpose?

At the international seminar devoted to a sustainable development of city transport systems, the manager of department "Scientific ensuring development of the city transport complex" State Unitary Enterprise NIIPI Genplan of Moscow, Candidate of Technical Sciences Elena Borovik noted that from the philosophical point of view transport represents the dual and inconsistent phenomenon as only the transport sphere at the same time belongs and to productive forces of society, and at the same time to a services sector [8].

Transport allows to reveal mechanisms of the person activity, promoting understanding of town-planning, social and other processes. However, transport takes away from the citizen an invaluable and irreplaceable resource—life. The last researches NIIPI of the General plan of Moscow showed that in transport of people carries out no more than 2 daily rated hours, and till 4–6 o'clock. And if city authorities can't achieve that the person reached from the house work in 5, 15 or 30 min, they should create comfort and in public transport, and in the privately owned vehicle.

Some directions of the listed problems, including, strategy of ensuring steady city mobility exist and is considered. It has increase in the amount of the transport sphere financing, and a system integrated approach to development of transport system development strategy, and introduction of the latest technologies in the transport sphere, and even work on established opinion change about guilt of designers in existence of a transport problem.

Around the world long ago, as theoretically, and on the basis of practical experience, the inefficiency of a road network productivity jams and increase elimination problems the solution by only traditional ways—physical expansion of road network and installation of traffic lights is proof. Even the developed countries can't expand a road network with the rates comparable to rates of vehicles gain. Innovative break in the solution of transport problems is necessary.

It doesn't exist and can't exist to generalize for every country and the cities of complex transport problems solution which the modern world faces. However, unprecedented development in the second half of the 20th eyelid of information and communication technologies opened for this purpose new opportunities. In the world active process of formation and development of the Intelligent Transport Systems (ITS) in transport sector of economy which led to obvious improvements in all means of transport work, in all countries where due attention was paid to it.

Intelligent transport systems are recognized in world practice as all-transport ideology of telematics achievements integration in all types of transport activity for the solution of economic and social character problems. Almost 20 years' experience of purposeful development of ITS in the USA, Japan, in the European union, China and other countries where serious successes are already achieved testifies to it, there were rather effective forms of stimulation and management of this process. Introduction of ITS has strategic character, defines as a whole competitiveness of the country in the world market. The transport policy of the developed countries of the world is based on development and advance of ITS-technologies, common information space creation in future multimodal networks.

Development of machinery and technologies, means of communications, and also globalization of economy are provided with dynamical development of transport and road branch, uniting transport systems of regions and the countries. In the report on a traffic security status in the world, prepared by World Health Organization (WHO), is underlined that «… promoting movement of the goods and people, road transportations benefit both to the countries, and separate persons. They facilitate access to workplaces, the economic markets, education, recreation centers and entertainments and to health services that, in turn, directly and indirectly has positive influence on population health. Nevertheless, growth of road transportations creates also considerable burden for health of people—in the form of a road and transport traumatism, diseases of respiratory tracts and consequences for the health, caused by reduction of physical activity. Air pollution, emissions of hotbed gases, consumption of non restorable resources, the household inconveniences caused by the neighborhood with a busy highway, and noise have number of additional negative economic, social and ecological consequences of movement of people and the goods on roads» [9].

Considerable growth of intensity of movement in city streets involves deterioration of traffic conditions, leads to growth of number of road and transport incidents (road accident) and victims in people, and also to sharp deterioration of level of transport service of a city as a whole. As researches show, ecological and social costs (the expenses connected with local air pollution, road and transport incidents and stoppers) can reach 10 and more percent of gross national product of region or the country and considerably to exceed the sums necessary for initiation of transition to "green" economy [10].

The sustainability of transport systems in large cities and megapolises is determined by the stability of their constituent subsystems, as well as the stability of relationships between them. This stability is ensured, to a considerable extent, the quality of governance. Now for the management of large systems, which also include transport, special instruments are created, such as decision support systems, expert systems and management information systems. Such systems are designed for the purposes of strategic management, as well as for solutions for local tactical tasks. Rational control allows not only to improve economic performance, but also to solve social tasks on improvement of transport service of the population and reduce the negative impact of the transport complex on the environment.

Intelligent transport systems are increasingly seen as one of the components of solutions to current and future problems in the field of transport. Recognizing ITS as an effective tool for achieving safe and inclusive sustainable mobility, their important role in promoting the growth of life quality is celebrated. In 2003 the Inland Transport Committee (ITC) of the UNECE has identified the use of telematics and intelligent transport systems (vehicles, infrastructure) as priority areas. For development of this direction in 2004 under the auspices of the world forum for harmonization of rules in the field of transport vehicles a round table on the ITS was organized, which has contributed to the preparation of the UNECE strategy on the development of a framework and practical implementation of the ETS.

Intelligent transport systems are recognized in world practice as all-transport ideology of telematics achievements integration in all types of transport activity for the solution of economic and social character problems. Almost 20 years' experience of purposeful development of ITS in the USA, Japan, in the European union, China and other countries where serious successes are already achieved testifies to it, there were rather effective forms of stimulation and management of this process. Introduction of ITS has strategic character, defines as a whole competitiveness of the country in the world market. The transport policy of the developed countries of the world is based on development and advance of ITS-technologies, common information space creation in future multimodal networks.

In world practice Intelligent transport systems are considered as service system of service to users—drivers, pedestrians and cyclists, passengers of public transport, carriers, transport operators, services of transport infrastructure operation, emergency services. At the same time, in society there is no uniform understanding of this term, it leads to that at regional levels commercial projects of the ITS local components ideologically and technologically not interconnected are realized. Lack of system approach to implementation of the ITS national projects blocks development of their market, stopping it at the level of rendering commercial services with use of the ITS local components.

Assessing the value of ITS for better functioning of the transport system, the authors of scientific developments note that ITS enhance its effectiveness [11] provide sustainable development of the territories [12], are used to reduce the negative impact of the transport sector on the environment and to reduce energy consumption [13]. At present, ITS becomes a tool of transport planning and is used for surveys [14], to decrease congestion [15] and planning joint travel [16].

For coordination of actions on introduction of ITS and development of policy in global research ITS in 2008 for the purpose of awareness increase and informing of politicians and the high-ranking politicians on technical and political aspects of ITS advance the International road federation committee on policy of ITS was founded. The committee studies advantages of the international cooperation and promotes removal of ITS problems for the general public, helping to develop effective strategy and, finally, successfully to introduce Intelligent transport systems. Directions of work of Committee:

- practical realization of ITS and corresponding political tasks;
- ITS financing;
- researches in the field of ITS, and also educational and social problems;
- standard and legal base for ITS;
- development of ITS of strategy and comparative analysis.

Mission of ITS International road committee on policy Representation and Committee is increase of ITS role awareness and understanding level, support of the bodies making decisions in advance of ITS as the effective instrument of transport policy in the field of safety objectives achievement, stability and efficiency, an exchange of experience between experts in the field of ITS from all over the world.

ITS development methodologically is based on system approach, forming ITS as systems, instead of separate modules (services). The uniform open architecture of system, protocols of information exchange, form of transportation documents, standardization of communication used technical means parameters, control and management, management procedures, etc. is formed.

National concepts of ITS development, national architecture of ITS and the development program form an organizational and methodical basis of ITS development, however, in most cases ITS is considered as service system, with all that it implies. So, for example, considering the conceptual scheme of ITS creation, by the general purpose determine the organization of transport all means interaction system form, the most effective use of a transport resource at the expense of joint transport operations with the most rational versions of structural and line schemes of movement of passengers and freight traffics, providing quality of transport services. Such approach is directed not on elimination of the above described problems, and on elimination of current situation consequences that in itself is incorrect.

2.2 Directions of Transport System Safety Increase

In the rationale of the "road map" of the UNECE of ITS in 2012–2020 [17] 20 directions for global action to promote use of ITS were allocated. These areas include steps towards a common terminology and a common understanding of the essence as well as tasks of the ITS and development implementation in its field. This applies both to the technical component (the development of technologies of communication vehicle-infrastructure, vehicle–vehicle; integration of different modes of transport) as well as to the activities in the field of management and improvement in the security of transport systems, including the environmental, analytical work and development of various techniques.

The importance of this direction is shown due to the numerous activities and analytical reports that are dedicated to improvement of transport system in general and the issues of transport security in particular. This security is understood in the broadest sense—from reducing the number of accidents and negative impact on the environment to the creation of "green" jobs in the transport sector.

Considering sharpness of the problems existing in a transport and road complex, and also need of their immediate decision, on a past on June 7–8, 2012 at Research institute of the motor transport in Moscow the International seminar "A sustainable development of city transport systems: calls and opportunities" were discussed such questions, as:

- Transport problems in the largest cities of Eastern Europe and the CIS countries;
- Principles of city transport systems providing a sustainable development: best practices and practice of the states of the CIS;
- Role of the national governments in ensuring city mobility steady and favorable for health;
- Infrastructure development, the organization of public and passenger transport services quality work and improvement—the only real alternative to use of cars and preservation of an urban environment;
- Parking policy: experience and decisions in the largest cities;
- Introduction of ITS as instrument of transport streams and traffic safety increases effective management increase;
- The analysis of public transport and cycle movement for land granting priorities the allocated strips and other methods organization experience: positive effects and possible problems;
- Use expansion ecologically "purer" vehicles and fuels in the cities.

Considering the situation which has developed both in Russia, and in other countries, it is possible to note unity of the purposes as producers of automobile equipment, and enterprises for creation and service of road infrastructure most important of which is increase of safety and comfort of movement, satisfaction of freights and passengers requirements for movement and decrease in negative impact on environment.

Experience shows that good results are yielded by only system approach to the solution of such complex problem, as ensuring steady functioning of transport system. Along with the artificial intelligence systems this field of research is one of the most dynamically developing and unites different classes of tasks.

Since the sustainability of the transport system in many ways is a guarantor of sustainable and economic development, ensuring quality control is a priority during the solution of the problems connected with the intellectualization of its subsystems and objects.

In addition, numerous objects of the transport system are sources of increased danger for road users and the environment. This applies to vehicles, the objects of the road network, infrastructure, providing the transportation process. The greatest problems are road traffic accidents, especially those connected with human victims. Numerous state programs illustrate the urgency of this problem. In different countries use various approaches to safety on roads. Striking example—Sweden which, after acceptance in 1995 of the law on traffic safety builds strategy of traffic safety reforms on the basis of Zero mortality Concept approach [16]. The vision zero regards road transport system as a whole, the components of which (roads, cars and pedestrians) guarantee the safety of each other. In the official publication of the Swedish road administration it is stated that the concept is in the responsibility for safety rests with all of the creators of the transport system: the road services, manufacturers, carriers, politicians, government officials, legislators, and the police.

Measures to provide road safety can be divided into two big groups of measures to prevent accidents and measures aimed at reducing the severity of their consequences (Fig. 1).Since a large portion of accidents associated with the «human factor», numerous developments of manufacturers of automobile electronics are designed to alert traffic participants and specialists in traffic management. First of all, this system alerts the driver of the parameters of traffic flow on the route [18]. The works of a great number of researchers are dedicated to the analysis of trends and development prospects of ITS [19–22]. ITS means are used to ensure the safety of road users—in intelligent vehicle systems (systems of active safety) [23] and systems of pedestrian recognition [24]. The development of warning systems is associated with the development of technology and communications infrastructure [25], which are used for traffic control and traffic management [26].

ITS helps to reduce accidents and the safety of transport systems [27]. Because of the fact that ITS technologies are creating applications and systems for traffic management and accident prevention, they reduce the workload on the driver, preventing his overloading [28].

If to analyze documents and development in the field of ITS, it is possible to find distinctions in understanding of the term. As a rule, one group of authors considers ITS as a way of administrative measures for traffic streamlining

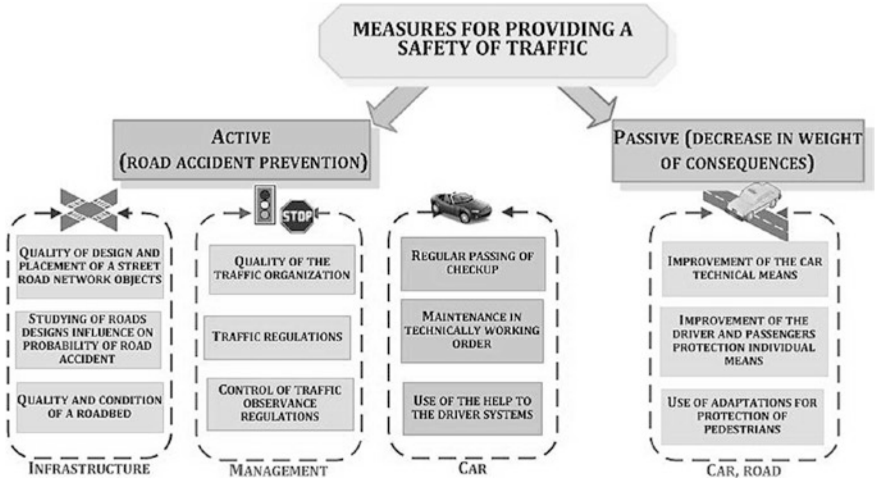


Fig. 1 The classification of measures for providing safety of road traffic

intellectualization. And in most cases measures are directed not on realization of "feedback" principle, and on the notification of movement participants, at the best-control of violations and reaction in the form of fiscal character taking measures. The second group of authors considers ITS as the way "intellectualizations" of the car. Though, there is also other term—IOS (intellectual onboard systems).

In world practice five main groups of ITS users are defined: drivers, pedestrians and cyclists, passengers of public transport, carriers, transport operators and services of transport infrastructure operation. Apparently from the specified list, neither about the car, nor about infrastructure (road) there is at all no speech while these two components just create problems.

3 Prospects and Risks upon Transition to "Green" Transport

The UNEP report [4] states that in order to reduce transport emissions of greenhouse gases it is required to increase the efficiency of energy use and to refuse energy-consuming vehicles both passenger and freight transport. To achieve economic goals and objectives of sustainable transport development and integrated planning of its development and regulation system load, you need to switch to fuels with lower carbon content and to implement a more extensive electrification of transport. As one of the ways of moving towards more sustainable transport it is proposed to include "green" conditions to the assistance plans to the car manufacturers, providing targeted investments aimed at increasing saving motor fuel, as well as for research in the development of more affordable on-board energy storage devices.

Part of measures to ensure the sustainability of transport can be planning for urban and suburban centers in accordance with development, providing for a mixed fleet of vehicles and reasonable growth. Such principles of urban development will help to reduce dependence on private vehicles and to ensure widespread use of public and non-motorized transport for short trips and for regular commuting into the city from the suburbs.

Taking into account that transport is an important economic sector in which only the European Union has over 16 million people, and its direct contribution to GDP of the EU reaches 11 %, it can play an important role in meeting new global challenges, “green economy”, developing new directions in the field of job creation and economic development. Moreover, having a high level of socio-economic significance, clean transport can play a positive role in improving the health of the population, ensuring a cleaner environment, improved the quality of life and achieving higher rates of economic growth. And thanks to the innovative transport policy it is possible to achieve the maximum positive effect for the environment and human health. Providing access to goods, jobs, services, education and entertainment through environmentally friendly, healthy, economically and socially sustainable transport system is a key factor in improving the environment and quality of life, economic and social growth.

Starting from the 80s, the United States, Europe and the Asia-Pacific region purposefully and systematically promote the ITS as a central theme in the implementation of transport policy, but the implementation of ITS on a global scale has become possible only in conditions of saturated communication space, when there are no serious technical problems with the transfer of large volumes of digital information in real time at any point in the transport network. Development of ITS is methodologically based on a systematic approach, forming the ITS as a system and not as a separate modules (services). Approaches to the creation of ITS is based on the principle of modernization, reengineering of the existing transportation systems.

Today in the world’s leading countries was formulated legal and regulatory framework was debugged process of strategic and ongoing planning of ITS development. Special organizational structure was created. Process of budget financing development and implementation of pilot projects of ITS deployment worked out at the national level. Experience of EU countries, the USA, Japan, China and other countries in the promotion of ITS projects, shows that in a market economy only a single state policy allows you to combine the efforts of the state and its subjects, business at all levels and sectors of the economy in addressing national goals in the transport sector. An important role in the dissemination of knowledge and experience in the development of ITS, establishing contacts in the global community of ITS play annual global and European Congresses of ITS accompanied by exhibitions and educational programs.

One of the main directions of ITS, which is actively promoted by the last 15 years—the realization of the concept of intelligent vehicle. International program “Vehicles with Advanced Security” operates. Even the first experiments of using the airborne intelligence systems have shown that they are able to reduce the number of accidents by 40 %, while the number of fatal accidents—50 %. In December 2008, the European Commission formally adopted an action plan on introduction the ITS in Europe and presented the draft directive, which creates a legislative basis for its implementation [2]. Due to the fact that the ITS can significantly contribute to the formation of a more environmentally clean, safe and efficient transportation system, was set the goal to accelerate the penetration in the European market that need to deploy the ITS software and hardware, which degree of development has been assessed as sufficiently mature. This initiative was supported by five general directorates, working closely with each other: for Energy and Transport, Information Society and Media, Research, Enterprise and Industry, as well as the environment. Action Plan for the introduction the ITS is based on a number which is in the process implementation of the initiatives of the European Commission, including the Action Plan on Freight Transport Logistics; Action Plan for the development of intra-urban mobility (Action Plan on Urban Mobility); introduction of the navigation system Galileo; Complex of measures to increase the environmental performance of transport (Greening Transport Package);i2010 initiative on intelligent vehicles, the program of implementation of the system eSafety; The 7th Framework Program for Research and Technology Development; program of introduction of the system eCall; program "European Technology Platforms".

Intelligent Car initiative which was launched in October 2008, aims to prevent road accidents involving two or more cars with the use of communications systems car-to-car, allowing to continuously monitor the vehicular traffic from special centers that can provide early warning about the dangers of collision [29]. For this control system, which can also warn of traffic jams, the potentially adverse road conditions, sudden changes in the weather, in most EU countries have already begun to reserve frequency range. In addition, these frequency bands for future vehicle communication systems have already been reserved in the United States and Japan.

According to the experts, the development of this system in the near future is likely to lead to the emergence of a standard system, in which each vehicle on the road will be connected with the rest of cars. Technology has the potential to create a world without real driving with on-board computers and system GPS, controlled from a single center of movement control.

Within the project e-Merge, which ran from April 2002 to March 2004 was developed specification of electronic system emergency service eCall, which in the case of an accident provides the ability to automatically notify a special public service and send a voice message. In December 2008 the European Commission instructed the organizations involved in the activities of the Forum eSafety to develop a plan of implementation of eCall.

Action Plan implemented within the framework of initiatives to reduce the adverse impact of transport on the environment (Greening Transport Initiative), aims to accelerate deployment of these systems in road transport, as well as their development of its interaction with other modes of transport. All road users, from passengers to freight carriers, need the reliable traffic information provided in real time for more effective planning routes and to avoid delays caused by traffic jams.

The introduction of the ITS plays an important role in the "greening" of transport. As one of the ways to influence on transport demand can be applied differentiation of charges levied by electronic payment systems for the passage of vehicles on certain routes. Furthermore, application of ITS for travel planning, dynamic navigation and support for the regime economically and eco-driving helps eliminate congestion, providing mobility with less harmful impact on the environment and reduce energy costs.

Relying on advanced technology ITS has a large value and to achieve the objectives which are placed in the framework of the EU to create a "Green transport corridors." This initiative involved promoting the concept of integrated freight transport, where different modes of transport complement each other in order to provide a more ecologically safe alternatives to long-distance transport between logistics centers.

ITS, according to the European Union, can create clear benefits in terms of efficiency of the transport system, its stability and security, while at the same time, contributing to the development of the EU internal market and competitiveness.

As noted in the documents of the European Commission, since the 80s the last century in Europe implemented a number of activities in this area. However, these measures are often have uncoordinated and fragmented nature. In addition, they have traditionally been aimed at solving specific problems, such as ensuring the ecological compatibility and energy efficiency of transport, congestion on the roads, traffic management, road safety, and safety of commercial vehicles and also the mobility of the urban population. At the current stage of development of these systems in Europe are considering the most urgent tasks: geographical continuity, interoperability of systems and services and standardization.

Currently, service that provides real-time information about traffic conditions and optimal routes trip (Real-time Traffic and Travel Information (RTTI)) contributes significantly to the growth of population mobility. This information (increasingly combined with the services of satellite navigation) is now offering both public and private sources.

In many parts of Europe ITS have become the foundation of effective management of traffic on intercity and urban routes facilitating the development of a flexible system to switch from one to another mode of transport in major transportation hubs. In the longer term is expected to reveal the full potential of the system arranged on the principle of cooperation between members of the movement, and infrastructure elements, which include systems that provide communication and information exchange between vehicles V2V (vehicle-to-vehicle), between the transport facilities and infrastructure V2I (vehicle-to-infrastructure) and between the different elements of infrastructure I2I (infrastructure-to-infrastructure). If necessary, these systems will be complemented by system of location determination and time Global Navigation Satellite System (GNSS).

Vice-President of the European Commission, Antonio Tajani, responsible for transport commented the decision of 16 December 2008: "Ensuring of ecological compatibility of transport, reducing congestion and saving lives on European roads are priority for the Commission. Intelligent transport systems will help us to make progress towards achieving these goals. Today’s initiative will contribute to a more efficient, safer and more sustainable mobility in Europe”.

Viviane Reding, EU Commissioner for Information Society and Media, in turn, said: “The proposed by the Commission Action Plan for the introduction ITS will provide much-needed policy instruments in addition to the work carried out in the framework of the “Intelligent Car” and the eSafety Forum to make cars safer, cleaner and more “intelligent”.

As noted in the documents of the European Commission, the potential of ITS can be fully revealed only when it will be implemented in Europe not occasionally and locally, as it is today but on a European scale. In this regard, the removal of existing obstacles to the deployment of the system acquires key value.

Structure of the European Union called upon to play a significant role in creating an enabling environment for accelerating coordinated deployment of ITS: the definition of political priorities, the selection of nonproprietary components for sharing or reuse and harmonization of clear timetable.

The European Commission believes that the complex of measures implemented across Europe will contribute directly to:

- solving the problem of the complexity of the deployment of ITS, arising from large number of stakeholders and the need for synchronization, both geographically and among the various partners;
- the market penetration of the most modern means of ensuring the mobility of the population and the development of public transport as an alternative to private transport;
- creating conditions for reducing costs and risks, as well as reducing the time of implementation of ITS;
- accelerating the pace of deployment of ITS in road transport, as well as ensuring ubiquitous availability of services throughout the EU;
- strengthening of leading role of European companies involved in the deployment of ITS in the world markets by stimulation of supply of innovative products and services for vehicle manufacturers, transport operators, logistics providers and users.

To achieve these objectives, the European Commission plans to use the financial support, standardization initiatives, legislative and other measures.

The Action Plan also contains a draft directive of the European Parliament and the Council, which lays down the general scheme of the introduction of ITS. Six priority areas were identified; each of them has a specific list of activities and a clear timetable for their implementation:

- optimal use of road, and data on travel and nature of traffic;
- continuity of traffic management and freight transportation. ITS services on European transport corridors and in conurbations;
- traffic safety and transportation security;
- integration of the vehicle into the transport infrastructure;
- security and data protection and also liability issues;
- European cooperation and coordination of activities in the field of ITS.

First direction: you have to know, where you ride

Measures provided in framework of the first lines of action were developing taking into account that many of the relevant modern level of development in the field of ITS are based on accurate information as to the characteristics of the road network, and the applicable regulations (For example, mode of one-way traffic and speed limits). In those cases, when it comes to road safety, it is extremely important that this information has been confirmed and available to all participants on a fair and equitable basis for the safe and orderly management of the movement.

This applies in particular to creation of electronic terrain maps, including the necessary processes of collecting, testing and timely update of data.

Second direction: ITS for everyone and everywhere

In keeping with the second direction of the Action Plan for the implementation of ITS in Europe is planned to ensure the continuity of traffic management and freight traffic and availability of ITS on European transport corridors and in urban areas.

Imposition of restrictions on the use of certain routes or transit through the certain areas are increasingly based on a number of different parameters such as vehicle dimensions, emission levels, distance and time of day. Solutions incorporated in the ITS and providing for the use of satellite positioning and mobile communications offer new opportunities for such regulation of access to infrastructure.

Third direction: the security of people, vehicles and cargoes

The third direction of the Action Plan for the implementation of ITS covers the measures to ensure road safety and transport security.

The aim is more efficient use of the newest active safety and driver assistance systems which have great opportunities in terms of safety features for passengers and other road users (including vulnerable road users).

Navigation systems and detection systems can help in providing remote monitoring of vehicles and cargoes in process of transportation, for example, the transport of hazardous cargoes or animals. They can show drivers safe parking space, will help to implement existing rules under the regime of work and rest, and will support the next generation of digital tachographs.

Among the planned activities are invited to facilitate the deployment of advanced driver assistance systems and related road safety and traffic safety of ITS systems, including their installation in new vehicles and, if necessary, in the previously released cars. These measures are planned for the 2009–2014 period. It is planned to develop legal and regulatory framework for safe human-machine interface included in the design of the car and the integration of moved devices based on the “European Declaration of Principles for safe and effective information and communication systems in the vehicle”.

Until 2014 it is planned to develop a number of activities including guidelines of the best practices, which relates to the impact of software and hardware of ITS on safety and comfort of vulnerable road users.

Development of appropriate measures was provided, including guidelines of the best practices on the safe organization of parking areas for trucks and commercial vehicles and on telematics-controlled parking spaces and reservation systems.

Fourth direction: general interconnection

In the fourth direction were planned actions for the integration of the vehicle into the transport infrastructure.

The ordering and integration of ITS software within a harmonious architecture peculiar to an open system can improve the efficiency and convenience of their use. In addition, according to the documents of the European Commission, it will reduce expenses and increase the ability of system expansion, it will provide an opportunity to use the plug&play function for the integration of future new or upgraded software tools such as used in the moved devices or use of GNSS services (Global Navigation Satellite System) for determining the position and time.

In accordance with the plans of this direction will be created architecture of open embedded software platform for software and hardware tools of the ITS, including standard interfaces. The results of this activity is planned to submit for consideration of relevant standardization bodies.

Fifth direction: the security of information

The fifth group of actions of the implementation of ITS in Europe is aimed at providing security and data protection, as well as to address issues of responsibility allocation. Integrity, confidentiality and availability of data must be provided in the interests of all road users, especially citizens.

Sixth direction: overcoming of national barriers

The sixth group of actions aimed at strengthening European cooperation and coordination of activity in the field of ITS.

As pointed out by the European Commission, coordinated activity of the implementation of ITS in the EU requires an active and effective cooperation between all stakeholders at European level. It is expected that such cooperation should lead to the convergence of requirements regarding the introduction of ITS, more efficient synchronization of the implementation process and overcoming barriers on the European integration. To support investment decisions by public authorities all over Europe it is necessary to extend information on the costs and benefits of ITS. Exceptional importance are agreements on common assessment methods and uniform tools for decision support in order to implementation of ITS in the EU. Coordination of efforts on introduction of ITS throughout Europe also requires greater participation of city and regional authorities. Finally, the implementation of the Action Plan for the introduction of ITS in Europe requires the formation of an adequate governance structure. States which are part of the EU should strive to reach agreement on key issues of introduction and functioning of ITS, as well as concerning transition methods from drawing up plans to coordinated action on their implementation, for example by collective investment or harmonization initiatives.

According to results of Meeting in the framework of the pan-European program on transport, environment and health (the PEP) held in 2009 in Amsterdam, as well as on the Symposium of the PEP 2010, dedicated to environmentally friendly, health preserving investment and jobs in the transport sector, Partnership to coordinate efforts of the countries-participants and development of joint projects on the transition to "green" transport was established [30].

It also states that the transition to a low-carbon transport system can be implemented through a combination of the following directions:

- system of transition to a low-carbon modes of transport, including renewable energy and alternative vehicles and fuels;
- reduction of emissions from this type of movement, including mobility management, promoting less polluting and more cost-effective transport;
- changing patterns of mobility in the direction of reducing the number of trips and shrinking distances.

During the debate on sustainable development by the participants of the United Nations on sustainable development (Conference "Rio+20" [4]) it was noted that the transport and mobility are essential for sustainable development as one of the factors increasing the level of social justice, improving human health, ensuring the sustainability of cities, establishment of relations between urban and rural areas and improvement of the productivity in rural areas. They emphasized the need to promote an integrated approach to development of the policy in respect of transport services and systems to promote sustainable development at the national, regional and local levels.

4 Safety Increase Through System of the Car Technical Operation

4.1 Cars Intelligent Onboard Systems

Tendencies of IOS improvement modern cars are characterized by emergence of nonconventional systems for the car of automatic control, such, as the electronic control system of the engine (ECSE), systems of malfunctions collecting and processing and some others. All of them are intended for increase of the consumer safety and convenience of driving.

As producers of Nissan though intellectual systems of cars have information bias declared, after all first of all are developed for safety of drivers and passengers therefore the various options, allowing to make driving the car safer are built in them. The main highlight of on-board computers for cars of Suzuki is opportunity to carry out car diagnostics, and thus not to be connected to the diagnostic socket. The Verona 4.2 computer can be installed on any injector car working at petrol fuel which keeps data on 80 last trips which are grouped in dates, thus full information is output to the screen of the computer in days. It allows the driver to define the most economic daily route. The device includes the function similar to actions of a tachometer, and displays exact information on engine turns, can be completed with the sensor of temperatures and tension of an onboard network [31].

On the CES 2012 exhibition technologies which will define our lives in the future were presented. One of them—an intellectual control system of the DICE car from Mercedes-Benz, the phrase “onboard computer” seeming ten years ago in relation to cars progress top, now means the standard from which car makers in further development make a start. Example of such searches the control system of the DICE car developed by request of Mercedes-Benz can couple.

DICE (Dynamic and Intuitive Control Experience) represents the interactive panel which will appear instead of the car modern dashboard, possessing function gesture control. The main functions which will be assigned to this panel, this obtaining road and technical information, and also data on interesting places on route. Through it will be possible to operate navigation, and also to get Internet access that will allow to adjust communication with the mobile phone, a tablet and the laptop of the driver, and also with other cars going nearby for coordination of joint actions and prevention of road accidents. The DICE system will be self-trained.

One more example—EMIRAI control system developed by Mitsubishi which cars in 10 years will possess. At the heart of this system management lies transformation of the car dashboard into the uniform screen of a back projection on which all information on the car, necessary for the driver will be broadcasted. And, the person himself will be able to program, which parameters he would like to see. Sideways from this screen one more display, smaller by the sizes, but touch will be placed. It can be used for input of information, direct driving and as the menu of the mobile phone. During car movement on this screen there will be the buttons necessary to control. The wheel in EMIRAI is made not round, but curved. On it also there will be a touch screen, and eighteen more buttons for driving and check of its condition. The special system which has been built in EMIRAI, will watch the physical condition of the person. It won’t allow him or her to drive while drunk or has serious problems with health which can affect driving process. Moreover, it will trace all changes happening in an organism during driving, and to report about any critical processes to the driver when his condition threatens with danger to it and passengers. EMIRAI provides also driving transfer to other person if the driver wanted would be tired or feeling bad. In backs of forward chairs of the car, according to founders of EMIRAI, have to be built-in 3D—the screens allowing people, going behind, to watch film in high quality. As consider in Mitsubishi, the EMIRAI system will allow to establish the new principles of intellectual interaction between the driver and his car. In mass use similar control systems of a car, according to Mitsubishi plans, have to appear only in ten years. And, all technologies necessary for this purpose, exist already now [32].

For integration of IOS all components activity and also accumulation and information output the electronic block serves in its structure [33]. Some given examples about the direction of design thought on the way of improvement of one of the car main consumer properties: comforts in management, testify that seeking to create “the perfect car”, producers don’t reflect that complication of a design and

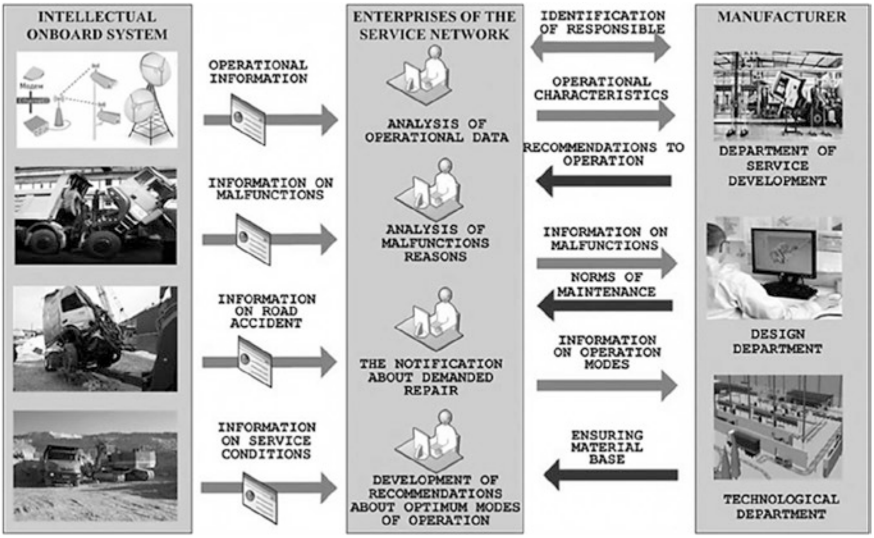


Fig. 2 The scheme of information streams organization with use of intellectual on-board systems

increase of technical characteristics repeatedly increases probability of problems emergence at its operation and service. IOS which has to provide feedback realization between the driver, service station and plant the manufacturer can reduce risk of emergence of emergencies.

Thus the following problems have to be solved:

- the notification of the nearest stations of service or services of emergency reaction about malfunction and the related road accident [34];
- accumulation of statistical data on the most frequent reasons of premature refusals emergence in certain service conditions—that will help to plan activity of the service centers;
- accumulation of analytical data from the dealers allowing the producer purposefully to improve a design of the car, increasing its reliability and safety.

Modern cars are impossible to imagine without the embedded electronic systems, the most advanced of which combine the functions of automotive onboard computer, solve the navigation and entertainment tasks (Fig. 2). Automobile concerns collaborate with developers of compact and productive processors that can be used in their models. NVIDIA exists on this market for a long time and NVIDIA Tegra in automotive computers is used not only in electric Tesla Motors, but also in the production of Volkswagen, the famous brands Volkswagen, Audi, Skoda and others.

To have their success on the market of automotive systems NVIDIA offers modern modular development platform NVIDIA Jetson, which will build and test a variety of automotive applications. Modern driver assistance systems have an important place (Fig. 3). Examples of such systems on the GTC-2013 GTU Technology Conference—(GPU—graphics processing unit)—showed Victor Ng-Thow-Hing—representative of Honda company. Research department of this

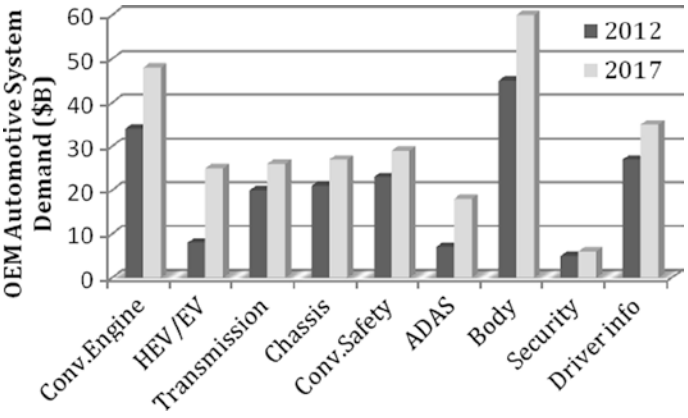


Fig. 3 The analysis of the current situation on development of modern onboard computer systems

company for a long time has been developing systems of augmented reality which draws the auxiliary images directly on the windshield of the car. Augmented reality systems are useful in navigation and they are capable to assist in identifying hazardous maneuvers and reduce accidents.

For example, the system can estimate the position and speed of oncoming vehicles and provides information to the driver about the safety of the left turn at the crossroads at the moment, in this case, the system draws on the windshield the arrow of planned rotation and paints it depending on the driving situation: green—if maneuver is safe, and red—if there is a risk of collision with the oncoming vehicle.

In addition, Strategy Analytics analysts also analyzed key factors which will be the engine of development onboard computers: the revolutionary options like parking and lighting systems will be habitual in the future, taking the place of night vision function, control of sleepiness, warnings about the difficulties of road traffic and the “blind spots” etc.

One of the most impressive examples of this intelligent system was introduced in the presentation Mario Tippelhofer, a research engineer from the laboratory of automotive electronics in Audi of America. Initiative of Audi Urban Intelligent Assist, developed in collaboration with leading American universities, is aimed primarily at the prediction of traffic events, possibility of deep settings of embedded system to user needs, intuitive interface and advanced interaction of onboard computer with the driver.

The main functions of onboard intelligent system Audi Urban Intelligent Assist:

- Smart Parking with provision detailed information about street and stationary parking with the issuance of parking options to choose from.
- Intelligent prediction of road traffic (Predictive Traffic) based on analysis of the current traffic situation, the preferences of the driver and the prediction of possible variants of behavior on the road by the results of emulating the traffic situation.

- Monitoring of the driver's attention (Driver Attention Guard) with intelligent interface with two-way interaction between man and machine which allows to return the driver attention to the road on the analysis of indications of the inner chambers, taking into account gained experience and models of predicting the behavior of the driver.
- Intelligent prediction of merging/separation traffic lanes (Merge/Lane Change Assist) with an intuitive interface to help in a timely and safe maneuvers on rebuilding the desired lane on the basis of advanced technology with 360° review and learning algorithm of recommendations taking into account driver's preferences.
- Realistic Navigation Assistant (Naturalistic Guidance) with normal voice prompts and intuitive maps with marks of iconic roadside objects and sights.
- Mobile application Time-2-Start, which allows to plan a trip in advance and arrive at the destination on time, taking into account the current data of traffic situation, prediction algorithms and emulating of road traffic.
- Single navigation system (Seamless Navigation) with a wireless interface between the mobile phone and onboard computer that provides uninterrupted tracking route driver, even when you leave the vehicle.

Besides the traditional options of entertainment and navigation plan, according to Delphi experts, future automotive onboard computers MyFi will inherit many typical functions of mobile Internet devices, which will be combined with external cloud services and opportunities of flexible optimization to requirements of specific user (Fig. 4). Significant attention will also be paid to security issues.

These projects include a plurality of individual algorithms and technologies which development and improvement is conducted in full swing. For example Vladimir Glavtchev an NVIDIA engineer and specialist on computer vision said in

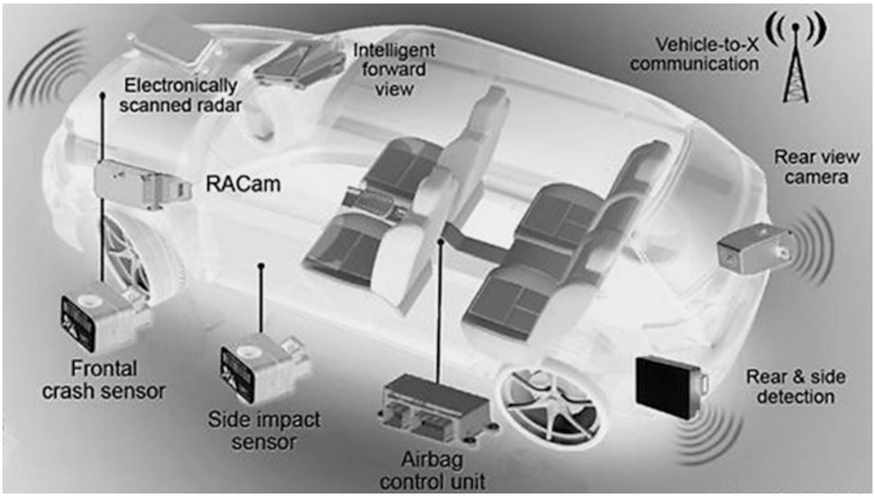


Fig. 4 Equipment arrangement on a car body card

his presentation about the solution of such interesting issues as multi-frame analysis of moving and static objects for the purpose of recognition and identification such as pedestrians, motorcyclists, cyclists, etc.

It is not necessary to emphasize once again how important these features to ensure safe traffic on the road. Now, when such algorithms already exist and have been successfully implemented, the main task is to optimize computational processes in order to minimize hardware requirements of computers which are necessary to identify and classify objects of road traffic. Onboard systems based on the GPU mobile class are turning out very relevant and popular.

4.2 Interaction with Service System for Increase of the Car Reliability

In the itself car as the car—the driver—environment—service "in a context of its interaction with various subsystems which realize actions for its safe operation makes sense to consider technical system as making systems" (Fig. 5).

In this sense purpose of IOS has to be reduced not only to informing of the driver, but also notify other subsystems which are responsible for its safety, in case of unforeseen situations which can lead to problems for other participants of movement.

Complication of the car design, intellectualization is more increasing than it, simplifying operation process, creates problems with service maintenance. To the service centers it is necessary not only to improve constantly processes, to train the personnel, to buy the new equipment, but also for new models to study statistical data on premature refusals to predict probability and time of their approach. Integration of ITS and the car IOS is necessary for the solution of these problems.

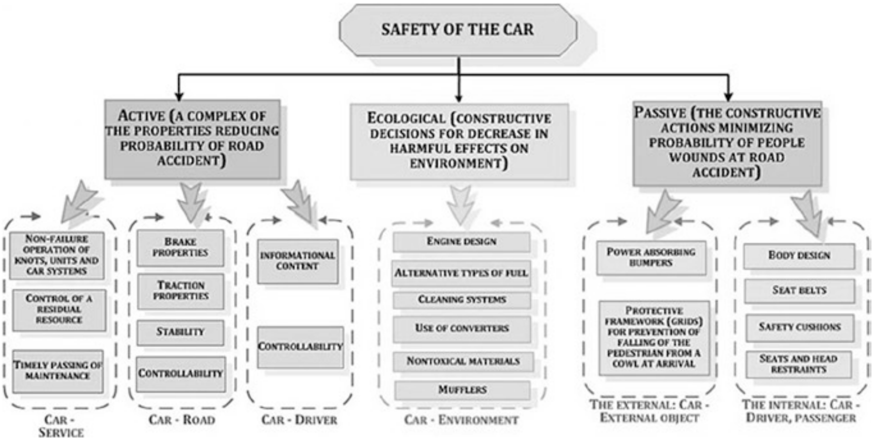


Fig. 5 Measures to provide road safety

The complexity of the design requires the development of a tool for efficient collection, storage and analysis of large amount of information about the condition of the vehicle and its systems. In addition, information should be of high quality. In the analysis of large systems, the optimal tool to quickly react to the changes of both external and internal parameters are decision support system (DSS), which is based on technology that uses an online database, data warehousing, online analytical system of information processing and intellectual analysis of data. The basis of a DSS is a complex of interrelated models with the appropriate information support of research, expert and intelligent systems, including the experience of solving the tasks of controlling and ensuring the participation of experts in the process of making rational decisions.

Since the adoption of decisions based on real data about the control object, analysis and strategic decision-making use aggregated information for the storage of which a data warehouse (DW) is created. The main goal to build DW is the integration, the updating and harmonization of operational data from disparate sources to provide a single, consistent view of the object of management in general. Databases contain the information gathered from multiple online databases OLTP systems (OLTP (On-Line Transaction Processing)—on-line transaction processing in real time).

DSS have the means to provide the user aggregate data for different samples from the original set in an easy to understand and analyze way. Aggregate functions form the multidimensional data make up a set (hypercube or metacube), so users can formulate queries, generate reports, receive data subset. This technology is a complex multidimensional data analysis, OLAP (On-Line Analytical Processing)—analytical processing in real time, which is a key component of data warehousing. Implementation technique involves various patented ideas: varieties architecture «client-server», time series analysis, object orientation, and optimizing data storage, parallel processes, etc. (Fig. 6).

Data on causes of appealing to service centers with details of all options is recorded in the database and serve as a baseline for subsequent analysis. For the formation of every sample one of the factors is considered, and the values of the others remain fixed. The parameters of the distribution laws of failures for each node are determined according to the created array data using Statistica [35].

However, in accordance with the empirical histogram data displays a graph of the distribution law and determined its compliance with sample data for a given level of significance. The results of the analysis are used for the development and correction of instructions designed for the service centers and for car owners, compliance with which allows to ensure reliable operation of the vehicle (Fig. 7).

Since the number of failures with developed dealer and service network is a large amount of data that depend on a significant number of factors, for aggregation abovementioned data OLAP technology is used, enabling the analysis of failure when selected combination of measurements. So, Fig. 8 shows three-dimensional OLAP cube with simple measurements.

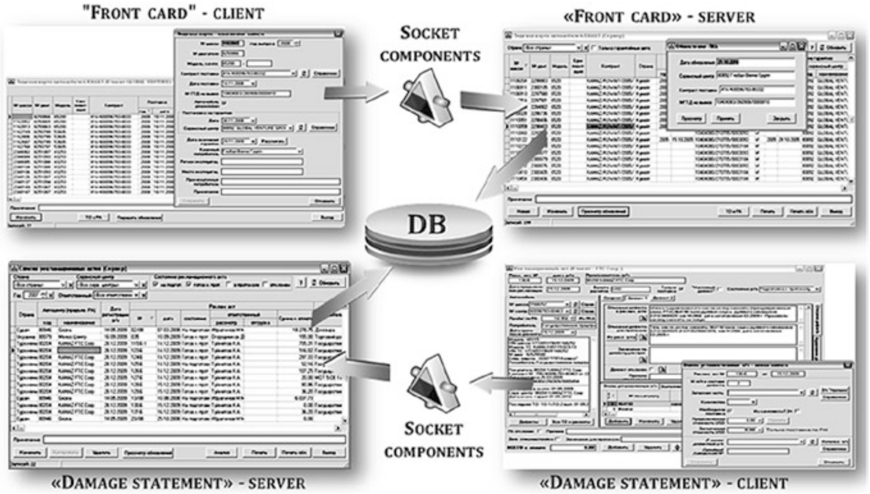


Fig. 6 Collection of information about refusals in firm service system

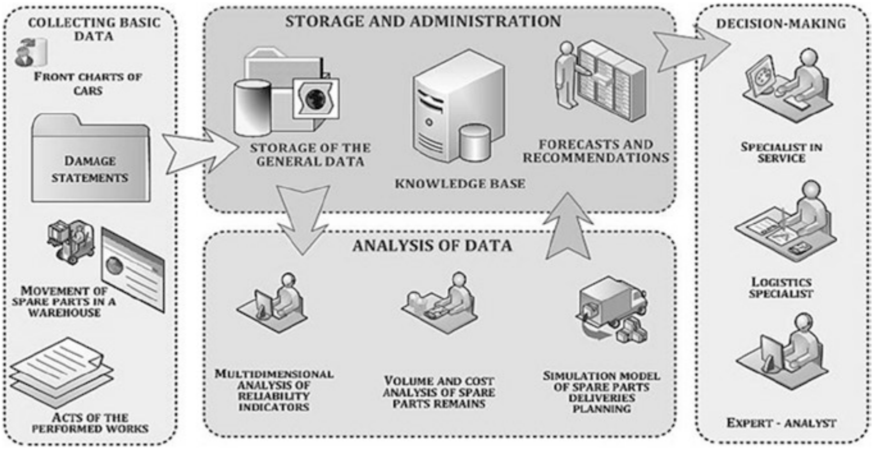
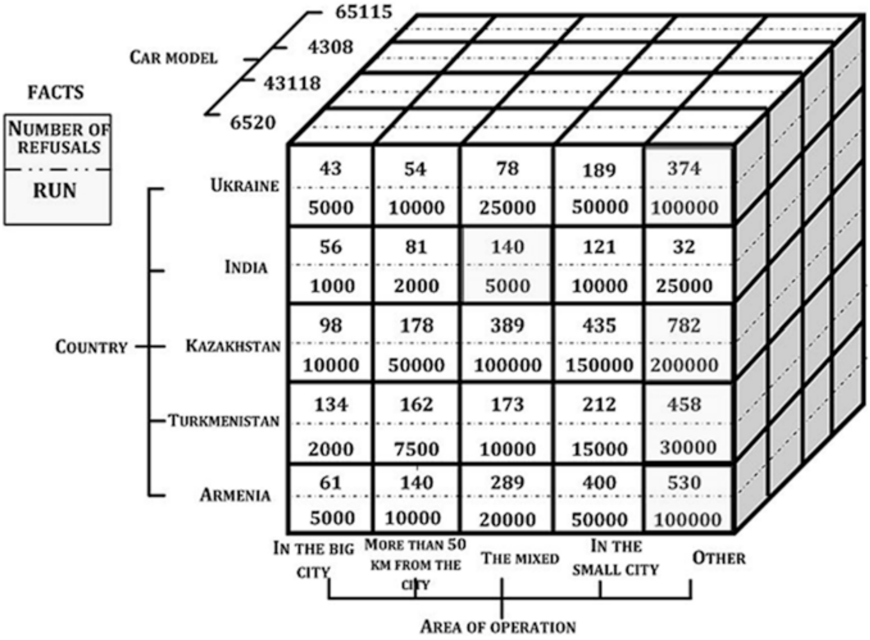


Fig. 7 Conceptual scheme of a dealer-service network DSS

For the rapid exchange of information communication systems are used, which synchrony information from ITBS with information systems of service centers, which, in turn, are linked with the manufacturer (Fig. 9). The transmitted data are the basis for improving the design of the car and increase reliability and safety of its operation.



	IN THE BIG CITY	MORE THAN 50 KM FROM THE CITY	THE MIXED	IN THE SMALL CITY	OTHER
UKRAINE	43 5000	54 10000	78 25000	189 50000	374 100000
INDIA	56 1000	81 2000	140 5000	121 10000	32 25000
KAZAKHSTAN	98 10000	178 50000	389 100000	435 150000	782 200000
TURKMENISTAN	134 2000	162 7500	173 10000	212 15000	458 30000
ARMENIA	61 5000	140 10000	289 20000	400 50000	530 100000

Fig. 8 Three-dimensional OLAP-cube with simple measurements

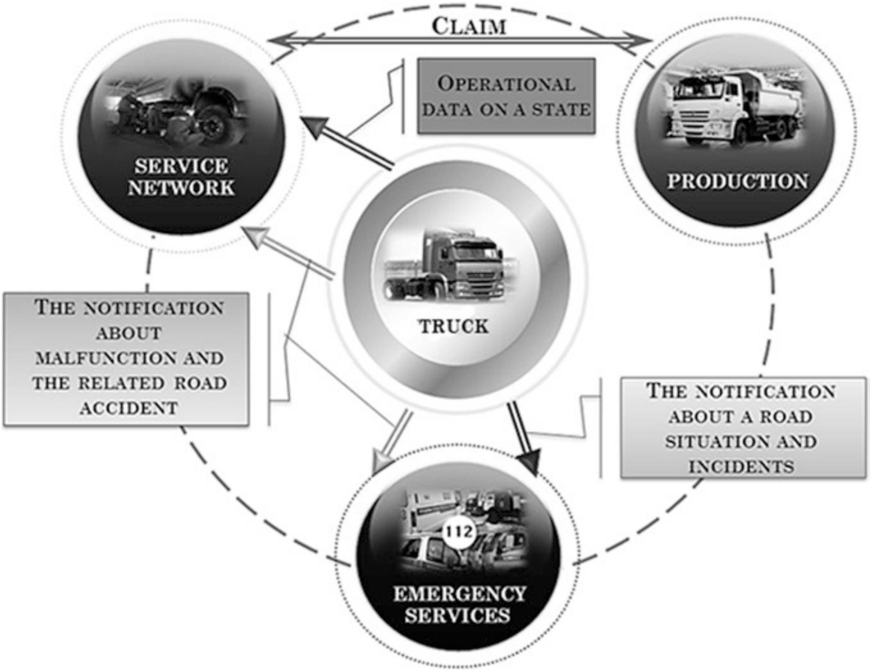


Fig. 9 Organization of feedback between objects of the transport system

5 ITS as Management System

5.1 Management of Vehicles Fleet

The larger the city, the more complicated its problems and the greater the likelihood of instability in the absence of effective measures to address these difficult problems. The most serious transport problems are often associated with urban areas and occur when the transport systems on a number of reasons are unable to meet numerous requirements for urban mobility. Efficiency of city functioning largely depends on the efficiency of the movement of labor, consumers and cargoes using the transport system between multiple initial and terminal points.

Experts in the field of urban transport planning are faced with the following problems: they need to effectively use public, land and financial resources for the optimization of the city's transport network by providing optimal mobility, elimination of the negative effects in the maximum extent (traffic jams, fatal accidents, pollution) and the provision in maximum extent of transport service to users.

Achievement of this balance represents the continuing problem for the planners of urban transport since the cities are becoming bigger and bigger and a growing number of people use the urban infrastructure and services of public transport.

The most significant problems of urban transport related to:

- its reliability: citizens will use public transport if they trust it. The credibility to provide services, schedules and the way of message serves the most important to the user;
- its comfortableness: people are in need of services. All types of public transport services should be provided to their users in the form of air conditioning, ensuring cleanliness, ticket machines, stations, protect the interests of passengers and providing the waypoint information in electronic form, etc..;
- the mismatch of public transport needs: many public transport systems or their elements either overloaded or underloaded. During rush hours the tightness creates discomfort for drivers, while the system itself is trying to cope with the increased demand for transportation. Insufficient number of passengers determines the financial instability of many transport services, particularly in the suburbs;
- difficulties of parking: since most of the time vehicles are in the parking lot, automobilization has led to increased demand for space for parking; as a result, there are problems associated with the use of available space, particularly in the central areas of the city. On the parked cars account for a very significant proportion of these spaces. There is also a link between traffic congestion and parking, since the search for parking lots creates additional delays and has a negative impact on local traffic;
- commuter transportation over longer distances, people are spending more time to get to work from the suburbs and back. One of the most important factors causing this trend, related to the availability of housing because housing which are located further away from the central areas of the city (which focuses on the

majority of jobs), is more affordable. Thus, suburban passengers are ready to sacrifice their time for affordable housing;
- traffic congestion: traffic congestion is one of the most common traffic problems in large metropolitan areas with populations, as a rule, exceeding the threshold of one million inhabitants. They associated, in particular, with the motorization and wide dissemination of cars, which leads to increase of demand for transport infrastructure;
- distribution of cargoes: globalization and the materialization of the economy leads to increase of the number of transported cargoes in the cities. Since the freight transportation are usually carried out using the same infrastructure, which are involved in the carriage of passengers, freight mobility in cities is becoming more problematic;
- loss of public space: the majority of roads are in public ownership, and access to them is free. The increase of traffic flows intensity has a negative impact on society; it comes to markets, public meetings, parades, games and social interaction. These activities were gradually supplanted by appearance of cars. In some cases, they were transferred to the shopping malls, in other cases they were abandoned at all. Traffic flows affects life and character of residents interaction and their use of street space;
- IT and intelligent transport systems which improve public transport, because operators are able to improve the quality of their services due to the presence of accurate information about the location and movement of vehicles. In addition, passengers can receive updated information on the respective web sites, stations and other information points;
- using land: transport, especially road transport, affects nature use of the territories. From 30 to 60 % of the territory of any major metropolitan area can be set aside for transportation due to excessive dependence of residents from some types of public transport. In addition, similar nature of the use of land for transportations also confirms the strategic importance of transport in economic and social development of cities.

To solve the above problems a number of projects was developed. Initiators and participants are organizations such as the European Commission, the International Union of Public Transport (UITP), the International Transport Forum (ITF) with OECD, the Pan-European Program on Transport, Environment and Health (PEP), the World Bank, the Working Party on Transport Trends and Economics UNECE Transport Division.

The European Commission has been working to improve the quality of life of citizens and strengthening the economy by stimulating of sustainable mobility in cities and the wider use of environmentally safe and energy efficient vehicles.

Consider the following envisaged measures:

- facilitation of implementation of a comprehensive policy, taking into account the full complexity of urban transport systems, the management and the necessary harmonization of different strategies, for example in the field of urban mobility, interaction, environment and health sectors;

- focusing on the needs of citizens on the basis of assisting in the preparation of reliable trip information and to ensure a high level of protection for passengers;
- facilitating the implementation of environmentally friendly urban transportations by introducing new, environmentally friendly vehicle technologies, alternative fuels, and smart charging to stimulate changes in the behavior of consumers of transport services in the choice of mode of transport;
- settlement of the problem of funding based on a study of available opportunities, innovative schemes of partnership between the public and private sectors and the potential new financial solutions;
- providing support in the exchange of experience and knowledge to provide wider access to this information and assistance to stakeholders in the use of that experience and relevant statistics;
- optimization of urban mobility for stimulation of effective integration, interaction and interconnection of different road networks;
- improving road safety, particularly for vulnerable participants as the young and the elderly.

International Union of Public Transport (UITP)—a global network of authorities, public transport operators, policy-makers, research institutes and enterprises of supplying and servicing of public transport. It is a platform for international cooperation, business development and the sharing of know-how between its 3400 members from 92 countries. UITP is the global advocate of public transport and sustainable mobility, as well as the initiator of innovation in this sector. The International Transport Forum (ITF) with the OECD is an intergovernmental organization with a membership of 54 countries. It acts as a strategic brain center for making transport policy and organizes an annual summit of ministers. Its purpose is to assist in the development of transport policies at the global level and to ensure that this policy will be contributed to economic growth, environmental protection, social inclusion and the preservation of life and wellbeing of people. Pan-European Program on Transport, Environment and Health (PEP), established in 2002, is aimed at equal association of the leading participants in all three sectors. The World Bank supports countries and cities, which are its clients, in their efforts to develop urban transport policies and projects aimed at solving problems. Transport systems of large cities are facing with them due to the continuous growth of the urban population, private ownership of the vehicles, traffic congestion and vulnerability of public transport systems.

According to the Transport Strategy of the Russian Federation for the period until 2020, ensuring, guaranteed by the Constitution of the Russian Federation, freedom of movement for citizens of a single economic space and free movement of goods and services requires a focused outstripping sustainable transport. In this document is formulated the priorities for public transport policy providing achievement of strategic goals, one of which is the harmonization of development of the transport system and improve its security. In addition, in the Transport Strategy of the Russian Federation for the period until 2020 indicated that the transport policy of Russia is built in accordance with the basic principles of sustainable development [36], which implies a reduction of the negative impacts of transport complex on the environment (Table 1).

Methodical documents PIARC (Permanent International Association of Road Congresses) contain the following important areas of UDM [37]:

- reduction of the intensity of cars motion in city centers;
- priority of public passenger transport and cars, used by several passengers (HOV—high occupancy vehicles);
- regulation of parking;
- the interaction between the street and road network and the urban environment.

Transport solutions that are available today, primarily oriented on the private road transport,—one of the main causes of climate change, environmental pollution and a threat to human health since in cities and outside the transport consumes more than half of the liquid fossil fuel and generates almost a quarter of the world's emissions of CO_2, related to the energy sector.

Table 1 Measures to reduce traffic intensity of road transport

Type of activities	A method of implementation
Coordination of the urban and transport planning	Disposition of urban territories, which reduces the need for transport
Investment to transport systems	Construction of bypasses of urban centers
	Development of public transport systems
More efficient use of existing transport systems	Decrease of intensity during rush-hours
	Automated of regulatory system
	Joint (collective) use of passenger car
	Priority of bus traffic
	Restriction on the movement of heavy freight transport
Perfection of public transport systems	Improving the quality of public transport maintenance
	Stimulation of use of public transport by the owners of individual vehicles
Creating restrictions for movement of road transport	Management of traffic flow movement
	Zones that are free from road transport
	Priority of public transport
	Restrictions of bandwidth
Restrictions of parking	Restrictions on street parking
	Regulation of parking rules on territories of private possessions
	Organization of parking on the approaches to urban centers
Economic and administrative methods	The fee for the use of roads
	The fee for parking
	The fee for the opportunity to travel on the territories
	Administrative prohibitions and restrictions

Research shows that the environmental and social costs (costs associated with local air pollution, traffic accidents and traffic jams) can reach more than 10 % of GDP in the region or country, and significantly exceed the amount required to initiate of the transition to a “green” economy [2].

The policy of “greening” the transport is based on three interrelated principles:

- elimination or reduction of unnecessary trips by combining land use planning and transport planning and localization of production and consumption;
- transition to a more environmentally efficient types of transport, such as public and non-motorized transport for passengers, rail and water transport—for the freights;
- perfection of using technologies and fuels to reduce their negative impact on the environment and reduce the social costs.

Some of the necessary measures: land use planning, providing a compact or based on the main transport corridors of urban planning; regulation of fuel types and vehicles; provision of information for making decisions by consumers and companies. Such powerful economic incentives, such as the reform of taxes and subsidies, can also contribute to more “pure” private vehicles and the transition to public and non-motorized transport.

Improving the energy efficiency of the transport sector, the use of clean Fuels and the transition from private to public and non-motorized transport will improve the state of the economy and public health. As the analysis of the European experience shows, the economic returns from investments in public transport at the regional level is almost twice exceed the cost. In African countries, Sub-Saharan reducing the sulfur content in fuel for vehicles would reduce the annual cost of health care and related with their sectors by 980 million dollars [38]. A well-known example in the Brazilian city of Curitiba, where fuel consumption is 30 % lower than in other metropolitan areas of the country, has inspired many other cities to ensure the adoption of similar programs.

Municipal authorities around the world use a variety of tools and strategies to improve the efficiency of their transport systems and the quality of life. The introduction of ‘tax on traffic jams “in central London has reduced the number of daily trips by car by 70,000 [39], and emissions CO_2—by 20 % [40]. Electronic payment system of road tolls and car quotas in Singapore reduced the growth rates of car use and motorization [41]. Bus rapid transit system (BRT) in Bogota allowed to decrease emissions by 14 % per one passenger [42], and this success was repeated in Lagos, Ahmedabad, Guangzhou and Johannesburg. In Europe, many of the cities follow the example of Zurich, where the main type of public transport is the tram, and not pricy subway [43]. Emission standards allowed to reduce dependence on personal transport [44], and the establishment of zones free from emissions, and the introduction of permits for the delivery cargoes with a time limit solve the problem of traffic jams and reduce pollution of the environment [45], improving productivity and quality of life of citizens.

The rapid growth of motorization and limited bandwidth of street and road network, especially in older cities with dense buildings, forced the authorities of megacities in different continents to seek new opportunities to combat congestion and vehicle emission to implement new ideas to create a comfortable urban environment, announcing an unconditional priority of high population mobility. In these conditions, only correct and obvious solution is the development of public transport [46].

Analysis of the status and functioning of the transport system of cities in Russia indicates that its stability and security every year reduced because of discrepancies between the growth rates of motorization and level of infrastructure development of street and road network. These trends persist, despite the measures taken to ensure transport safety, as well as the fact that the level of motorization in Russia is far from similar indicators in European countries (Figs. 10 and 11).

According to the chief of the analytical department of PricewaterhouseCoopers in Russia Leonid Kostroma, Russia should catch up with current levels of developed countries such as Japan, France and the United Kingdom in 2025, when by 1000 people in Russia will account for 400 cars. Today Russia by the level of motorization of the population is about the same level as Brazil, ahead of China and India, as well as countries in Eastern Europe such as Slovakia and Ukraine.

At the same time vehicle fleets of developed countries will grow much more slowly because of the high motorization of population and saturation of automotive markets.

Moreover, in European countries, Japan and the United States is now observed a reverse process—demotorization, the level of providing the population by cars in developed countries decreases, in particular, due to the increased costs of

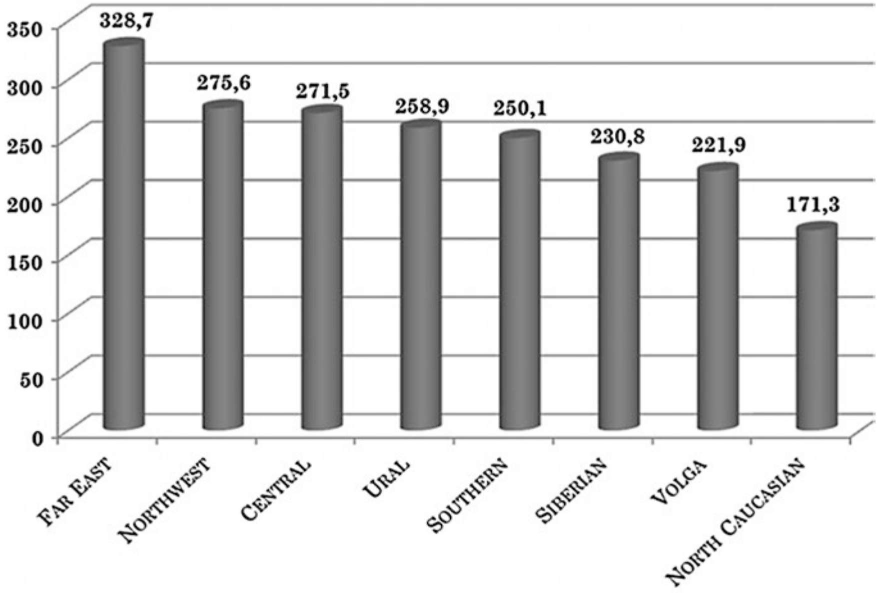


Fig. 10 Rating of federal districts of Russia in terms of providing by cars per 1000 people [45]

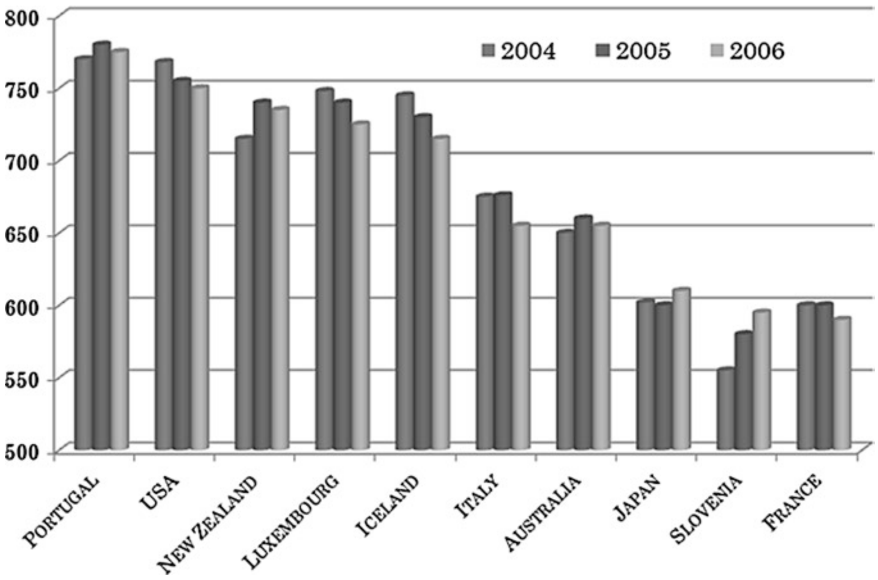


Fig. 11 Top 10 most automotive countries of the world by number of vehicles per 1000 people [49]

ownership and maintenance of vehicles (including the growth of gasoline prices, insurance costs and an increase in paid parking). In addition, the growth of the population of large cities affects this process. In these cities is offered a developed transport infrastructure, which have cheaper price and comparable in quality of movement with a private car [49].

In US motorization is traditionally considerably higher than in Europe, and in the national average is 811, and in the big cities—more than 900. A characteristic feature of motorization in European cities is the slowing down and stabilization its growth. This is explained by the difficulties of using the cars in the city. There are no restrictions on the purchase of a vehicle in any country in Europe, but the number of urban vehicle fleet has remained unchanged for many years. This has been achieved due to the policy of complex solutions of zoning of the city, the development of kinds of public passenger transport and the use of economic mechanism of limits concerning use of private car in the city [50].

Results of research of consumer preferences of the young population of the USA and Europe have confirmed the hypothesis that the youth's interest in cars is reduced. Thus, the share of American consumers who consider that the car is obligatory purchase declined from 93 % in 1996 to 86 % in 2010. According to experts, these trends are still not typical for Russia, but do not exclude that in the big cities after some time we can observe similar changes [49].

However, it is impossible to get rid of the influx of cars in the business centers, trade and administrative centers of the city. In addition, the resettlement of citizens in the suburbs boosts the demand for daily trips to work and back. Fully satisfy the demand for the use of the car in the city cannot be done nowhere in Europe.

The reason—the limitations of bandwidth on the city roads, lack of parking spaces for the organizations. Therefore several directions were produced for reducing the traffic load on the city [50].

- Development, a broad discussion, adoption and implementation of the master plan of the city, oriented on the considerable amount of time (15–20 years).
- Zoning of territory of the city.
- This process is common to all cities. Its main purpose—preservation of the historic part of city from destruction, development of public passenger transport improving the environment.
- The introduction of payment for the use of a personal vehicle in the city.
- This is one of the most unpopular, but very effective measures to reduce the traffic load in the city. The fee is set for the ride on the highway, the entrance in the zone of the city, and parking. Its price increases with approaching the center, and by time—during rush-hours.
- Development of public passenger transport.
- Development of street and road network.
- Dataware of road traffic.

As optimization of the transport system can be done in two ways: regulation density of traffic flow and more environmentally friendly vehicles, for each of these areas methods to achieve their best values have been developed. So, to adjust the density of the transport stream is possible by using fiscal measures (restrictions on entry in busy areas, traffic control, etc.), as well as better use of capacity of the network (the higher occupancy rates of vehicles, replacement of more capacious and so on). Improvement of environmental performance of vehicles can be achieved through fleet renewal and replacement by a more ecological one.

As stated in article [51], according to the statistics, the environmental impact of large parks is higher than personal vehicles because of the large annual mileage. The personal car average mileage is 12,000 miles/year, while the average car in park passes 23,000 miles/year. The share of new cars in the park is significant, because updating is more common than in individual owners. In addition, to stimulate the owners of parks for rational operation is easier than individual owners. Therefore, to analyze the potential benefits from fleet management subsystem of public passenger vehicles was selected (Fig. 12).

5.2 Priority Development of Public Transport

At its twenty-fourth session the Working Party on Transport Trends and Economics endorsed the proposal of the Secretariat about converting of the report with an overview of the transport situation in the countries—members of the UNECE and emerging trends in the development of an annual publication on Transport Trends and Economics in the ECE region and asked the countries answer to the secretariat questionnaire concerning the transport situation in 2011

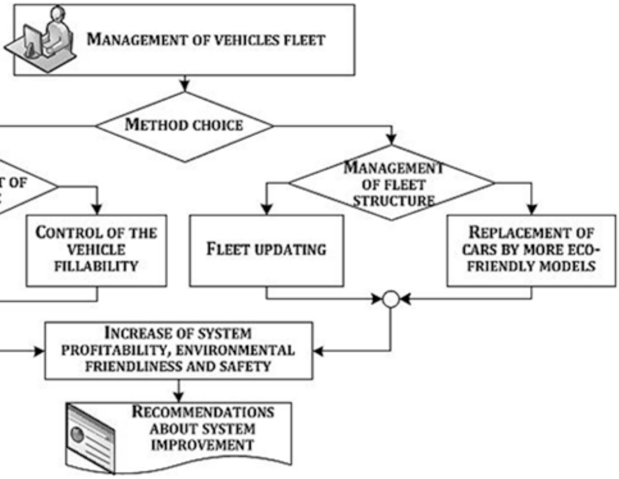


Fig. 12 Management methods of vehicles fleet

and the expected changes in 2012 (ECE/TRANS/WP.5/50, paragraphs 31 and 32). At its seventy-fourth session of the Inland Transport Committee took note of the draft publication and approved the decision of the Working Group about the review of the transformation in the annual publication on Transport Trends and Economics in the ECE region (ECE/TRANS/224, paragraphs 20 and 21) [52].

Considering the status and problems of transportation systems, Working Group on Transport Trends and Economics notes that many of them are associated with urbanization and the status of megacities. Thus, according to one research [53], in 2011 there were an estimated 11 megacities. Apart from Karachi, this select group of cities includes Shanghai, Mumbai, Beijing, Delhi, Buenos Aires, Metro Manila, Seoul, Sao Paulo, Moscow and Jakarta. Istanbul and Bangkok, where the population is more than 9 million people are on the 12th and 13th places in the list of the largest cities in the world. In addition, each of the mayors of the 25 largest cities in the world is responsible for a greater number of people than the prime ministers of most countries. For example, London which occupies 23th place in the world has more inhabitants than in countries such as Denmark, Ireland, New Zealand and Paraguay, and if Karachi—the largest city in the world—was a country, it would occupy a higher place than Hungary, Greece or Portugal. The total population of 11 world megacities—cities which are home to more than 10 million people—equal to the number of inhabitants in Japan.

According to recent statistics, 80 % of EU citizens live in urban areas, and 40 %—in large cities with a population of over 200,000 inhabitants. In their daily lives they use same space, and for the movement—the same infrastructure. Public transport, cars, trucks, cyclists and pedestrians use the same infrastructure. On average, a resident of Europe makes 1000 trips per year, and in half cases at a distance of less than 5 km. Walking and cycling can serve as a real alternative to many of these movements for a short distance. The urban mobility has 40 % of all CO_2 emissions by road transport and up to 70 % of emissions from transport of other pollutants. One of the three fatal accidents accounted for the city. Problems associated with traffic congestion, are also concentrated in cities and around them. European cities are increasingly facing with problems resulting from transport and traffic [54].

The car is still the dominant means of movement in the cities. So in urban agglomerations of the EU about 75 % run accounts for cars. This leads to the formation of such a number of congestions that in some European cities, the average speed during the rush-hours is lower than in time of horse-drawn carriages. The increasing use of car associated with security problems of the environment, as well as with reduction in the already insufficient investment in public transport.

Transportations of road transport are largely dependent on the availability of petroleum products, and they accounted for most of the transport emissions into the atmosphere. In addition, residents of almost all European cities are experiencing consequences of air pollution; its level exceeds the limits set by the EU for particulate matter. During the last decade there has been significant progress in reducing pollutant emissions, but there are still problems associated with so-called “hot spots” or places with the highest crossing routes, and an alarming increase in traffic flows can reverse the progress made in the improvement of urban air quality and reducing greenhouse gas emissions.

For all major cities in Europe the question of how to increase mobility and at the same time reduce the size of congestion, accidents and pollution is a common problem. City residents like no other experiencing the immediate negative consequences of their own mobility and are probably ready to look for innovative solutions for sustainable mobility.

One of the significant alternatives to the car serves the public transport, which plays an important role in the large cities, where it transports by 2.5–3 times more passengers than private transport. Public transport is very important for approximately 40 % of households in the EU who do not have a car. According to forecasts, without further intervention the public transport in the next decade will retain their market share only in large urban areas, where it has a clear advantage in terms of reputation, reliability and speed of movement (Table 2).

For the improvement of public transport there are different strategies ensuring its benefits:

- provision of higher quality services on public transport, including increasing their diversity, fast and more convenient service;
- the reduction of tariffs and offering the discounts (for example, lower tariffs for not rush-hours or for certain groups of passengers);
- the introduction of more comfortable structures of passenger tariff and payment systems using “smart cards”;
- implementation of programs to reduce the costs of commuter trips, financial incentives of commuter trips, as well as other programs of transport demand management, promoting use of alternative modes of transport;

Table 2 Share of cars in total passenger turnover

Country	Total passenger turnover (train + bus + cars) billion. Pass.km	The share of cars in total passenger turnover (%)
Russian Federation	867	68
France	663.1	84
United Kingdom	707.1	92
Italy	850.9	82
Belgium	142	75
Sweden	119	83
USA	5007.5	90
Japan	1335.5	65
Czech Republic	81	78
Poland	337.4	88
Hungary	76.5	69
Lithuania	32.6	92

- improvement of programs of informing of the passengers and marketing;
- realization of programs of construction of intercepting parking lots and their advertising;
- preparation of guidance on multi-modal access system, including maps, schedules, contact numbers and other information about how to reach the destination by public transport;
- establishment of tariffs for parking and travel on the roads, which would stimulate the use of public transport.

Another alternative to cars is automated passenger routing transport—modern system of transportation, in which an automated self-propelled vehicles operate on specially allocated for them fixed guide ways. Two of the most well-known such species is the Docklands Light Rail railway in London and 14 line of the Paris subway. Automated passenger routing transport is attractive by high intensity work and low operational costs due to a reduction number of staff. Operation of vehicles has more flexible nature because of the lack of the need to ensure proper working conditions and the driver's position about remuneration. Automated passenger routing transport is particularly suitable for situations when you need to provide transportation of small number of people throughout all day. Construction costs of these systems are competitive in the case of new roads, but the unproductive costs are higher with the centralization of the management system and the use of automated technologies. At the same time in terms of bandwidth, they are much more effective in achieving the objectives of sustainable development than any system based on the use of vehicles operated by driver.

Personal rapid transit system—a type of automated passenger routing transport, can effectively overcome the difficulties associated with the adherence to the timetable of public transport, while maintaining the advantages of individual trip. These systems presuppose operation of a small self-propelled vehicle, which moves along the guide path. Bristol University has developed a system of urban light rail transport. In this case, the vehicle represents 4-seater capsule, which moves on rubber wheels on their own guide way. Management is provided by a computer that responds to magnetic implants of guide way. These vehicles with electric drive provide the place for bicycles, wheelchairs and luggage. Fare payment system is based on the principles of operation of the vehicle, and not individual trip. Thus, the four people who use the vehicle pay the same tariff as the passenger, moving alone, which increases the competitiveness of vehicle in comparison with the transportation on passenger car.

In the documents of the THEPEP (Transport, Health and Environment Pan-European Program) it is noted that positive examples of measures taken to improve the quality of urban environment and support the process of redistribution of means of transportation by increasing the share of walking and cycling in combination with the use of public transport encourage. It includes the improved bicycle infrastructure and urban traffic by using bicycles in Paris and Barcelona, charging for entry in the congested areas of London, Stockholm and other cities and measures adopted in new York in order to “prohibit the movement of vehicles” in heavily congested areas and their transformation into parks [54]. In addition it is noted that electro-mobility is becoming more accessible and widespread. Many corporate car parks and collaboration patterns of using a rental car across the entire pan-European region rely on electric and/or hybrid vehicles, and the introduction of e-bikes are allowed to use the cycle movement not only for rehabilitation and recreation, but also as a viable means of transportation.

Among the factors constraining the development of alternative ways of movement is the fact that only 68 countries have adopted policies at the national and sub-national levels, promoting walking and cycling, and only 79 countries have adopted measures for the protection of pedestrians and cyclists, isolating them from other motorized high-speed means of transport. This indicator is significantly higher in countries with high income level (69 %) than in low-and middle-income countries (34 %) [56].

Safe public transport systems are increasingly viewed as an important tool for safe increase of mobility of the population, especially in urban areas suffering from growing traffic congestion. In many cities with high income the policy of reducing the use of personal motor transport is particularly emphasized through investment in the development of public transport networks. Investments in safe public transport are also seen as a mechanism for stimulating the growth of physical activity and, therefore, strengthening the health of the population.

More than 100 countries adopted policy measures on investments in public transport at the national or subnational levels. In most countries with high-income public transport is regulated properly and therefore significantly more secure than private vehicles: however, in many countries with low and middle income levels, whose economy is growing rapidly, the growth is not regulated, leading to increased road traffic injuries among its users.

For increase of motivation of car owners of transition to public transport in the cities such system of city passenger transport which, on the one hand, will provide comfort and safety of movement of passengers at the smallest both temporary, and monetary expenses has to be created, and with another—will be formed taking into account street road network capacity, from the point of environment load minimization view, and also from the point of traffic safety view.

For the population the public transport becomes attractive only when will be able to make the worthy competition to the cars which are in private use, first of all, from the point of provided services comfort and quality view [43], that is possible, in turn, only at scientific approach to development of city passenger transport route network. Besides, the structure of the bus fleet functioning on each of routes, qualitatively and quantitatively has to correspond to volumes of passenger traffics and ecological requirements of the modern city.

Thus, one of the purpose achievement ways set within the Global "green" new course, transition from private cars to public, more eco-friendly, to transport is without prejudice to mobility of the population.

5.3 Decision-Making Support Systems as Mode of Transport System Parameters Optimization

As the quality of the decisions on the management of transport systems depends on the quality of information, adequacy of methods of its analysis, as well as on an efficient tool for working with large arrays of data for these purposes decision support systems (DSS) are created. They are automated computer systems that combine the properties and abilities of management information systems and database management systems. For analysis and development of recommendations in the DSS information search, data mining, knowledge retrieval in databases, reasoning based on precedents, simulation modeling, evolutionary computation and genetic algorithms, neural networks, situation analysis, cognitive modeling, etc. are used. If the operations of the DSS are methods of artificial intelligence, we talk about intellectual DSS, or IDSS. The design of the DSS significantly depends on the type of tasks for which it is developed, from the available data, information and knowledge, and also from users of the system. There are three main parts in the DSS:

- Data system for collection and storage of information received from internal and external sources, as a rule, it is a data store.
- The system of dialogue that allows the user to specify what data to choose and how to handle them.
- The system of models—ideas, algorithms and procedures that allow to process data and to analyze them. The user has the experience, knows the situation and follows certain considerations when fetching data. In the processing of data, use different procedures, from simple summing to statistical analysis and nonlinear optimization.

Conceptual scheme DSS for the management of the transport system of the city is shown on Fig. 13.

The simulation model is the intellectual core of the designing DSS. Simulation modeling is the tool that allows you not only to perform a qualitative analysis of the processes but also to explore the effects of any changes in these processes.

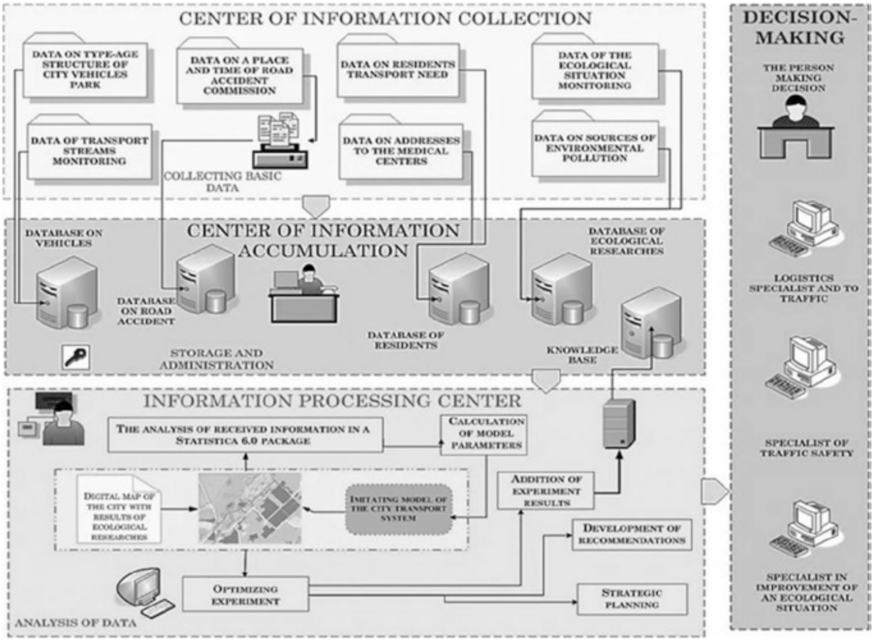


Fig. 13 Conceptual scheme DSS for the management of the transport system of the city

What's more it allows you to choose the variant which satisfies all specified limitations and issues optimal system parameters [57].

The software developed for these purposes allows you to build models that reflect the processes as they were in reality, and then conduct a series of virtual experiments specifying the model time. Thus it is possible to study the process using the single test as well as set of tests that allows you to find the optimal process parameters and the results will be determined by their random nature.

Economic effect of ITS application is determined by the reduction of transportation costs by optimizing routes and increasing efficiency of the vehicle fleet. Environmental effect is to reduce the negative impact on the environment and can be achieved through rational redistribution of traffic flows on the city road network. Social effect will be to reduce the risk of disease due to urban air quality.

The multidimensional intellectual data model is installed in traffic control center and serves for gathering, storage and formalization of road network parameters. The operative information which comes to Control center in a mode of real time from various sources is necessary for correct reproduction in a model of real situations: from servers of the municipal enterprises, from the equipment for operative monitoring of a road situation (GPS/Glonass systems).

Storage of the information in the form of an OLAP-cube and its subsequent processing will allow to estimate street network parameter dynamics with high accuracy on different measurements (quantity of vehicles, a road section, a season, average speed, traffic light availability etc.). Packages of the formalized data are continuously transferred in a simulation system for changing of model parameters. Information analysis of the city transport system's parameters' changes by the day time, day of the week, month of the year makes it possible to predict possible city roads situation changes in subsequent periods. Furthermore, modeling workarounds with changing system parameters allows you to choose the most optimum of them and to build a knowledge base of the best solutions for fixed traffic and environment parameters. Such databases are used for operational decision-making management in the case of emergencies in the transport system.

5.4 Optimization of Public Transport System Parameters

Road transport is the main source of environmental pollution in Naberezhnye Chelny, because the main stationary sources are outside or on its borders. On spatial-planning organization of the city natural landscape situation has materially affected: the city is focused on water areas of Nizhnekamsk reservoir, Shelninsky Bay, and forests located on their shores. Linear structure open type with the "classic" functional zoning was laid in the basis of planning organization of the city with a parallel location of industrial and residential areas, suburban recreation zones. Longitudinal highways which connect the residential areas of the city compose a transport-planning frame of the city that gives rise to attribute the planning scheme of its road network to rectangular. The main "diameter" of the city is a longitudinal thoroughfare, which includes M. Jalil avenue, Naberezhnochelninsky avenue, and Mira avenue [4].

Charts of dispersion of pollutants, received by results of natural supervision (Fig. 14), allowed to highlight problem areas one of which is a complex junction formed by the intersection of Prospect Mira, Peoples' Friendship and Syuyumbike (Fig. 15). Analysis of statistics on the road traffic accidents showed that this site is a place with a high concentration of road accidents. It creates problems for the normal functioning of the transport system and of the environment because the frequent occurrence of the congestion situations exacerbate the negative impact of transport on the environment.

For a more detailed analysis of the area its simulation model was built using the Russian software developer AnyLogic.

There are several factors that were taken into account:

- geometry portion of the road network;
- traffic density;
- intensity of pedestrian traffic in the area with the distribution lanes;
- emissions of pollutants from motor vehicles and emissions quotas;
- modes of traffic lights on the previous and subsequent sections.

As the limitations of the model the emissions' quota was set that should not be exceeded:

$$Q_{aut} = \frac{M_{Li} + M_{Pi} + M_{pr}}{M_{kv}} \leq 1 \tag{1}$$

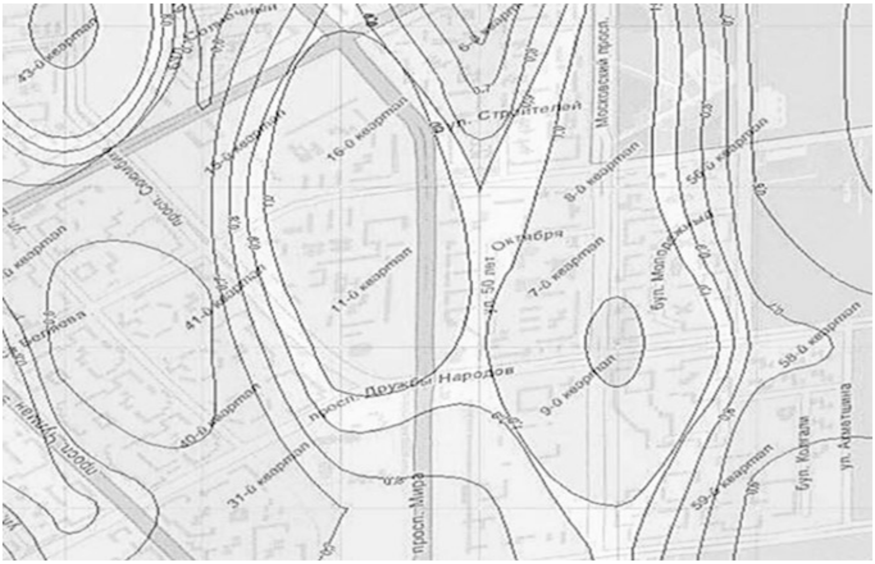
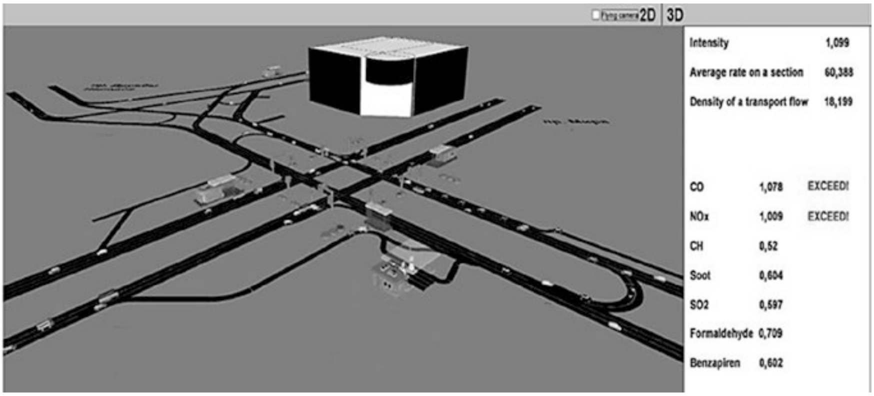


Fig. 14 Map of carbon monoxide dispersion

Fig. 15 Simulated interchange of road network scheme



```
Intensity                     1,099
Average rate on a section     60,388
Density of a transport flow   18,199

CO            1,078   EXCEED!
NOx           1,009   EXCEED!
CH            0,52
Soot          0,604
SO2           0,597
Formaldehyde  0,709
Benzapiren    0,602
```

Fig. 16 The view of the simulation model of the considered section of the road network

Model experiment on the flow characteristics, established as a result of field observations showed that there was an excess of carbon monoxide and nitrogen dioxide emissions on the considered section during the congestion situations (Fig. 16). The first stage of optimization experiment allowed us to determine optimal parameters of the traffic flow (the density, the intensity and the speed) that provide not exceeding quota emissions of pollutants.

Since the considered site is the confluence of the two main avenues of the city, it forms a significant number of public transport routes, which connects the new and old parts of the city. One of the methods of optimization of parameters of traffic flow on this site is the improvement of the route network. The second direction is connected with the use of the bus routes greater capacity, which will reduce the density of traffic flow and reduce emissions of harmful substances. Similar methods are described in articles [57].

In the second stage of the optimization experiment the part of the public transport's replacement for the more environmentally friendly was done and the vehicular traffic emissions calculated for the original parameters were determined. Such replacement leads to considerable decrease in volumes of emissions of pollutants (Table 3).

Table 3 Change of substances by public transport polluting emissions volumes when using gas motor fuel

Substance name	The volume of emissions		
	100 % of fleet on diesel fuel	50 % of fleet on gas motor fuel	100 % of fleet on gas motor fuel
CO	1036	0870	0691
NOx	0974	0907	0830
CH	0499	0437	0386
Soot	0581	0102	0043
SO_2	0578	0422	0361
Formaldehyde	0681	0663	0627
Benzαpiren	0579	0514	0489

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ITS Services Packages as a Tool for Managing Traffic Congestion in Cities

Renata Żochowska and Grzegorz Karoń

Abstract Traffic congestion understood as transportation crowding is an important factor for increasing inconvenience of life and passing through element of transportation infrastructure in urban areas. Measures aimed at mitigating the negative effects of such situations should be taken at different levels of traffic management: strategic, tactical and operational. This requires a close cooperation and coordination between planners, designers and traffic engineers. The article presents strategies for managing congestion in cities using packages of ITS services. It also presents the concept of an integrated approach to this issue in the context of the theory of traffic flow.

1 Introduction

The increasing growth of the attractiveness of cities induces natural mobility needs of residents and other users of transportation system. However, the road network in urban areas is determined by limited capacity and is often not able to take the growing volume of traffic formed both during peak periods, and in cases of different types of unplanned events (e.g. vehicle crashes, collisions and accidents). Such situations, in turn, contribute to the crowding of elements of the transportation infrastructure, and result in significant queues, congestion and even block a part of the city [14, 31].

These situations require rational decisions in the planning and control of traffic, taking into account the interdependence between the individual elements of transportation system and its surroundings. For this purpose, a variety tools for

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managing traffic congestion have been applied [16, 34]. Existing solutions include not only the changes in the traffic operations or shaping the transport arrangement of the city, but also an effective influencing on the travel behavior of urban residents. These activities are undertaken more and more often with the use of control systems and traffic management based on modern technologies.

2 Cities as the Areas Particularly Vulnerable to Traffic Congestion

The urban area is a complex spatio-structural arrangement that constitutes the territorial socio-economic system. In the context of analysis of relationships between the transportation system and land use of the city three major subsystems may be recognized. These are [2]: activity, travel demand and supply of transport subsystems.

One of the subsystems—the **activity system**—is represented by a set of individual socio-economic needs and behaviors of users of the system (e.g. residents, businesses, institutions, organizations) that are associated with the specific transportation needs in different territorial units of the city. Different locations of any human activities and households, which are places of residence, affects the size of the transportation needs and their spatial and temporal distribution.

Another subsystem—**travel demand system**—derives from the need of access to urban functions and services and is determined by the spatial dispersion of the elements of activity system (households and business objects) in the area of the city. The travel demand flows are the results of human choices in ways they pass through the transportation network. They are also related to the need of transportation of goods. Individual users of transportation system make decisions as to how to travel (i.e. the destination, mode of transport and the route). The results of these choices are aggregated traffic flows in a transportation network consisting of vehicles carrying people and goods.

The last subsystem—**supply of transport system**—is a transport offer of the city that is described by the specified attributes of a quantitative and qualitative character. Each element of the transportation network is determined by a certain capacity, corresponding to the largest number of units of the traffic flow that can be charged to it within a specified period of time. In a situation where the size of the traffic flow reaches the level of capacity the effect of traffic congestion occurs. This leads to a decline in the quality of the functioning of transportation system of the city, which in turn causes an increase in time and travel costs and a decrease in the active and passive accessibility.

Problems associated with excessive traffic load are noticeable and burdensome not only on most roads of high transportation importance. In urban areas, traffic congestion is increasingly spreading to the surroundings, leading to the situation in which the roads in housing estates are used as detours for the crowded arterials [1]. This causes a decrease in the level of safety, efficiency and effectiveness of travel. These phenomena also impact negatively on the environment and health of inhabitants, and therefore affects the quality of the functioning of whole settlement units as a system.

Depending on the causes and the way of formation it may be distinguished two types of traffic congestion: the structural (recurring congestion, recurrent congestion) and the incidental one (random congestion, non-recurring congestion) [7, 31]. The **structural traffic congestion** results from an excessive demand for transportation that appears in peaks of each cycle (e.g. hourly, daily, weekly, seasonal, yearly) in relation to the limited capacity and it is typical for elements of transportation network, which are known as so-called bottlenecks of transportation system. They have a high vulnerability to disruption of traffic flows [33]. On the basis of structural congestion the time-dependent O-D matrix and the corresponding alternate routes may be specified [13, 26].

The **incidental traffic congestion** is the result of accidental temporary conditions or special circumstances (e.g. random incidents, road and street roads, mass events, poor condition of roads, adverse weather conditions, etc.). In the travel modeling this type of congestion may be used to determine so-called spatial sensitivity expressed as a function, which largely depends on the experience of road users, their knowledge of networks and information from management systems (ITS subsystems transmitting information about road conditions). This information may be delivered to travelers in two ways: as information by the roadside (e.g. variable message signs, information about the degree of crowding of traffic lane, dynamic lane assignment, variable speed limit assignment, information about the current arrival and waiting time at public transport stops) or information transmitted to the vehicle (e.g. radio, satellite navigation, Internet) [13].

It should be emphasized that it is often difficult to clearly identify the proper cause of disruption and thus traffic congestion may be due to many different factors. The degree of interaction between different factors may be varied both in time (in different days and periods of the day) and in space (at various elements of transportation network). Some factors give rise to the next ones [31]. In the case of permanent increase in traffic, due to physical exhaustion of the capacity of the road network, the system becomes more vulnerable to disruption caused by a typical and unplanned events, accidents and car crashes, adverse weather conditions or road works [33]. These incidents may occur at any time and in places where previously there was no traffic congestion and thus cause the spread of the disruptions in space and time.

Congestion in the urban transportation network is observed both on the roads as traffic disruption and effect of shockwaves, as well as in means of transport as overloading of buses and trams, that affects the broadly understood inconvenience of life in the city. Decline in the quality of the functioning of the transportation system due to congestion is acceptable to its users as long as the present discomfort is balanced by profits from the displacement. At some point, however, one should take adequate actions, leading to an increase in the attractiveness of the transportation system of the city. For this purpose packages of ITS services are applied. The impact of intelligent transportation systems (ITS)—in the context of the relationships among supply, demand and activity subsystems with special emphasis on the diverse needs, behaviors and transportation preferences—has been

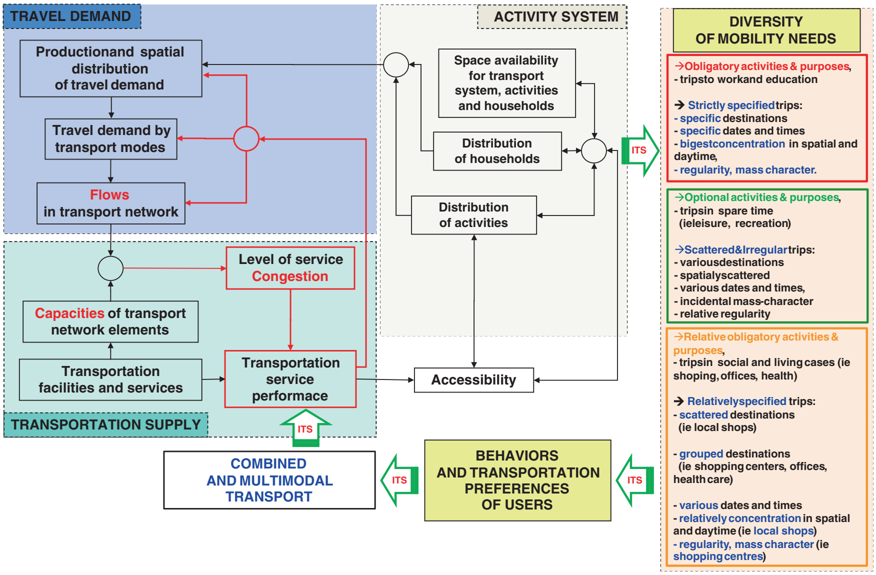

Fig. 1 The impact of ITS services in the areas of supply, demand and activity subsystems

presented in Fig. 1. This interaction should be taken into account when building predictive transportation models both for the certain investments and for the diagnosis of the entire system and the socio-economic development of the city [10].

3 The Impact of Traffic Management on Decision-Making Processes

The main objective of traffic management systems is the minimizing of congestion and travel time as well as maximizing the performance of the transportation network. For effective results the still changing traffic patterns should be continuously observed based on available data. It is a derivative of the decisions made by travelers mainly relating to choice of the way they pass through the transportation network [25, 32]. Knowledge about the impact of traffic management parameters on the performance of the transportation infrastructure helps to improve the quality of predictive models used in dynamic processes.

Traffic congestion should be considered as a result of the interaction between users of the transportation system, that cause the negative effects of an economic and an exploitation nature [34]. It is therefore the relative phenomenon, which refers to the difference between the performance of the road system expected by the users and the way in which this system operates [16]. In such an approach traffic congestion may be seen in the context of qualitative gap between expected and realized quality of transportation system. The expectations of users concerning efficiency of the road system are thus fundamental to understand the way they percept the congestion. The same levels of traffic congestion may be seen as very burdensome (unacceptable) as well as satisfactory by different travelers. It depends on the characteristics of road users, such as age, driving experience, temperament, and more. Further factors may be related to destination of travel and knowledge of transportation networks by travelers [32].

The expectations of users with regard to travel conditions are not static. They are characterized by a high level of heterogeneity, which affects the perception of congestion [16]. Under some conditions a certain level of traffic congestion is acceptable [30]. It should also be noted that the reliability of the location of the queue, its duration, and the starting point are besides delay arising from the extension of the travel time the main factors when analyzing the impact of traffic congestion on the behavior of travelers [4].

Traffic flows on the individual elements of the urban network are the result of the transportation processes that are realized in the transportation system of the city and its surroundings. That, in turn, is the effect of decision-making sub-processes made by users of the transportation system in different time horizons. Among these sub-processes one may distinguish:

- short-term—related to the current decisions of drivers when passing through the individual parts of the road network (e.g. choice the traffic lane at the approach of the intersection, decision on overtake on the section of the road),
- medium term—related to the choice of paths in the network and to the search for free parking places,
- long-term—related to decisions of network user on traveling and on choice of means of transport.

For each of these sub-processes one may influence at different levels of management. There are three levels of management in traffic engineering: operational, tactical and strategic one [3]. The examples of tasks at particular level of management have been shown in Table 1, and interrelationships between the different decision-making sub-processes and management levels have been presented in the form of a hierarchical structure in Fig. 2. In the case of disruption of traffic flows it is necessary to take appropriate actions on each of the presented level of management.

Traffic congestion management in an efficient manner requires the integration of the activities at different levels—from strategic level and ending at the operational one. It is necessary, therefore, constant cooperation and coordination between the various agencies working in the area of a given region and between transport and other branches of the national economy, e.g. public safety services [1]. It is also important to provide consistency between the actions taken at various levels of management, which is conditioned by cooperation of planners, designers and traffic engineers, whereby the scope of their activities is dependent on the time horizon.

Until recently traditional models used by road authorities have focused mainly on the management of road systems in urban areas so as to maximize their ability to take over the current and future expected travel demand. This approach seeks to maximize the physical use of available capacity of the road. The road system is

Table 1 Relationships between decision-making sub-processes and levels of management in the city

Decision-making sub-process	Level of management	Examples of traffic management using the ITS services
Short-term	Operational	Stabilization of traffic (e.g. via traffic lights)
		Dynamic assignment of traffic lanes to the direction or means of transport (e.g. by usage of variable message signs)
Medium term	Tactical	Direct impact on the decision-making sub-process for path selection in the network using the information (e.g. using variable message signs and navigation inside the vehicle, information on the stop)
		Diversification of traffic congestion to limit formation of congestion (e.g. load balancing at alternative routes by the proper traffic management)
Long-term	Strategic	Direct impact on the sub-process for deciding to travel and for choosing of mean of transport (e.g. using the information supplied by the media)
		Indirect effects (through the tactical level) to identify appropriate criteria and constraints to optimize the coordination of traffic (e.g. preferring public transport)
		Indirect effects (through the operational level) on the parameters of the control signals to fulfill a certain priority

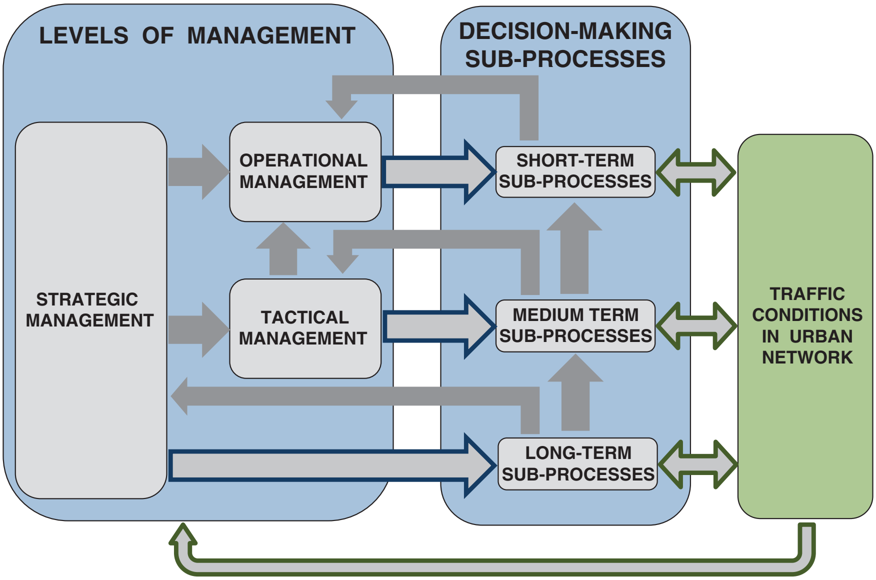

Fig. 2 The hierarchical structure of traffic management from the point of view of impact on decision-making sub-processes

assessed in terms of capacity expressed in the form of volume of traffic, density, or synthetically—the level of service. Obtaining more favorable values of these parameters in terms of capacity of the facility has been regarded as an improvement of traffic conditions [16]. Such an operational approach is used to identify the location of the “bottlenecks” of the system. Their objective is to minimize the delay and negative impact at the place, which is characterized by a special inconvenience for users. However, the methods whose purpose is to maximize the traffic flows along the major sections of the road may result in the transfer of disruptions to less stable areas of the city and in the increase the risk of recurring and unpredictable traffic problems.

Effective congestion management should therefore include not only changes in the transportation system of the city and its surroundings, but also in an appropriate way of affecting the decisions of its users in terms of the way and time of planned trip. The wide variation in the pattern of the users of the transportation system and of the purposes of their trips requires the use of various packages of ITS services. Example integration of multimodal travel information and transportation systems with priority for public transport has been presented in Fig. 3. The ITS services satisfy with this enormous role in shaping the desired travel behaviors.

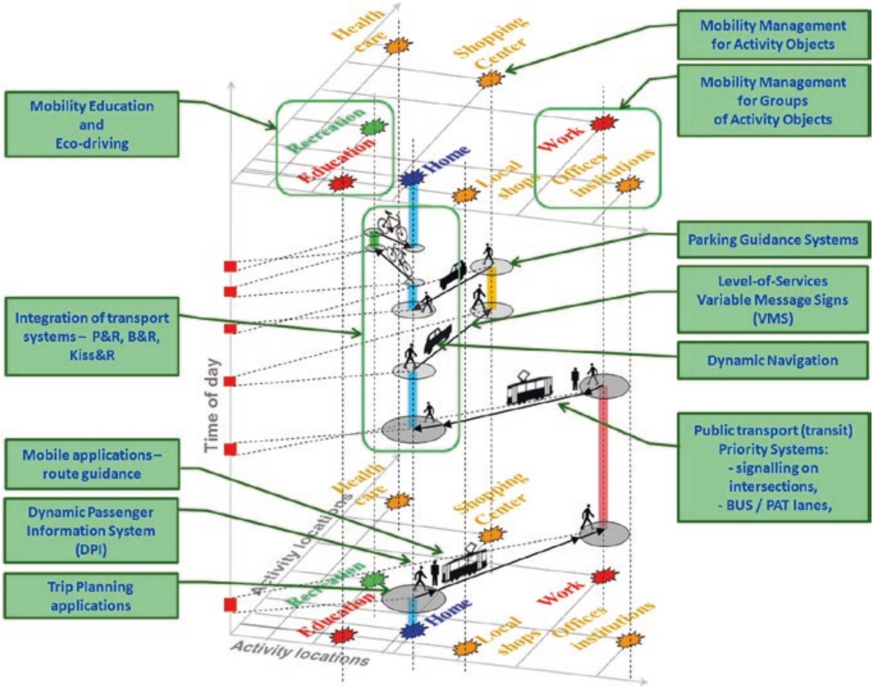

Fig. 3 Design of ITS services with respect to their impact on the travel behavior

4 The Management of Traffic Congestion Using the ITS Services

Considering the problems of traffic congestion in systematic way one can distinguish two principal areas of possible actions: the area of travel and transport demand management and the area of supply—understood as the transportation system—and the use of packages of ITS services. These two areas permeate each other. Currently, the ITS services are also used as a tool for transport demand management.

In urban areas with dense development the opportunities to invest in additional transportation infrastructure are very limited. In the transportation corridors located in such areas there is increasingly lack of the physical space to build more traffic lanes. Therefore, an effective solution to traffic problems is associated with the search for other possible strategies [34]. In this context, traffic congestion management using the ITS services may include:

- operational activities—technical solutions to increase existing capacity without investing in the development of transportation infrastructure,
- demand management—activities that affect the shaping of transportation needs in such a way as to decrease the degree of utilization of existing capacity.

Examples of solutions used in respect of those basic strategies have been shown in Fig. 4. There is a strong positive correlation between the increase in the additional capacity of the road infrastructure and increasing of transport demand [19, 20]. Therefore, an important way to obtain effective results in terms of traffic congestion management is the use of measures influencing the travel behavior of road users.

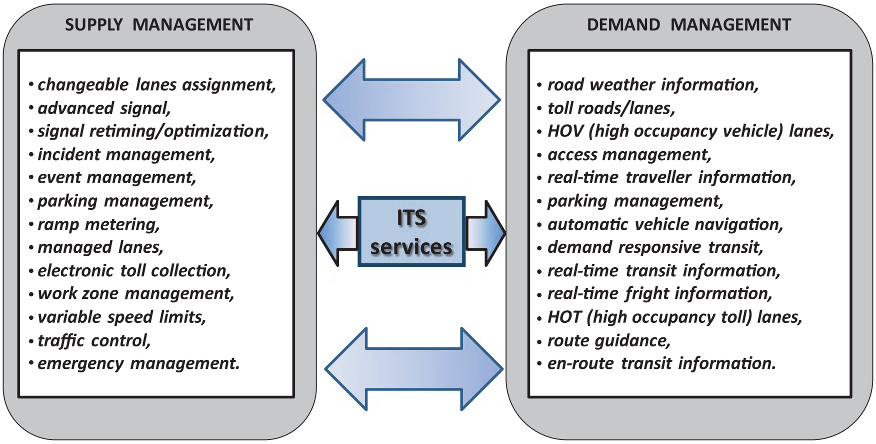

Fig. 4 Traffic congestion management with the usage of the ITS services

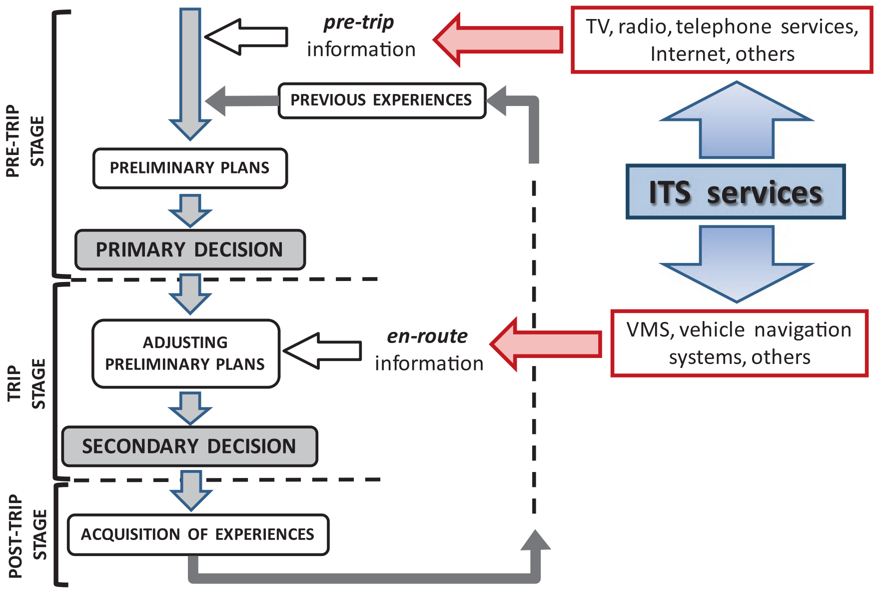

Fig. 5 The impact of the information provided by the ITS services on the decision-making process of users of the transportation system

Technological development allows to apply strategies related to the information about the current time and travel conditions (Real-Time Travel Information). It is important to provide this information to users before deciding to travel, because the information may influence their decision as to which way of pursuing trip (choice of means of transport, time of departure, travel routes), taking into account individual preferences [25]. Impact of the information on decision-making process of users of the transportation network has been shown schematically in the Fig. 5.

The choice of route is also a part of the demand management system, through the use of strategies to choose the route (Route Strategies). These activities are focused on providing users in advance the precise and valid information on traffic conditions. Following such strategy road users choose less crowded routes and thereby they avoid traffic congestion as well as their passing through the transportation network does not cause the increase of traffic problems. Sources of traffic information commonly used by travelers are: radio and TV communications and Internet services with an updated estimated time of travel (mainly based on average speed of driving). Development of ITS services allows application of real-time information about trip (Real-Time Travel Route Information) in the field. They are usually presented in the form of an interactive map with a preview video of selected places where the traffic congestion frequently takes place and indication of road works and detours. These maps may be viewed in mobile devices (phones, PDAs, laptops), and displayed on variable message boards in order to allow travelers to make decisions regarding the selection of a route while driving [13].

For a long time In-Vehicle Navigation Systems, determining a static route based on the distance between the source and destination of trip, have been commonly used. The use of instantly updated information about the times (speeds) of the trip—provided wirelessly by the ITS services—enables dynamic route calculation "from the intersection to intersection".

Also online route planning systems (Web-Based Route-Planning Tools) become popular because more and more network services, both independent and belonging to operators of public transport, allows to plan a trip using the certain means of transport. Further development of these applications enables planning a route using different modes of transport (multimodal journeys) with regard to the current degree of traffic congestion on the roads as well as in vehicles [13].

The ITS services (e.g. sensors and recorders to measure the volume of traffic, availability of parking spaces, actual transit times, arrival and departure from the stops, etc.) provide technological possibilities of acquiring the data. Technologies that ensure to deliver data to users include Internet, LAN, WAN, telephones, wired and wireless technologies, including mobile phones and PDA mobile devices, information kiosks, variable message signs on roads, streets, bus stops, car parks and on-board in vehicles navigation systems.

The Electronic Payment System is a complement of information systems for integrating the charges for all services associated with travel (ticket, parking, toll) using the media accepted by various service providers. Also Parking Pricing is the way of managing the travel demand by car. The charges depend on changes in traffic congestion resulting from the location of the car park or the time of day. Variable Pricing, depending on the traffic congestion at payable sections, in zones with access regulations and parking lots, constitutes the incentive to use these places at other times of the day or to plan the trip by using public transport.

Demand management strategies associated with the travel time (Time Travel Incentives) are obviously aimed at shortening the time and increasing reliability of the trip. The main reasons for low reliability of the trip include breakdowns of vehicles, unfavorable weather conditions, traffic incidents, changes in the traffic control as a result of maintenance, reconstruction or building new transportation infrastructure and planned events. In such cases the strategies for planning and coordination of departures a large number of vehicles at the same time from specific places (Coordinated Event or Shift Scheduling), for example, from large car parks of business centers or during mass events, may contribute to reduce traffic congestion.

The occupation of the part of the roadway due to road works is a specific type of traffic flow disruptions, occurring more and more often [5]. Such places require special supervision from the point of view of safety of both road users and workers performing these works [27, 28]. The work zone traffic management systems and traffic control systems at merging (DLMS—Dynamic Lane Merge System), that detect the formation of the queue and apply the variable message signs (CMS, VMS) to organize the traffic flows before merging may be the solutions in the field of the ITS services in such cases.

Travel time for different modes of transport can also be shaped by minimizing delays at intersections with traffic lights. For this purpose, the priority for public transport and HOV vehicles (Transit/HOV Signal Priority Systems & Queue Jumps) has been applied. High-Occupancy Vehicle (HOV) Lanes is the solution to facilitate the passage of vehicles carrying more than two people (“2+”), including buses, taxis, minibuses, and cars in car-pooling/ridesharing systems. Lanes designated for such vehicles may be open round the clock or during certain hours (taking into account rush hours). HOV Lanes may be used as an additional lanes at entrances at fast road to bypass the queue of vehicles trying to enter the traffic on the road, also with the systems controlling the order of traffic at the ramps (Ramp Metering). The High-Occupancy Toll (HOT) Lanes, enabling the use of HOV lanes to vehicles with one person (the driver) for a fee, are the modification of HOV lanes. The effectiveness of these solutions is dependent primarily on the enforcement of the rules regarding the use of these lanes, but appropriate solutions for the ITS services can significantly improve the traffic control in this area [13].

However, individual solutions do not always provide the desired results. Planning the ITS services in urban areas one should carefully analyze the causes of disruptions and focus the efforts on those elements of transportation system that actually need improvement. The comprehensive approach that will include both operational solutions to improve traffic in the city, and elements of demand management that will lead to the proper shaping of travel behavior of residents is necessary in this situation.

Tools supporting the process of selecting a package of ITS services in the city should be built on the basis of appropriately constructed models which reflect in a systematic way the complexity of the phenomena occurring in the city. The use of multi-criteria optimization in this field will provide a comprehensive approach to improve the functioning of the transportation system, the living conditions and the environment in the city. The Fig. 6 shows schematically the concept of such an approach.

The starting point is the identification of transport problems in the city. On this basis, the certain groups of users, affected by such problems, are separated.

The primary purposes of the application of ITS includes:

- increase the capacity of transportation network (e.g. traffic management systems at freeways, changeable lanes assignment, ramp metering),
- reduction of travel time (e.g. guiding the vehicles on alternative routes, coordination of traffic lights, electronic toll collection, traffic incident management systems),
- improvement of road safety (e.g. surveillance cameras for speed, work zone management, advanced traffic management systems),
- preference for public transport (e.g. providing priorities for public transport vehicles at intersections),
- improve the effectiveness of emergency services (e.g. event management systems, automatic vehicle location systems, navigation of vehicles of emergency services to the place of the event),

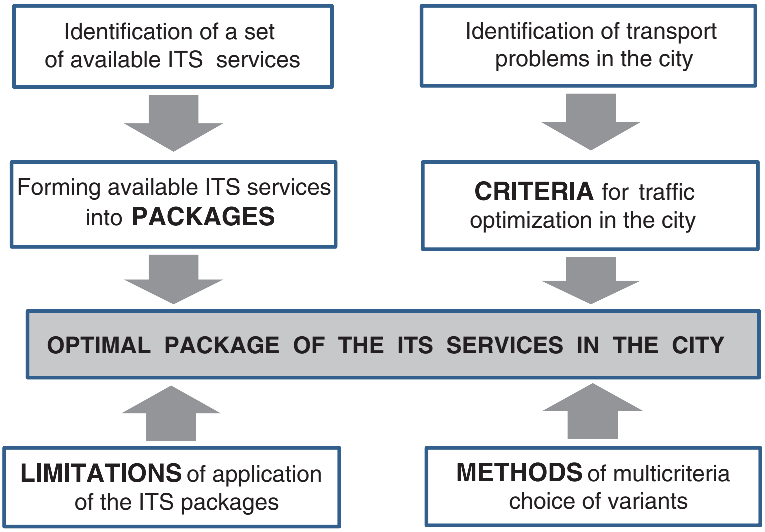

Fig. 6 Selection of the optimal package of ITS services in the city as a the optimization problem

- reduction of adverse emissions (e.g. demand management systems, urban traffic management systems).

These purposes are the main criteria for optimization problem of selection of the ITS service package. Using the appropriate measure for each of them one can assess the level of fulfillment in terms of different criteria for a specific group of users of transportation system. These measures are indicators of the effectiveness of the application of the particular ITS services package.

An important element of the optimization problem is the proper identification of set of ITS services available in the city. It is the basis for the grouping of services into packages in such a way that the expected results do not duplicate, but complement each other. The use of each package of ITS services is determined by the restrictions of an economic, legal and technological nature. Choosing the right mathematical apparatus as a multi-criteria optimization method guarantees the desired results in the form of widely understood optimization of traffic in the city.

Traffic flows passing through the road network of the city may be many times exposed to various types of disruptions [14, 31]. According to Woch [22] the critical nodes of transportation network are the places of disruptions where reserve capacity is stuck in the smooth flows that accompany disturbed ones. The appropriate change in the traffic assignment at critical nodes may improve the capacity and reduce the total delays in the network. Therefore, it is important to precisely identify the location of disruption. Using the feature of hierarchy of transportation network the nodes may be decomposed into smaller parts, called **elementary nodes** [22]. Only analysis at the level of elementary nodes gives a proper assessment of the degree of disruption of the traffic flows in the transportation network.

According to Woch [22] the complex nodes are those in which the individual traffic flow may be repeatedly disrupted. With this assumption, the entire urbanized area may be regarded as a single complex node.

5 The Smoothness of Traffic Flows as a Criterion for Selection of Optimal Structure of Traffic in the City

From the point of view of smoothness of traffic flows the congestion is a significant nuisance. In urban areas, there are often smaller distances between vehicles than in other areas. It results from the lower speeds that are forced by a large number of intersections (nodes of transportation network) [1, 21]. This implies that the transportation network is particularly vulnerable to disruptions of traffic flows, leading to the spreading of so-called "shockwave" and creating queues of vehicles.

According to Woch [22], each complex node may be decomposed into a specific number of elementary nodes. In addition, each place of disruption of smoothness of traffic flow on the section may also be represented as elementary node. The set of numbers of elementary nodes may therefore be represented as:

$$\boldsymbol{J} = \left\{1, \ldots, j, \ldots, \bar{J}\right\} \tag{1}$$

where $\bar{J}$ is the size of the set $\boldsymbol{J}$, that is the number of elementary nodes in the analyzed urban network.

The appropriately aggregated characteristics of elementary nodes should be used to determine the optimal traffic conditions in the transportation network. The average delays—which correspond to the traffic flow passing through the elements of transportation network—are closely dependent on the speed, density, and intensity both of the analyzed traffic flow and of other flows in the network—flows interact at each elementary node. It should also be noted that the values of these three fundamental characteristics of traffic flow [35] for each elementary node may be different.

Let $\boldsymbol{I}$ stands for a set of numbers of traffic flows, i.e.:

$$\boldsymbol{I} = \left\{1, \ldots, i, \ldots, \bar{I}\right\} \tag{2}$$

where $\bar{I}$ is the size of the set $\boldsymbol{I}$, that is the number of traffic flows passing through the elements of analyzed transportation network in the city.

In the set $\boldsymbol{I}$ one may distinguish some subsets denoted as $\boldsymbol{I}^j$ such that each of them contain numbers of traffic flows passing through the j-th elementary node. For this purpose, it was assumed that on the Cartesian product $\boldsymbol{I} \times \boldsymbol{J}$ the mapping α, that transforms components of this product into the elements of the set $\{0, 1\}$, is given, i.e.:

$$\alpha{:}\boldsymbol{I} \times \boldsymbol{J} \longrightarrow \{0, 1\}, \tag{3}$$

for which the quantity $\alpha(i,j) = 1$ if and only if the i-th traffic flow pass through the j-th elementary node, otherwise $\alpha(i,j) = 0$.

Then the set $\boldsymbol{I}^j$ may be defined as:

$$\boldsymbol{I}^j = \{i \colon \alpha(i,j) = 1, i \in \boldsymbol{I}\}, \quad j = 1, \ldots, \bar{J} \tag{4}$$

Similarly, the subsets $\boldsymbol{J}_i$ such that each of them contain the numbers of elementary nodes through which the i-th traffic flow pass, may be defined as:

$$\boldsymbol{J}_i = \{j \colon \alpha(i,j) = 1,\ j \in \boldsymbol{J}\}, \quad i = 1, \ldots, \bar{I} \tag{5}$$

The choice of each package of ITS services results in a specific traffic arrangement described by traffic assignment in the transportation network [9]. The set of numbers of packages of the ITS services has been defined as:

$$\boldsymbol{SP} = \left\{1, \ldots, sp, sp', \ldots, \overline{SP}\right\} \tag{6}$$

where $\overline{SP}$ is the size of the set $\boldsymbol{SP}$, that is the number of packages of ITS services that can be implemented in the analyzed urban network.

In order to describe the fundamental characteristics of traffic flow for each of the packages of ITS services, it was assumed that on the Cartesian product $\boldsymbol{I} \times \boldsymbol{J} \times \boldsymbol{SP}$ the proper mappings v, k and q, that transforms components of this product into the elements of the set $\mathbb{R}^+ \cup \{0\}$, is given, i.e.:

$$v \colon \boldsymbol{I} \times \boldsymbol{J} \times \boldsymbol{SP} \to \mathbb{R}^+ \cup \{0\}, \tag{7}$$

$$k \colon \boldsymbol{I} \times \boldsymbol{J} \times \boldsymbol{SP} \to \mathbb{R}^+ \cup \{0\}, \tag{8}$$

$$q \colon \boldsymbol{I} \times \boldsymbol{J} \times \boldsymbol{SP} \to \mathbb{R}^+ \cup \{0\}, \tag{9}$$

where

- $v(\mathrm{i}, \mathrm{j}, \mathrm{sp}) \equiv \mathrm{v}_\mathrm{i}^\mathrm{j}(\mathrm{sp}) \in \mathbb{R}^+ \cup \{0\}$ has interpretation of **speed** of the i-th traffic flow passing through the j-th elementary node by applying sp-th package of the ITS services,
- $k(\mathrm{i}, \mathrm{j}, \mathrm{sp}) \equiv \mathrm{k}_\mathrm{i}^\mathrm{j}(\mathrm{sp}) \in \mathbb{R}^+ \cup \{0\}$ has interpretation of **density** of the i-th traffic flow in the j-th elementary node by applying sp-th package of the ITS services,
- $q(\mathrm{i}, \mathrm{j}, \mathrm{sp}) \equiv \mathrm{q}_\mathrm{i}^\mathrm{j}(\mathrm{sp}) \in \mathbb{R}^+ \cup \{0\}$ has interpretation of **intensity** of the i-th traffic flow passing through the j-th elementary node by applying sp-th package of the ITS services.

The values of $v_i^j(sp)$, $k_i^j(sp)$ and $q_i^j(sp)$ for i-th traffic flow which does not pass through the j-th elementary node by applying sp-th package of the ITS services are zero.

Thus, for individual sp-th package of the ITS services the traffic conditions described by the fundamental characteristics in j-th elementary node may be presented in the form of vectors:

$$\boldsymbol{V}^j(sp) = \left\langle v_i^j(sp) \colon i \in \boldsymbol{I}^j \right\rangle, \quad j = 1, \ldots, \bar{J}, \quad sp = 1,\ \ldots,\ \overline{SP}, \tag{10}$$

$$\boldsymbol{K}^{j}(sp) = \left\langle k_i^j(sp) \colon i \in \boldsymbol{I}^j \right\rangle, \quad j = 1, \ldots, \bar{J},\ sp = 1, \ldots, \overline{SP}, \tag{11}$$

$$\boldsymbol{Q}^{j}(sp) = \left\langle q_i^j(sp) \colon i \in \boldsymbol{I}^j \right\rangle, \quad j = 1, \ldots, \bar{J},\ sp = 1, \ldots, \overline{SP}. \tag{12}$$

Average delay $w_i^j(sp)$ which corresponds to the passing of the i-th traffic flow through any j-th elementary node by applying sp-th package of the ITS services, is therefore dependent on traffic conditions in the node, i.e.

$$w_i^j(sp) = w_i^j\left(\boldsymbol{Q}^j(sp)\right), \quad \forall i \in \boldsymbol{I},\ \forall j \in \boldsymbol{J},\ \forall sp \in \boldsymbol{SP} \tag{13}$$

In turn, the average delay $w_i(\boldsymbol{Q}(sp))$ corresponding to passing of the i-th traffic flow through the transportation network are equal to the total delay in all elementary nodes of the network, which may be written as:

$$w_i(\boldsymbol{Q}(sp)) = \sum\nolimits_{j \in \boldsymbol{J}_i} w_i^j\left(\boldsymbol{Q}^j(sp)\right), \quad i = 1, \ldots, \bar{I} \tag{14}$$

where $\boldsymbol{Q}(sp)$ is a matrix containing the values of traffic intensity for all traffic flows on all elementary nodes of the urban network by applying sp-th package of the ITS services, i.e.:

$$\boldsymbol{Q}(sp) = \left[q_i^j(sp) \colon i \in \boldsymbol{I},\ j \in \boldsymbol{J}\right], \quad sp = 1, \ldots, \overline{SP}. \tag{15}$$

The queuing model with moving buffer assumes that the road is divided into elementary segments of length $1/k_{\text{jam}}$ [8, 17], where k_{jam} stands for the jam density. It is treated as a device of service for the vehicles. Thus it represents the minimal length that each vehicle needs. This length is determined by the maximum density k_{jam} of the vehicles on the road, at which the traffic flow stops. In contrast, smooth traffic flow, which refers to the stochastically stabilized flow (i.e. flow without disruption, that prevents the acceptance of a specific probability distribution of the headways), is described using the maximum density k_{smooth} referring to the smooth flow, in which the vehicles travel with the speed v_{smooth} at no additional delays (no waiting time), and with the same intensity of service μ of vehicles by all minimal distances $1/k_{\text{jam}}$ that are components of path of the smooth flow:

$$\mu = k_{\text{smooth}} \cdot v_{\text{smooth}} \tag{16}$$

Thus k_{smooth} is the maximal number of vehicles forming smooth flow. The Eq. (16) is analogous to the relationship [6]:

$$q = k \cdot \bar{v}_{\text{t}} \tag{17}$$

where $\bar{v}_{\text{t}}$ is a time-mean speed [15]. Formula (17) known as the fundamental equation of traffic flow allows to determine the shape and analytical form of curves (speed-flow, speed-density, and flow-density) of the fundamental diagram of traffic flow, based on the actual measured data—an example is given in [35].

In the single channel queuing model (e.g. one traffic lane) the passage through the minimal distance is a service of vehicles. So, the smooth passage means the passage with the expected speed and without additional delay, as each elementary segment of the road contains sufficient reserve capacity to absorb its waiting time. In this case vehicles in front of them have certain gaps larger than minimal gaps, which compensate any temporary disruption, leading to the formation of a queue and delay due to waiting time in the queue. Obviously, the gap between vehicles in smooth traffic flow—taking place on the road consisting of distances $1/k_{\text{smooth}}$—is dependent on the expected (mean) speed v_{smooth} of free traffic flow and shall take into consideration the safety distance (safe gap), mapped by shifting the exponential distribution of headways on the road.

Such mapping is also related to the fact that in description of the traffic flows of high density the small variances of gaps are taken into account. In addition, in dense traffic flows a minimal safety distance (safe gap) is relatively small, with the result that the probability of disruption—in the form of sudden deceleration (stop) of vehicles—increases. Therefore, the probability (risk) of the formation of queues of vehicles is growing. Taking into account the possibility of the formation of queues of vehicles during such disruption, the **necessary and sufficient condition of smooth traffic flow** may be written as:

$$\mathrm{E}(Lp(\boldsymbol{Q})) \leq 1 \tag{18}$$

which means that **in the smooth traffic flow** the expected length of the queue, expressed as the number of vehicles $Lp(\boldsymbol{Q})$, that occur at the minimal distance $1/k_{\text{smooth}}$, is not greater than one vehicle.

The probabilistic description of the forming queues and their impact on the smoothness of traffic flows passing through the network, and thus on the efficiency of the traveling of vehicles in dense traffic flows, may be used to search for the optimal intensity (intensity) of traffic flows on the sections of the road. At the time, when optimizing traffic flows, the fundamental measure of the smoothness theory of traffic flows—**a function of the expected smoothness of traffic flows**—may be taken as a function of the criterion [22]. i.e.:

$$F_i^j\left(\boldsymbol{Q}^j(sp)\right) = \left[1 - p_i^j\left(\boldsymbol{Q}^j(sp)\right)\right] \cdot q_i^j(sp), \quad i = 1, \ldots, \bar{I},\ j = 1, \ldots, \bar{J}, \tag{19}$$

where

$F_i^j\left(\boldsymbol{Q}^j(sp)\right)$—the function of the expected smoothness of the i-th traffic flow in the j-th elementary node, assuming the intensities of traffic flows are consistent with the vector $\boldsymbol{Q}^j(sp)$,
$p_i^j\left(\boldsymbol{Q}^j(sp)\right)$—the probability of the queue in the i-th traffic flow in the j-th elementary node, assuming the intensities of traffic flows are consistent with the vector $\boldsymbol{Q}^j(sp)$.

By using sp-th package of the ITS services for the i-th traffic flow, the searching the optimal its intensity $q_{\text{smooth}\,i}(sp)$, comes down to finding the maximum value for the function of the expected smoothness $F_i^j\left(\boldsymbol{Q}^j(sp)\right)$ for each elementary nodes, through which the i-th traffic flow pass, and then to determine the optimum intensity for this flow over the entire path in the transportation network. This will be the optimal intensity $q_{\text{smooth}i}(sp)$ for the i-th traffic flow. The above procedure may be written as:

$$q_{\text{smooth}i}(sp) = \min_{j \in \boldsymbol{J}_i} \left\{ q^j_{\text{smooth}i}(sp) \right\}, \quad i = 1, \ldots, \bar{I}, \tag{20}$$

where

$$q^j_{\text{smooth}i}(sp) : F^j_i \left(q^j_{\text{smooth}i}(sp) \right) = \max_{q^j_i(sp) \in \boldsymbol{Q}(sp)} \left\{ F^j_i \left(q^j_i(sp) \right) \right\} \tag{21}$$

where

$q_{\text{smooth}i}(sp)$—the optimal intensity for the i-th traffic flow passing through the network, assuming the intensities of traffic flows are consistent with the vector $\boldsymbol{Q}(sp)$,
$q^j_{\text{smooth}i}(sp)$—the optimal intensity for the i-th traffic flow passing through the j-th elementary node, assuming the intensities of traffic flows are consistent with the vector $\boldsymbol{Q}(sp)$,
$F^j_i \left(q^j_{\text{smooth}i}(sp) \right)$—the function of the expected smoothness at the optimal intensity $q^j_{\text{smooth}i}(sp)$ of the i-th traffic flow in the j-th elementary node, assuming the intensities of traffic flows are consistent with the vector $\boldsymbol{Q}(sp)$.

The optimal intensities for the individual network elements are not equal to their capacities—they are smaller. This follows from the fact that the intensity of the traffic flow equal capacity of the node occurs when all vehicles are moving in the states close to the saturation states with very limited levels of service, and thus the function of the expected smoothness of traffic flow reaches zero—no vehicle is moving freely. The permanent small disruptions are the results of very high density of traffic flow. They are caused by gaps between vehicles that are close to minimal distances (minimal gaps)—the variation of the gaps is equal to or close to zero. In such situation the high probability (risk) of the formation of queues is caused by delayed reaction of human-vehicle system.

Traffic flow with the intensity equal to (or close to) capacity is characterized by the **conditional capacities** $q^{*j}_i(sp), q^{*j}_i\left(sp'\right), \ldots,$ and **unconditional capacity** $q^{*j}_i(sp^*)$. All of them depend on the variants of traffic assignments $\boldsymbol{Q}^j(sp), \boldsymbol{Q}^j\left(sp'\right), \ldots, \boldsymbol{Q}^j(sp^*)$ for the remaining traffic flows. This approach takes into account the specific traffic control in the network, which is the result of proper selection of packages of the ITS services. The specific traffic assignment is the result of this selection. The functions of the expected smoothness $F^j_i\left(\boldsymbol{Q}^j(sp)\right)$ of the i-th traffic flow in the j-th elementary node for various packages $sp, sp', \ldots, sp^*$ of the ITS services and different capacities $q^{*j}_i(sp), q^{*j}_i\left(sp'\right), \ldots, q^{*j}_i(sp^*)$ as well as different intensities $q^j_{\text{smooth}i}(sp)$, $q^j_{\text{smooth}i}\left(sp'\right)$, …, $q^j_{\text{smooth}i}(sp^*)$ optimal in terms of smoothness of traffic flow, that correspond to these packages, have been presented in Fig. 7.

Therefore, for different traffic assignment in elementary node, there are different functions of the expected smoothness of traffic flows, that are

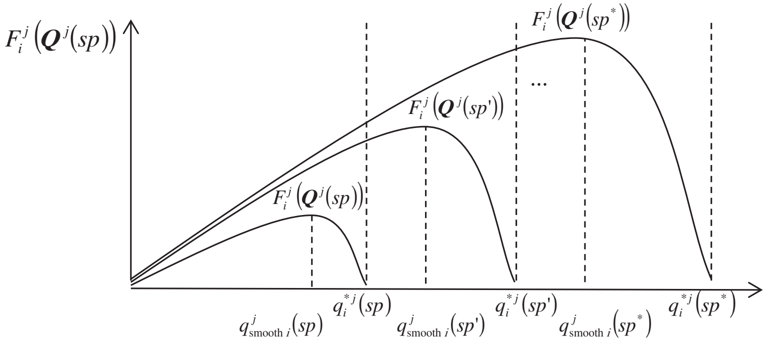

Fig. 7 The functions of the expected smoothness of traffic flows for various packages of the ITS services (based on [22])

determined on the basis of changes in **function of the probability of disruption** $p_i^j\left(\boldsymbol{Q}^j(sp)\right), p_i^j\left(\boldsymbol{Q}^j(sp')\right), \ldots$, (these are conditional probabilities of waiting in the queue of vehicles) and of the **unconditional probability** $p_i^j\left(\boldsymbol{Q}^j(sp^*)\right)$. The maximum value of the conditional capacity occurs in the absence of interaction with the other flows and is called **unconditional capacity** $q_i^{*j}(sp^*)$ of the j-th elementary node for the i-th traffic flow, which corresponds to the unconditional capacity $p_i^j\left(\boldsymbol{Q}^j(sp^*)\right)$.

The probability of disruption, resulting in the queues of vehicles, increases nonlinearly with increasing of the intensity and of the density of the traffic flows. In a similar way, **the waiting time** in the queue of vehicles is increasing, if such disruption has occurred. In addition, the smaller the conditional capacity is—and thus the smaller optimal intensity, due to the low level of smoothness of traffic flows—the faster the waiting time in the queue due to disruption is growing. As in the case of the probability of formation queues, the expected delays for the i-th traffic flow in the j-th elementary node are also the conditional values $w_i^j\left(\boldsymbol{Q}^j(sp)\right)$, i.e. dependent on the variants of traffic assignment for other flows in the network. The functions of expected delays for the i-th traffic flow in the j-th elementary node in form of the expected waiting time $w_i^j\left(\boldsymbol{Q}^j(sp)\right)$ in the queue for different packages of ITS services sp, sp', …, sp^* and the appropriate capacities $q_i^{*j}(sp)$, $q_i^{*j}\left(sp'\right)$, …, $q_i^{*j}(sp^*)$ have been presented in the Fig. 8.

The presented above main assumptions about the smoothness of traffic flow may be supplemented by the postulated way of describing the traffic conditions in congested transportation networks [22]. In such networks, with dense traffic flows and a high risk of the disruption (even in the form of a short queue of vehicles) the probability of such an incident $p_i^j\left(\boldsymbol{Q}^j(sp)\right)$ seems to be a **better measure of the probabilistic description of the capacity constraints** than the expected waiting time $w_i^j\left(\boldsymbol{Q}^j(sp)\right)$ in the queue, because the probability takes into account the risk of delay in the traffic flow **from the point of view of the person that plans a trip**. That is particularly important in congested networks, in which a high probability

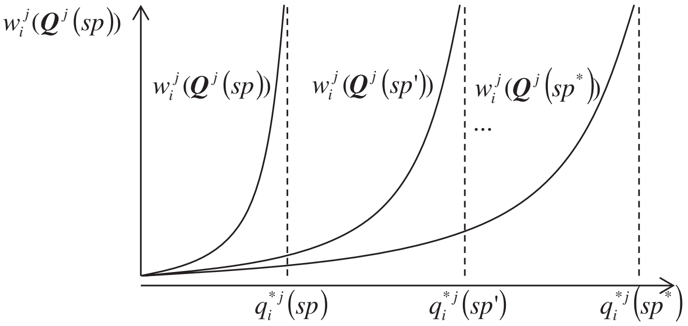

Fig. 8 The functions of the expected delays of traffic flows for various packages of the ITS services (based on [22])

of queues is most often associated with high expected value of extension of travel time—as a result of the high risk of the large number of secondary disruptions and queues because of a sequence of following forms of congestion [24]: the single interaction → the multiple interaction → bottleneck → triggerneck → gridlock [31].

In this way it is possible to assess the risk of delays not only in the bottleneck, but also in the area of impact of such disruption—in the area of the potential gridlock. The areas with a high risk of disruption may be covered by the activities in terms of demand and mobility management, with the use of measures in the form of mobility plans for individual objects, for groups of objects as well as for urban districts and for the entire city [13].

Moreover, the number and the size (range) of queues, resulting from these forms of congestion, seems—contrary to appearances—to be a better measure of disruption arising from the breakdown of the smoothness of traffic flow than the expected waiting time in the queue. This is due to the fact that the latter may significantly change due to additional factors, that are independent of the initial disruption, which was the direct cause of the queue.

To determine the relationship between the smoothness and the intensity of traffic flows leads to the optimization problem of traffic assignment in the transportation network [22, 23]. According to Woch [22] the optimal traffic assignment in the transportation network is conditioned by optimization of traffic assignment in each elementary node of the network. Only the analysis of elementary traffic conflicts in the nodes provides an accurate assessment of the smoothness of traffic flows. For this purpose, Woch proposed a dual algorithm, allowing on the one hand to separate the critical node (approach from the point of view of "network"), and on the other—to identify the disrupted traffic flows (approach from the point of view of "traffic flows"). The algorithm, modified based on the Ref. [23], has been presented in Fig. 9. Between blocks at the same stage of considerations, a bidirectional feedback, allowing the simultaneous and complementary analysis, is found. Disruptions of the smoothness of the traffic flows usually occur

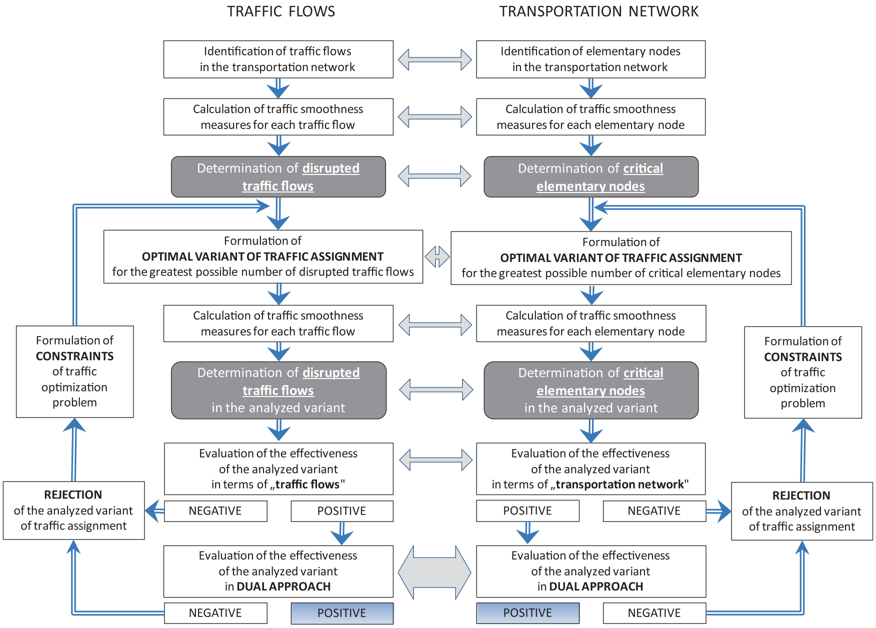

Fig. 9 Dual algorithm of optimization of traffic assignment in transportation network

in the critical nodes. So, on the one hand disturbed traffic flows indicates the location of the greatest potential benefits from the improvement of traffic assignment, and on the other—the structure of the queues in the complex critical nodes maps the reserve capacity in their elementary nodes. This allows for such selection of the package of the ITS services, that leads to the optimal variant of the traffic assignment.

6 Conclusions

The problem of minimizing the negative effects of congestion in urban areas requires the adoption of appropriate activities at different levels of management. In modern cities traditional methods associated with the development of road infrastructure are not sufficient. Only a comprehensive and systematic approach based on different congestion management strategies may bring the desired results. The best results are obtained with the proper coordination and integration of activities of planners, designers and traffic engineers.

From the point of view of traffic flow, the analysis of traffic congestion in dense urban networks, requires both modeling of disruptions, their causes and how they impact on the elementary traffic flows in the transportation network nodes [2], and modeling the transportation network vulnerability to disruption [33, 34]. The basic tools used to find solutions in terms of changes in the traffic assignment, in order to make the traffic flow smoother, by changing the distribution of points of traffic conflicts, may be the methods of microsimulation of traffic flows [11, 12, 18]. Measures of traffic disruption and searching for the optimal intensity of traffic flow, at a certain degree of congestion, allow to choose the optimal variant of the control and management of traffic and congestion, at strategic, tactical and operational level [34]. The spatial relationship of the traffic flows in the form of O-D matrix, should be taken into account here [26]. It also requires the use of certain methods of their identification [20, 29].

The consequences of disruptions of the traffic flows are currently particularly heavily felt by the users, mainly due to the concentration of traffic flows in dense congested networks in urban areas. Traffic congestion in the transportation network is characterized by minimum values of reserve capacities or lack of them. In addition, some reserves which could compensate for the effects of disruptions are "caught in the network" (e.g. due to the limited accessibility of the road, resulting from its technical class—the queue of vehicles "caught" on the freeway or expressway, passing through the agglomeration with a dense network of streets and urban roads).

This paper presents a dual approach to optimize of traffic based on the assumption of a smooth passing of the traffic flow through the elements of transportation network. Choice of the best variant of traffic assignment is an iterative process in which successive solutions are improved both from the point of view of the most disrupted traffic flows, and from the point of view of the critical nodes of the network, characterized by the worst values of measures that assess traffic conditions. Such analyzes should be carried out on the greatest level of accuracy (for elementary nodes).

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The Traffic Flow Prediction Using Bayesian and Neural Networks

Teresa Pamuła and Aleksander Król

Abstract The article presents two short-term forecasting models for determining the traffic flow volumes. The road traffic characteristics are essential for identification the trends in the distribution of the road traffic in the network, determination the capacity of the roads and the traffic variability over the time. The presented model is based on the historical, detailed data concerning the road traffic. The aim of the study was to compare the short-term forecasting models based on Bayesian networks (BN) and artificial neural networks (NN), which can be used in traffic control systems especially incorporated into modules of Intelligent Transportation Systems (ITS). Additionally the comparison with forecasts provided by the Bayesian Dynamic Linear Model (DLM) was performed. The results of the research shows that artificial intelligence methods can be successfully used in traffic management systems.

1 Introduction

The knowledge of the characteristics of the traffic flow is an obligate condition for identification of the trends of traffic distribution in the network, determination of the roads capacity and variability of the traffic over the time. The description of the road traffic data plays a key role in the operation of Intelligent Transport Systems. These systems provide the helpful navigation information to the road

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users and allow the traffic supervisory authority to adjust the strategy of the traffic management to the actual traffic conditions [1].

Neural Networks (NN) are an efficient tool for classification and identification of the road traffic parameters [2, 3]. Due to their properties, first off all the ability of mapping of the multiparameter relationships as a result of the learning process. Neural Networks are applied for prediction of the traffic flow volume at the different time horizons [4]. The short term prediction of the traffic flow volumes are particularly useful for the control decision making at the crossroads [3, 5]. Modeling of the time course of the traffic flow with the use of NN is an element of the adaptive algorithms for traffic control [6, 7].

The Bayesian networks describe the set of dependences between some random variables. A Bayesian network allows to calculate the probabilities of some states with possessing the knowledge about some other states, thus it is possible to apply such the ability for the prediction [8].

The paper presents the comparison of the prediction abilities of the mentioned above neural prediction model with the prediction model based on the Bayesian networks. Both models were developed basing on historical data about the traffic volume variability. Described approaches are compared with Bayesian dynamic linear model (DLM) predictions, which is one of willingly used methods for time series analysis. The real data measured in road network of Gliwice city are used here for learning and validation. The study includes three classes of time series, which were specified on the basis of the statistical analysis [9] of the road traffic on different days of the week. The results of the prediction process will be applied for selection of the signaling modes within the crossroads and to support of the area-traffic management.

The results of comparison are gathered in the tables in the last chapter and then the conclusion summarizes the research outcomes and proposes further development of presented methods, which is aimed mainly on the improvement of the prediction accuracy.

The database of traffic flow volumes was acquired by the use of the vehicle detectors located on the main driveway to Gliwice. Gliwice, which is placed on the periphery of Upper Silesia agglomeration and has a population of almost 200,000 inhabitants is a representative research training ground for the medium-sized city. The achieved measurements include wide range of traffic flow volumes and allow to examine the different variability schemes.

The data from two video detectors located at the ends of a transit road in Gliwice town are used. Data were recorded 24 h/day for a period of one year from 1 July 2011 to 31 March 2012. The data were initially divided into groups according to the classes of the time series, such as: working days, Saturdays and Sundays [2]. Such distinction was necessary due to quite different time structure of the road traffic. Part of the data has been used to prepare training sequences and test sequences.

The observed rate of change in the measurement of the volume of traffic shows, that 5 min, coinciding with the period of measurement, prediction horizon takes into account the intensity of the fastest changes in traffic flow. Adopted to predict

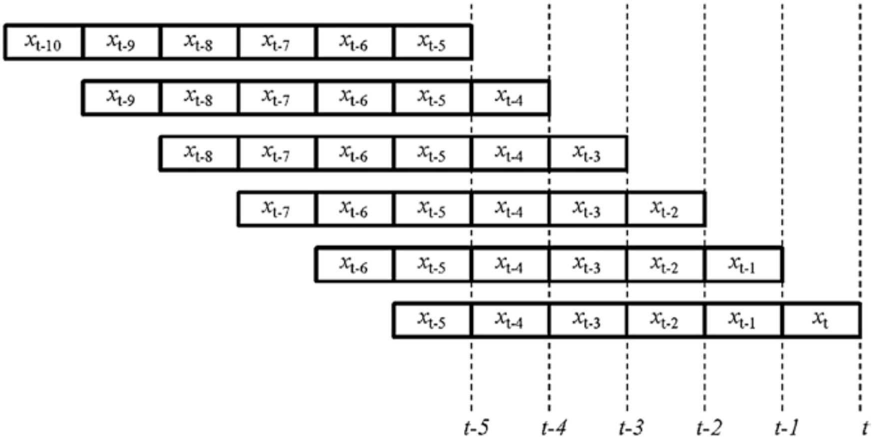

Fig. 1 The principle of the vehicle counting

the time window with a length of 6 measurement periods. This means that the model predictions, defines the data the last six traffic flow values within 30 min. The result of the model is the expected value of the traffic after the next 5 min.

2 Traffic Flow Measurement

The data was recorded automatically using the video-detection system. The length of the measurement window was 30 min, and a new count was started every 5 min, thus every 5 min the new input containing mean traffic flow in the past 30 min was provided. In this way there were six input values during the period of 30 min (Fig. 1).

The data incoming every 5 min can be treated as random variables. These random variables are strongly dependent on each other because consecutive measurements cover almost the same time interval. In fact, such data allows to calculate the number of vehicles passing in 5 min interval.

3 Traffic Flow Statistics

3.1 Traffic Flow Distribution

The number of vehicles detected in a given time interval should obey a Poisson distribution. It is important to assume the single vehicle detections are independent on each other. It is true excluding the very rare cases of passing convoys. If n

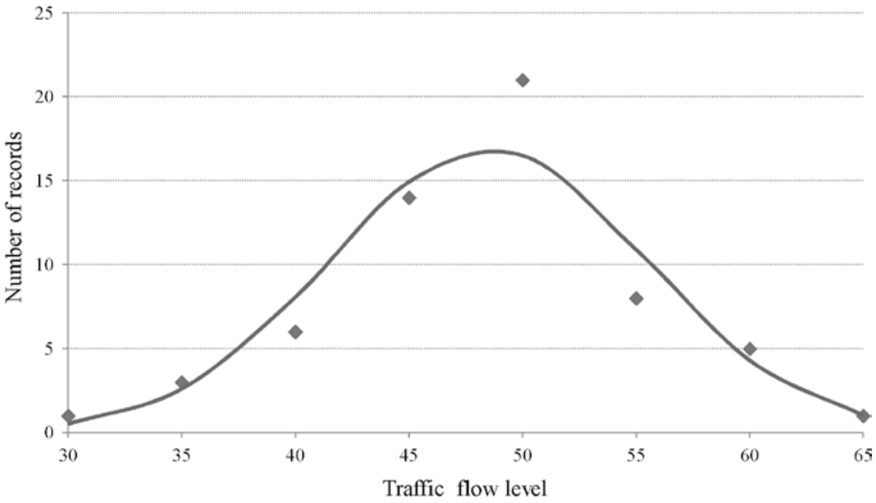

Fig. 2 Traffic flow distribution for Wednesdays in August between 1 p.m. and 2 p.m. compared with the Poisson distribution with λ = 48.5

denotes the constant average number of vehicles per the time unit, the probability of the k vehicles being detected at time interval t can be expressed as:

$$P(X = k) = \frac{(nt)^k e^{-nt}}{k!} \tag{1}$$

The product of nt is sometimes replaced by the average number of events detected in the time interval and denoted by λ. The important feature of Poisson distribution is that the expected value and the variance are equal and equal to λ:

$$E(X) = V(X) = \lambda \tag{2}$$

For very rare events ($\lambda < 1$) only the probabilities of a few events occurrence are significantly greater than 0. If $\lambda \gg 1$ Eq. (1) becomes awkward to use, but in this case the original distribution can be approximated by the normal distribution ($\mu = \sigma^2 = \lambda$):

$$P(X = k) = \frac{1}{\sqrt{2\pi\lambda}} e^{-\frac{(k-\lambda)^2}{2\lambda}} \tag{3}$$

The real data obtained in the video-detection system match well the theoretical distribution, but it concerns only the values calculated for 5 min intervals. As an example the traffic flow distribution for Wednesdays in August between 1 p.m. and 2 p.m. is shown in Fig. 2. The number of detected vehicles varies from 30 to 65 and the whole range was divided into intervals with a width of 5. The mean value is equal to 48.5 and the variance is equal to 47.7.

The compliance of the empirical and the theoretical distributions was confirmed also by the use of Chi-Square test (Table 1). The *p*-value was here about 0.96,

Table 1 Comparison of empirical and theoretical distributions

Traffic flow level	Real number of records	Theoretical distribution (Eq. 3)
30	1	0.500810
35	3	2.600963
40	6	8.064806
45	14	14.929730
50	21	16.500920
55	8	10.888370
60	5	4.289591
65	1	1.008944

$p = 0.96$

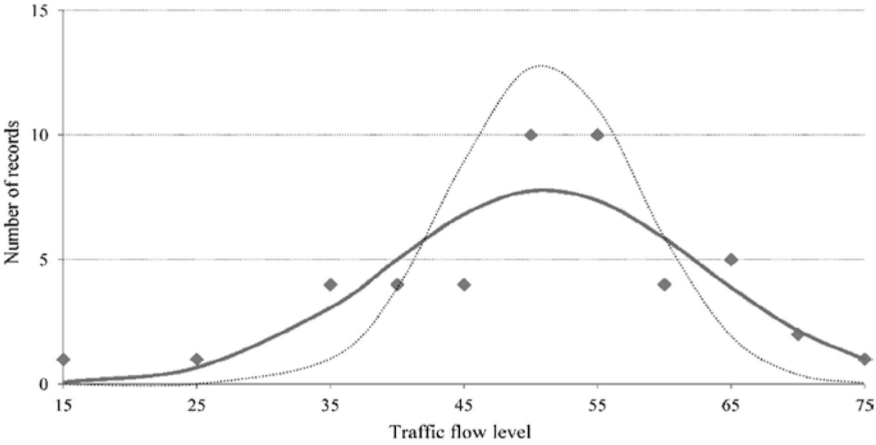

Fig. 3 Traffic flow distribution for Thursdays in August between 4 p.m. and 5 p.m. compared with the normal distribution ($\mu = 51.2$ and $\sigma 2 = 141.9$) and Poisson distribution with $\lambda = 48.5$

thus there is no presumption against the hypothesis of the compliance of both distributions.

Such good compliance concerns the low and the moderate traffic flow volumes. When high traffic flow volumes were considered (at the rush hours) the measured distributions diverged significantly from the Poisson distribution. It can be explained by the assumption that at the rush hours the traffic is flowing under the congestion conditions and the successive car detections are not independent from each other. As the example the traffic flow distribution for Thursdays in August between 4 p.m. and 5 p.m. is shown (Fig. 3). The mean value is equal to 51.2 and the variance is much greater and equal to 141.9. The distribution remains near normal, but much more diffuse.

Table 2 Descriptive terms of the time of the day

Term	Hours
MORNING	4, 5, 6, 7, 8, 9
DAY	10, 11, 12, 13, 14, 15
AFTERNOON	16, 17, 18, 19, 20, 21
NIGHT	22, 23, 0, 1, 2, 3

If distributions including more data e.g. different week days, different months were examined this observation remained true—the distribution was normal, but the variance was much greater (three and more times) than the mean value. It happened independently on the choice of the time of a day. It is due the fact that some other factors disturb the pure Poisson process and make the distribution more blurry.

3.2 Data Classification

When analyzing the distribution of road traffic over the time of day it can be noticed two peaks: one in the morning and the second in the afternoon. It is rather calmly in the night and the traffic is moderate during the day, between peaks. This obvious and rough pattern applies to all week days. But detailed study finds out that three different patterns should be distinguished. The time structure of road traffic appeared to be different for working days, Saturdays and Sundays. To confirm these two groups of tests were performed:

for each week day and for each time of day the average number of vehicle counts per one record was calculated,
for each week day and for selected traffic volume levels the average number of records per day was calculated.
For such collections of values the multi-resolution arrays were created and then with the use of Chi-Square tests the probability of mutual independence was determined. The contractual descriptive terms of the time of the day are gathered in Table 2.

Both mentioned above tests were applied for all week days (from Monday to Sunday) and for working days only. Results are shown in Table 3. The cells described by p contain the calculated p-value, which should be at least equal to the typically assumed significance level value of 0.05.

The value of p over 0.05 means the distribution due one criterion is likely to be independent on the second criterion. Thus the data presented in Table 2 clearly demonstrate that the structure of the traffic is similar for all working days

Table 3 The results of the independence tests

Average number of vehicle counts per one record—working days only							$p = 1$
Time of day	MON	TUE	WED	THU	FRI		
MORNING	202	205	202	203	199		
DAY	298	300	297	305	311		
AFTERNOON	226	232	231	236	250		
NIGHT	39	43	42	44	51		

Average number of vehicle counts per one record—the whole week							$p = 0$
Time of day	MON	TUE	WED	THU	FRI	SAT	SUN
MORNING	202	205	202	203	199	170	201
DAY	298	300	297	305	311	217	174
AFTERNOON	226	232	231	236	250	117	87
NIGHT	39	43	42	44	51	50	43

Average number of detection per day—working days only							$p = 0.77$
Volume level	MON	TUE	WED	THU	FRI		
0–150	239	229	228	226	217		
150–300	183	195	200	185	186		
Above 300	154	152	148	165	173		

Average number of detection per day—the whole week							$p = 0$
Volume level	MON	TUE	WED	THU	FRI	SAT	SUN
0–150	239	229	228	226	217	310	323
150–300	183	195	200	185	186	254	230
Above 300	154	152	148	165	173	12	15

(other, not shown here tests prove the same), but other patterns must be used for Saturdays and Sundays.

4 Description of Methods Used for Prediction

4.1 Bayesian Networks

A Bayesian network presents graphically the relationships between some random variables. The name origins from the Bayes' theorem, which postulates the belief revision in the light of new facts. Let's assume that an event (B) can occur in several mutually exclusive ways (which complete all the possibilities), then the joint probability of the event B occurrence should be expressed as:

$$\mathrm{P}(B) = \sum_{i=1}^{n} \mathrm{P}(A_i)\mathrm{P}(B|A_i) \tag{4}$$

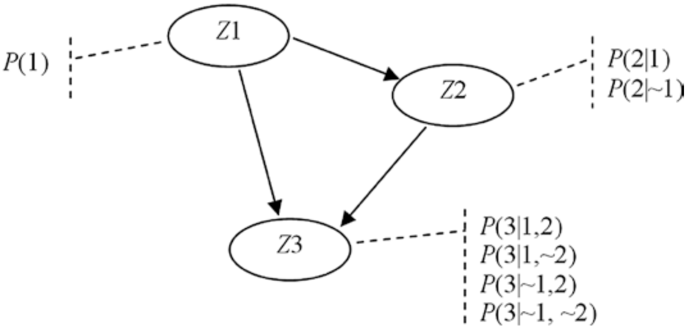

Fig. 4 A simple Bayesian network with binary (only true and false states) random variables

where

A_{i}	the exclusive possibilities of the B event implementation
$\mathrm{P}(B\|A_{\mathrm{i}})$	conditional probability of the B at condition of A_{i}

Now assume that the B event has already occurred: this knowledge allows us to recalculate the prior probability of $\mathrm{P}(A_{\mathrm{k}})$ to the new value $\mathrm{P}(A_{\mathrm{k}}|B)$:

$$\mathrm{P}(A_k|B) = \frac{\mathrm{P}(A_k)\mathrm{P}(B|A_k)}{\mathrm{P}(B)} \tag{5}$$

Despite of the simplicity both formulas are powerful tools allowing to perform the bidirectional inference in any network of probabilistic relationships.

Formally a Bayesian network is an acyclic directed graph, the vertices correspond to the random variables and the edges correspond to the direct cause—effect relationships between pairs of variables. There is a table containing the conditional probabilities related to each vertex. This table describes the chances of particular states $\mathrm{P}(X \mid P_1, P_2,\ldots)$ of given vertex X taken at different states of its direct parents P_1, P_2, … (Fig. 4). For the vertices without parents (so called root causes) the conditional probabilities become the simple probabilities [6].

The study used GeNie package developed at Decision Systems Laboratory at the University of Pittsburgh [10]. GeNie package implements the classical model of Bayesian network with additional elements supporting the use of diagnostic and decision-making processes. There is a large number of available algorithms for performing Bayesian inference. The user interface allows to enter data in the graphic form.

4.1.1 Bayesian Inference

The graph topology and the tables of conditional probabilities determine the relationships between random variables and thus allow for calculation of the probability of any state of any variable with the assumption of the knowledge concerning the remaining variables. This process is called belief updating and is performed with the use of the joint probability formula and the Bayes' formula. Because of fact that in some cases the structure of the Bayesian network can be complex and the number of possible network states can be large, the calculation may appear to be computationally hard [11].

4.1.2 Bayesian Network Construction and Learning

The knowledge of a Bayesian network is contained in the graph topology and in the tables of conditional probabilities. Thus all these properties must be determined when the network is being constructed. There are two main possibilities for the construction of a Bayesian network [12]:

- building by an expert (it may concern both the topology and the values of the probability)
- automatic generation with the use of learning data—the series of cases containing the values of random variables.

Here the automatic mode was chosen, but the topology of the Bayesian network was determined empirically. The conditional probabilities associated with the vertices are found with the application of the built-in EM algorithm.

The EM (Expectation–Maximization) algorithm is the iterative procedure to estimate the maximum likelihood in the incomplete data. It endeavors to estimate the model parameters for which the observed data are the most probably [13]. Every iteration consists of two steps:

- the E-Step (expectation): missing data are estimated given the observed data and the current estimation of the model parameters,
- the M-step (maximization): the likelihood function is maximized with the assumption the missing data are now known.

4.1.3 The Structure of the Bayesian Network for Prediction

It was assumed that the expected volume of the traffic flows depend on values observed at the current and a few previous moments. Additionally each of previous values affects all the next. It corresponds to the structure presented at Fig. 5. The vertices marked x-t correspond to values measured at the past time moments. The vertices marked xout1 and xout2 hold the forecast for respectively one and two steps ahead.

An alternative structure of the Bayesian network was examined too: there is an additional node, which represents the time of a day. This new node affects all other nodes and contains 24 states, which simply correspond to hours (Fig. 6).

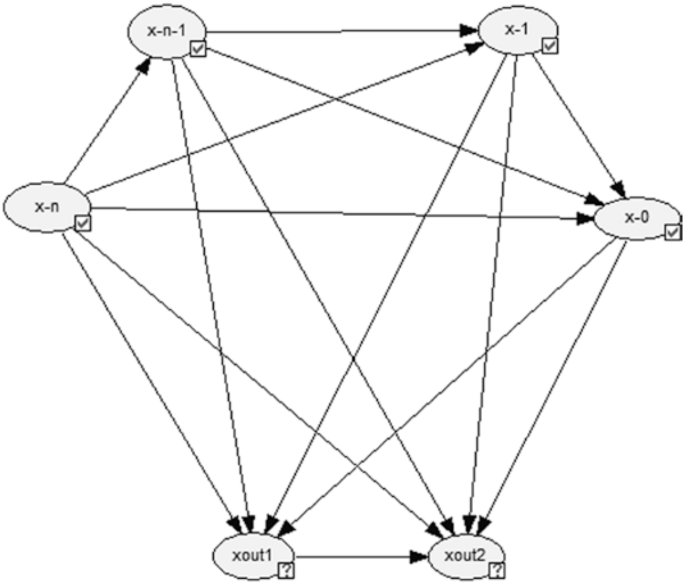

Fig. 5 The structure of the Bayesian network used for prediction

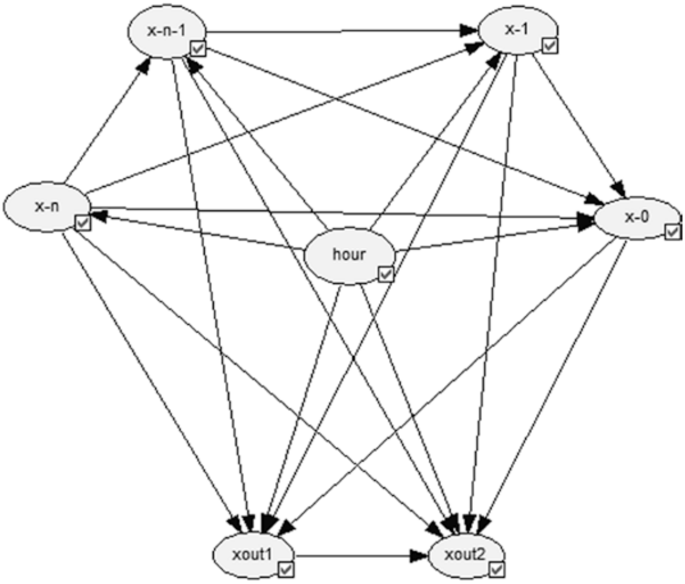

Fig. 6 The structure of the Bayesian network with 'hour' node

4.1.4 Input Data Preprocessing

The input data are given as a time series of the traffic flow volume. So a single value can be any integer number. Meanwhile the nature of a random variable requires to determine some states, which can be taken. Thus the process of discretization must be performed at the beginning. It was assumed that each of variables can take 20 states. This number is a compromise between the accuracy of the prediction and the efficiency of the Bayesian inference. As was shown above the variance of the incoming data is equal or often greater than variance of the Poisson distribution. Thus in this case the standard deviation is assumed to be somewhat greater than the square root of the number of detected vehicles. Such value is greater than the single state width. The discretization was done by the built-in hierarchical algorithm. It starts with the number of states equal to the number of input values, and then at every step the number of states is reduced by one by merging states with the nearest mean values. The discretization stops when the number of states reaches the required value.

4.1.5 Determination of the Forecast Value

As was mentioned above the input data was divided into three classes: working days, Saturdays and Sundays. These three data sets were used as learning data for Bayesian network with the structure described above, giving three different prediction models. The models were applied to the data concerning a number of selected days. For each moment, the states corresponding to the previous values of the traffic flow should be set, then after the belief update the variables xout1 and xout2 contain the forecast (Fig. 7).

The output (predicted value) is also expressed in terms of states. Instead of a single value the distribution of possible states is obtained. The required value is the weighted average of them (Eq. 6).

$$x_{out} = \sum_i p_i m_i \tag{6}$$

where

x_{out} predicted value,
p_i probability of *i*th state,
m_i the mean value corresponding to *i*th state.

4.2 *Neural Networks*

Feedforward (static) neural network is a set of interconnected artificial neurons without feedback connections. The data flow only in one direction—from inputs through hidden layers towards outputs. The simplified basic model of a single artificial neuron is shown at Fig. 8.

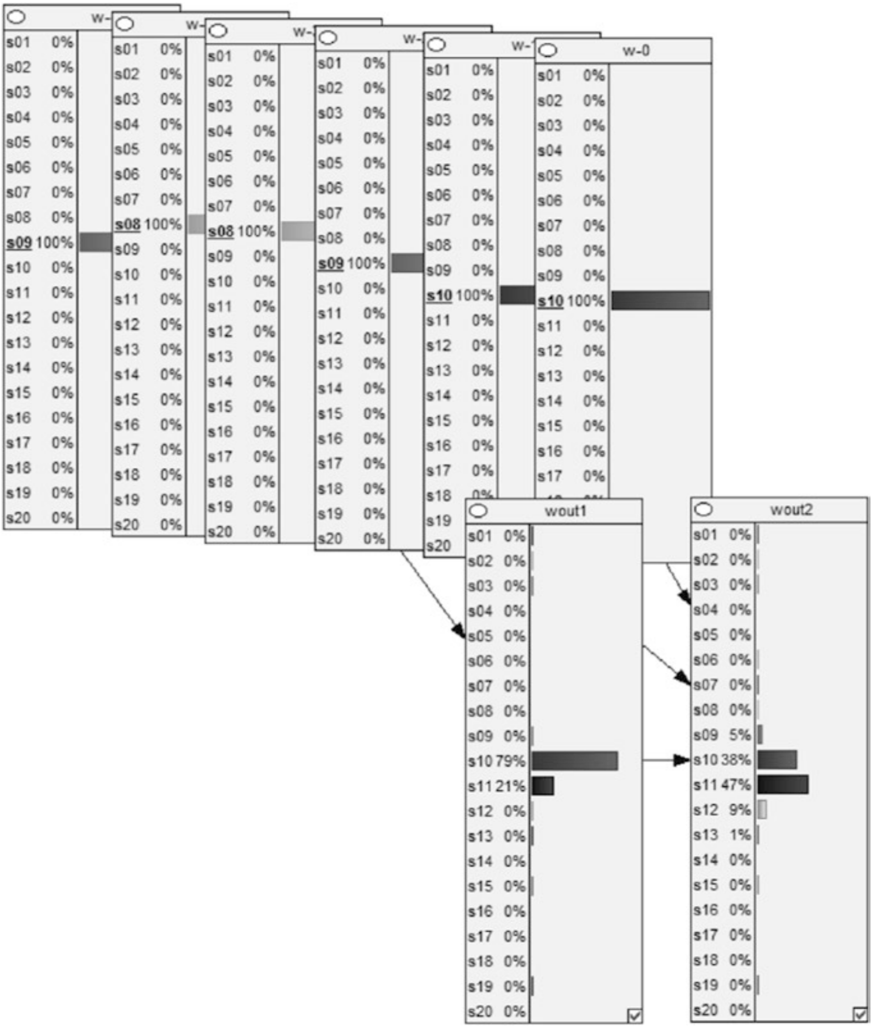

Fig. 7 The predicted value expressed as a distribution of states

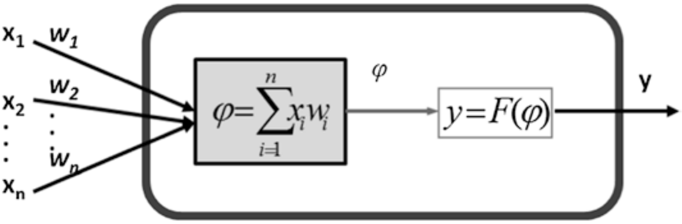

Fig. 8 The simplified basic model of a single artificial neuron

The input signals x_1, …, x_R reaches the neuron, then their weighted sum is calculated and the transfer function is applied to form the output signal:

$$y = f\left(\sum_{1}^{R} w_i x_i\right) \tag{7}$$

For the prediction of traffic a one-way network with sigmoidal transfer function for each neuron was proposed. A two-layer structure of the network was chosen, because the mapping of properties of waveforms requires a multi-dimensional decision-making area. The features of traffic, such as: cyclical changes of fluctuations, different speed, acceleration changes must be taken into account.

4.2.1 The Neural Networks Structures

The proposed networks had a structures of 6-22-1, 7-22-1 with one output, and 5-22-2, 6-22-2 with two outputs. Diagrams of those networks shown in Figs. 9 and 10.

The input vector consists of six or seven successive previous measurements of traffic intensity for the network with one output. The value of traffic flow was predicted for the next 5 min. A 5 min measurement period was chosen, which means

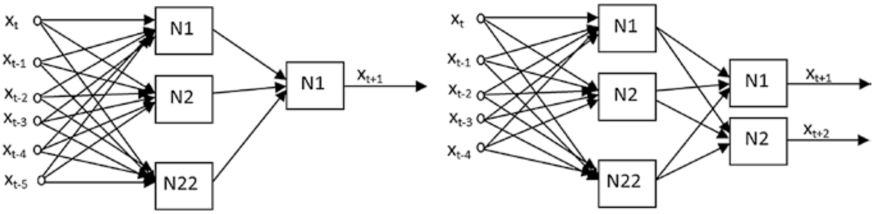

Fig. 9 The structure of the simple neural network

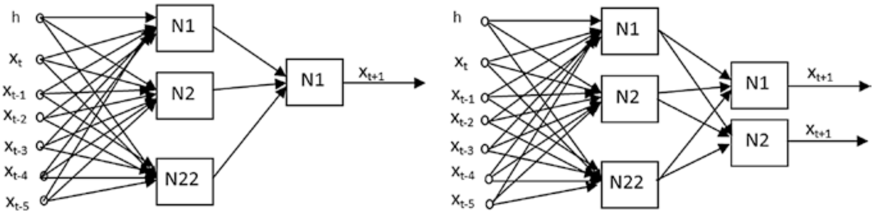

Fig. 10 The structure of the neural network with the ‘hour’ input

that the network receives as input a moving half-hour window every 5 min interval. The time window contains 5 or 6 elements of the time series of intensities traffic flow. The number of neurons in the hidden layer was determined experimentally. The prediction error is adopted as a selection criterion.

The networks have been tested with different numbers neurons in the hidden layer. The best solution was a network containing 22 neurons in the hidden layer. The networks had one or two outputs, that corresponds to the next value (values) of the value of the traffic flow in the analyzed time series.

For each traffic class a different neural network was elaborated. Weights of the neurons in the networks were evaluated by backpropagation using sets of learning sequences.

4.2.2 The Training Sequences and the Learning Process Parameters

To training set contained data collected in July, September, November, January and March. To test the network we have used data from randomly selected days of the remaining months. The length of the measurement period is 1/2 h, in which travelling vehicles are counted, a new count is started every 5 min. This means that inputs provide traffic data to the network describing the mean traffic flow in the past 1/2 h.

For each of the three classes of traffic time series (working days, Saturdays) the same structures of the neural networks were used. Depending on the group the learning sequence consisted of 3000–5000 vectors. For a group of Mon–Fri the training set was the longest, and the shortest was for the Sundays group.

The learning process terminates, when the error mean square (RMS) value is between from 0.022 and 0.034. The neural network learning rate is between 0.5 and 0.9 and momentum $\alpha = 0.4$–0.7. For all neural networks we have used a backpropagation learning method.

4.3 Bayesian Dynamic Linear Model

The approach basing mostly on historical data is sometimes criticized due to neglecting of incoming actual values. So called Bayesian forecasting is devoid of this disadvantage. The main assumptions is that the forecast is expressed in terms of probability distributions. The subjective probabilities represent the current uncertain knowledge and the beliefs of the forecaster.

The model of time series is here a dynamic model. The term dynamic means that all changes in this process happen with the passage of time. If the internal model dependencies are linear, it is called Dynamic Linear Model (DLM) [14]. Depiction as Bayesian indicates that the forecast is based on the past knowledge, but constantly inflowing new information become a part of the knowledge and can significantly influence the forecast. Let's assume D_i denotes the state of knowledge at *i*th moment and F_j denotes the forecast for *j*th moment. Then the process of Bayesian forecasting can be formally expressed as:

D_0	initial information set,
$(F_j \vert D_i)$	determining the forecast distribution for *j*th moment at *i*th moment, certainly must be $j > i$,
$D_i = \{I_i, D_{i-1})$	updating the knowledge with the new information acquired at *i*th moment.

The simplest and most widely used is the first-order polynomial model described by following equations (term a ~ N[b, c] means random variable *a* is normally distributed with known mean *b* and known variance c^2).

$$Y_t = \mu_t + \upsilon_t, \upsilon_t \sim N[0, V_t] \tag{7a}$$

Observational equation, here Yt is an observation at time t, it is the sum of series level μt and the observational error (noise) υt,

$$\mu_t = \mu_t - 1 + \omega_t, \quad \omega_t \sim N[0, W_t] \tag{7b}$$

Evolution equation, the series level can be treated as locally constant, but it undergoes to the random walk with evolution error (drift) ω_t. For all time moments s and t errors ν_t and ν_s are independent, ω_t and ω_s are independent, and ν_t and ω_s are independent. Variances V_t^2 and W_t^2 can be known or unknown and constant or variable at every time moment. Initial information is assumed to be normally distributed random variable with known mean and known variance. The details of the implementation of such model depend on the available knowledge concerning both variances.

Let's assume now, that both variances $\left(V_t^2, W_t^2\right)$ are known at each time moment. Then the forecast can be recursively expressed as:

$$m_t = A_t Y_t + (1 - A_t) m_{t-1} \tag{8}$$

where

m_t, m_{t-1} the mean value of the series at moments $t - 1$ and t,

$$A_t = R_t/Q_t, R_t = W_{t-1} + W_t, \quad Q_t = R_t + V_t. \tag{9}$$

Here, the forecast (mt—estimated series level value) is a weighted average of the prior level estimate m_{t-1} and the observation Y_t. The value of the weight A_t lies between 0 and 1. The value rather close to 0 means $R_t < V_t$, so the prior mean value of the series is much more informative than the current observation, which is burden with the noise. If this value is close to 1 the prior distribution is diffuse and in such way it is less informative than the observation.

The model here described has a specific feature, which can be recognized as a limitation: when the forecasts more than one step ahead are considered, only the distribution is available instead one sharp value. For the k–step ahead forecast it is expressed as follows:

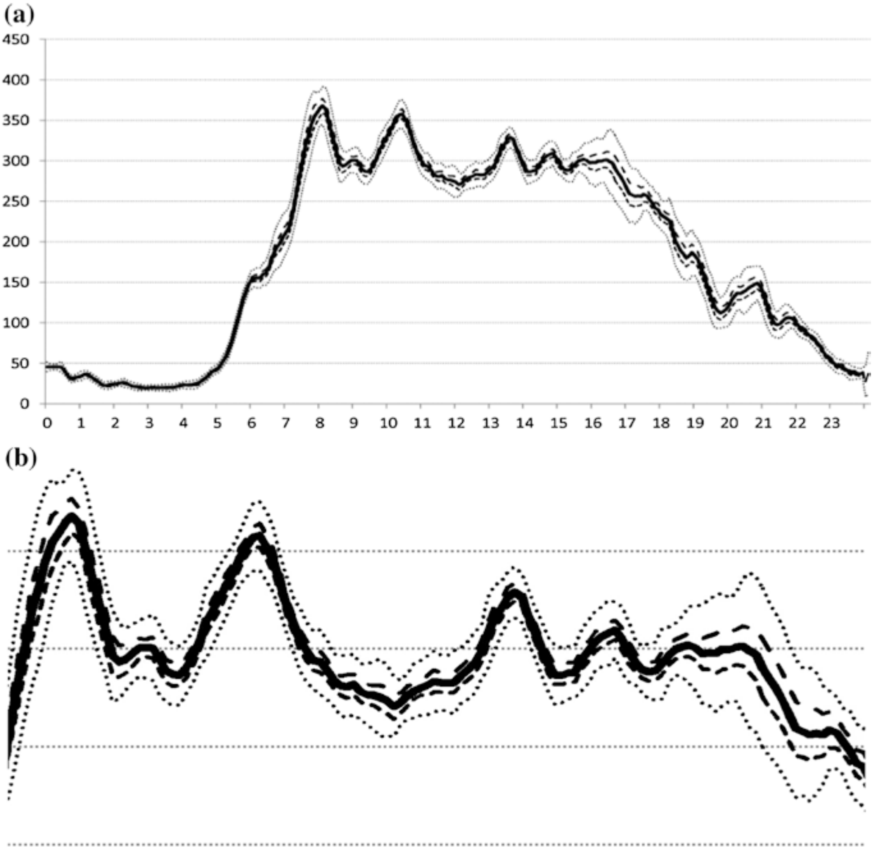

Fig. 11 Distribution of the level, noise error and level drift error: all over the day (**a**) enlarged interval between 7 a.m. and 6 p.m (**b**)

$$(Y_{t+k}|D_t) \sim N\left[m_t, Q_t(k)\right] \tag{9a}$$

$Q_t(k)$ represents the sum of all standard deviations of the level from t to t + k moments and the noise standard deviation at t + k moment, which make the distribution more diffuse:

$$Q_t(k) = W_t + \cdots + W_{t+k} + V_{t+k} \tag{9b}$$

As was mentioned above the values of V_t, W_t are required at every time moment. In this work they were calculated using the historical data.

1. For each week day category (working days, Saturday, Sunday) the calculations were performed separately.
2. For each historical series belonging to appropriate category the moving average with period of 6 was calculated (it responds to half an hour). The specificity of

road traffic variability allows to assume that so obtained averaged series well describes the level evolution.

3. For each series element the difference between average and real values was calculated (it is an equivalent of the noise).
4. For each element of averaged series the difference between the current and previous values was calculated (it is an equivalent of the level evolution).
5. The values of respectively V_t, W_t for each time moment were obtained by calculating the standard deviations of this two data sets.

Figure 11a, b shows the typical distribution of traffic flow level (solid thick line), noise error (thin dotted line) and evolution drift (thin dashed line). This data refer to all Thursdays, but the ratio of the noise error (V_t) to the evolution drift (W_t) is similar in all the cases. As can be easily found the noise error is several times greater than the evolution drift. It means that the weight At is rather close to 0, so rather the prior mean value of the series is taken as the base of the forecast.

5 Research Results

The Bayesian network (BN) and neural network (NN) models without and with 'hour' input (BNH and NNH respectively) have been evaluated. For the comparison purposes also the Bayesian Dynamic Linear Model (DLM) has been joined into tests. The research results are shown in charts and tables. Figures 12, 13, 14 and 15 show the forecast for one step ahead compared with the real series for selected days. The time window is narrowed to period from 7 a.m. to 7 p.m. due to present more details. As can be seen the predicted data fit to the real value of the traffic flow volume. The analysis shows, that the significant errors appear mainly at the rapid changes of the trend.

The best results were obtained for the class of working days. This can be explained by the greater reproducibility of similar traffic flow values, particularly during the morning and the afternoon peaks.

The forecasts quality was checked using standard error indicators: root mean squared error (RMSE), mean absolute error (MAE) and the mean absolute percentage error (MAPE) (Eq. 10a). RMSE and MAE inform about the mean of the absolute deviations of the forecast from the real value. Significant differences between RMSE and MAE indicates the occurrence of some single great deviations. MAPE evaluates the relative accuracy and additionally allows to compare the accuracy of different forecasts obtained regardless to used data range.

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - y_i^p)^2} \tag{10a}$$

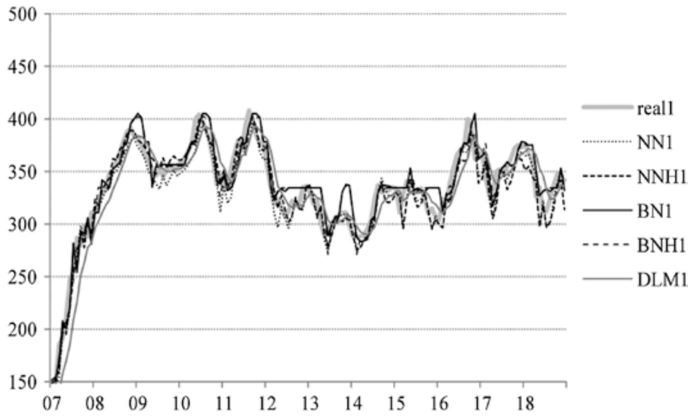

Fig. 12 One step forecast for 15.09.2011 (Thursday)

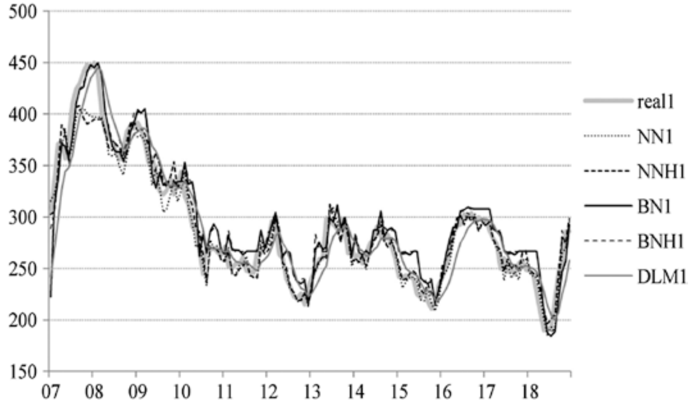

Fig. 13 One step forecast for 15.03.2012 (Thursday)

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|y_i - y_i^p\right| \tag{10b}$$

$$\mathrm{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{y_i - y_i^p}{y_i}\right| \tag{10c}$$

where

y_i, y_{ip} real value and the forecast for *i*th moment,
n number of measurements.

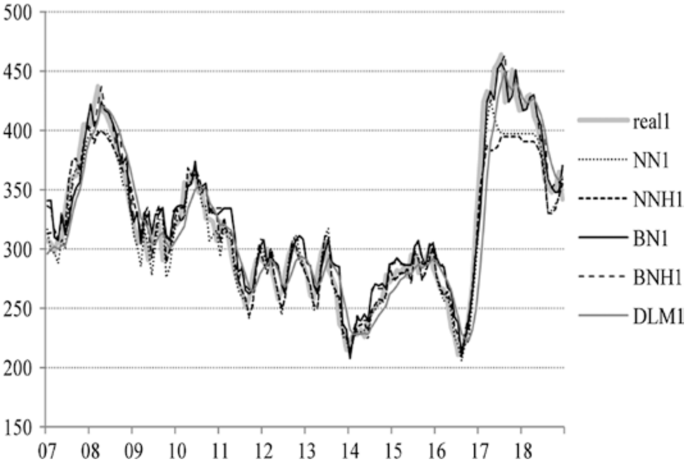

Fig. 14 One step forecast for 09.11.2011 (Wednesday)

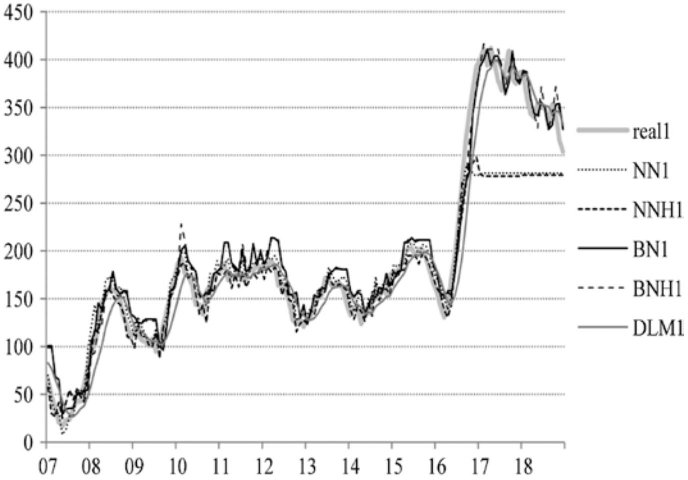

Fig. 15 One step forecast 27.11.2011 (Sunday), the scale is changed due to lower traffic volume

Additionally another error indicator was proposed: for the road traffic management purposes an important data is the knowledge about the trend. Regardless to the certain value of the forecast, the information on whether the traffic will diminish or grow can be very useful. To evaluate this Trend Tracing Indicator (TTI) was introduced:

$$\mathrm{TTI} = \frac{1}{n}\sum_{i=2}^{n}(y_i - y_{i-1})(y_i^p - y_{i-1}^p) \tag{11}$$

Table 4 List of days being tested

Week day	Dates
Wednesday	14.09.2011, 09.11.2011
Thursday	15.09.2011, 15.03.2012, 17.11.2011, 19.01.2012
Sunday	27.11.2011, 04.03.2012

Table 5 Averaged values of error indicators

	MAE1	MAPE1	RMSE1	TTI1	MAE2	MAPE2	RMSE2	TTI2
NN	14.593	0.059	20.204	72.375	21.271	0.088	28.920	63.755
NNH	14.790	0.059	21.526	73.809	20.156	0.086	27.584	62.277
BN	15.871	0.074	21.480	75.354	20.054	0.093	27.638	63.411
BNH	15.023	0.070	18.679	74.953	19.123	0.088	24.804	66.916
DLM	17.013	0.075	23.288	53.384	22.909	0.101	31.481	37.959

The TTI informs about the trend compliance between the actual series and the forecast: the great positive value confirms the good compliance, the value close to 0 or even negative indicates the large discrepancies.

All described methods were applied for some randomly chosen days, which are shown in Table 4. Thursdays and Wednesdays are commonly the subject of study when analyzing the traffic flow because of typicality, Sundays were added due to quite different traffic flow structure.

The obtained values of error indicators were too ambiguous to point out the best method. In such situation the multicriteria ranking was created. Eight criteria were taken into account: MAE, MAPE RMSE and TTI for both outputs. The error values were calculated for the forecasts in the period from 6 a.m. to 8 p.m. These values were averages for all eight days being tested. Such determined error indicators are gathered in Table 5.

All the values in Table 5 except TTI are destimulants, thus the following formula (12a) must be used to conversion the values into 0–1 interval. Value of 0 corresponds to the worse result, 1 corresponds to the best one.

$$w_{ij} = \frac{\max_i(x_{ij}) - x_{ij}}{\max_i(x_{ij}) - \min_i(x_{ij})} \tag{12a}$$

For TTI, which is stimulant conversion is performed using:

$$w_{ij} = \frac{x_{ij} - \min_i(x_{ij})}{\max_i(x_{ij}) - \min_i(x_{ij})} \tag{12b}$$

where

$\mathrm{x_{ij}}$ *j*th error indicator for *i*th method,
$\mathrm{w_{ij}}$ *j*th rate for *i*th method.

Table 6 Multicriteria ranking for all examined methods

	MAE1	MAPE1	RMSE1	TTI1	MAE2	MAPE2	RMSE2	TTI2	Final evaluation
NN	1.000	1.000	0.669	0.864	0.433	0.863	0.384	0.891	0.76
NNH	0.919	0.963	0.382	0.930	0.727	1.000	0.584	0.840	0.79
BN	0.472	0.102	0.392	1.000	0.754	0.535	0.576	0.879	0.59
BNH	0.822	0.341	1.000	0.982	1.000	0.871	1.000	1.000	0.88
DLM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00

The ranking is shown in Table 6. The final evaluation is the average of all eight partial rates.

As can be seen Bayesian networks seem to be most promising in application for prediction. Particularly with the time of day taken into account. A bit worse results were obtained with the use of neural networks, and what is astonishing the inclusion of an hour input did not cause significant improvement of the forecast. It is a sign that some details of neural network structure and learning process should be still refined. This is especially important because the learning of a neural network is much faster than for a Bayesian network. Additionally it happened that some single results of neural network were significantly the best of all. By far the worst forecasts were provided using Bayesian DLM. In that case the lack of the sharp forecast for more steps ahead was crucial. Further study on the process of determination of the both variances (for the level evolution and the noise) can lead to better performance of this model.

6 Conclusion

The performed comparison of neural network and Bayesian network, which were applied for traffic flow prediction has proved that both approaches are here suitable. The neural network seems to be slightly more accurate while tracing the trend, but the difference is of the order of fluctuations. It can be a result of input data discretization, which is required for Bayesian networks. On the other hand Bayesian network provides not only a single predicted value, but the whole distribution of possible states. This information can be very useful in some cases.

The results of the comparison of prediction models using neural networks and Bayesian networks indicates the small differences of their behavior. The average forecast error MAPE for working day for the NN model is 6 %, and for the BN model is 10 %. It also can be due to the discretization. Both models understate the forecasts, the generated predictions are generally worse for holidays and Saturdays. The best results were obtained for the traffic on the working days.

The analysis of the input (measured) data and of the models behavior suggests that additional parameters, such as holidays, vacation, seasons and random accidents should be taken into account.

The obtained results confirm the possibility of the application of both models for selection of the signaling modes within the crossroads and to support of the area-traffic management.

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Dimensioning of Multiple Capacity Transport Line with Mutual Traffic Correlation

Srećko Krile

Abstract Transport networks need very effective optimization tool for good utilization of transport line capacities. Planning and dimensioning of capacities can be done in definite planning horizon or to satisfy offered traffic from point to point in the network, crossing multiple lines on the path. Such approach is the crucial part of every Intelligent Transport System (ITS) today. Capacity dimensioning is an important element of resource management and it can be seen as CEP (capacity expansion problem). The mathematical model for optimal capacity sizing of N different transport types (capacity types—commodities) is explained, minimizing the total expansion cost. In the case of CEP for multiple line capacities with mutual traffic correlation such problem could be more demanding. With such approach an efficient heuristic algorithm for three different capacity types is being developed and tested on two different scenarios, for long-term capacity planning and for strategic multi-stop route creation in airline industry.

1 Introduction

Transport systems or networks consist of transport lines. Any line capacity (link) can be seen as limited resource that has to be extended (expanded) or reduced (shortened) during time. Also, variable capacity serves different traffic flow from point to point in the network, that is influenced by generated demands respectively to different directions (ending points) or destinations. The capacity management problem in shipping is extended to transportation problem of different load (cargo) types transported by one mean on the path. Such problem is very interesting in optimal transportation of any type of commodity by multi-purpose transport means e.g. ships, airplanes, trucks and trains. Special case is transportation of containers,

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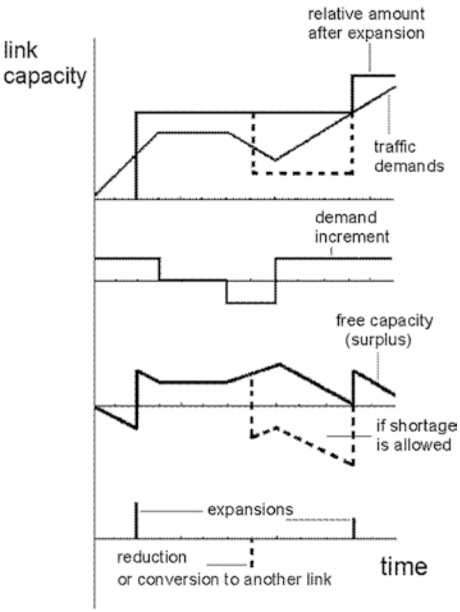


Fig. 1 Capacity planning for only one capacity type over the finite time period

where different contingents of cargo are transported by one mean (ship, train etc.) with limited capacity, showing mutual traffic correlation. Amount of different cargo loads (e.g. contingent of containers) is in firm correlation because the total capacity of the transport mean is limited, e.g. in shipping Gross Tonnage (GT) or in container Twenty-foot Equivalent Unit (TEU). Periodical expansion of the transport line capacity is the only way how network can ensure more traffic, but it has to be done in a rational manner. Adding transportation capacity could be very expensive. Expansion can be done anytime, at early beginnings, in the middle or at the end of planning period. An example for the expansion of only one capacity type we can see in Fig. 1. If reductions or conversions (doted lines) are possible the shortages or idle capacities can be minimized. With such network management technique the network provider (NP) can efficiently allocate the scarce and valuable capacity to users.

On the other hand we want to dimension the transport line with many points of load/discharge; see Sect. 4. Taking into account cargo demands for each cargo type, and various loading ports with sufficient amount of cargo (number of containers) waiting to be loaded, we need optimal transportation plan to minimize shipping and loading/unloading expenses. Also, it can help in definition of ship capacity arrangement or for comparison of ships with different types of transport capacity. In both cases the transportation problem can be seen as Minimum Cost Multiple Commodities Flow Problem (MCMCF); see [1]. It is very hard (NP-hard) optimization (combinatorial) problem. Such problem is still the subject of many scientific papers. In this chapter such problem is solved with network optimization approach explained in the context of operational research methodology. Brief explanation of mathematical model and algorithm implementation are formulated in Sects. 3 and 4 respectively for each problem. Many testing results can be seen after mentioned sections.

2 Capacity Planning Over Finite Time Period

In this part of the chapter we are looking for the optimal expansion sequence to decide at which moment and in what amount of the appropriate new construction has to be done. The main goal is to ensure both: minimal expansion cost and fulfillment of traffic demands.

An example for capacity type differentiation we have in many transport systems but here we are talking about the case where capacity types are in firm (mutual) correlation, serving the traffic from the same starting to the same ending position, see [2, 3]. For example, if unused (idle) capacity of one capacity type exists it can be redirected (re-used) to another capacity type. Capacity conversion (redirection) can be allowed anytime and in all possible directions (combinations) or with some restrictions. In the first case the capacity types are not ranked. But in most cases the capacity types are ranked that means that some conversions are allowed but others are not.

With capacity conversion we can prevent money loss caused by bad utilization of capacity with much lower expenses. Similar problems of capacity expansion for transportation line with multiple capacity type differentiation and mutual traffic correlation have been analyzed.

From previous discussion it is clear that the capacity expansion problem (CEP) of different capacity types exists. In line capacity planning over time we want to satisfy given demands at the lowest possible cost, see [3]. So we are looking for an optimal decision in which moment and in what amount of each capacity type expansions (new constructions) has to be done.

Two strategies can be applied: fulfillment of traffic demands can be a must or traffic loss can be allowed at a pre-defined rate. In both cases we need an optimal decision in which moment and to what amount of specified capacity type the expansion has to be done; see [4, 5].

We expect that traffic demands rise in time which can be addressed through introduction of more transport capacity; see Fig. 1. But in some periods traffic demand increment can be zero (that means stagnation) or can be negative (decreasing). In both cases idle capacities can appear and may cause significant loss of money. So the optimal expansion of line capacity must be carefully done. The reduction (disposal) of line capacity is not an acceptable solution so if we have capacity types with traffic correlation the conversion can be more appropriate solution.

The Capacity Expansion Problem (CEP) is formulated as minimization of the cost function over a set of variables confined within a constraint set. The expansion problem for three and more different multiple capacity types with allowed shortages is a very complex problem. Although it can be solved with many different approximation techniques it is still the subject of many scientific papers, see [6]. Some papers that have significant influence on this chapter are: Luss [7], Castro and Nabona [8] and Cheng and Gavish [9].

After the brief explanation of the capacity expansion problem (CEP) the mathematical model is formulated in Sect. 3 of this chapter. In Sect. 3.1 the heuristic algorithm approach is explained. In Sect. 3.2 the basic heuristic solution are explained. In Sects. 3.3 and 3.4 some limitations and improvement are announced. In Sect. 3.5 different heuristic options are proposed. In Sect. 3.6 one numerical test-example is presented and discussed in relation to algorithm complexity and computational savings, as same as about efficiency of algorithm options and their possible application.

3 Mathematical Model for CEP

The CEP for a finite planning period is similar to a multi-period inventory problem but it also has elements of multi commodity assignment problem. Because of nonlinear cost functions over time, showing the effect of economy of scale, we can apply any nonlinear optimization technique. Instead of a nonlinear convex optimization (NP-complete), that can be very complicated and time-consuming, a network optimization method can be efficiently applied. The main reason on such approach is the possibility of discrete capacity values for limited number of capacity types so

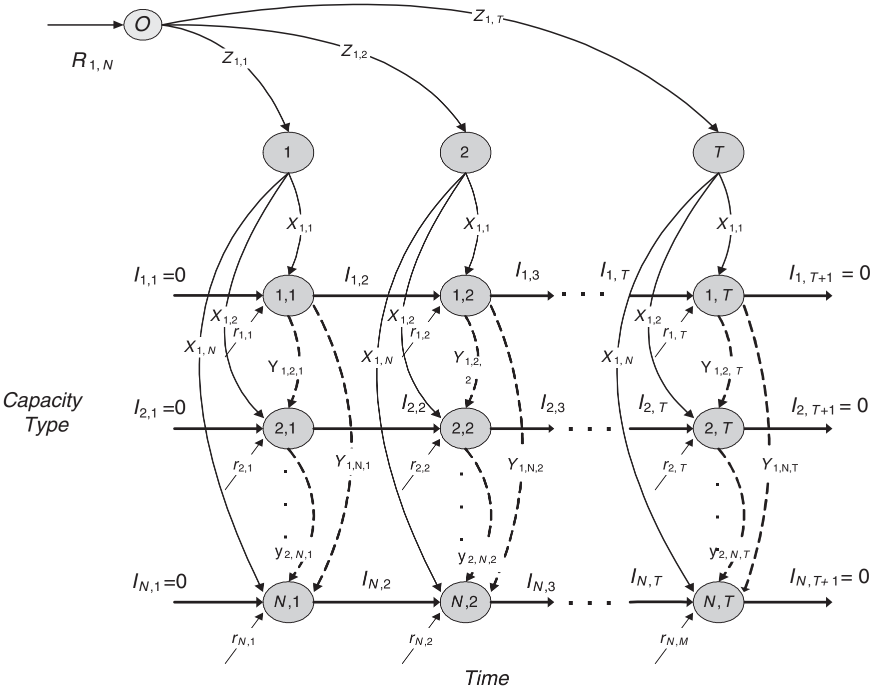


Fig. 2 A network flow representation of the capacity expansion problem

the optimization process can be significantly improved. In that sense CEP-problem can be formulated as Minimum Cost Multi-Commodity Flow Problem (MCMCF); see [10]. It can be easily represented by multi-commodity the single (common) source multiple destination network and the flow diagram can be seen in Fig. 2.

Each line capacity (called commodity) is expanded over time to serve N demand types. Commodity i for $i = 1, 2, \ldots, N$ is designed primarily to serve demand of type i, but it can be converted to satisfy demand j ($j \neq i$). In such conversion process any limitation can be introduced. Figure 2 gives a network flow representation of CEP for $N = 3$ and T time periods. The ith row of nodes represents the capacity states for each period t for appropriate capacity type i. At each node (i, t) there is an external traffic demand increment $r_{i.t}$, possibly negative. For convenience, the $r_{i.m}$ is assumed to be integer. Horizontal links (branches) are representing capacity flows between two time periods. An unused capacity (surplus) can be utilized in the next time period but maintenance of idle capacity could be too expensive. Contrary, shortages (negative values) can produce unsatisfied demands. Period $T + 1$ may be introduced when all capacity states values are zero; see (4). It means that after planning period all traffic demands must be satisfied. The sum of traffic demand for capacity type i between two periods

$$R_i(t_1, t_2) = \sum_{t=t_1}^{t_2} r_{i,n} \tag{1}$$

The sum of demands for the whole planning period and for all capacity types has to be positive or zero:

$$\sum_{i=1}^{N} R_i(1, T) \geq 0 \tag{2}$$

It means that we don’t expect reduction of total capacity on the line after whole planning period; in other words we presume the increase of capacity. Horizontal links that connect nodes represent the capacity $\mathrm{I}_{\mathrm{i.t}}$ between any time period t and t + 1. Positive value represents inventory (surplus) and negative value represents shortage (lack of capacity). The vertical links represent link expansions (new constructions) with $x_{i.t}$, or link capacity conversions with $y_{i,j.t}$ in the appropriate time period. Common node “O” is the source for all capacity expansions.

Capacity points are noted with α_t at time period t in which the relative amount of capacity for each capacity type ($I_{i,t}$) is known (in defined bounds) and which at least one capacity state value $I_{i,t} \leq 0$.

$$\alpha_t = (I_{1,t}, I_{2,t}, \ldots, I_{N,t}) \tag{3}$$

$$\alpha_1 = \alpha_{T+1} = (0, 0, \ldots, 0) \tag{4}$$

Let C_t be the number of capacity points ($C_1 = C_{T+1} = 1$), and the total number of capacity points in C_p. Reduction of C_p can be done through imposing appropriate capacity bounds or by introducing adding constraints.

Let G (E, A) denote a network topology, where E is the set of nodes representing possible line capacity states (capacity points) in each time period T and A, the set of links (arcs), representing the capacity changes between time periods. Vertical set of nodes for each time period is represented by the capacity point α_t.

On diagram from Fig. 2 each horizontal link is characterized by link weight value. Each weight $w_{i,m}$ depends on the capacity situation on the transport line between two time periods, defined by the capacity expansion values $x_{i,t}$, conversion values $y_{i,j,t}$ and traffic demands $r_{i,t}$. It means that the link weight (cost) is the function of used capacity: lower amount of used capacity gives lower weight (cost). The lack of capacity can decrease the link weight values same as idle capacity can increase it. If the link cost corresponds to the amount of used capacity, the objective is to find optimal expansion strategy that minimizes the total cost incurred over the whole planning period. The main condition is that given traffic demands must be fully satisfied without shortages on the end of planning period.

The CEP is formulated as minimization of the cost function over a set of variables confined within a constraint set. In general it is the multi-constraint optimization problem (MCP) but in this chapter we are concerned with one-dimensional link weight vectors for $T + 1$ links on the path $\{w_{i,t,}\ t \in A,\ i = 1, \ldots, N\}$. We have only one capacity constraint for each capacity type and for each time period denoted with $L_{i,t}$ ($L_{1,t}$ $L_{2,t}$, … $L_{N,t}$). Definition of the single-constrained problem is to find an expansion sequence from the first to the last node in the network from Fig. 2, such that:

$$w = \min \sum_{i=1}^{N} \sum_{t=1}^{T} w_{i,t}(I_{i,t}, x_{i,t}, y_{i,j,t}) \tag{5}$$

where

$$I_{i,t} \le L_{i,t} \tag{6}$$

A path obeying the above condition is said to be feasible. Note that there may be multiple feasible expansion solutions. The total cost over time includes cost for capacity expansion $c_{i,t}(x_{i,t})$, capacity conversion cost $g_{i,j,t}(y_{i,j,t})$, idle capacity and capacity shortage cost $h_{i,t}(I_{i,t+1})$, and penalty costs in form of joint set-up cost cost $p_t(z_t)$. If the link weights correspond to the costs the objective is to find optimal expansion policy that minimizes the total cost incurred over the whole planning period. The CEP problem can be formulated as follows:

$$\min\left(\sum_{t=1}^{T}\left\{\sum_{i=1}^{N}\left[c_{i,t}\left(x_{i,t}\right)+h_{i,t}\left(I_{i,t+1}\right)+\sum_{j=i+1}^{N} g_{i,j,t}\left(y_{i,j,t}\right)\right]+p_t(z_t)\right\}\right) \tag{7}$$

so that we have:

$$I_{i,t+1} = I_{i,t} + x_{i,t} + \sum_{j=1}^{i-1} y_{j,i,t} - \sum_{j=i+1}^{N} y_{i,j,t} - r_{i,t} \tag{8}$$

$$I_{i,t} = I_{i,T+1} = 0 \tag{9}$$

for $t = 1, 2, \ldots, T;\; i = 1, 2, \ldots, N;\; j = i + 1, \ldots, N (i < j)$.

Normally, the objective function is a nonlinear function, consisted of many different costs functions. They are usually represented by nonlinear variable cost functions. It can be assumed that all costs functions are concave and non-decreasing, reflecting economies of scale.

3.1 Algorithm Development

It is this approach that the network optimization method is efficiently applied. The network optimization can be divided in two steps. In the first step we are calculating the minimal weights $d_{u,v}(a_u, a_{v+1})$ between all pairs of capacity points for whole planning horizon. The calculation of each weight value is called: capacity expansion sub-problem (CES). The number of all possible CES values depends on the total number of capacity points. It requires solving repeatedly a certain single period expansion problem (SPEP).

In the second step we are looking for the shortest path from the first to the last node in the network with former calculated weights between node pairs (capacity points); see Fig. 3. Suppose that all values (CES) are known, the optimal solution

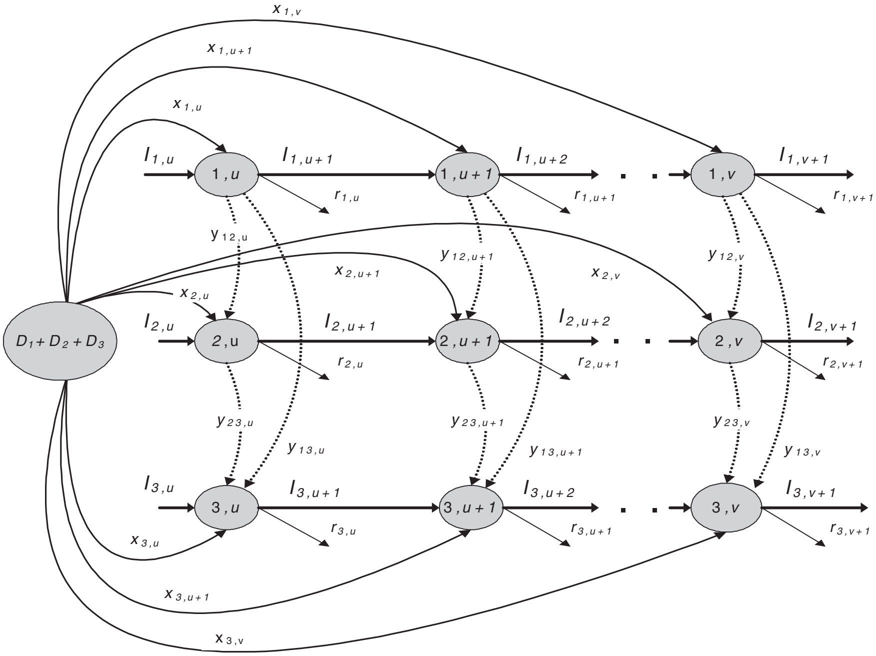


Fig. 3 A network flow representation of a sub-problem for N = 3

for CEP can be found by searching for the optimal sequence of capacity points and their associated capacity state values for each time period. On that level the CEP problem can be seen as a shortest path problem for an acyclic network in which the nodes represent all capacity point values, and branches (links) represent CES values; see Fig. 3. Similar approach we can find in [11–13]. Then Dijkstra's or Floyd's algorithm or any similar algorithm can be efficiently applied; see Lee and Luss [5].

In CEP we have to find many weight values $d_{u,v}(a_u, a_{v+1})$ that emanate two capacity points, from each node (u, a_u) to node $(v+1, a_{v+1})$ for $0 \le v \ge u \ge T+1$. We can calculate $d_{u,v}(\alpha_u, \alpha_{v+1})$:

$$\min\left\{\sum_{t=u}^{v}\left(\sum_{i=1}^{N}\left[c_{i,t}(x_{i,t}) + h_{i,t}(I_{i,t+1}) + \sum_{j=i+1}^{N} g_{i,j,t}(y_{i,j,t})\right] + p_t(z_t)\right)\right\} \tag{10}$$

where

$$I_{i,v+1} = I_{i,u} + D_i(u,v) - R_i(u,v) \tag{11}$$

$$R_i(t_1,t_2) = \sum_{t=t_1}^{t_2} r_{i,t} \tag{12}$$

$$D_i(u,v) = \sum_{t=u}^{v}\left(x_{i,t} + \sum_{j=1}^{N}\left(y_{j,i,t} - y_{i,j,t}\right)\right), \quad i \ne j \tag{13}$$

for $\mathrm{i} = 1,2,3,\ldots,\mathrm{N}\ \mathrm{t} = 1,\ldots,\mathrm{T}$.

D_i value represents the amount of total capacity changes for capacity type i for appropriate time period. The total cost between two capacity points for periods u and v includes many costs: the capacity expansion cost $c_{i,t}\left(x_{i,t}\right)$, idle capacity or capacity shortage cost $h_{i,t}\left(I_{i,t+1}\right)$, capacity conversion cost $g_{i,j,t}\left(y_{i,j,t}\right)$ and joint set-up cost $p_t(\mathrm{z}_t)$. The last one can be used as a strategic penalty cost with strong influence to optimization process.

3.2 *Basic Algorithm Option*

Let the value $d_{u,v}(a_u, a_{v+1})$ represents the minimum expansion cost between two capacity points denoted by a_u and, a_{v+1}. To compute the Capacity Expansion Sub-problem (CES) value $d_{u,v}$ it is convenient to describe the problem as a single source multi-commodity and multi-destination network. To solve CES it requires solving repeatedly a certain single period problem. Let $\mathrm{SPEP}_{ij}\left(t, D_i, \ldots D_j\right)$ be a *Single Period Expansion Problem* associated with period t for capacity type $i, i+1, \ldots, j$ and corresponding values of *capacity change intention*

$D_i, D_{i+1}, \ldots, D_j$. A detailed explanation of various SPEP solutions (strategy) for three different capacity types can be found in previous work of Krile [12].

The computational effort is $O(T^3 N^4 R_i^{2(N-1)})$. If there are no limitations on capacity state values the complexity of such algorithm approach depends on traffic demands R_i and it is pretty large, increasing exponentially with N.

The expansion sub-problem for N facilities $i = 1, 2, \ldots, N$ on the path between routers u and v is as:

$$\min\left\{\sum_{m=u}^{v}\left(\sum_{i=1}^{N} c_{i,m}(x_{i,m}) + h_{i,m}(I_{i,m+1}) + \sum_{j=m+1}^{N} g_{i,j,m}(y_{i,j,m})\right)\right\} \tag{14}$$

where

$$I_{i,v+1} = I_{i,u} + D_i(u,v) - R_i(u,v) \tag{15}$$

$$R_i(u,v) = \sum_{m=u}^{v} r_{i,m} \tag{16}$$

$$D_i(u,v) = \sum_{m=u}^{v}\left(x_{i,m} + \sum_{j=1}^{N} y_{j,i,m}\right), \quad i \neq j \tag{17}$$

for $\mathrm{m} = 1, 2, \ldots, \mathrm{M} + 1;\ \mathrm{i} = 1, 2, \ldots, \mathrm{N};\ \mathrm{j} = \mathrm{i} + 1, \ldots, \mathrm{N}$.

Let C_m be the number of capacity point values at router position m (for link between core routers). Only one capacity point for the link that connects to the edge router: $C_1 = C_{M+1} = 1$.

The total number of capacity points is:

$$C_p = \sum_{m=1}^{M+1} c_m \tag{18}$$

In the CEP we have to find many cost values $d_{u,v}(a_u, a_{v+1})$ that emanate two capacity points, from each node (u, a_u) to node $(v+1, a_{v+1})$ for $v \geq u$. The total number of all connections is:

$$N_d = \sum_{i=1}^{M} C_i \left[\sum_{j=i+1}^{M+1} C_j\right] \tag{19}$$

For every CES calculation many different solutions can be derived depending on D_i polarity. They are consisted of expansion and conversion amount solutions.

The most of the computational effort is spent on computing the sub-problem values. The number of all possible $d_{u,v}$ values depends on the total number of

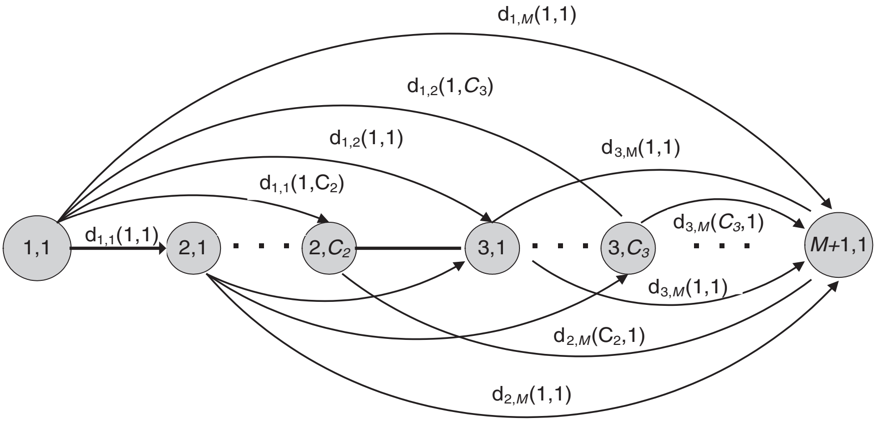


Fig. 4 The CEP problem can be seen as a shortest path problem for an acyclic network in which the nodes represent all possible values of capacity points and the links represent CES values

capacity points. A lot of expansion solutions are not acceptable and they are not part of the optimal sequence. It is the key for efficiency of implemented algorithm.

In contrast to the problem with restriction $r_{i,m} \geq 0$, expansion and conversion may be realized for any link on the path so the algorithm for optimal CES has to find three locations for changes (link capacity), one for each facility type $u \leq (m_1, m_2, m_3) \leq v$. But in this case we assume that all changes for a sub-problem are made on the same link; it is more appropriate for real application. So, the algorithm is looking for unique location m on the path section between routers $u \leq m \leq v$ to minimize the equitation (14). Such limitation reduces the computation complexity significantly without influence on optimal expansion sequence.

Suppose that all links (sub-problems) are known, the optimal solution for CEP can be found by searching for the optimal sequence of capacity points and their associated link state values. The number of all possible $d_{u,v}(a_u, a_{v+1})$ values depends on the total number of capacity points; see Fig. 4. It is very important to reduce that number (C_p) and that can be done through imposing of appropriate capacity bounds or by introduction of adding constraints. In this chapter we can see that many expansion solutions are not acceptable and they are not part of the optimal sequence. With such approach algorithm can be significant improved. So we can obtain the near-optimal result with computational savings.

3.3 Single Location Expansion Problem

Approach described in chapter above requires solving repeatedly a certain single location expansion problem (SLEP) in all possible modifications, looking for the best result. Let $\mathrm{SLEP}_{i,j}(m, D_i, \ldots D_j)$ be a *Single Location Expansion Problem* associated with link m for facility (capacity) type $i, i+1, \ldots, j$ and corresponding values of *capacity change intention* $D_i, D_{i+1}, \ldots, D_j$.

Solving SLEP for three different capacity types we have many expansion solutions divided into three different scenarios (expansion strategies):

A. capacity changes of one capacity type are not correlated with changes of others;
B. capacity changes of two capacity types depend on each other, but change of the third is independent;
C. capacity changes of all three capacity types depend on each other.

From three expansion scenarios (expansion strategy) many different expansion solutions can be derived, depending on D_i polarity.

Zero value of any capacity type at the beginning of period t means that any change of capacity is allowed.

In algorithm application from the policy group a. we have only one possible solution, but from policy group b. it can be varied in two combinations, swapping the place of the first and the second facility.

Further, we can combine all three capacity types, so there are finally six combinations for policy group b. In policy group c. exists only one expansion solution, but also can be varied in three combinations, depending on facility order number (first, second, third). Expansion solutions for policy group c. depending on D_i polarity (only for positive value of first capacity type $D_f \geq 0$) are shown in Table 1.

Because of (14) the main condition for any expansion solution must satisfy:

for policy (a):

for policy (b):

$$x_{i,t} = D_f \geq 0 \tag{20}$$

$$x_{i,t} = D_f + D_s \geq 0 \tag{21}$$

for policy (c):

$$x_{i,t} = D_f + D_s + D_t \geq 0 \tag{22}$$

In policy groups (b) and (c) we have expansion solutions with conversions of capacity from one type to another. It can be done as stand-alone policy, or together with expansion. That means that conversion is just complementary with expansion in satisfying of demands.

Conversion can be applied when idle capacity occurs or negative demands are present. Special case is occurred when conversion y_{ij} eliminates both: demands for capacity type i, and idle capacity for capacity type j, so adding expansions are not necessary. Negative conversion value denotes conversion in opposite direction: $y_{ij,t} = -y_{ji,t}$.

Also we make distinction between two cases: *the partial expansion* and *the excessive expansion* option.

Table 1 Possible expansion solutions from strategy c

Expansion solutions from strategy c	$D_f \geq 0$										
	$D_s > 0$ $D_f > 0$	$D_s < 0$ $D_f > 0$				$D_s < 0$ $D_f < 0$		$D_s > 0$ $D_f < 0$			
$D_s + D_t$	>0	>0	<0		=0	<0		>0	<0		=0
$\lvert D_f \rvert$ $\lvert D_s + D_f \rvert$	–	–	≥1	**<1**	–	≥1	**<1**	–	≥	**<1**	–
$\mathbf{X_f = D_f + D_s + D_t}$	Exp (−)	Exp (+)	Exp (−)	**Red**	Exp Xf = Df	Exp (−)	**Red**	Exp (+)	Exp (−)	**Red**	Exp $X_f = D_f$
$\mathbf{Y_{fs}}$	D_s	–	$D_s + D_t$	$\mathbf{D_s + D_t}$	–	D_s	$\mathbf{D_s}$	$D_s + D_t$	–	**–**	–
$\mathbf{Y_{st}}$	–	$-D_s$	D_t	$\mathbf{D_t}$	$-D_s$	–	**–**	D_t	$-D_s$	$\mathbf{-D_s}$	$-D_s$
$\mathbf{Y_{ft}}$	D_t	$D_s + D_t$	–	**–**	–	D_t	$\mathbf{D_t}$	–	$D_s + D_t$	$\mathbf{D_s + D_t}$	–

The partial expansion means that demands are satisfied by expansion of capacity type *i* plus by conversion of capacity type *j*, only if shortage of facility *j* does not occur.

The excessive expansion means that the expansion amount of capacity type *i* is partially used to expand facility *i*, and partially to satisfy capacity type *j*, with conversion amount $y_{ij.}$ In Table 1. The partial expansions are denoted with (−) and the excessive expansions are denoted with (+). Unacceptable expansion solutions are emphasized in bold.

A lot of them are not acceptable and are not part of optimal sequence. For this problem an acceptable expansion solution has to satisfy some basic properties:

$$x_{i,t} \geq 0 \tag{23}$$

$$x_{i,t} \cdot D_{i,t} \geq 0 \tag{24}$$

$$y_{i,j,t} \cdot D_{i,t} \leq 0 \tag{25}$$

$$y_{i,j,t} \cdot D_{j,t} \geq 0 \tag{26}$$

Property (23) limits the expansion only to positive value.

Property (24) implies that the expansion of capacity type i cannot be acceptable if that facility has intention to be reduced on location (link) $m\left(D_{i,m} < 0\right)$.

Expansion is also possible through conversion, so (25) and (26) imply the similar restriction as (23). Zero value of any capacity type means that any change of capacity is allowed.

For scenario A we have only one possible expansion solution. For scenario B we can combine all three capacity types in couples. In scenario C only one expansion solution exists. Totally, we have five different expansion solutions.

In scenarios B and C we have expansion solutions with conversions of capacity from one type to another. It can be done as stand-alone expansion or together with expansion. That means that the conversion is just complementary with the expansion in satisfying of traffic demands.

Conversions can be applied only when idle capacities are noticed or negative demand increments are present. Special case is occurred when conversion $y_{i,j,m}$ eliminates both: demands for capacity type *j*, and reduces idle capacity of capacity type *i*, so adding expansions are not necessary. Also we make distinction between two options: the partial expansion and the excessive expansion. The partial expansion $x_{j,m}$ means that demands are satisfied by expansion of appropriate capacity type *j* plus by conversion $y_{i,j,m}$ of capacity type *i* with higher quality level, but only if shortage of facility *i* is not occurred.

The excessive expansion means that the expansion amount $x_{i,m}$ is used to partially expand facility *i* and to satisfy demands for lower capacity type *j*, with conversion amount $y_{i,j,m}$.

3.4 The Improvement of Algorithm

The key for this very effective approach is in fact that extreme flow theory enables separation of these extreme flows which can be included in optimal expansion solution from those which cannot be; see Castro and Nabona [8]. Most of the computational effort is spent on computing the sub-problem values. Any of them, if it cannot be a part of the optimal sequence, is set to infinity. It can be shown that a feasible flow in the network given in Fig. 3. corresponds to an extreme point solution of CEP if and only if it is not the part of any cycle (loop) with positive flows, in which all flows satisfy given properties; see Zangwill [14]. One may observe that the absence of cycles with positive flows implies that each node has at most one incoming flow from the source node. This result holds for all single source networks. That means that optimal solution of $d_{u,v}$ has at most one expansion (or reduction) for each facility.

Using a network flow theory approach, adding properties of extreme point solution are identified. These properties are used to develop an efficient search for the link costs $d_{u,v}$. Absence of such cycles with positive flows implies that extreme point solutions for CEP satisfy the following properties:

$$I_{i,m} \cdot x_{i,m} \leq 0 \tag{27}$$

$$I_{i,m} \cdot y_{i,j,m} \geq 0 \tag{28}$$

$$I_{j,m} \cdot y_{i,j,m} \leq 0 \tag{29}$$

$$I_{j,m} \cdot x_{i,m} \cdot y_{i,j,m} = 0 \tag{30}$$

if $x_{i,m} \cdot y_{i,j,m} \neq 0$

$$I_{i,m} \cdot I_{j,m} \cdot y_{k,i,m} \cdot y_{ki,j,m} = 0 \tag{31}$$

if $\quad y_{k,i,m} \cdot y_{ki,j,m} \neq 0$
for: $\quad i, k, j = 1, 2, 3 \; i \neq k \neq j; \;\; m = 1, \ldots, M + 1.$

Properties (27) to (31) imply that the capacity of any capacity type is changed through an expansion, reduction or by conversion only if it doesn't make cycles with positive flows.

Equations (27) and (28) imply that the capacity of any capacity type can be increased by an expansion or by a conversion only if there is no idle capacity. Similar rule exists for reduction of idle capacity. Equation (29) implies that capacity can be reduced only if there is no capacity shortage.

Equation (30) implies that incoming flow of facility, going to be converted (reduced) in partially or excessive expansion solution, has to be zero. If not, cycles with positive flows can be occurred; see Fig. 5. On diagram dotted lines mark a cycle with positive flows from the common source. One of the capacity values ($I_{2,m}$ or $I_{3,m}$) must be zero.

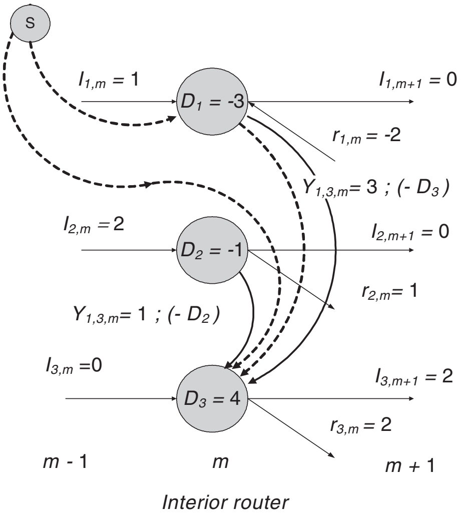


Fig. 5 An example of single location expansion solution that cannot be a part of the extreme solution. *Doted lines* mark a cycle with positive flows from the common source. Both capacity values at the beginning of the period t must be zero

Property (31) is used for simultaneous multi-conversion solution from scenario C. Only one incoming flow of converted (reduced) facility can exist. It means that two incoming flows are not allowed in the same time. In the case of simultaneous conversions, incoming flows have to be zero.

We can say that any acceptable SLEP expansion solution for any CES have to satisfy properties (23)–(26) and (27)–(31). So many expansion solutions are not a part of optimal sequence and could be eliminated from further computing. It means that any of sub-problem value if it cannot be a part of the optimal sequence is set to infinity.

To reduce the complexity we can introduce the basic and adding properties based on extreme flow theory, see Zangwill [15]. With such algorithm approach we can ensure the close to optimal result, using significantly less effort in computational procedure. In all numerical test-examples it can obtain the best possible result (close to optimal expansion sequence). The key for algorithm improvement is in fact that extreme flow theory enables separation of these extreme flows which can be a part of an optimal expansion solution from those which cannot be. Any of them, if it cannot be a part of the optimal sequence, is set to infinity.

One may observe that the absence of cycles with positive flows implies that each node has at most one incoming flow from the source node. This result holds for all single source networks. That means that the optimal solution of du, v has at most one expansion for each capacity type. If conversions exist (as a part of partial expansion option) such flow can be a part of extreme flow only if there are no cycles with positive flows. All basic and adding constraints for the CES problem with three capacity types are identified in paper Krile [16] and Krile and Kos [3].

The total number of capacity points is the measure of the complexity of the CEP-problem Trough many test-examples we compared this heuristic with algorithm on exact approach. Results are given in Table 2. The basic heuristic solution

Table 2 Comparison of algorithm options on one test-example

Traffic demand increment				Algorithm option	The best possible result found	Number of capacity points	Number of acceptable sub-problems	Computational savings in perc. (%)
Time period	$r_{1,t}$	$r_{2,t}$	$r_{3,t}$					
1	−10	−10	10	Full approach	7809.72	2305	293860	–
2	10	10	−10	Basic_A	7809.72	2305	158379	46.18
3	0	0	0	M_H	7809.72	1645	127249	56.69
4	10	10	20	A_H	8227.97	1405	67221	77.12
5	−10	−10	10	R_H	8227.97	1245	31062	89.43
6	10	10	10	P_H	8227.97	289	17383	94.08
				T_H	52259.06	7	13	99.99

$c_{it}(x_{it}) = f_i^{\,t-1}(A_i + B_i\, x_{it}^{ai})$, $A_1 = 3000$, $B_1 = 25$, $a_1 = 0.9$, $A_2 = 1000$, $B_2 = 20$, $a_2 = 0.85$, $A_3 = 2000$, $B_3 = 30$, $a_3 = 0.95$
$h_{it}(I_{i,t+1}) = f_i^{\,t-1} H_i\, I_{i,t+1}$, $H_i = 400$ ($I_{it} > 0$), $H_i = 300$ ($I_{it} < 0$); for $i = 1, 2, 3$
$g_{it}(y_{ij,t}) = f_i^{\,t-1} G_i$, $G_i = 100$
$p_t(z_{,t}) = 0$
For all periods and for all facilities it is the same value $f = 0.9$. Values are independent of time period t
Optimal usage of the capacity (the best expansion sequence)
$Y_{2,3,1} = 10$, $Y_{2,3,2} = -10$, $x_{2,4} = 30$, $Y_{2,3,4} = 20$, $Y_{2,3,5} = 10$, $x_{2,6} = 30$, $Y_{1,2,6} = -10$, $Y_{2,3,6} = 10$
Minimal cost: 7809.72

(denoted with Basic_A) with no limitation on capacity state value shows the savings in percents on average near 45 % that is proportionally reflected on computation time savings; see diagram in Fig. 9.

3.5 Testing of Different Algorithm Options

Many numerical examples were solved for N = 3, T = 6 and results obtained by heuristics are compared with results obtained by algorithm based on exact approach, that is calculating all possible expansion solutions for each sub-problems.

Traffic demands are defined for each time period with number of channel capacity units for each capacity type (satellite link). Values are given in relative amount, increasing or decreasing over the planning horizon. Also, they are nonlinear that is more appropriate for real application.

$$\begin{aligned}
&\mathrm{a}(\mathrm{r}_1 = -10, \mathrm{r}_2 = 10, \mathrm{r}_3 = 0, \mathrm{r}_4 = 10, \mathrm{r}_5 = -10, \mathrm{r}_6 = 10)\\
&\mathrm{b}(\mathrm{r}_1 = 0, \mathrm{r}_2 = 10, \mathrm{r}_3 = 0, \mathrm{r}_4 = -10, \mathrm{r}_5 = 0, \mathrm{r}_6 = 10)\\
&\mathrm{c}(\mathrm{r}_1 = 10, \mathrm{r}_2 = -10, \mathrm{r}_3 = 0, \mathrm{r}_4 = 20, \mathrm{r}_5 = 10, \mathrm{r}_6 = 10)\\
&\mathrm{d}(\mathrm{r}_1 = 10, \mathrm{r}_2 = 10, \mathrm{r}_3 = 0, \mathrm{r}_4 = 0, \mathrm{r}_5 = 10, \mathrm{r}_6 = 0)
\end{aligned}$$

Tables 3 exhibits results for some numerical test-examples with combinations of traffic demands given above. Bounds for idle capacities and capacity shortages are not defined, same as for expansion and conversion values.

In testing we used the capacity expansion cost function as follows:

$$c_{i,t}(x_{i,t}) = f_i^{t-1}\left(A_i + B_i \cdot x_{i,t}^{a,i}\right) \tag{32}$$

where A_i is a fixed charge cost per expansion of capacity type i, B_i is a variable cost per expansion unit, a_i represents the factor of concavity, and f_i is the discount factor. For our test-examples we put: $A_1 = 3000$, $B_1 = 25$, $a_1 = 0.9$, $A_2 = 1000$, $B_2 = 20$, $a_2 = 0.85$, $A_3 = 2000$, $B_3 = 30$, $a_3 = 0.95$. For all periods and for all facilities we use the same value $f = 0.9$.

All holding costs of excess capacities and shortage penalty costs show linear growth:

$$h_{i,t}(I_{i,t+1}) = f_i^{t-1} H_i \cdot I_{i,t+1} \tag{33}$$

For example shown in Table 2:

$H_i = 400$; for all $I_{it} > 0$

$H_i = 300$; for all $I_{it} < 0$; $i = 1, 2, 3$

For examples shown in Table 3:

$H_i = 500$; for all $I_{it} > 0$

$H_i = 10$; for all $I_{it} < 0$; $i = 1, 2, 3$

Table 3 Results of test-examples

Demands			Excessive expansions allowed	Heuristic algorithm approach	The best solution found	Number of capacity points	Number of acceptable sub-problems	Savings in perc. (%)
r_{1t}	r_{2t}	r_{3t}						
a	b	c	Yes	OSH	1809.88	1617	276,630	–
				BasicH	1809.88	1617	148,986	4614
				AH	3265.19	1147	73,207	7354
				RH	3265.19	1009	53,144	8079
				PH	3265.19	265	3943	9857
				TH	3265.19	7	21	9999
			No	OSH	4873.21	1617	254,700	–
				BasicH	4873.21	1617	135,437	4682
				AH	7092.18	1147	70,429	7235
				RH	7092.18	1009	51,464	7979
				PH	7092.18	265	3943	9845
				TH	7092.18	7	21	9999
b	a	d	Yes	OSH	1972.64	1259	267,100	–
				BasicH	1972.64	1259	142,670	4659
				AH	2442.96	565	25,266	9054
				RH	2442.96	526	21,109	9210
				PH	2442.96	115	1,445	9946
				TH	2442.96	7	21	9999
			No	OSH	3829.13	1259	247,156	–
				BasicH	3829.13	1259	123,390	5007
				AH	8748.13	565	24,529	9008
				RH	8748.13	526	20,716	9162
				PH	8748.13	115	1445	9942
				TH	8748.13	7	21	9999
a	a	c	Yes	OSH	6221.59	2122	621,668	–
				BasicH	6221.59	2122	247,968	6011
				AH	9718.46	1228	74,965	8794
				RH	9718.46	1090	52,367	9158
				PH	9718.46	289	4160	9933
				TH	17750.09	7	15	9999
			No	OSH	9072.39	2122	579,960	–
				BasicH	9072.39	2122	211,369	6350
				AH	14719.56	1228	71,868	8761
				RH	14719.56	1090	51,138	9118
				PH	14719.56	289	4,160	9928
				TH	21538.47	7	15	9999

Conversion cost doesn't depend on y_{it}. It is the constant value:

$$g_{i,t}(y_{i,j,t}) = f_i^{t-1} \cdot G_i \tag{34}$$

For all examples $G = 100$; for $y_{ij,t} \neq 0$ and $i = 1, 2, 3$. In numerical examples from Table 2 the joint set-up cost: $p_t(z_{,t}) = 0$.

For all these cost functions:

$$c_{i,t}(0) = h_{i,t}(0) = g_{i,t}(0) = p_t(0) = 0 \tag{35}$$

In our tables of results for each test-example the total number of capacity points is denoted. Because of (18) the possible number of sub-problems (CES) is well-known, that is the measure of the complexity of the CEPS-problem. Also, for each test-example in the tables we gave the number of acceptable sub-problems, satisfying basic and additional properties of optimal flow. Savings in percent, shown in the last column, is value of algorithm efficiency in comparison with previous algorithm option, proportionally reflected on computation time.

In real application we normally apply definite granularity of capacity state values. For traffic demand values R_i we put only discrete values (only integer). It reduces the number of the capacity points significantly. Because of that the minimal step of capacity change (*step_I*$_i$) has strong influence on the algorithm complexity.

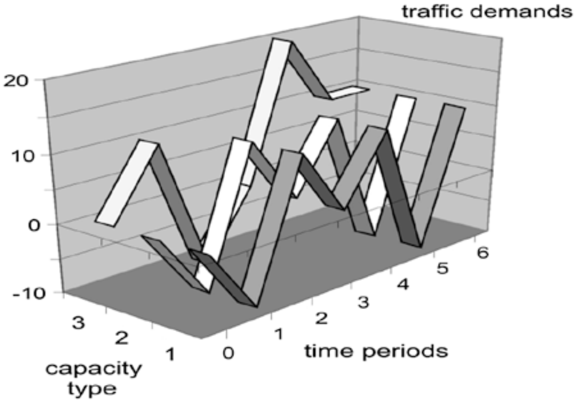
However, in real situation we cannot accept Basic_A option because the existence of negative capacity value for more than one capacity type per capacity point (one period) can block the whole system (traffic congestion). So we have to introduce some limitations on the capacity state values, talking about algorithm options:

(a) Only one negative capacity value in the capacity point. Such option is denoted with M_H (Minimal-shortage Heuristic option);
(b) Total sum of the link capacity values (for all quality levels) is positive A_H (Acceptable Heuristic option);
c) Total sum is positive and only one value can be negative. Such option is denoted with R_H (*Real Heuristic option*);
(d) Algorithm option that allows only non-negative capacity state values is denoted with P_H (*Positive Heuristic option*);
(e) Only null capacity values are allowed. A trivial heuristic option (denoted with T_H) allows only zero values in capacity point (only one capacity point).

3.6 An Example and Discussion

We compared the efficiency of algorithm in above mentioned options. We made many similar numerical test-examples for N = 3 and T = 6 and some results are in Table 3. On the Fig. 6 we can see traffic demand in the form of traffic increments for each time period and for each of three capacity types. One of test examples is shown in graphical form on Fig. 7. Results are given in Table 2. The best

Fig. 6 Traffic demands



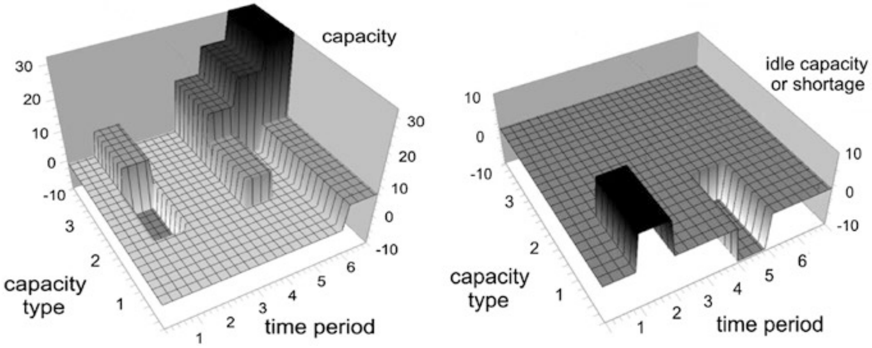


Fig. 7 The best expansion sequence is on the *left side*. On the *right side* we can see the lack of capacity in period 4–5

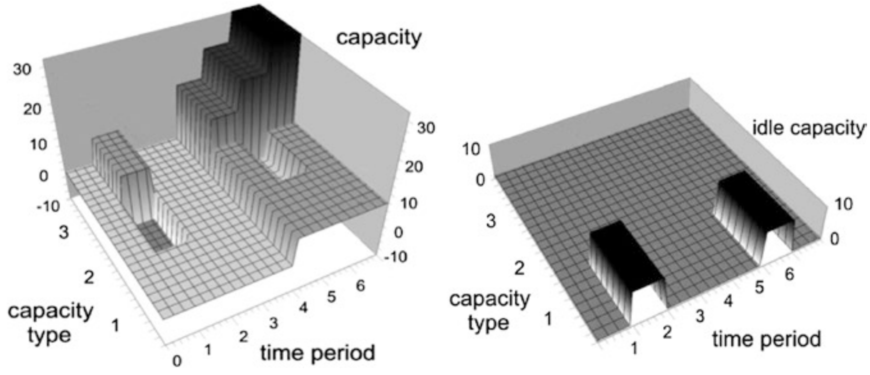


Fig. 8 The near-optimal result gained by heuristic option of much lover complexity. On the *right side* we can see that lack of capacity doesn't exist

expansion sequence is achieved with M_H algorithm option, too. On right part of Fig. 7 we can see the capacity surplus (idle capacity) between periods 1 and 2, and shortage exists between periods 4 and 5 with amount of −10 for the second capacity type. Further decrease of complexity (near 20 %) is occurred.

After that we made comparison with other algorithm options. With A_H and R_H algorithm options we got very good (close to optimal) results; see Fig. 8. In that case shortages don't exist. The complexity is significantly decreasing, but small deterioration of result exists (<10 %) The results of T_H are much further from optimum and it is unacceptable for real application.

The average value (trends) of the best result (the minimal cost) and algorithm complexity we can see on the same diagram from Fig. 9. Only for few test-examples the best expansion sequence (the minimal cost) can be found no matter of algorithm option we use. For the most test-examples the algorithm option M_H can obtain the best result with average complexity savings more than 75 %. For other algorithm options the reduction of complexity is obvious, but significant deterioration of result appears. Only for some test-examples of them the final results are still in acceptable limits. In the most cases the trivial algorithm option (T_H) shows the significant deterioration and it is not acceptable for real use. A good fact for all algorithm options is that efficiency rises with increase of value N; see Fig. 10.

Today network provider (NP) needs an efficient resource management tool for better utilization of capacities. Continuous increase of traffic makes NP to introduce more capacity on the transport line. It has to be done in optimal way through a finite planning period, consisting of number of intervals. That problem is in firm correlation with resource allocation and dimensioning strategy. Inappropriate capacity (lack) could result in traffic congestion possibilities.

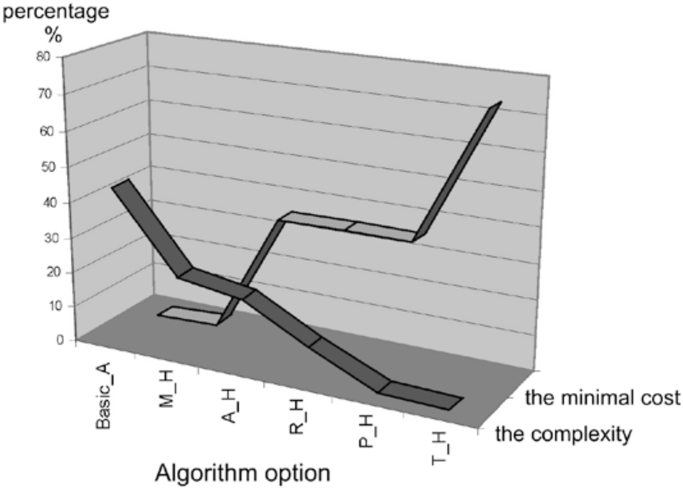


Fig. 9 Trends of algorithm complexity and result deterioration. Values are given in perc. (%) respectively to referent algorithm

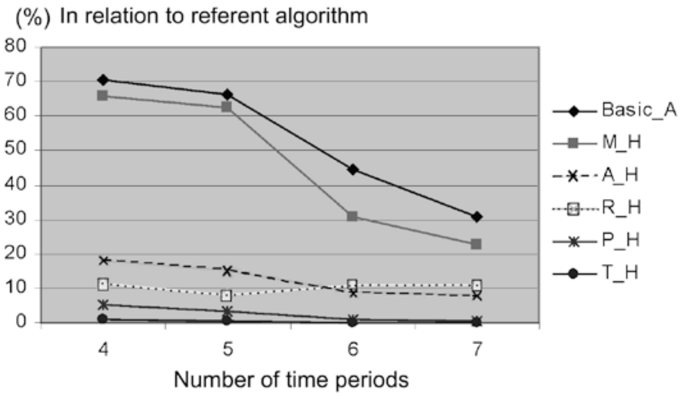


Fig. 10 The complexity savings increase with value T

On the other hand, too much capacity (idle) can cause huge expenses. In the case that different capacity types are in firm correlation it can increase the complexity of the optimization process very much.

In this section such CEP algorithm for multiple capacity type (commodity) allocation on transport line with mutual traffic correlation is discussed. The network optimization is applied instead of well-known polynomial programming technique because the problem recognizes only discrete capacity state values. In this section the algorithm for three capacity types is tested, representing the method of CEP algorithm development for M different capacity types. In the most of cases the algorithm option M_H can find the best expansion sequence (minimal cost) but with reasonable algorithm complexity.

At the same time it can ensure fulfillment of traffic demands with minimal exploitation loss caused by lack of capacity. From further testing results it is obvious that some algorithm options (heuristics) are very effective, too, with acceptable deterioration of result. They can be efficiently applied to short-term or medium-term line dimensioning for finite number of time periods.

4 Dimensioning of Transport Line with Many Points of Load/Discharge

One of the most important problems in transportation is to find the sequence of distribution between multiple sources and multiple destinations (stops), minimizing the transportation cost and better utilization of the line capacity.

Amounts of different passenger/load contingents are in firm correlation because the total capacity of transport mean (ship, airplane, train etc.) is limited, see [17]. Taking into account traffic demands for each starting port and each destination, with sufficient amount of passenger/load waiting to be transported, we need optimal transportation plan to minimize shipping and loading/unloading expenses, transportation cost and other cost (e.g. airport costs connected with expenses at airport and loading process). It can help in definition of optimal line capacity arrangement or to evaluate the route efficiency. The problem of optimal transportation from multiple (several) ports of loading (sources) to multiple destinations (sinks) is very hard (NP-hard) optimization (combinatorial) problem.

4.1 Previous Research and References

The most important issues to enhance the airline operation efficiency are flight routing and fleet scheduling. Generalized approach to multi-commodity transportation problem we can find in the early paper of Wollmer [18]. Wollmer find out that capacity of the air corridors are virtually unlimited; however the number of flight assignments would be constrained by number of planes, pilots, same as with upper bound of seats for defined airplane type (capacity).

Many network flow techniques and models exist to solve the complex mathematical problem in flight routing. Model for fleet routes is based on the multiple commodity network flow problem (MCNFP) introduce in paper of Yan and Tseng [19].

Allocation of the expenses and revenue are the basic things that must be considered to evaluate the route profitability. Some costs can be caused directly and some indirectly, see Chang and Schonfeld [20]. In fleet routing and multi-stop flight scheduling the crucial elements are the setting the available airplanes, the airport slots, the airplane rental charges, airport service cost (quota), fuel consumption, maintenance cost and other cost elements, which lead to the minimization of all expenses and maximization of the company's profit (Yan and Young [21]).

Short-term flight scheduling model is developed and applied to Taiwan airlines. Such model is defined as a non-linear integer program that is known as NP-hard problem. Non linear problem is more difficult to solve than the traditional flight scheduling problem that is defined as integer linear program. The heuristic methods and algorithms can improve such approach significantly [22].

Another group articles are concerned by vehicle routing problems. In the paper of Garaix et al. [23] the optimization of routing vehicles in freight or passenger transport is presented. During this representation for vehicle routing problem the fixed sequence arc selection problem is raised (FSASP). They proposed a dynamic programming solution method (ODT) for solving that problem. In the article written by Stojković et al. [24] DAYOPS model is presented. Every arc presents each flight leg which means a distance between departure and arrival. Model can be used to re-optimize the route schedule at the high level and at the lower level, see Givoni and Rietveld [25].

Maintenance costs include engine repair, consumption parts for airplane, technical support, technical documentation, maintenance staff, and other maintenance costs [26].

Airport service costs include landing cost and handling cost for airplane, passengers, luggage and freight transportation. Each airport determines the cost for using the airport for landing and handling their airplanes [27].

4.2 Mathematical Model

Different loads/passenger contingents are differentiated with i for $i = 1, 2, \ldots, N$. The plane with defined capacity is shipping from the first to the last airport marked with $M + 1$, with possible set of intermediate ports marked with K. The objective is to find a loading and transportation strategy that minimizes the total cost incurred over the whole voyage route consisting of M airports on the path ($M \leq K$). We need the loading plan for various passenger contingents in each airport to serve N passenger loads from loading airport to destinations (landing point).

The transportation technique explained above can be seen as the capacity expansion problem (CEP), see [15]. Transmission portions of the airplane space are capable to serve N different passenger loads (multi-commodity) for $i = 1, 2, \ldots, N$. For each passenger load we need a part of airplane capacity, so it looks like capacity expansion problem.

New capacity portion on the board of aircraft can be assigned to appropriate passenger load up to the given limit (maximal capacity), see [28, 29]. Used capacity can be dimensioned in two forms: by expansion or by reduction. Expansions/reductions can be done separately for each passenger contingent (load). Figure 11

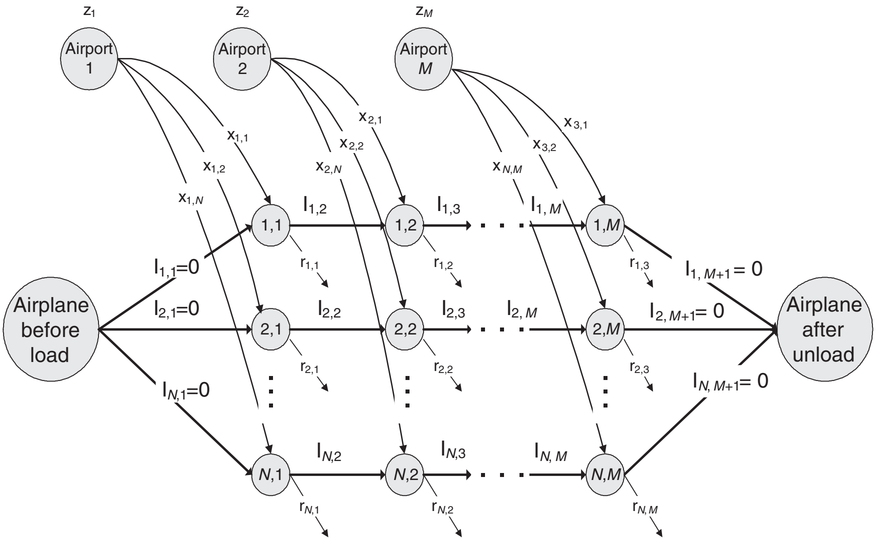


Fig. 11 Transportation problem in airline transport can be represented by a flow diagram of oriented acyclic network

gives an example of network flow representation for multiple contingents (*N*) and *M* airports on the route. So the transportation problem can be represented by a flow diagram of oriented acyclic network.

Let $G(V, E)$ denote a network topology, where *V* is the set of vertices/nodes, representing capacity states on the board and *A*, the set of arcs (links) representing traffic changes (loading/unloading, transportation, airport services etc.) between airports. Each link on the route (path) is characterized by *z*-dimensional link weight vector, consisting of *z*-non negative weights. In general we have multi-constrained problem (MCP) with multi-dimensional link weight vectors for $M + 1$ links on the path $\{w_{i,m}, m \in A,\ i = 1, \ldots, N\}$. The constraints for capacity bounds are denoted with $L_{i,m}(L_{1,m}L_{2,m}, \ldots L_{N,m})$. For an additive measure (load of passengers) definition of the constrained problem is to find a path from the starting to the end airport with minimal weight to satisfy maximal traffic load. It is equivalent with minimal cost that is the function of all expenses. Shorter distance gives lower weight. Also, the weight of each link corresponds to the amount of used capacity. As it is an additive measure more people on board cause lower transportation cost of one passenger. The objective is to find the optimal routing policy that minimizes the total cost with maximal passenger load on the path. In the context of MCP we can introduce easily the adding constraints e.g. max. length of the route.

In that CEP model the following notation is used:

i, *j* and $k =$ indices for passenger load. The *N* facilities are not ranked, just present different types of passenger contingents from 1, 2, …, *N*.

$m =$ indices the airport of boarding and landing. The number of air of calls on the route including departure airport *M* ($m = 1, \ldots, M$).

$x_{i,m} =$ quantity of *i*th load of passenger amounts being loaded on board in airport *m*

$r_{i,m} =$ unloading of passenger *i*th contingent in airport *m*. For convenience, the $r_{i,m}$ is assumed to be integer.

$I_{i,m} =$ the total amount of passengers transported from port *m* to $m + 1$. The amount of passenger load *i* at departure from airport *m* is equivalent to arrival at airport $m + 1$. Before the first airport of loading, $I_{i,1} = 0$. After last airport $I_{i,M+1} = 0$ for $i = 1, \ldots, N$.

$$I_m = \sum_{mi=1}^{N} x_{i,m} - r_{i,m} \tag{36}$$

for $i = 1, \ldots, N;\ m = 1, \ldots, M$.

Capacity values cannot be negative.

$L_{i,m} =$ maximal amount of contingent *i* to be boarded on airport *m*.
$z_m =$ the total amount of all passengers related to airport taxes.

$$z_m \le I_m \tag{37}$$

$lon_m =$ maximal length of the each hop, not to exceed the length of the whole route *LON*.

4.3 Algorithm Development

Instead of a non-linear convex (polynomial) optimization, that can be very complicated and time-consuming, the network optimization methodology is efficiently applied. The main reason on such approach is the possibility of discrete capacity values for limited number of contingent loads, so the optimization process can be significantly improved. The multi-constrained routing can be formulated as Minimum Cost Multi-Commodity Flow Problem (MCMCF). Such problem (NP-complete) can be easily represented by multi-commodity the single (common) source multiple destination network.

Definition of the single-constrained problem is to find a path P from starting to end airport such that:

$$w(P) = \min \sum_{m=1}^{M+1} \sum_{i=1}^{N} w_{i,m}\left(I_{i,m}, x_{i,m}, r_{i,m}\right) \tag{38}$$

where

$$I_{i,m} \leq L_{i,m} \tag{39}$$

satisfying condition: max. distance of

$$P = \sum_{m_1}^{m_2} lon_i \leq LON \tag{40}$$

A path obeying the above conditions is said to be feasible. Note that there may be multiple feasible paths between starting and ending airport (node).

Generalizing the concept of the capacity states after loading/unloading each passenger contingent (load) m between airports on the route we define as *a capacity point*—α_m.

$$\alpha_m = \left(I_{1,m}, I_{2,m}, \ldots, I_{N,m}\right) \tag{41}$$

$$\alpha_1 = \alpha_{M+1} = (0, 0, \ldots, 0) \tag{42}$$

In formula (41) α_m denotes the vector of capacities $I_{i,m}$ for each load i and for each airport m, and we call it capacity point. On the flow diagrams (Fig. 11) each column represents a capacity point of the node, consisting of N capacity state values (for ith passenger load).

Let Cm be the number of capacity point values at airport m (passenger load values for each contingent after departure from airport); see Fig. 12. Only one capacity point is for starting and for end airport on the route: $C_1 = C_{M+1} = 1$. The total number of capacity points is:

$$C_p = \sum_{m=1}^{M+1} C_m \tag{43}$$

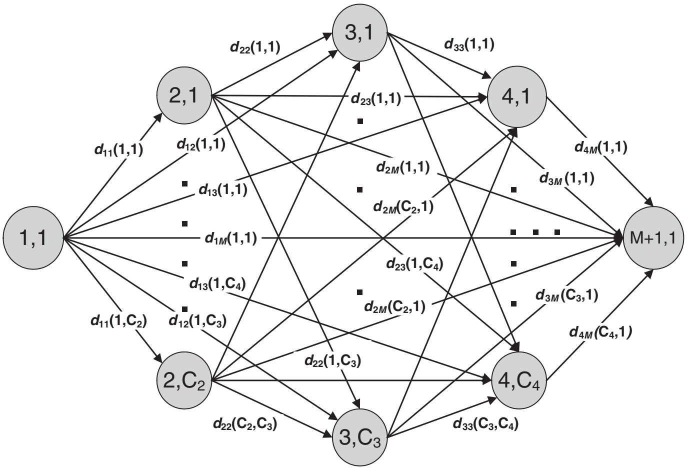


Fig. 12 The shortest path problem for an acyclic network in which the nodes represent all possible capacity points

Horizontal links (branches) are representing capacity flows between two neighbor airports on the route.

Formula (43) implies that zero values are before loading on the starting point same as after unloading on the ending point.

The objective function for CEP problem can be formulated as follows:

$$\max\left(\sum_{m=1}^{M+1} f_m(I_m) - \left\{\sum_{i=1}^{N} c_{i,m}\left(x_{i,m} - r_{i,m}\right)\right\} - h_m\left(I_{\max} - \sum_{i=1}^{N} I_{i,m}\right) - g_m(z_m)\right) \tag{44}$$

so that we have:

$$I_{i,m+1} = I_{i,m} + x_{i,m} - r_{i,m} \tag{45}$$

$$I_{i,1} = I_{i,M+1} = 0 \tag{46}$$

for $m = 1, 2, \ldots, M+1;\ i = 1, 2, \ldots, N;\ j = i+1, \ldots, N.$

In the objective function the total cost (weight) includes some different costs. As we want to incorporate minimization of expenses with profit calculation in the same optimization process than we have to introduce freight cost (passenger tickets). In that case all expenses have to have negative polarity; see (46). Freight cost (passenger tickets) is denoted with $f_{i,m}\left(I_{i,m}\right)$. We have to differentiate freight cost for each passenger load (contingent). It means that profit will be reduced by transportation costs.

Transportation cost is denoted with $c_{i,m}\left(x_{i,m} - r_{i,m}\right)$. The idle capacity cost $h_{i,m}\left(I_{\max} - I_{i,m}\right)$ could be taken in account, but only as a penalty cost to force the usage of maximal capacity (prevention of unused/idle capacity). The airport taxes cost $g_m(z_m)$ has to be introduced, too. With that cost we can include all airport expenses. Costs are often represented by the fix-charge cost or with constant value. It should be assumed that all cost of functions is concave and non-decreasing (some of them reflecting economies of scale) and they differ from one airport to another. The objective function is necessarily non-linear cost. With different cost parameters the optimization process could be strongly influenced, looking for benefits of the most appropriate transportation solution. Generally, the objective function is the exponential cost showing the economy of scale.

Instead of maximization of the profit we can use minimization of negative value, so we have simplification of very complicated minimax transportation problem. The network optimization can be divided in two steps. At first step the minimal transportation weights du, v is calculated between all pairs of capacity points (neighbor airports on the route). The calculation of each weight value between any couple of capacity points has been named: capacity expansion sub-problem (CES). At second step we search for the shortest path in the network with former calculated weights between node pairs (capacity points). It is well known shortest path problem for an acyclic network in which the nodes represent all possible values of capacity points; see Fig. 12. Then Dijkstra's algorithm or any similar algorithm can be applied, see [30].

In our optimization process number of passengers on board do not influence on voyage speed neither to oil (gasoline) consumption but it could be easily incorporated.

The loading strategy consists of loading/unloading plan for each airport and for each passenger contingent. The starting airport on the route can be only for loading and the last airport on the route can be only for unloading; other airports on the route may be for both. Some source airports can have limitation on passenger capacity, but most of them are main airports with capacity exceeding the plane's earning capacity (than capacity of airplane).

4.4 Testing Results and Discussion

In route definition we have starting airport (1) and ending airport (5), but three middle airports can also be included in the route, see Fig. 13. In Fig. 14 we can see traffic demands (possible transfer of passengers). That information is gathered through market research or from statistics. This graph also provides the percentage of the potential passengers for particular destination in reference to total airplane capacity. In input data of seven traffic demands it is obvious that most passengers are interested in the transfer from 1–4 airport and from 2–5 airport (40 %).

According to all costs and the price determination (tickets, oil consumption, etc.) we can design the route which will be more profitable. On the Figs. 15 and 16 we have an optimal route definition (loading and unloading amounts for particular airport). Amounts are given in percentage of airplane capacity. In our test-example

Fig. 13 Airports and distances (an example)

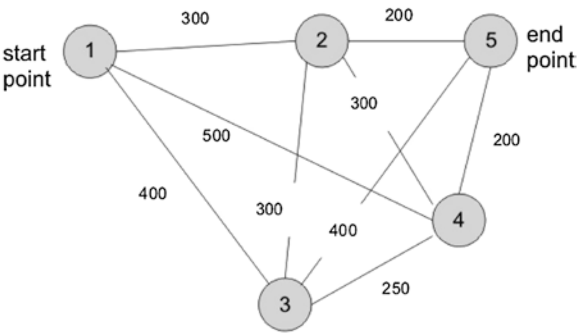


Fig. 14 Potential transfer of passengers between airports given in percentage of the airplane capacity

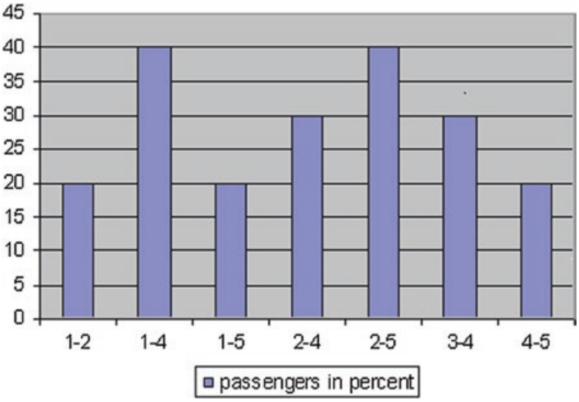
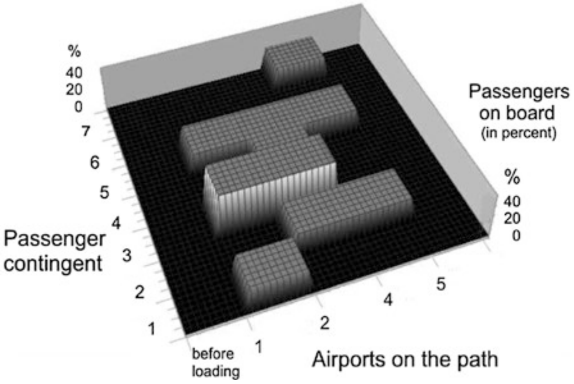


Fig. 15 Optimal solution given by loading and unloading amounts in each airport on the route



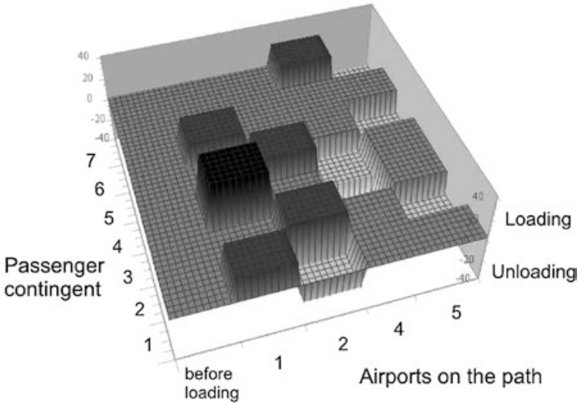


Fig. 16 Airplane's occupancy on the route with particular passenger contingent

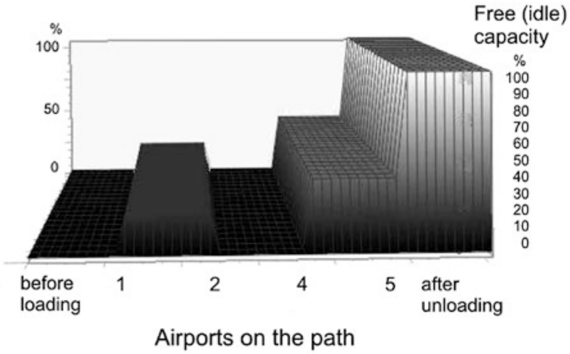


Fig. 17 Free capacity of the airplane on the route

the optimal route will be from airport 1 to airport 2, to airport 4 and finally to airport 5, excluding airport 3.

The optimization solution extracts the airport 3 because it is not profitable to go away from the path (long distance). Figure 17 represents the idle capacity of the airplane during the voyage.

We can see that only from airport 2 to airport 3 we have free capacity (20 %) and from airport 4 to airport 5 (40 %). For this example all prices for tickets/km are equal but it can be differentiated.

The transportation problem is extended to capacity management problem of different passenger contingents transported by one airplane on the route with multiple loadings points (boarding) and multiple unloading points (landing destinations)—multi stop routes. The proposed algorithm shows ability to solve very complex transportation problem. This approach consisting of successive iterations decreases complexity to acceptable level. In the same time it ensures to shipping companies very fine modulation of many input values, leading optimization process in wanted direction.

With optimizing their routes companies can ensure a significant savings and be profitable by following the demand and easily adapt to its changes. Such optimization tool can help in sizing of appropriate airplane, too. So with the smaller planes sometimes company can transport the lower number of passenger if the demand for that particular returning flight is not so high. With such optimization technique we can check the efficiency in opposite direction of the route (5 to 1). With comparing the data from both directions we can find the most appropriate and efficient route. Another one possibility in route definition is the change of starting or ending airport.

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Part II
ITS Case Studies

Design of an ITS for Industrial Enterprises

Alexandr Rakhmangulov, Aleksander Sładkowski and Nikita Osintsev

Abstract One of the factors limiting the increase in quality of traffic with the increasing complexity of the freight traffic in Russia is the lack of interaction consistency of the main modes of transport and transport uncommon in areas of direct transport service production and transport units. Lack of practical operating experience of intelligent transport systems in Russian enterprises, poor prevalence of well-known methods of accumulation and analysis of knowledge in transport, decision-making (genetic algorithms, neural networks, knowledge bases, Big Data methods, etc.) require improvement of the existing interaction methodology between industry and transport, in particular transport and technological systems providing direct cargo transport services. This methodology should be based not only on modern progress in technology and organization of rail transport, but also taken into account the economic and informational factors and constraints that arise in the interaction of industrial and mainline rail. This article proposes an approach to the formation and composition of intelligent transport systems in industry. This approach is based on the original combination of analytical and simulation models of transport and technological system realizing the complex of transport and logistic methods of functioning organization of rail transport and technological systems. Intelligent transport system of proposed functional composition is focused on improving the efficiency of interaction between production and transport in terms of complicating the structure of freight traffic and the increasing quality requirements for freight.

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1 Introduction

Nowadays the development of the competitive environment in the field of freight rail transportation in Russia is carried out on the basis of railcar parks transferring to property of operator companies. The clients increasing numbers of transport, reduction of the average transportations volume falling per one client, decreasing demand regularity of transportations is the main objective reasons for complication of transport streams structure [1, 2].

The analysis showed that private railcars in the beginning of 2012 have almost increased to 100 % (Fig. 1a), while the park structure of wagons type practically has not changed. Despite the increase in the total number of load railcars (Fig. 1b), the traffic volume on the mainline railway transport has almost not increased (Fig. 1c), but the turnover value increasing are observed (Fig. 1d).

This demonstrates the irrational using of railcar park by operator companies due to the establishment of their restrictions on the railcar using of other operator companies. As a result their empty runs are growing, railcars turn time have increase, capacity reserves and capacity of railway stations and stages this leads to even further increase the railcar idle time, demand increasing for new rolling stock (Fig. 2) [3]. As a result of noted phenomena the speed and timeliness of cargo delivery have decrease, the service cost of the operator companies are increasing. Insufficient, in such conditions, the actions coordination of the rolling

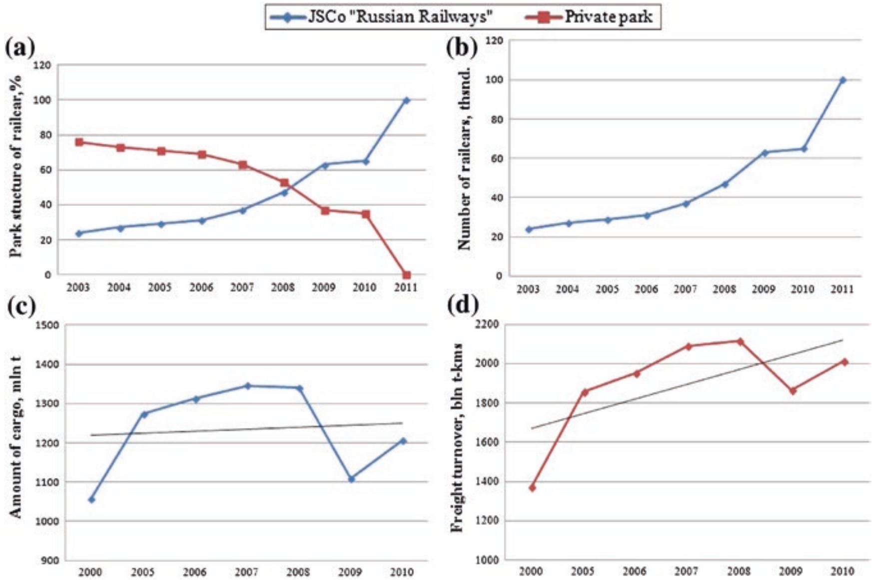

Fig. 1 **a** Dynamics of park structure of freight wagons for the period 2003–2011, %; **b** Dynamics of load railcars park, thsnd.; **c** Dynamics of transportations volume on the mainline railway transport, mln. t; **d** Dynamics of mainline railway transport turnover, bln. t-km

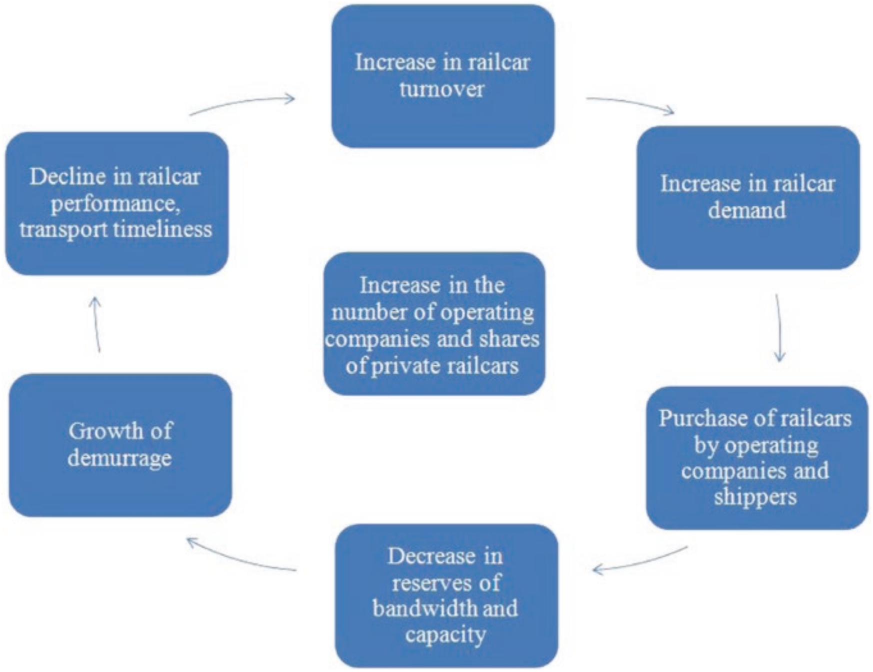

Fig. 2 Principal causes of timeliness decreasing of freight railway transportation

stock company owners of the regulation by own railcar parks on a railway network are one of the reasons of irrational usage of throughput and process abilities of railway stations and stages, led to decrease the freight traffic timeliness indicators.

Considerable losses in the circumstances have grown in interaction places of the main and industrial railway transportation [2, 4–6]. As a research result of the emergence reasons of the established delays in the admission and processing of railcar flows at the special railway tracks was made the group and reasons systematization of these delays and corresponding technological consequences (Table 1) [7].

Total annual losses from such delays for special railway tracks including some technological stations and processing 2–3 thousand railcars per day, make 70–80 million rubles per year or more than 20 % of the general expenses connected with a railcars turning.

Reason details and technological impact of delays in the processing of railcar flows at the special railway tracks of large metallurgical enterprises numbers revealed the following influencing the effectiveness of the control objects:

1. The railcar flow movements of routes. The railcar flow movement on routes, including the industrial railway stations with low amount of reserve capacity, increases the down time (37 % loss of railcar idle);
2. The incoming railcar flows of empty railcars, which didn't have freight operations at the special railway tracks. These losses are occurring when large

Table 1 Causes and technological consequences of delays in the railcar flows processing on special railway track

No.	The main causes of delays in the railcar flow processing	Technological implications	Control object
1	The action divergence of the shunting managers	The railcars movement on inefficient routes	The railcar flow routes on special railway tracks
2	The lacking control of empty rail cars using at the special railway tracks	The routes existence of empty railcars movement without loading operations at the special railway tracks	Empty railcars
3	The lacking control of railcar flow parameters	High irregularity parameters of railcar flows and level using of the throughput and overworking abilities of technological railway stations	Railcar flows
4	The coordination lacking between railway transport of enterprise and OJSC "RZD" by the railcar flows management on the polygon contiguity	The excess dead time of railcars at the OJSC "RZD" junction station on the emergence requirement waiting of railcars in main production	The railcar flows on the range interaction between industrial and mainline transport

volumes of lacking traffic and lacking control of the empty railcars routes advancing (7 % loss);

3. The railcar flows characterized by significant irregularity of the power and value of the railcars idle time at the special railway tracks. The management of such "non-standard" railcar flows requires adjustment decisions in the case of insufficient information and ensures consistency in managing work. This leads to a further increase of the variance parameters such threads from normal (routine) values and, ultimately, to fluctuations in the value of reserves bandwidth and processing capacity of industrial plants and delays in the railcar flow promotion (20 % loss);
4. The railcar flows on the ground junction of the special railway tracks to the mainline rail transport. The disagreement graph supplying of railcars and goods to company with actual demand are causes delays of individual jets railcar flows at technical service stations of polygon, junction station or at industrial railway stations (36 % loss).

As shown by the cause analysis of excess railcars downtime at the special railway tracks, the main cause is management actions misalignment of railcar flows on different special railway tracks (stations) and polygon contiguity to the network of mainline railway transport.

The effective form of interaction organization of the mainline and industrial railway transport are transport technological system (TTS) which are based on the systematic implementation of the multi-level control functions of the transportation process, including: the technical operation of vehicles and devices; regulation of technological processes at the level of individual cargo fronts, industrial railway stations and shunting areas; railcars flow organization at the special railway tracks; the interaction of long-distance transport on the polygon contiguity; infrastructure development TTS at the regional and national levels. The levels selection of TTS based on the grouping management functions of transportation process, as well as on the value risk evaluation associated with the irrational choice of management decisions on some level [2, 6].

A variety of control functions by the operation of the TTS on different levels, the inconsistency of the criteria for the optimal solutions selection, the necessity for processing big amount of data makes the actual task of the rational justification of the composition and structure of intelligent transport systems as part of the information system TTS.

Researches in the application field of various mathematical methods and models for planning and organization of the transport process, executed in the period from the 1960s prior to 1990s. [8–11] allowed to form the theoretical framework for traffic management in integrated transport systems [12, 13].

Currently, research works are active, dedicated to improving and practical using of the formations methods and functioning of integrated (intelligent) transport system [4, 14–16].

However, the modern stage development of intelligent systems in transport is characterized by the orientation staff (in accordance with the planned scheme) or operational emergency (by selecting from a variety of options planned schemes) traffic flow management [17–19]. This functional and physical architecture of modern intelligent transport systems insufficient are support decision making in emergency situations (situation management), not provided by the planned schemes. Another significant drawback of modern intelligent transport systems transport is the functions and tasks fragmentation, the systematic management lacking of transportation process at different organizational levels.

In these conditions it is required to improve existing approaches to the formation of intelligent transport systems, particularly, on the industrial railway transport, based on a systematic consideration of the various functions t of transportation process management.

2 Logistics Performance of the Transport Management System

In the formulation development process software intelligent transportation systems of industrial enterprises the following tasks were solved:

- systematic parameters of the material, financial and information flows in the TTS identified managed parameters;
- the complex methods management TTS are developed;
- the optimization criteria for each method are defined and optimization models are developed;

- the integral criterion of optimization parameters TTS are justified and generalized mathematical optimization model are developed;
- the analytical and simulation model TTS proposed to use as the basis for the formation of intelligent transport systems of industrial enterprises are developed.

Dynamics analysis of the main indicators of railway transport in Magnitogorsk, Chelyabinsk, Lipetsk, Novotroitsk, Asha, Beloretsk transport nodes, executed in the period from 1996 to 2012, helped to identify and organize the internal and external environment of railway transport technological systems, having a significant influence on the efficiency of interaction between different transport modes and production (Table 2).

Table 2 Supporting elements of the transport and logistics system

Logistics element	Supporting functions of logistics element
Input	Research of the supply marketplace Flows requirement identification Delivering methods identification Supplies costs analysis Supplies quality analysis Supply planning Supply controlling Parameters correction (quality) flows or flow requirements
Output	Marketing researching of sales area Market requirement determining in LS products Selection and formation of channels and product LS distribution Pricing Flow services formation Deliveries and services traffic planning Parameters of supplies and services controlling Supply parameters adjustment, services flow or internal LS flows, taking into account changes in the sales area
Reprocessing	Promising and production planning The organization of the coordinated functioning of all divisions of the overworking element on the basis of the uniform technological schedule of their work Operational control over compliance with the parameters of the production schedule, quality control, production and operational control of production processes Personnel management Improvement of technical and technological support Spoilage elimination Production cost reduction
Accumulative	Inventory level optimization (level storage costs) Operational control of inventory levels, settings, incoming and outgoing material flow, i.e., the control parameters of an inventory management system Material flows management, their distribution in ls Improvement of technical and technological support of material flow process Defects elimination in the material flow processing
Traffic	Selection of the optimal material flow scheme transportation in logistic system The choice of the system of promotion material flows Operational management of the material flow parameters Technical support improvement of the transportation process

This view TTS allows you to apply universal logistics methods for optimization and control of parameters of transport and logistics flows.

As the basis of TTS parameters systematization was used representation of this system as transport and logistics. It includes five structural elements (Fig. 3): input, output, storage, transport and processing. Transport and logistics flows as follows as: material flow—cargo, railcar and train flow; the services flow is formalized describes the bandwidth and capacity of the transport device used to promote material flow, as well as the entire infrastructure TTS necessary for flow processing; the information flow, the data flow on the change of parameters of elements of TTS and all logistics flows; financial-economic flow—the data flow about costs arising in the functioning process and development of the railway TTS.

Selected logistic approach allowed us to group management functions of logistics flows (Table 3) by the levels of organization TTS. The levels allocations it was made on the basis of risk assessment of non-performance of the TTS functions and the losses resulting from it from untimely transportations [2].

The technical level related with control TTS functions, ensuring the achievement of the parameters of the transport and logistics flows defined in the higher organization levels. These features are characteristic for engine repairs, carrying out technical maintenance of the transportation process, as well as areas of direct interaction between different modes of transport and service production on the loading area or terminal.

Technological level are related with control functions TTS, providing change of parameters of the transport process to reduce transportation and warehousing (logistics) costs when traffic flows power are changing. These functions are implemented in the areas of transport service of several loading areas (freight or industrial railway station) or more technologically or geographically related industries.

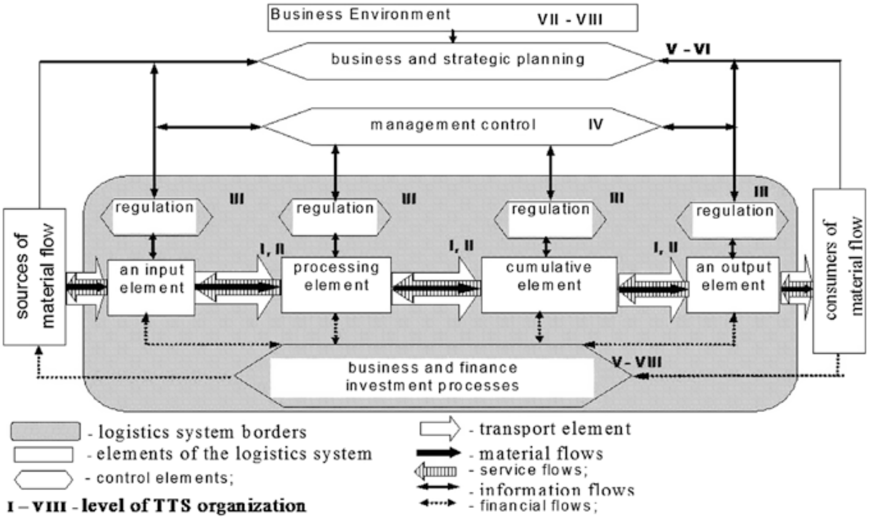

Fig. 3 Representation of railway industrial TTS as transport and logistics system

Table 3 Levels of functioning organization of industrial railway transport-technological systems

Designation level	Name level	Level functions	Basic level of transport and logistics system
I	Technical support of the transportation process	Transportation process providing by technically serviceable vehicles, devices, cargo handling machines and devices	Technical
II	Direct interaction of different modes of transport, transport and service production (loading area, terminal)	Transport service production accordingly with established applications, graphics	
III	Transport service of several loading areas (industrial railway station, freight station)	Structure and capacity changing of railcar flows, throughput, and capacity within the railway station borders	Technological
IV	Transport service of several technologically related industries of one company or several geographically close companies (railway section, dispatch circle)	Structure and capacity changing of railcar flows, throughput, and capacity within the railway station borders	
V	The special railway tracks of industrial enterprise or their combination accepted by PPJT	The transport organization changing within the special railway track borders, elaborate and implementation of the development strategy of the special railway tracks	Organizational
VI	Railway transport node	Organization transportations changing in borders of railway transport node, development and realization of development strategy of railway transport node	
VII	Regional transport technological system	Development of transport and logistics infrastructure in the region	Socio-economic
VIII	Macrologistic TTS	The development of transport and logistics country infrastructure	

At the organizational level are implemented function changes the organization of transportation and development strategy TTS. Organizational level related with the special railway tracks and with railway transport node.

On the socio-economic level functions are implemented in the development of transport and logistics infrastructure in the region or country, as well as monitoring the interaction of socio-economic factors and the development level of transport and logistics infrastructure. The socio-economic level of the TTS organization related with regional transport-technological system as a set of mainline railway system and industrial railway transport in the region, as well as macrologistic TTS, which represents an organized set of consignors, consignees and transport along of material logistics flows jets.

Presented in Table 3 levels of railway industrial TTS organization are used as the basis for the parameters systematization of the transport and logistics flows. This systematization is necessary to identify those parameters that, on the one hand, it is necessary for the effective functioning of the TTS on the logistics principles, and on the other, is not provided with the calculation of necessary methods, assessment and use in the organization and management of transportation process.

Complex of parameters and indicators for every transport and logistics stream at the levels of the TTS organization are determined (Table 4) [7], includes common parameters and indicators, first proposed to describe TTS: the complexity factor of freight traffic flow and railcar flows; the timeliness of transport services primary production and transport customer; railcar flow urgency factor.

The complexity factor of freight and railcar flows it is proposed to calculate, accordingly with the Pareto rule, as the ratio numbers of low-power jets, which account for no more than 20 % of the average daily traffic of powerful jets numbers, providing 80 % of the volume. The complexity factor have used for calculating the amount of operational management information in the messages, starting with the II organizational level of TTS, and in the effectiveness assessing of the organizational structure of operational management.

For timeliness indicators calculation of freight traffic transportation in TTS, the technique based on the deviations accounting of the actual moments of transport and cargo parties arrivals at the loading areas. Settlement formulas of timeliness indicators are presented in Table 5. Standard values in Table 5 are defined as a result of optimum parameters calculation of control stocks systems which describes functioning of the II organizational level of TTS.

For calculating the freight transportation timeliness in the TTS was developed a methodology, based on deviations controlling of the actual arrival moments of the transport shipments at loading areas. These deviations proposed to be assessed with urgency factor of railcar flows—K_c^t. Value of urgency factor in time moment t,generally, are defined as the given value at unit of difference value between the settlement (expected) moment of arrival transport and cargo party (its actual size) at the loading area and the requiring moment (the optimum size of transport and cargo party). The choice of calculation method K_c^t depends at the system inventory management [2].

Urgency factor for these railcar flows are determined by the formula

$$K_c^t = \frac{q_{\max} - \left(q^t - q_c\right)}{q} = 1 - \frac{q^t - q_c}{q_{\max}} \quad (1)$$

where $q_{\max}$ is maximum capacity (warehousing capacity); q^t—stock at the time t; q_c—safety stock.

Table 4 System parameters of transport and logistics flows through the organization levels of railway industrial transport-technological systems

Organization level of TTS	Material flow	Service flow	Information flow	Economic and financial flow
I—technical support of transportation process	Indicators of reliability of vehicles, facilities, cargo handling machines and devices	Good technical condition of vehicles, devices, loading and unloading freight cars and devices	Requests for repairs Schedule repairs	Costs of current repairs Depreciation
II—direct interaction of different modes of transport, transport and service production (loading area, terminal)	Railcar supply size Interval time between railcar supplies	Capacity (receptacle) of loading area (terminal) pac Processing capacity of the terminal	Requests for railcar and freight supplies Schedule maintenance for loading areas (main production workshops) The parameters of the systems inventory management—the size of the transport of consignments, the interval between railcar supplies, the maximum warehouses capacity	Warehousing costs Production costs (damages) Investment in the transport and storage infrastructure development
III—transport service of several loading areas (industrial railway station, freight station)	Priority service of loading areas Trains composition of (including the size and the railcars ordering) Intervals between trains departure	Capacity of receiving-and-departuring ways and parks Bandwidth capacity of railway station	Statistical characteristics of railcar flows at the station The complexity factor of railcar flows structure—value of railcar turnover at the station Formation plan of shipping routes	Re-formation costs of trains Transportation costs for the railcar supply and removing for loading areas The accumulation cost of trains The total costs associated with railcars dead time at the station

(continued)

Table 4 (continued)

Organization level of TTS	Material flow	Service flow	Information flow	Economic and financial flow
IV—transport service several technologically related industries one company or several geographically close companies (J.D. area dispatch circle)	The railcar flows distribution at the stations The train composition at the stations district Train traffic intervals between different shunting areas	Bandwidth and processing capacity of transport and storage infrastructure of shunting area The level of information load of employees of the operational traffic control	Indicators of timeliss of freight Diurnal regularity utilization of the bandwidth and processing capacity railway stations and the district spans Consolidation of the Heads of the transportation process for railway stations	Total transport and storage costs and losses
V—industrial railroads	The distribution of freight railcars fronts Composition of formed trains on the external network Intervals between gear trains	Capacity and processing ability of private usage ways The detail level of collected information and control system data, the depth of their processing and the degree of efficiency	"Contact" plant train timetable Intrafactory trains formation plan (selection by groups) Single process of interaction of industrial railroads with contiguity station Promotion of traffic volumes of industrial railroads Demurrage of railcars and statistical characteristics of railcar volumes	Costs associated with cars demurrage on the roads of private usage Investment costs for increased bandwidth and processing capacity of railway stations, and hauls freight fronts Overhead costs associated with managing the transportation process

(continued)

Table 4 (continued)

Organization level of TTS	Material flow	Service flow	Information flow	Economic and financial flow
VI—railway junction	The power and intensity of traffic volumes in the node The size of freight shipments	Capacity and processing ability transport and logistics infrastructure node	Companies applications for supply and cleaning of railcars and additional operations The timetable and structure of export and transfer of trains Routes traffic volumes in the node Coefficient of urgency of traffic volumes	Total transport and production costs in the node The cost of development to the central transport and storage infrastructure
VII—regional transport-technological system	The power and intensity of traffic volumes in the node The size of freight shipments	Regional infrastructural factors: the density of railway ways and roads, availability of transport corridors in the region; availability and the total processing ability of transport and logistics centers	Road train formation plan Train schedule Geography of the region belonging to climate zone Indicators of the region's transport (freight volumes, the volume of transport services per capita)	Total regional transport and manufacturing costs The cost of the development of regional transport and logistics and industrial infrastructure
VIII—macrologistical TTS	The power and intensity of traffic volumes in the node The size of freight shipments	Capacity and processing ability of objects of transport and logistics infrastructure multimodal and intermodal transport	Scheme of multimodal and intermodal transport Social and economic factors: population; per capita income; gross regional product; industrial production; volume of retail trade; imports and exports	The share of transport and logistics costs in the cost of production The cost of development of the national transport and logistics infrastructure

Table 5 System of timeliness indicators of freight transportation in TTS

Indicators/calculation formula
1. Freight transportation indicators for the specified date
1.1. Average deviation value of an freight arrival time from the appointed term $\overline{t_o} = \frac{\sum_{i=1}^{n} \lvert t_{i,\phi} - t_{i,H} \rvert}{n}$ 1.2. Average value exceeding the scheduled time of cargo arrival $\frac{\sum\limits_{i=1}^{n} \left(t_{i,\phi} - t_{i,H} \right)}{n}$ *with* $t_{i,\phi} > t_{i,H}$ 1.3. Maximum size of appointed term excising $\max \left(t_{i,\phi} - t_{i,H} \right)$ $i = 1, 2, \ldots, n$ 1.4. Average deviation of the cargoes arrival time from the assigned, percentage $\frac{\overline{t_o}}{t_{\max}} \times 100\,\%$ where n—cargo deliveries number (parties, railcars supply) during the reporting period; $t_{i,\phi}$—actual time of cargoes arrivals; $t_{i,H}$—scheduled time of cargo arrivals; $t_{\max}$—maximum allowable deviation of the cargoes time arrivals from the appointed date
2. Regularity indicators of the cargoes arrival
2.1. Intensity of cargo arrival $\frac{n}{T_o}$ 2.2. Minimum consignment for a time unit $\min(n_i),\ i = 1, 2, \ldots, T_o$ 2.3. Average time between the cargo proceeding $\frac{\sum\limits_{i=1}^{n-1} \left(t_{i+1,\phi} - t_{i,\phi} \right)}{n-1}$ 2.4. Maximum time between the cargo proceeding $\max \left(t_{i+1,\phi} - t_{i,\phi} \right),$ $i = 1, 2, \ldots, n-1$ 2.5. Minimal time of cargoes arrivals $\min \left(t_{i+1,\phi} - t_{i,\phi} \right),$ $i = 1, 2, \ldots, n-1$ 2.6. Deviation from the established regularity of cargoes receipt, percentage $\frac{\Pi_{\phi akm} - \Pi_{n\pi aH}}{\Pi_{n\pi aH}} \times 100\,\%$ 2.7. Cargoes arrivals percentage with setting (consistent) regularity $\frac{\sum_{i=1}^{n} n_i}{n} \times 100\,\%, \forall n_i,$ *if* $\Pi_{\phi akm,i} = \Pi_{n\pi aH}$ where T_o—duration of the reporting period (in shifts or hours depending on the adopted of accounting timeliness); n_i—cargoes number delivery (parties, railcars supply) during i-d interval time (days, shifts, hours); $\Pi_{n\pi aH}$—planned (set) values 2.1–2.4; $\Pi_{\phi akm}$—actual values of indicators 2.1–2.4. $\Pi_{\phi akm,i}$—actual values of indicators 2.1–2.4, which are calculated for the i time interval

(continued)

Table 5 (continued)

Indicators/calculation formula
3. Urgency indicators of freight transportation
3.1. Average time of freight transportation $\bar{t}_n = \frac{\sum_{i=1}^{n} t_i}{n}$
3.2. The maximum deviation from the average time of cargo shipping $\max\left(\bar{t}_n - t_i\right),\ i = 1, 2, \ldots, n$
3.3. The percentage of cargo arrivals in excising time $\frac{\sum_{i=1}^{n} \delta_i}{n} \times 100\,\%,$ $\delta_i = \begin{cases} 1, & if\ t_i > t_H; \\ 0, & if\ t_i \le t_H \end{cases}$
3.4. The average deviations from the reference time cargo shipping $\frac{\sum_{i=1}^{n} \lvert t_i - t_H \rvert}{n}$
3.5. Average speed of cargo shipping $\bar{v} = \frac{\sum_{i=1}^{n} \left(\frac{L_i}{t_i}\right)}{n}$
3.6. Value of vehicle daily mileage $\bar{v} \cdot \bar{t}_n$
3.7. The cargo arrivals percentage of the standard time $\frac{\sum_{i=1}^{n} \delta_i}{n} \times 100\,\%,$ $\delta_i = \begin{cases} 0, & if\ t_i > t_H; \\ 1, & if\ t_i \le t_H \end{cases}$
where t_i—transportation time of i shipment, day (hours); t_H—the normative time of cargo shipping, day (hours); L_i—distance of cargo transportation of i shipment, km

For cumulative elements TTS the calculation K_c^t by formula (1) can be made in case, for example, it is required to provide uniform process of railcars accumulation on a railway or in park of ways. For an inventory management system with a constant amount of transport-freight party is necessary to ensure a regular supply shipments of a certain size at given points in time. Calculation K_c^t in this case it is expedient to make by formula

$$\mathcal{K}_c^t = \frac{t_p}{t_m + (t_m - (t + t_\partial))} = \frac{1}{2 - \frac{(t + t_\partial)}{t_m}} = \left(2 - \frac{(t + t_\partial)}{t_m}\right)^{-1} \quad (2)$$

where t_m is required moment of the next batch flow arriving. Moment t_p are calculated as the reaching moment of the ordering point and projected on the basis of the current intensity of stock consumption in storage element; t_∂—time expenses of the next batch flow delivering to the cumulative element. This value will forecast (determine) with based on the current location of the next shipments and average speed of delivery.

For systems inventory control with “two control levels” are applied the formula (1), at condition of achievement of point value ordering.

If it's necessary to ensure urgent delivery, for example, perishable cargoes, the value of the urgency factor calculated by the formula (2) are multiplied by a coefficient of nonlinearity include losses arising from delays in the cargo party arrival.

Generally, coefficient of nonlinearity are calculated according with formula

$$\xi^t = \left(1 + \frac{C_n}{\mathcal{K}_c^t \cdot C_m}\right)^{-1} \tag{3}$$

where C_n is damages (losses) due of the cargo party arriving delay; C_m—transportation costs for party delivering (tariff).

Urgency factor are calculated by formulas (1)–(3) for every transport-freight party of one appointment through certain planning intervals. On the basis of the considered system parameters of transport and logistics flows was developed complex mathematical models, optimization, and management practices of TTS. These methods and models are encouraged to use as mathematical support of intelligent transportation systems of industrial enterprises.

3 Modelling of ITS Services

Requirements for maintenance of the transportation process and quality of freight transport are parameters of transport and logistics flows at lower organizational TTS levels. These requirements are adjusted for transport costs and have used for organization and management of transportation process on III–V organizational levels.

However, the conditions for the TTS functioning according with criterion of minimum total transport and storage costs are created only at the highest organizational levels, because only in the presence of sustained organizational, informational, financial and economic relations between elements TTS are possible implementation of the designed range of transportation logistics methods and models (Table 6).

For the optimal resources allocation at the technical level of the TTS organization with failures minimizing of technical equipment and devices are proposed to use a mathematical model [20], based on the idea of the directions priority of the resources in those elements of the system repairs, the resource consumption is minimal, and the failures number and cost of their removal—maximum. As soon as achieved the minimum of the objective function (growth failure have stopped) for the given reserves values, it navigates to the new restrictions at the resources usage. For this are changed the boundary conditions of the problem—setting the new quantity of repairing division reserves. Using of developed model [2] allows us to consistently improve the efficiency of maintenance units (TTS at the technical level of the organization) and to reduce the intensity of its work.

Local optimality criteria's for each level of the TTS organization have subordinated to the global optimum—minimum sharing of logistics costs in prime cost of the finished product, which is, generally, have provided to minimize the size of the transport-freight party. Famous methods of optimal size of the transport-freight

Table 6 Range of transportation logistics organization methods operation of railway industrial TTS

Organization TTS level	Methods operation	Optimization criterion and characterization method
I—technical support of transportation process (technical means and devices)	Optimal allocation of resources in the system repair in accordance with the requirements in proper technique	Minimum of hardware failures and devices growth
II—direct interaction of different transport modes, transport and servicing production (loading area)	Selection of the optimum size of freight consignment	Optimal batch size chosen by the minimum total transport and storage costs, depending on the type of inventory management system
III—transport servicing of loading areas (railway station)	Railcar distribution at railway transport nodes	The priority of the process steps defined by the minimum transportation costs, subject to the submission of applications for railcars
IV—transport servicing of several technologically related industries of one company or several geographically close companies (railway area)	Methods of "structural technologies" (optimization of the loading capacity and capacity of the transport device)	Minimum transport costs resulting from the operational alignment values of bandwidth and capacity of transport systems through the application of technological methods of "structural technologies»
V—railway transport nodes (industrial railway transport)	Optimization of routes traffic volumes	Minimum transport cost of promoting traffic volumes as a result of his passes for stations with a lower level of operational bandwidth usage
VI—railway transport unit	Optimization of the structure of traffic volumes	Minimum transport costs and loss of customers due to changes in transport rate of movement of certain groups of railcars by changing the composition formed in the transport unit trains
VII—regional TTS	Methods of enhancing of the capacity and processing ability of regional elements TTS	Minimum of total regional transport and manufacturing costs as a result of the consistent development of transport infrastructure in the region
VIII—macrologistical TTS	Methods for selecting the placement of elements of macrologistical TTS	Minimum share of logistics costs in production costs as a result of the deployment of rational macrologistical TTS

batch determining (level II organization TTS) not fully take into account the totality of the transport costs that occur at different levels of the organization TTS, as well as losses associated with a deviation from the required parameters supply. Currently in Russia, using approach of tariff setting for transport services does not take into account the additional costs necessary requirements compliance to supply the best parties, it causes by insufficient widespread in practice management inventory systems [1, 21]. It is offered to consider the level of the TTS organization at calculation of the optimum size of transport-freight party. On the lower levels of parameters regulation of the transport process is carried out in places of direct transport service production; therefore, despite the significant transportation costs, including the establishment and maintenance of reserves bandwidth and processing capacity, the quality of transport service is not sufficient.

Experiments with simulation model of Magnitogorsk railcar transport hub has shown that the expansion of the TTS boundaries and improving of it's of organization level, required quality of freight transportation can achieve with lower transport costs (Fig. 4). Obtained values T have proposed by using as coefficients for the value adjustment of transport costs in the calculation formulas of the optimal size of the transport-freight party. The probability Pk should be used in the calculation of standard indicators of cargo transportations quality index ($t_{\max}$ and T_o) at VI organization TTS level.

A mathematical model of optimization problem is optimization of railcars distribution, particularly empty, at loading areas [22], solved on III-d organization l TTS level, allows you to determine the optimal size of the railcar supply at loading areas of industrial enterprises with consideration: restrictions on the volume of railcars requirements; railcar type and railcar loading restrictions of different owners with special cargoes; transport costs (calculated the optimal route for every railcar group); wasting time for waiting railcars groups inclusion in the part of plant trains. The solution of this model is determined not only daily plan of railcars distribution at loading area, but the plan of plant train formation, cumulatively, ensuring downtime minimum of the railcars on the non-public tracks of industrial enterprises.

Technological ways of implementing so-called by "structural technologies" on railway transport (IV level of functioning TTS organization) are considered in details in the works of Prof. Trofimov [23]. These methods are based on the power redistribution between the elements of the railway transport system, consisting of two types

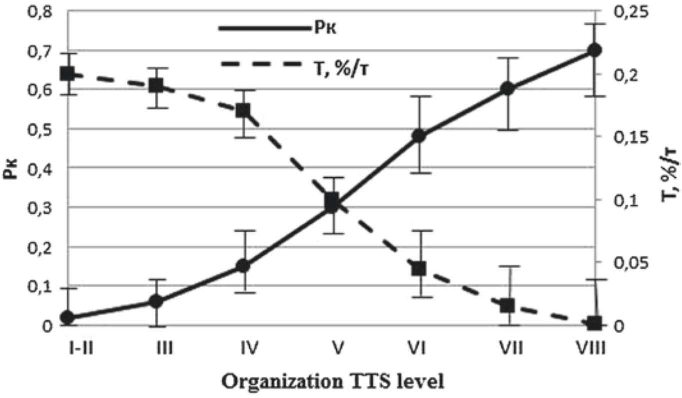

Fig. 4 The dependence of transport costs and freight transportation quality of the organizational TTS level. T—% specific tariff changing, %/ т ; P к —the accomplishment probability of setting values of the quality indicators freight transportations

elements—“bunkers” and “channels”. Bunker are displayed as warehouses, receiving-and-departure tracks, loading areas, i.e., the devices which have railcars parking and railcars accumulation. In the model with channels using have represented laps, the connecting tracks, sorting slides, as well as technological operations (inspection, loading, unloading). In the channel railcars accumulation is impossible.

In this study, “structural technology” proposed to analyze as one of the methods of complex transport and logistics methods of functioning organization of the railway industrial TTS, located on the IV level of the organization.

As part of the developed complex of transport and logistics methods, the implementation of structural technology requires as input information about requirements of loading areas in railcars the needs of freight fronts in cars (quality requirements of transport service). These data have formed on the II and III levels in the calculation of the optimal size of the transport and freight party and the optimal allocation of railcars at loading areas.

The selection results of the optimal technological methods of structural technologies for operational conditions, in turn, is used as initial data for solving the problem of railcars routes optimization in TTS and railcar flows optimizing railway transport nodes or on the non-public tracks of industrial enterprises, i.e. respectively on V and VI the organization TTS levels. The original data in these cases are data of the levels utilization of the transport elements, defined by selected technological methods of structural technologies.

It is formalized process of capacities redistribution between the TTS elements by changing way of work technology it is represented so-called “adaptation communications”. It is possible to transfer bandwidth capacity or capacity by these communications. The realization of adaptation communications is enabled through the changing:

- bandwidth capacity of other channels (connection type “channel–channel”);
- bunkers capacity (“bunker–channel”).
- capacity of other bunkers (“bunker–bunker”);
- bandwidth capacity of channels (“channel–channel”).

The bandwidth capacity increasing of some channels it is possible not only with transferring from other structure elements. Bandwidth capacity of separate transport devices have manages to be regulated on a time frame. The temporary capacity increasing in comparison with average size, as a rule, during the subsequent period is followed by its reduction. It is formalized if this process it is possible to present in the communications form from the channel to itself, but in other time moment.

Link adaptation is characterized by two additional parameters—time activation of management reserves (delay in the implementation of selected technological methods) and the tradeoff coefficient of bandwidth capacities (losses of capacities transferring), studied in details of works [2, 23]. Table 7 presents the methods classification of structural technology by implemented type of communication adaptation, as well as the features and limitations of these methods implementation.

Mathematical model problem of optimal distribution of railcar flows at structural elements of TTS and choice of technological ways of structural technologies implementing is presented in the work [2], it is proposed to amend the condition to ensure

Table 7 Method of "structural technology"

Connection	Implementation method	Technological solution	Circumstances	Restrictive
Channel–Channel	Variables means transferring	Locomotives transferring	Is determined by the extent of locomotives unification, locomotive crews	Lack of locomotive capacity Small radius curves Lack of electrification Specific production conditions The accepted system of locomotives fixing;
		Handling equipment transferring	Additional using of polytypic mechanisms Mechanization of auxiliary operations;	Mechanisms using of own coursing;
		Personnel transferring	Inspection brigades transferring (individual employees), locksmiths transferring	Time duration transferring;
	Adjustment of train formation plan	Groupnote changing of formed trains	Groupnote increasing at high loading station Groupnote reducing at low loading station	Consistency in operational work of shunting managers
		Order changing of railcars allocation in train	Rejection of groups selection, of order setting of railcars at high loading of station Groups selection at low loading of station	Consistency in operational work of shunting managers

(continued)

Table 7 (continued)

Connection	Implementation method	Technological solution	Circumstances	Restrictive
Channel–bunker	Tracks specialization changing	Free station using, main, chassis and exhaust tracks	Maximum using of existing station tracks at low loading station Using for short-term parking main chassis and exhaust trackss at high loading station	Transportation process safety
	Maximum capacity using of separate tracks	Groupnote increasing accumulated in the sorting train park structures with re-sorting	Railcars accumulation on a single sorting track of multiple destinations with re-sorting repeating	Lack or high load shunting operation of the exhaust tracks
		Trains group note reducing, formed at the technological stations	Railcars accumulation on technological stations from loading operations on one	High station loading of trains reformation
	Free track ends using	Substitution of railcars groups of one of trains at the free ends of tracks	Used in the loading stations—unloading bulky (homogeneous) cargoes	The trains length must be less than the capacity of the station tracks
		Railcars substitution at the tracks, occupied railcars to the address of another freight point	Usedata the stations on loading and unloading of cargos with several items	Free exhaust tracks existence and switching equipment
Bunker–channel	Maximum using of station capacity	Placement groups (railcars supply) at separate ways	Used to railcar supply process increasing to the loading operations	Free station tracks available
Bunker–bunker	Specialization ways changing	Train reception and processing on tracks, reserved by other operations (cargo, railcar, destination)	Sequential changing of specialization ways, with subsequent restoration of standard technology	Free station tracks available
	Specialization changing of tracks parks	A trade-off between specialization parks receiving/departure	Train receiving at park of departure; complete for departure train exhibiting at receiving park	Scheme of the mutual location of parks, tracks, configuration station
		Technological convergence of sorting park and park of departure	Trains departure from sorting park End of the train formation in the park of departure	Scheme of the mutual location of parks, tracks, configuration station

(continued)

Table 7 (continued)

Connection	Implementation method	Technological solution	Circumstances	Restrictive
Fictitious channel–channel	Temporary increasing of bandwidth capacity, with further reducing	Priority execution of less time-consuming operations	Prime disbandment of trains with smaller quantity of uncoupling	Workshops compliance of sequence of railcar supply and removing; an operational plan of loading and unloading operations
Fictitious channel–channel	Temporary increasing of bandwidth capacity, with further reducing	Priority execution of less time-consuming operations	Initial loading (unloading) of railcars closest to the loading areas	Workshops compliance of sequence of railcar supply and removing; an operational plan of loading and unloading operations
			Primary trains separation, which has a closing group	Requirements compliance of train formation plan
	Temporary increasing of bandwidth capacity, with further reducing	Short-term intensification of compliance technology monitoring	Enhanced control of certain operations of the technological process	Low executive discipline of staff and workers
		Refusal to perform the individual operations of the technological process	Temporary failure of the control surveying, technical and commercial inspection	Violation of technology at the nearby stations and loading areas; high probability of technical and commercial spoilage, norms violation of railcars loading

the required capacity of the accumulating elements, describing the loading areas, at given points in time. In addition, it is proposed to carry out the original data correction of the mathematical model of the method choosing of structural technologies by organizing data exchange models developed for other levels of TTS. This improvement of structural technology creates real prerequisites of its realization as is provided accounting a set of the limiting factors and conditions arising from various transport and logistic and resource flows at the different levels of the TTS organization.

Fluctuations in the operational mode of the level of reserves bandwidth and processing capacities of technological stations in TTS have a significant impact on the effectiveness of railcars flow promotion on some routes. For costs reducing of railcar-hours the railcar flow movement on routes passing through the stations with the lowest level of the current reserve bandwidth by adjusting these routes, it is necessary to estimate the value of these reserves [7]. This task is proposed to solve the V level of functioning TTS organization.

Nowadays, in difficult conditions of operatively data collection about separate shunting operations with railcars in the existing information systems, effective is the assessment of reserve bandwidth and processing capacity of railway station using the mathematical apparatus of the fuzzy set theory [24, 25, 26].

In difference of the traditional mathematical methods demanding the accurate and unambiguous information of regularities, methods of fuzzy set theory allows on the basis of both exact quantitative indices, and approximate quality standards, to generalize data on the various factors having various impact on the size of the current reserve of the throughput and overworking station ability. As a result of researches the following groups of such factors were revealed:

- group of technical factors (characterize a station hardware—arrangement of tracks, shunting and handling equipments);
- group of technological factors (characterize a volume and complexity of technological operations currently performed at the station, the elements employment of the arrangement of tracks);
- group of subjective factors (qualitatively characterize complexity of operational management of station working in these or those conditions—depending on the level of the organization, informatization, automation of work, weather climatic conditions, time of day, etc.);
- group of factors "personnel" (characterize the personnel competence, work management at station).

For every factor (almost identified 34) are built identifying functions, qualitatively determine the influence of the factor on the spare amounting of bandwidth and processing station capacity. Identifying functions are given a task of preference degree (number in the interval from 0 to 1) for all values of the parameters estimated provision of bandwidth and processing station capacity. These functions are based on subjective opinions of experts who have knowledge in this area, and functions correction is possible at changes in a management system of railcar traffic flows in PTS. To estimate the amount of bandwidth and processing station capacity can be used a variety of approaches and methods of the fuzzy sets theory, the choice of which is depends on the amount of input information and the calculations complexity: method of maximum convolution, absolute solution, main parameter, compromise solution, benchmark comparison and other methods.

General view of the task of assessing reserve of bandwidth and processing station capacity is as follows [2]: there are many railway technological stations, each of them is characterized by the provision of bandwidth and processing capacity $A = \{a_1, a_2, \ldots a_i, \ldots, a_m\}$. By the way, every station is characterized by a set of indicators that affect the reserves bandwidth and processing capacity $K = \left\{K_1, K_2, \ldots K_j, \ldots, K_n\right\}$. Between each member of the set A and each member of the set K is a fuzzy relation, denoted by μ_{ij}, which reflects the compliance level of the i-th reserve bandwidth and processing station capacity estimates for the j-th indicator $\left(\mu_{ij} \in [0, 1] : i = 1, \ldots, n;\ j = 1, \ldots, m\right)$. As a association result of all indistinct relations between ai and Kj result is a matrix of fuzzy relations. It is required to choose variant ai from a variety A, i.e. station with the highest reserve of the bandwidth and processing capacity.

The received estimates of reserves are offered to be used, first of all, for control of effective management system of railcar traffic flows by an expenses assessment of the railcar-hours resulting from the admission of traffic volumes along the routes passing on stations with low operational reserves level of bandwidth and processing capacity.

Results of operational calculation reserves of the bandwidth and processing capacity of the TTS railway stations are offered to be used as arches estimates of a transport network by representing structure of TTS. Further calculation of optimal movement routes is made with using by standard mathematical methods of shortest routes searching at a transport network, for example, by a creation method of “table of optimal ways” [7].

Generally, the optimization algorithm of railcar traffic flows movements in TTS implemented at the V level of functioning TTS organization consists of following integrated activities:

1. Formalized description of special railway track in transport network. Determination of static assessments of transport network arcs (the specific transport costs for railcars moving between railway stations at special railway tracks);
2. Calculation of integral dynamic assessment of transport network arcs, i.e. the adjustment of the static estimates of arcs with actual railway stations loading of siding track (method of assessing level of station loading based on the fuzzy set theory);
3. Determination of railcar traffic flows power of departuring and arriving at the stations with using by methodology of data generation on the routes movement of railcar traffic flows on the special railway tracks and statistical analysis (prediction) of railcar traffic flows parameters by method of routing formation data of railcar traffic flows and operational statistical analysis of movement parameters of railcar traffic flows;

4. Operational mode solution of static multiproduct transport problem of linear programming in a network setting, as the result is determining optimal routes of railcar traffic flows on the transport network;
5. Generating recommendations to managers for adjustment of train formation and routes changing of railcars movement.

Main technological method of operational management structure of railcar traffic flows at the VI level of functioning TTS organization provides correction of plan train formation. However proposing technology completely eliminates using of term "the plan of train formation" and is entirely based only on the methods of train forming (re forming), composition is determined by current railcars demand (cargoes) of other elements of the logistics system.

The application ordering of these or those technological decisions in the operational mode is defined by dynamics of two factors: railcars requirement (cargoes); railcars existence (cargoes) at railway station. Railcars requirement is estimated by the urgency coefficient attributing for every railcar (railcar groups) of same destination—$K_{C,ij}$, where ij—destination number (index), i means number (index) of railcar consignor (railcar groups or cargo, but j—number (index) railcar consignee [2]. The technological solutions of various factors combinations are presented in Table 8.

Table 8 System of technological methods which are implementing methods of structure optimizing of railcar traffic flows in TTS

Destination power *ij*	Value $K_{C,ij}$	Technological solutions	Technological method
Reducing	Increasing	Value combining ij with other values	Train group note increasing
Reducing, constantly	Increasing	Value including ij in train line-up of early departure	
Reducing, constantly	Reducing	Train formation by railcars with low urgency coefficient and train delaying at formation station	
Increasing	Reducing	Railcars including in destination ij in line-up of few trains	
Reducing	Increasing	Include in train line-up the railcars of destination ij beyond established limit at line-up size	Train size changing
Increasing	Increasing	Destination allocation ij in independent destination	Group note train reducing
Increasing	Increasing	Train departure with railcars of allocated destination, if train size more than norm	Train size changing
Reducing	Increasing	Train departure without closing group	
Increasing	Reducing	Train selection by groups on loading or low-power sorting stations	Management of railcar allocation ordering in trains
Reducing	Increasing	Train selection by groups on high- power sorting stations	

As a result of using the described technological methods and decisions there is a change of quantity and an allocation ordering of railcars or railcars groups as a part of the forming (reforming) trains at railway station. Thus railcars loading of various stations and operational work will be various. These distinctions are defined by dynamics of material flows (dynamics of his power and structure), and requirement dynamics in material flow of logistic elements. Therefore choice of concrete technological decisions is defined at stations also by work loading degree of other railway stations on the polygon.

For polygon stretching or complex transport network it is recommended to consider a difference in loading of separate railway stations by method of value adjustment of railcar urgency coefficient.

For example, if the neighboring station is overloaded, urgency coefficients of all railcars which have processing at this station, have to be lowered at a size proportional to extent of station loading. Concrete values for various stations have to be defined by technical and economic calculations.

Realization of the presented TTS management methods at the I–VI levels of the functioning TTS organization can be limited to the throughput and processing capacity of railway stations and spans.

There is a problem of structure adaptation of regional TTS to change power, structure and routes of the railcar traffic flows movement. This method of strengthening optimization of bandwidth and processing capacity of regional TTS elements (the VII level of the TTS organization) is based on sequences formation of the adaptation decisions differing with size of expenses:

- structural adaptation or design changing of transport system—a combination of reconstructive, organizational and technological solutions;
- system adaptation or work system changing—system change of railcar traffic flows organization, costly reconstructive activities, such as construction of a hump yard;
- adaptation goals—most comprehensive solution, implemented as a rule, in conditions of significant changes in the external environment, such as a change of transport mode to private transport, system indicators changing of estimates of transportations quality.

Transition to the next level adaptive solutions is carried out after reaching the “barrier effectiveness” of the solutions of the lower level. This barrier is determined by the evaluation of economic efficiency of these solutions.

Optimization problem of the amplification bandwidth and processing capacity of t elements of a regional TTS calculated with optimal choice for the aggregate cost of solutions sequence of the proposed to implement technological solutions at the lowest levels of the TTS organization. Difference of proposed method of bandwidth and processing capacity strengthening of railway transport from famous is the combination of reconstructive measures with organizational and technological, which significantly reduce total costs of the TTS development.

Further TTS efficiency is associated with the network development of regional logistics centers (VIII) coordinated functioning to achieve its global objectives.

Analysis of the theoretical and practical bases of formation of a regional network of transport and logistics centers as the TTS infrastructure basis at the macro level, showed insufficient elaboration of the question of logistical capacities development and deployment, especially taking into account factors of demand for logistics services, dynamics and forecast of economic region [27, 28].

We offered that choice of TTS elements locations at the macrolevel be guided by region competitiveness offering factors system including groups of socio-economic factors, geographical and infrastructure, and also group of transport work region indicators of potential placement of logistic centers. Since, system factors are estimated by both quantitative and quality indicators, and also have hierarchical difficult structure, it is offered to consider their influence on placement of objects of TTS infrastructure with using by "integrated assessment of region appeal". Integrated assessment of region appeal is a relative indicator and doesn't depend on the territory sizes or region population. Therefore all private appeal factors are included in summary values calculation with measure units expressed by relative sizes or mark estimates.

Developing methodology of location choosing of logistic center based on calculation of the integrated assessment of region appeal which includes the following stages:

1. Assessment calculation of a private factor for potential regions by method of the statistical analysis "Pattern" and determination of weight coefficients of each factor by analysis of hierarchy method. The method of the statistical analysis "Pattern" allows receiving estimates on private indicators means by ratio of actual values factors with their best values [29]. As each factor in various extent influences of choice locations of logistic center and efficiency of its work in the future, at the first stage weight coefficients of each factor are defined by the method of analysis hierarchy (MAH) [26].
2. Evaluation of potential location of the logistics centre taking into account of weighting factors for each group of factors.
3. Calculation of consolidated coefficients for every group of factors. Appeal level of region for logistic center placement is offered to be estimated by assessment comparison of competitiveness of analyzing region to assessment of competitiveness of region standard. As the reference region it is expedient to use the real-life or conditional region having best competitiveness characteristic. Values of consolidated coefficients for every group factors are offered to be made by methodology which are offered in work [30].
4. Regions ranking of potential logistic centre by value of integrated assessment of region attractiveness. Value of integrated assessment of region attractiveness proposed to be calculated as mean of consolidated ratios of three groups factors.

Considering that region appeal is defined on the basis of three consolidated coefficients which for each considered region make various contribution to the general integrated appeal assessment, it is offered to compare values of consolidated coefficients among themselves. Comparison of consolidated coefficients will allow revealing group of factors on each subject which values need to be improved for the purpose of regions appeal increasing, and also will allow developing recommendations about formation of TTS infrastructure elements [28].

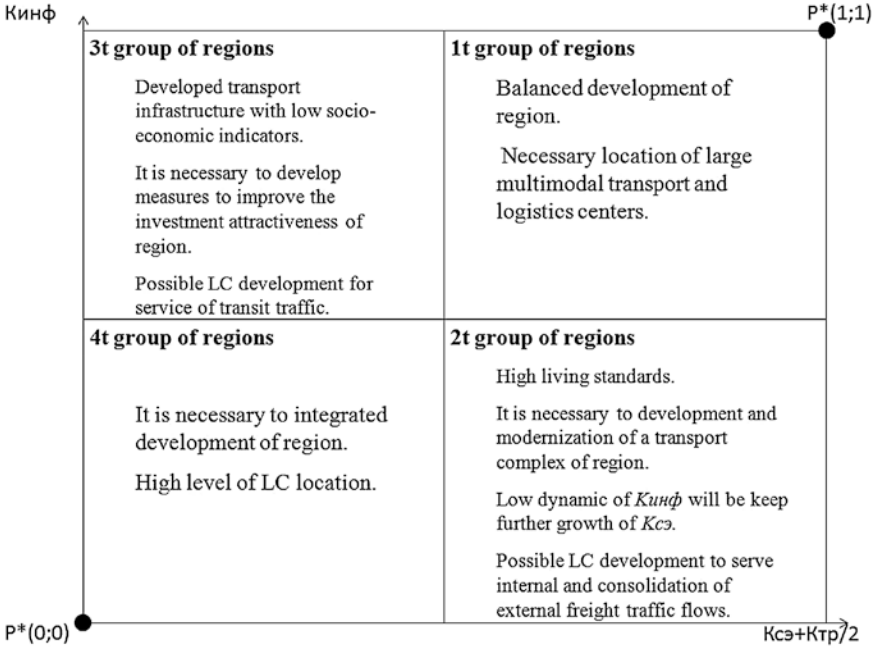

Fig. 5 Matrix of group regions on the appeal level to placement of TTS elements

Matrix of group regions [28] on the appeal level to placement of TTS elements with comparing values of consolidated coefficients among themselves is presented Fig. 5.

These methods of selection logistics centers as the TTS infrastructure elements are offered to be used as a basis for development of strategic plans for funds investment into TTS development. Novelty of developed method is account as socio-economic factors of market environment, and technological (transport) restrictions determined by functions of lower levels of functioning of TTS organization. Factor of transport work of region is one these restrictions.

4 The Model of Logistic Flows in Transport-Technological Systems

Considering an approach consistency with description of logistic flow at different levels of functioning TTS organization, are proposed system of organization of freight and railcar traffic flows in TTS based of idea of balance achieving between freight owners requirements reducing of supplies sizes and transfer quantities, in one case, and the using level of reserves of bandwidth and processing capacity of transport devices (actually, transport costs), in another case. Thus, determining factor in this balance of freight traffic flows are performed freight owners requirements. Insofar as TTS functions in dynamics, changing requirements of transport clients should be compensated by changing of actual level of load TTS elements. For achieving of uniform (required) loading items TTS transport and logistics flows it is necessary to use logistics flows management system, which would provide information, financial and service support solutions and actions to changing load and performance TTS elements. This balanced state flows in the elements of TTS are encouraged to call dynamic balance.

Basis of the generalized mathematical optimization models for TTS generally is idea of balance achieving between freight owners requirements reducing of supply's sizes and transfer quantities, in one case, and the using level of reserves of bandwidth and processing capacity of transport devices (actually, transport costs), in another case. Thus, determining factor in this balance of freight traffic flows are performed freight owners requirements.

For determining conditions to achieve and maintain balance with changing parameters of transport and logistics flows, TTS seems as transport and logistics system, consist of cumulative elements S_i, connect with transport elements or arcs, which have flows $q_{Si+1,Si}$ (Fig. 6). Cumulative element describes not only warehouses suppliers, customers or inventory warehouses, but some railway tracks, railway tracks of parks, as well as the capacity of individual vehicles or groups, for example, train size.

Main parameters of cumulative element will assume its capacity q_i and time t_{Si} , required to complete exhaustion (replenish) supply q_i, with specified intensity of discharge (recharge) supply. Parameters of transport element—bandwidth capacity $d_{Si+1,Si}$ and time $t_{Si+1,Si}$, spent to move element of flow capacity $q_{Si+1,Si}$.

Then achieve a balance thread, skipping logistics chain or network, is provided if accumulation intensity of flow in every vertex-provider S_{i+1} not less than intensity of spending flow in corresponding top-consumer S_i. In other words, it must satisfy equality condition of intensities of accumulation and expenditure flow, respectively, in the initial and final vertices of each arc logistics network

$$\frac{q_{i+1}}{t_{i+1}} = \frac{q_i}{t_i} \tag{4}$$

Since nodes of logistics network, with same intensity may vary by size of accumulated or consumed group of flow elements, for example, size of generated or consumed of transfer quantity, it is necessary to consider limitations on the throughput capacity of arcs network. This means that bandwidth capacity of each arc logistics network should be sufficient to ensure that, regardless of cumulative value of

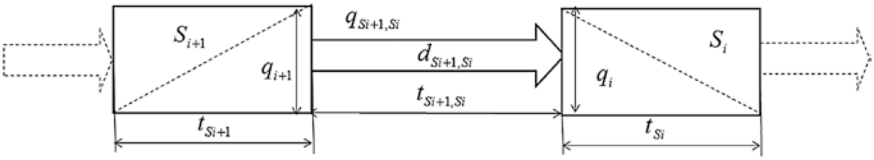

Fig. 6 Scheme of formalized TTS representation

supply at the top of the supplier, through each t_{Si} time interval at the top- consumer has formed a reserve in the amount qi. This condition is ensured if duration of spending flow in the top of consumer is not spending less time on the group of flow movement on arc (Si + 1, Si)

$$t_{Si} \geq t_{Si+1,i} \tag{5}$$

at the same time, if within time period t_{Si} in top-consumer comes as many thread groups size qλi, their total amount is equal to the quantity demanded

$$\left\lfloor \frac{t_{Si}}{t_{Si+1,Si}} \right\rfloor \cdot q_{Si+1,Si} = q_{Si} \tag{6}$$

where $\left\lfloor \frac{t_{Si}}{t_{Si+1,Si}} \right\rfloor$ is number of groups elements of flows received by top consumer in the period t_{Si}.

System of logistics flows network will be called balanced, if conditions are executed (4–6) [2].

Accomplishment of balanced state of logistic flows actually means equality of accumulation intensity and flows expenditure in adjacent tops of a network, and also capacity compliance of arch connecting these tops, intensity of flow between them. In practice this uniform advance of flows in logistic chains is provided with technological, organizational and reconstructive methods presented in the previous part which realization is interfaced to an expenditure of additional resources (streams). In the developed model these decisions are displayed by parameters adjustment of tops and arches of a network. This adjustment models process of an expenditure of resources necessary for change of accumulation intensity of a railcar traffic flows in network tops, and also time changing of flow movement on network arches.

Flow expenditure of various types is also offered to be described corresponding logistic networks with modeling of resource flows movement. For example, defect of capacity of an arch can be eliminated by time reduction for the movement of a traffic volume on this arch or increasing of size of group flow. In the described model such changes are displayed by redistribution of size capacity between arches of a network or the flows movement of capacity in the corresponding logistic network. It is similarly modeled: movement of financial flows arising in case of increases requirements in costs of flow movements, for example, for flow movement of bandwidth capacity in case of change of station work technology; on the information flow movement, with requirement of information transferring about railcars dislocation. Thus, flow movement of each type is modeled by logistic network. Set of logistic networks movement of various logistic flows is combined in system. Number of logistic networks in system generally can be various, and their concrete structure is defined by the solved task. As traditional concepts of a logistic network or system are applied to designation of material streams system, further we will call logistic networks movement of all set of logistic flows by resource networks.

Communications between resource networks of different types in system are offered to be described by functional dependences between: supplies and requirements for various resources; time costs for accumulation, consumption and movements of various resources.

General principle description of functional relationships between vertices and arcs resource networks of different types is that parameter values of vertices and arcs $\left(q_i, t_{Si}, q_{Si+1,Si}, t_{Si+1,Si}\right)$ networks of one type depend on existence of certain resources quantity and time of their processing in interfaced tops of resource networks of other types. In each couple of resource networks one network is the defining requirement for resources (further—“a basic network”), and another—sets resource restrictions on these requirements (further—“the limiting network”). A basic network which in turn isn’t limiting for one other resource network in system of networks, network of material flow movement, in our case—empty railcars flow or transport network is, as a rule. Other resource networks in various couples of networks can act at the same time as the basic, and limiting networks. For example, the limiting network of the information flows necessary for making decisions on flow distribution of empty railcars will be basic for the resource network of movement of financial and economic flows modeling costs of information supporting of management process.

Functional communications between resource networks represent dependences of each of four parameters of a basic network $\left(q_i^B, t_{Si}^B, q_{Si+1,Si}^B, t_{Si+1,Si}^B\right)$ from a resource supply in tops of limiting network—q_i^R. Arches of the limiting network correspond to the direction of resource flows movement, and parameters of arches ($q_{Si+1,Si}^R$ and $t_{Si+1,Si}^R$) determine intensity of resource flows promotion. Compliance of parameters of basic and limiting networks is presented in Table 9.

Table 9 Parameters compliance of basic and limiting networks in model of empty railcars park regulation

Parameter basic network	Physical sense of parameter q_i^R limiting networks (by type of resource)			
	Capacity	Bandwidth capacity	Information	Costs
q_i^B—supply or requirement	Maximum q_i^B	Intensity	Amount of information about size q_i^B	Storage costs of a supply unit q_i^B in current t_{Si}^B
t_{Si}^B—accumulation duration of supply consumption	Minimal t_{Si}^B	Duration of supply changing per unit	Information quantity of value t_{Si}^B	q_i^R—storage costs q_i^B during the unit time t_{Si}^B
$q_{Si+1,Si}^B$—group size of flow elements	Flow movement on arc	Maximum $q_{Si+1,Si}^B$	Information quantity of value $q_{Si+1,Si}^B$	Flow movement expenses $q_{Si+1,Si}^B$ during a time $t_{\lambda i,i}^B$
$t_{Si+1,Si}^B$—time of movement of elements group on arc	Interval between groups of flow elements	Minimal $t_{Si+1,Si}^B$	Quantity of information about value $t_{Si+1,Si}^B$	Group movement expenses $t_{Si+1,Si}^B$ during a time $t_{Si+1,Si}^B$

Note In table columns, depending on the color, presents: without fill—absolute quantities q_i^R; with light fill—derived from absolute values; with darkest fill—specific values

General view of functional communication between parameters of resource networks [2]

$$x_i^B = k \cdot q_i^R + \Delta q_i^R \tag{7}$$

where B and R is signs of facilities of top i, consequently, for basic and limiting network; B and R present herself indexes of resource networks—natural numbers;

x_i^B—one of parameter of basic networks: q_i^B, t_{Si}^B, $q_{Si+1,Si}^B$ or $t_{Si+1,Si}^B$;
k—conversion, correction or account coefficient defining a resource expense q_i^R. For financial-economic resource network, k defines a tariff or costs size; for information resource network—number of administrative information (in the conditions of a shortcoming or poor quality of information is determined by a technique [2] on the basis of an probability assessment of resources distribution on tops of a resource network); for networks of bandwidth capacities and capacities—k = 1, if measure unit of bandwidth capacity or capacity coincide with dimension of group elements of flow of a basic network;
q_i^R—resource in i top of limiting network;
Δq_i^R—reserve (negative value) or deficiency (positive value) of a resource.

Type and structure of bounding networks is determined by presence or absence of reallocation possibility of resources between nodes of these networks. Generally, when redistribution will be possible, limiting network describes oriented connected graph. In specific case, when initial values of resources supplies in tops aren't known, limiting network is set by connected without circuit-free graph (tree) with one root, value q_i^R which determines size of a total supply of this resource. If redistribution is not provided, limiting network describes the empty graph (not containing arcs), for tops which $q_i \geq 0$ and $t_{Si} = 0$. This network is used in the case when the initial supplies value of resources is known. Otherwise, values q_i for tops of empty column are set by functional communications (4), which is q_i^R and Δq_i^R—this is, accordingly, consumption and reserve (deficit) resource in only the top, simulating a total resource of this type.

In independence of type and structure of limiting networks, set of functional communications between them represents a tree which root is one of parameters of top or an arch of a basic network. Leaves of such tree contain parameters defining supplies of various resources and always being constants.

Criterion function of a regulation problem of empty railcars park is reduced to finding of a minimum of total supplies in tops of all financial and economic resource networks, that is a minimum of total costs of accumulation, storage and advance of empty traffic volumes, costs of correction of work technology of railway stations on the basis of expeditious redistribution of capacities and/or capacities, and also costs of accumulation and information transferring.

$$F = \sum_{r=1}^{R} \sum_{i}^{N} q_i^R \to \min \tag{8}$$

where r—ordinal limiting network belonging many financial and economic resource networks R. Objective function (8), cumulatively with system limitations (4)–(7), forms linear optimizational model (if Eq. (7) is linear).

Costs calculation of accumulation (expense) of flow for top or costs of flow movement on an arch of a resource network is carried out by round of a tree of functional communications between tops of various resource networks and summation of an expense of financial and economic resources in tops of this tree.

Method and algorithm based on use of principles of dynamic programming are developed for the solution of the presented model. Essence of a method consists in finding (8) ways of movement of all resource streams, optimum criterion, in system of resource networks. These ways represent an ordered sets of tops (arches) of resource networks. Definition of optimum ways is offered to be carried out consecutive comparison of expenses of financial and economic resources necessary for flows movement at every arch, an arch choice with minimum expenses [26].

5 The Model of an Industrial Enterprise ITS

Developed mathematical model of dynamic balance of transport and logistic and resource flows of TTS is generally continuous as time interval between moments of power flows changing and size of supplies aspires to zero. Transport and logistic models which optimize parameters of flows are discrete. For accuracy increasing of results and solution of tasks of functioning TTS organization it is offered to use all complex of mathematical optimizing models totally with simulation model.

For interference establishment of parameters of transport and resource flows at different levels of functioning TTS organization it is offered to combine system and dynamic models with discrete event and analytical (optimizing). Modeling results of lowest levels of organization are used as basic data for models with higher levels. In turn, by results of modeling of TTS of higher levels change of structure of these models is carried out as correction of basic data for low-level models, and, i.e. some elements and communications between them can be added or be excluded.

Generally, modeling results of all levels of TTS organization are used as basic data for system and dynamic model of flows resource of all TTS. In turn, modeling results of flow resource and transport flows (received as a result of work of system and dynamic models VI–VIII of levels of TTS organization) are input data of mathematical model of dynamic balance (4–8).

Integrated scheme of interrelation of separate models (blocks) as a part of developed combined analytical and simulation model is presented in Fig. 7. Apparently from the scheme, interaction of separate blocks is carried out by data transmission about modeling results. Each pair of model blocks exchanges by specific data. Maintenance of data flows which blocks as a part of combined analytical and simulation model exchange, is presented in Table 10. In process of abstraction level increasing of combined model there is flows generalization of

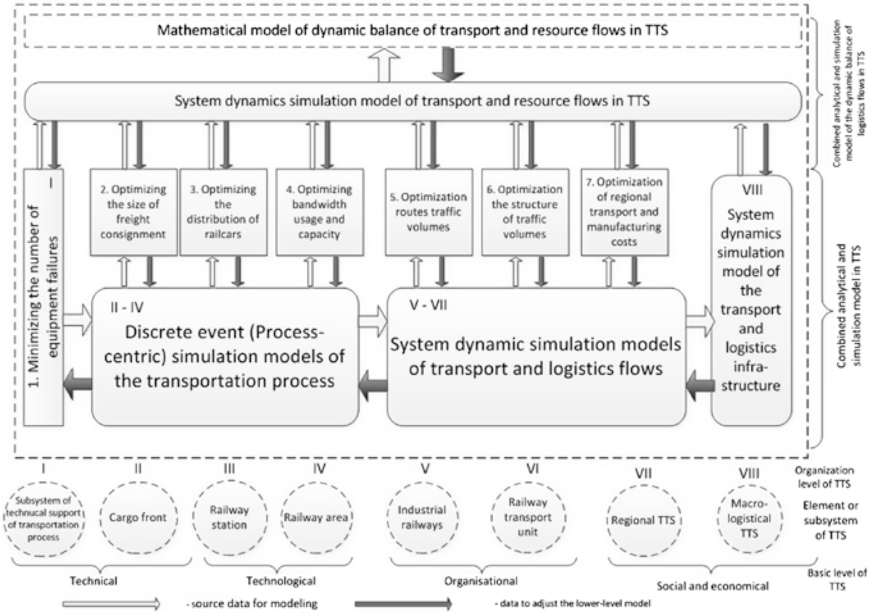

Fig. 7 Scheme of blocks interrelation of combined analytical and simulation model of TTS

data transferred between blocks of model. At the lower level of model—level of discrete and event models of transportation process—shunting, cargo operations with separate railcars, and also train operations are modeled. Following abstraction level of model—is level of mathematical optimizing models. As a result of their decision optimum parameters of transportation process for various levels of TTS organization are defined. Besides, results of mathematical modeling are used as input data at following abstraction level—is level of generalized flow system and dynamic model. Main objective of this model—present TTS functioning as a system of transport and logistic and resource flows which parameters has impact as the bandwidth capacity and capacity of elements of transport and logistic infrastructure—internal factors, and external—social and economic, geographical factors and indicators of transport work region of TTS elements placement.

Parameters of flows system received as a result of work of generalized system and dynamic model are used for solution of optimizing mathematical model of dynamic balance (4–8). As a result of its decision calculating optimum parameters of transport and logistic and resource flows, and also required values of bandwidth capacity and capacity of TTS infrastructure elements. Optimization results of flows system are transformed to administrative decisions on parameters adjustment of transportation process and development of transport and logistic infrastructure at each level of TTS organization.

At the following stage of model solution process repeats. For each level of TTS organization are determined periods of optimization depending from planning

Table 10 Maintenance of data flows which blocks as a part of combined analytical and simulation model exchange

Levels of interacting units models (see Fig. 7)	Data type	Data of logistics flows TTS				
Lowest	Highest		Material	Flow of services	Information	Financial
1. Minimizing number of bounce technology	System dynamic simulation model of transportation and logistics and resource flows in the TTS	Input data	Intensity using of material resources in system repairs	Extent of fixed assets, security personnel qualifications	Amount of reserves in the system of repairs	Cost of repairs
		Results	Resource supplies	Adjusted value of depreciation of fixed assets and staffing qualifications	Adjustment of the regulatory framework for system repairs	Supply of financial resources
	(II–IV). Discrete-event simulation models of transportation process technology	Input data	Number of serviceable equipment and devices	Scheduled preventive maintenance plan	Probability of failure of technical facilities and devices	–
		Results	Ratio using of technical equipment and devices for time and performance	–	The number of applications for unscheduled repairs	–
(II–IV). Discrete-event simulation models of transportation process technology	2. Size optimizing of transport consignment	Input data	Intensity of unload (loading)	Capacity of loading areas (terminals), their employment	Dynamics of supplies levels and moments of requirements for transport	–

(continued)

Table 10 (continued)

Levels of interacting units models (see Fig. 7)	Data type	Data of logistics flows TTS				
Lowest	Highest		Material	Flow of services	Information	Financial
(II)–(IV). Discrete-event simulation models of transportation process technology	2. Size optimizing the of transport consignment	Results	Optimal size of freight shipments	Adjusted values are capacity (capacity) loading areas (Terminal)-terminal capacity of processing	Optimal parameters for railcars	–
	3. Optimize allocation of railcars at loading areas	Input data	Number of railcars of various groups on the station, trains composition	Loading stations (reserve the bandwidth and processing capacity), station railcars	Railcar demand for freight wagons fronts (for wagons), trains on schedule	–
		Results	Revised data on the number of cars on the station and train personnel	Revised data of loading stations	Optimal parameters of railcars supply (size, points in time) at loading areas	–
	4. Optimize using bandwidth and capacity	Input data	Railcar location at tracks of station, trains composition	Employment of railroad development locomotives, etc. vehicles using	Entities of railcar supply at loading areas	–

(continued)

Table 10 (continued)

Levels of interacting units models (see Fig. 7)	Data type	Data of logistics flows TTS				
Lowest	Highest		Material	Flow of services	Information	Financial
II–IV. Discrete event simulation models of technology of transportation processes	4. Optimization using of banwidth capacity and storage	Results	Location changing station wagon and whole trains	Adjusted employment of tracks element, the use locomotives and other vehicles	Data about executed orders entities for railcar supply-removing of railcars	–
	V–VII. System dynamic simulation models of transport and logistic flows	Input data	Structure and power of railcars traffic flows	Bandwidth and processing capacities of TTS elements	Routes movement of railcars traffic flows	–
		Results	Adjusted structure and intensity of railcars traffic flows	Dynamics usage of bandwidth capacity and capacity of elements TTS	Adjusted routes of railcar traffic flows	–
V–VII. System dynamic simulation models of transport and logistic flows	5. Optimization of railcars traffic flows	Input data	Structure and intensity of railcars traffic flows	Intensity processing of railcars traffic flows at stations and skip of railcars traffic flows by spans	Routes movement of railcars traffic flows	–
		Results	Adjusted structure and intensity of railcars traffic flows	Adjusted values of processing intensity of railcars traffic flows at stations and skip of railcars traffic flows by spans	Adjusted routes of railcar traffic flows	–

(continued)

Table 10 (continued)

Levels of interacting units models (see Fig. 7)	Data type	Data of logistics flows TTS				
Lowest	Highest		Material	Flow of services	Information	Financial
V–VII. System dynamic simulation models of transport and logistic flows	6. Optimization of railcars traffic flows structure	Input data	Structure and intensity of railcars traffic flows	Forecast time costs for the accumulation and processing of railcars traffic flows at stations	Urgency coefficients of railcars traffic flows parameters of entities railcar supply-removing of railcars, road plan of train formation, transfer and export	–
		Results	Adjusted structure and intensity of railcars traffic flows	Settlement expenses of time for accumulation and processing of railcars at stations and the corrected values of intensity of processing railcars traffic flows at stations and the admission of railcars traffic flows by spans	Timeliness shipments, adjusted road train formation plan, transfer and export of trains	–
	7. Optimization regional transport and production costs	Input data	Structure and intensity of regional freight and railcars traffic flows	Bandwidth and processing capacity of elements of a regional TTS	Road plan of train forming, train schedule	–
		Results	Adjusted structure and intensity of regional freight and railcars traffic flows	Adjusted values of bandwidth and processing capacity of elements of a regional TTS	Road plan of train forming, train schedule, development plan of the regional transport and production infrastructure	–

(continued)

Table 10 (continued)

Levels of interacting units models (see Fig. 7)	Data type	Data of logistics flows TTS				
Lowest	Highest		Material	Flow of services	Information	Financial
V–VII. System dynamic simulation models of transport and logistic flows	VIII. System dynamic simulation models of development of transport and logistic infrastructure	Input data	Structure and intensity freight and railcars traffic flows macrologistic TTS	Bandwidth and processing capacity of elements macrologistical TTS	Schemes of multimodal and intermodal transport, development plan transport and production infrastructure in the regions	Regional transport and production costs, costs development of regional transport and logistics and industrial infrastructure
		Results	Adjusted structure and intensity freight and railcars traffic flows macrologistic TTS	Adjusted values of bandwidth and processing capacity of elements macrologistical TTS	Adjusted schemes of multimodal and intermodal transport, development plan transport and production infrastructure in the regions	Proportion of transport and production costs, costs development of regional transport and logistics and industrial infrastructure

(continued)

Table 10 (continued)

Levels of interacting units models (see Fig. 7)	Data type	Data of logistics flows TTS				
Lowest	Highest		Material	Flow of services	Information	Financial
2. Size optimization of consignment	System dynamic simulation models of transport and logistic resources flows in TTS	Input data	Optimal sizes of consignments, time intervals between railcars supplies	Capacities of loading areas (terminals)—processing capacities of terminals, theirs occupation	Entities for railcars supply, schedule maintenance for loading areas (main production workshops)	Inventory costs, production costs (loss)
		Results	Adjusted sizes of consignments, time intervals between railcars supplies	Adjusted values of capacities of loading areas (terminals)—processing capacities of terminals	Adjusted parameters of entities for railcars supply, schedule maintenance for loading areas (main production workshops)	Investment in the development of transport and storage infrastructure
3. Optimization distribution of railcars at loadin areas		Input data	Optimal: order service at loading areas, train composition, interval between the trains departure	Usage of capacity of receiving-and-departure tracks and parks, usage of bahwidth capacity of a railway station	Statistical characteristics of railcars traffic flows at the station, value of coefficients of complexity of railcars traffic flows, value of railcars turnover at station, forming plan of shipping routes	Cost re-formation trains, transportation costs on railcars supply-removing railcars at loading areas, cost of the trains accumulation, total costs associated with railcars downtime at station
		Results	Adjusted: order service at loading areas, train composition, interval between the trains departure	Adjusted values of capacity of receiving-and-departure tracks and parks, usage of bahwidth capacity of a railway station	Adjusted forming plan of shipping routes	Adjusted cost of the trains accumulation, total costs associated with railcars downtime at station

(continued)

Table 10 (continued)

Levels of interacting units models (see Fig. 7)	Data type	Data of logistics flows TTS				
Lowest	Highest		Material	Flow of services	Information	Financial
4. Optimization usage of bandwidth capacity	System dynamic simulation models of transport and logistic resources flows in TTS	Input data	Distribution of railcar traffic flows at stations, structure of trains formed at stations area, train service intervals between stations of different shunting areas	Bandwidth and processing capacity of transport and storage infrastructure of shunting area, level of information utilization of staff of operational management of transportation process	Timeliness values of cargo transportation, uniform use of bandwidth and processing capacity of railway stations and spans of area, consolidation of operational managers of transportation process at railway stations	Total transport and storage costs and losses, including those associated with low quality of transport service enterprises of area
		Results	Adjusted distribution of railcar traffic flows at stations, structure of trains formed at stations area, train service intervals between stations of different shunting areas	Adjusted values of bandwidth and processing capacity of transport and storage infrastructure of shunting area, level of information utilization of staff of operational management of transportation process	Regulatory values of timeliness values of cargo transportation, uniform use of bandwidth and processing capacity of railway stations and spans of area, consolidation of operational managers of transportation process at railway stations	Adjusted (regulatory) values of transport and storage costs and losses

(continued)

Table 10 (continued)

Levels of interacting units models (see Fig. 7)	Data type	Data of logistics flows TTS				
Lowest	Highest		Material	Flow of services	Information	Financial
5. Optimization of routes movement railcars traffic flows	System dynamic simulation model of transport and logistic resources flows in TTS	Input data	Optimal distribution of railcars at loading areas, optimal composition formed at the external network of trains, intervals between the gear trains	Bandwidth and processing capacity of special railway tracks	Contact schedule of plant trains movement, plan forming of plant trains (collection groups), turn-around time of railcars on the special railway tracks, routes movement of railcars traffic flows	Costs connected with a turn of railcars at special railway tracks and with management of transportation process
		Results	Adjusted: distribution of railcars at loading areas, optimal composition formed at the external network of trains, intervals between the gear trains	Adjusted values of bandwidth and processing capacity of special railway tracks	Adjusted: contact schedule of plant trains movement, plan forming of plant trains (collection groups), turnaround time of railcars on the special railway tracks, routes movement of railcars traffic flows	Investment costs for the increased bandwidth and processing capacity of railway. stations, spans and loading areas
6. Optimization of railcar traffic flows structure		Input data	Power and intensity of railcar traffic flows in node, size of transport consignments	Values of bandwidth and processing capacity of transport and logistic node infrastructure	Entities of enterprises on the supply-removing railcars and additional operations, schedule and composition of transfer and export of trains, routes of railcar traffic flows node, values of urgency coefficients of railcar traffic flows movement	Transport and production costs in the node

(continued)

Table 10 (continued)

Levels of interacting units models (see Fig. 7)	Data type	Data of logistics flows TTS				
Lowest	Highest		Material	Flow of services	Information	Financial
6. Optimization of railcar traffic flows structure	System dynamic simulation model of transport and logistic resources flows in TTS	Results	Adjusted values of power and intensity of railcar traffic flows in node, size of transport consignments	Adjusted values of bandwidth and processing capacity of transport and logistic node infrastructure	Adjusted: parameters of entities supply-removing railcars, schedule and composition of transfer and export of trains, routes of railcar traffic flows node, values of urgency coefficients of railcar traffic flows movement	Cost of development hub transport and storage infrastructure
7. Optimization of regional transport and production costs		Input data	Power and intensity of regional freight traffic flows	Value of infrastructure regional factors	Road plan of train formation, train schedule, geographical factors of region, indicators of transport work in region	Total regional transport and production costs
		Results	Adjusted values of power and intensity of regional freight traffic flows, size of transport consignments	Modify infrastructure regional factors in the development of regional logistics and production infrastructure	Adjustment: road plan of train formation, train schedule	Costs for the development of regional transport and logistics and industrial infrastructure

(continued)

Table 10 (continued)

Levels of interacting units models (see Fig. 7)	Data type	Data of logistics flows TTS				
Lowest	Highest		Material	Flow of services	Information	Financial
VIII. System dynamic simulation model of the transport and logistic infrastructure		Input data	Power and intensity of freight traffic flows, sizes of transport consignments	Values of bandwidth and processing capacity of objects of transport and logistic infrastructure of multimodal and intermodal transportations	Schemes of multimodal and intermodal transport, values of socio-economic factors	Share of transport and logistics costs in the production cost
		Results	Adjusted values of power and intensity of freight traffic flows, sizes of transport consignments	Adjusted values of bandwidth and processing capacity of objects of transport and logistic infrastructure of multimodal and intermodal transportations	Adjusted scheme of multimodal and intermodal transportation	Costs for the development of regional transport and logistics and industrial infrastructure
System dynamic simulation model of resource flows TTS	Mathematical model of dynamic balance of logistics and resource flows in TTS	Input data	Intensity of transport and logistic flows	Description of TTS structure on the passage of transport and logistics and resource flows as a set of transport and storage elements	Intensity (quantity and quality) of information flows (determined depending on the amount of information in the message and the timeliness of their receipt)	Intensity of financial flows (determined depending on the magnitude of costs at every level of the organization IDT)
		Results	Optimal of Intensity of transport and logistic flows	Adjusted capacities and bandwidth capacities of TTS elements	Requirement for quality information flows	Intensity of financial flows and investment in infrastructure development of TTS

durations accepted at these levels. If, for example, at the II–V levels duration of optimization period makes one change (or days), at the VI level period of optimization makes decade (month), and at VII and VIII levels—from a year to five years.

Main instrument of achievement of a strategic TTS is information system providing coordination of parameters of structural elements and transport and logistic flows both between levels of TTS organization, and between structural divisions of one level. As universal approach for creation of information model of functioning of TTS it is offered to present all information flows in system in form of a flow of entities for units of transport or resource flows.

Entity—is purposeful information message containing a data set—requirements of TTS element to the next links. One entity can become the reason of "generation" of a set of new entities as for entity implementation for works of different types of resources can be demanded, for supply which it is necessary to execute a set of works, etc.

As universal parameters of entity it is offered to use data on the addressee of entity, and also about quantitative and quality indicators of work for which entity is formed. For requirements description of technological links for works and resources and estimates of entities implementation are used qualitative, time, quantitative and spatial parameters (Table 11).

If as primary entity to consider entity of consumer for railcars delivery, for its performance by each TTS element, entities flow to the links previous in a technological chain is generated. Primary entity for railcars "generates" a set of entities for technological processes, each of which, forms entities for technological operations which are a part of this process.

For executing entity, operation need to have material, labor and technical resources, requirement in which is satisfied by means of formation with TTS element to adjacent links of a technological chain of entities for appropriate resources (Fig. 8) [2].

As a result of consecutive formation of a entities flow for services (works) and resources, it is formed peculiar "tree" of entities which can be used for operational planning and performance control of technological processes. In a general view

Table 11 Universal parameters of entity

Parameter	Entities types			
	On services	On resources		
		Labor	Technical	Material
Qualitative	Service type	Specialty and worker rank	Type of equipment	Type of resource
Time	Start time and duration of services	Start time	Start time of operation	Moment of resource requirements
Quantitative	The volume of services	Workers quantity	Equipment quantity	Resource quantity
Spatial	Service amount	Resources consumer	Resources consumer	Resources consumer

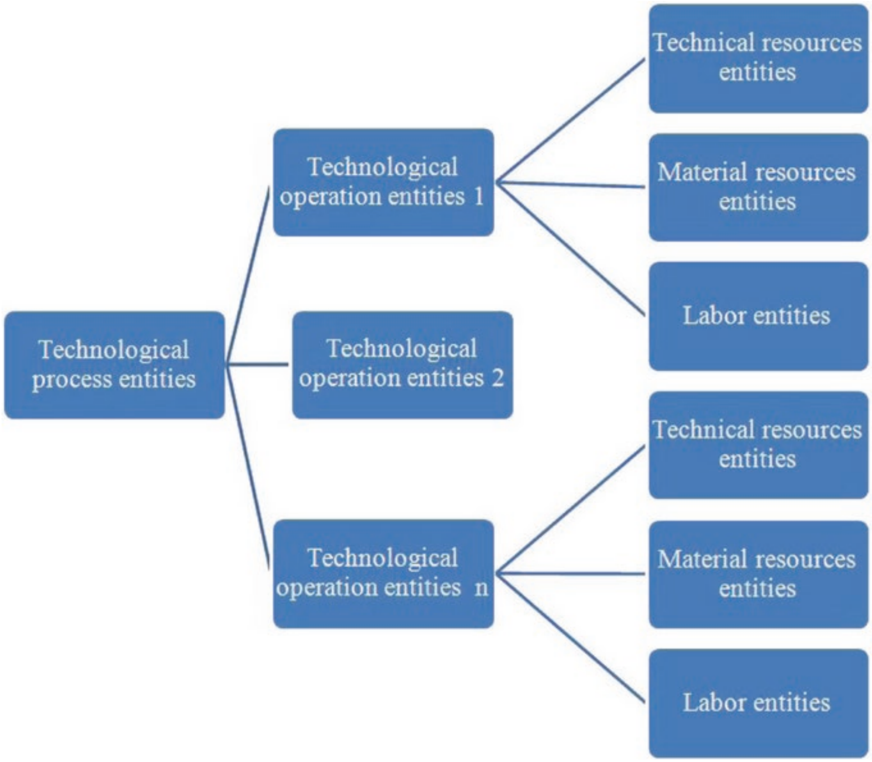

Fig. 8 Diagram of information formation of entities flow in TTS

"tree" of entities represents the structure having the final number of elements. Last element of the entities "tree" will be the entity on technical, material or the labor resources which isn't demanding for the performance of other technological operations.

Information system which is carrying out effective collecting, transfer, accumulation, processing and display of the administrative information necessary for TTS functioning has to provide performance of the following main functions:

- exchange of horizontal operational and tactical flows of information between divisions and technological links of TTS—an exchange of entities for works and resources and data on implementation of these entities;
- vertical streams movement containing information of coherence level of functioning of the TTS elements and costs of entities implementation;
- processing of operational and tactical information flows and formation on the basis of their analysis of internal strategic flows information necessary for decision-making on adaptation and development of TTS;
- processing of external and internal strategic information flows for the purpose of quantitative and quality standard of social and economic contradictions in

internal and external environments of enterprise, stage identification of enterprise development, timely forecasting of crisis situations and a strategic choice of next stage of development.

6 Recommendations for Software Implementation of ITS Models

As the software product realizing various approach to simulation and mathematical modeling within one combined analytical and simulation model it is expedient to use AnyLogic system [31]. This system of simulation modeling unites three approaches for simulation modeling known today—system and dynamic, discrete and event and agent based. For the solution of optimizing models in AnyLogic system, is used mechanism of integration into simulation model of external libraries of linear and nonlinear optimization programs, and also built-in instrument of combinatory optimization of OptQuest. AnyLogic system provides interaction of the developed combined analytical simulation model with databases of existing information systems.

Flexible interface of AnyLogic system allowing designing models by ready library objects provides effective control of the developed model under conditions of concrete TTS, and also to organize interactive support of made administrative decisions in real time.

As an example we will consider representation of operations of transportation process by means with description of railway objects with using “Railway library” of AnyLogic system. Trains, locomotives and railcars are presented in the form of the “entities” processed by these objects. Scheme of gridiron development of station is set by group of vector figures—broken lines and circles, according to representing railway tracks and their connections (railroad switches) (Fig. 9). Group of such vector figures is specified as the parameter of object of “RailYard” which carries out check of a correctness of the gridiron scheme, fixes employment of its separate elements in the advance course of trains on station, and automatically threws railroad switches.

For creation of new trains in the fixed or casual timepoints in library there is an object of “TrainSource” generating entities in the form of class copies “Train”,

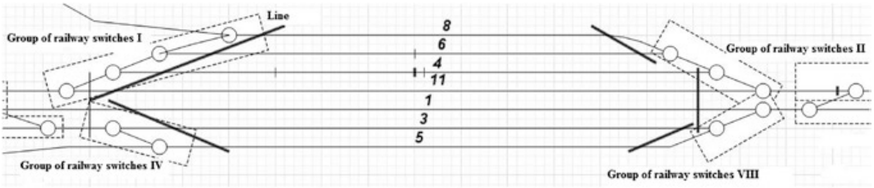

Fig. 9 Submission example of the scheme of railway station in system of simulation modeling of AnyLogic 5.9.0

containing data about railcars and locomotive, which are, in turn, class copies of "RailCar". Created train "is located" on the defined railway track—a certain broken line.

Train service in model is imitated by means of object of "TrainMoveTo" which key parameter is the movement route set by list of gridiron elements, a final element of a route or defined automatically depending on position of railroad switches on a route. For modeling of shunting work as the most rational way based on a task of list of gridiron elements. This list has to be received as a result of a way choice of train destination and check the elements of gridiron which sequence forms a movement route till a chosen way.

Vacancy checking system of a certain station track of appointment is carried out in model by means of RailYard is TrackEmpty function (Track_N). If "Track_N" is free, it is remembered as track destination.

Choice of track destination of shunting structure or train in model can be made not only on a vacancy condition one of tracks on which, according to technology, train is arrived, but also on the basis of more difficult criteria, for example, criterion of a minimum of railcars idle time at station reached as a result of definition of optimum sequence of railcars supply on loading areas.

These calculations need to be carried out until a start moment of shunting train movement. If decision on a delay of shunting train is for some reason made, in model it is necessary to provide time accounting and reasons of idle time. For the process of decision-making and delays in the operations of transportation process is rational to apply the method, based on the representation of gridiron elements in form of contingent resources used in the trains movement or shunting trains on these elements.

Implementation of this method in the model is performed using a threading chart that includes three object "Enterprises library": "Seize" (resource using), "Release" (resource releasing) and "ResourcePool" (supply of resource) (Fig. 10).

Seize object during the train passing (entity) uses the specified number (usually one) of resource from "supply", placed in the appropriate object ResourcePool. Resources number in object decreases by one unit.

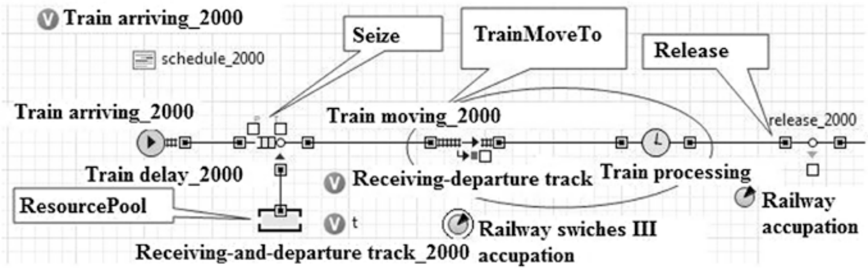

Fig. 10 Fragment of flow diagram example in AnyLogic 5.9.0, imitating a train delay of gridiron elements delay

If all resources are settled (appropriate track or all station tracks are occupied), next train will be delayed on that track where it will stay at the time checking (proceed into Seize). Delay duration is automatically fixed by “Seize” object. When train releases an element of gridiron, corresponding entity of train “passes” through Release object. Thus, unit of a resource is released and number of “free” resources (tracks) in object of ResourcePool increases by unit, that means an element vacancy for operations performance of transportation process with other trains.

Described method is applied to check delay of any gridiron elements—receiving-and-departure track, main, exhaust ways, loading areas, stages, and also groups of railway switches. Flow chart of AnyLogic describing the movement of shunting structure on railway station, in general view will represent following sequence of objects (Fig. 11) [2]:

- TrainSource—generates the departure moments from a nearby station (block) trains on the stretch, adjacent to the simulated station;
- Seize and ResourcePool—provide vacancy checking of span, which have train arriving to station and considers employment of span;
- TrainEnter—“place” train on span;
- TrainMoveTo—simulates trains movement on span before input light. As the “target traffic” in this case, you must specify intersection point of imaginary line representing input light, with a broken line, corresponding” of span in the model. Figure 2 these lines are shown in red colour and denoted in this example, the location of limiting posts.
- Objects connective TrainExit and Exit—transform train to abstract entity, which movement simulates process of a choice of train route movement at station.

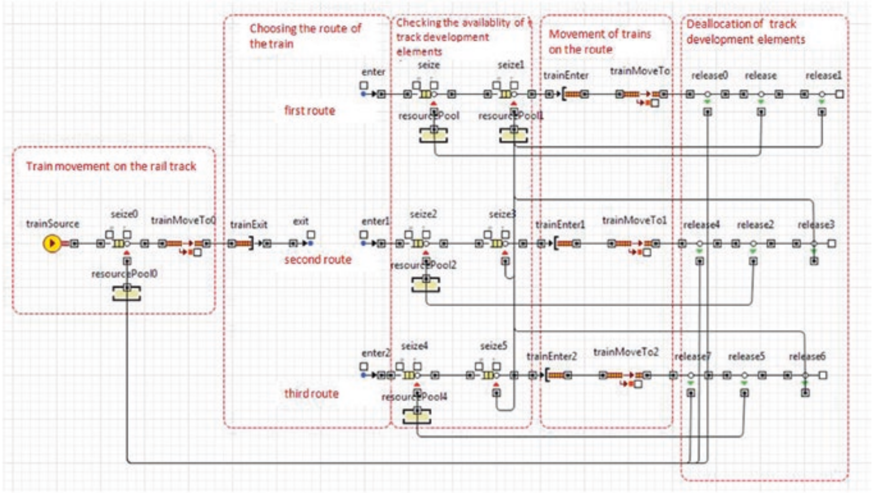

Fig. 11 General view flow diagram AnyLogic 5.9.0, simulating the train reception at railway station

In object “Exit” is realized algorithm of free track checking, train purpose or other algorithm of a choice of an optimum route. In a result one of few objects “Enter” is selected, every of them are conditional beginning of chosen route. Entity goes on an entrance of chosen object “Enter”. If alternative routes are more than five, instead of construction of object “Exit” and many objects “Enter” its rationally use the object “SelectOutput5”, allowing you to select one of five possible train routes;

- sequence of objects Seize and ResourcePool—provides verification of vacancy gridiron elements, through which passes selected route, and their delay in process of trains moving. If at least one of elements in this sequence is busy, then delay value is saved in object for further analysis to determine bottlenecks at the station. Entity passing through this sequence of objects Seize and ResourcePool simulates process of rout setting on the control panel route relay interlocking. As a result, all the elements of gridiron that are included in route are busy, which excludes in the model, their simultaneous using for performing various switching operations;
- TrainEnter—transform abstract entity to the train for simulating of its movement at station. It is necessary to place train on the same way on which it was with receipt in object TrainExit;
- TrainMoveTo—simulates train movement on route specified by list of gridiron items;
- sequence of objects “Release”, every of which releases a resource unit corresponding to gridiron element, held during the route.

Presented flow diagram of AnyLogic system can be used as standard for the description of various shunting movements at railway station. The offered way not only prevents emergence in model situation of trains collision, but also provides accounting of a trains delay of trains because of employment of gridiron elements.

Data of train movements, railcar supply’s, uncouplings generated by discrete event model are used in system dynamic model for intensity correction of flows and supplies in storages. On the other hand, routes changing of movement of railcar traffic flows, volumes of transportations, acceleration or delay of separate flows, structure correction of railcar traffic flows, decisions about which are made at higher levels of organization and are modeled with system dynamic model, used for adjustment parameters of elements of discrete event model.

By authors of this work proposed four stages of construction and research continuous simulation model of dynamic balance in TTS. First step is to define structure of simulation model, educated (in terms of system-dynamic simulation) “storages”, “flows” and “valves”. “Storages” correspond to cumulative elements of TTs, the “flow”—individual jets of freight or railcar flows, “valves” determine intensity of every thread. Depending on simulated level of TTS organization, by storage can be described as a separate loading areas or receiving-and-departure tracks, and whole railway station or special railway tracks.

At the second stage clarifies and sets values for the “valve”, which determine intensity of each flow. To obtain an adequate model, intensity of traffic or resource flows rationally define by distribution law of a random variable whose parameters are defined in the statistical analysis of flows.

At the third stage in model are specified bandwidth and processing capacity of structural elements of TTS. For this purpose, every storage is represented as two storages connected by one flow. Storage, which receives the input flow, shows the dynamics of number of delayed railcars due to lack of processing capacity of station. Storage is located before output flow allows to study dynamics of number of delayed railcars due to the lack of bandwidth capacity of span. Negative values of supplies in these storage elements correspond to reserves quantities bandwidth and processing capacity of stations and spans. Presents a system-dynamic model to evaluate bandwidth capacity and capacity of transport device in various settings railcar traffic flows in the system. Model value flows is proposed to use as the source data for discrete event model of technology of railway stations TTS.

7 Methods of ITS Deployment

The basis of the developed technique is the method of amplification (development) bandwidth, processing capacity, and capacity of elements of a regional TTS implemented at the VII level of functioning TTS organization. This method is a generalization of methods and models of functioning TTS at lower levels of the organization of this system. Method development TTS can also be applied at the VIII level of TTS organization—selecting schemes and patterns macrologistical TTS, but at this higher level of organization a significant impact on the effectiveness of promotion of transport and logistics flows have not only infrastructural factors, but also socio-economic factors of the placement region of elements of TTS. Obviously, development of infrastructure TTS has an impact on socio-economic factors of the region concerned, however, the study of such feedbacks is not the subject of this work. Therefore, the proposed method allows to determine requirement for new infrastructure elements (e.g., logistic centres) for passage of transport and logistics flows, and to choose the most favourable regions. For such decision methodology provides the construction of a system-dynamic model of relationship of socio-economic factors.

The overall algorithm of the proposed method involves building on each level of organization TTS combined analytical and simulation models used to assess the possibilities for implementing method of organization of functioning of the TTS, the calculation of changing parameters of the transport process and elements of the TTS, as well as to determine required amount of financial and information resources. The model solution at every higher level of organization TTS requirements for the parameters of transport-logistics and resource flows at lower levels. For compliance checking with these requirements are necessary calculations on the model systems at lower levels.

Obtained data from models of different levels is used for decision of combined analytical and simulation models of intelligent transport systems, taking into account the restrictions on the global resource flows. As a result of this global optimization adjusts parameters of the transport and logistics flows at each level of organization. The result of calculations in using this methodology is consistent strategic plan (target program) development of TTS. This plan defines scope of work and stages not only gain of bandwidth capacity and capacity of the infrastructure elements of TTS, but requirement for implementation of the developed methods of organization TTS functioning, providing targeted to raise level of TTS.

Main input data, needed to perform calculations of models are: values of bandwidth, processing capacity and capacity of elements of TTS; parameters of transport and logistics intensity flows, structure, irregularity indicators, etc., content of information flows—trains schedules, plans, train formation, requirements for timeliness of transportation, level of socio-economic region development; intensity of financial flows—actual costs of operation of TTS and planned (minimum) size of investment in the development infrastructure TTS. At every level of organization TTS this data set is specified with regard to the requirements and characteristics of level (set of specific data for levels of organization are presented in Table 10).

The developed method of forming intelligent transport systems in industrial enterprise includes the following main stages:

1. Evaluation of effectiveness of existing system repairs, optimization of resources in the system repairs and calculation of maximum level of reliability of technical means and devices which can provide a system repair with available resources;
2. Calculation of optimal size of transport consignments for all loading areas of investigated system. This identifies actual level of organization, which is analyzed TTS, and adjustment of value of transport costs on the basis of which is the calculation of optimal transport shipments. In addition to transport costs, adjusted inventory costs, if TTS is at the IV level of organization, and requirements for timely transportation;
3. Development of operational plan of railcars distribution at loading areas, taking into account the complexity of railcar traffic flow and load level of industrial railway stations. Determine requirements for the information flows (information system)for collection and transmission of information about railcars location at industrial railway stations, requirements of loading areas in railcars and cargoes, data about trains movement of contact schedule and shunting procedures, as well as data about factors influencing loading level of bandwidth capacity of stations. Determine requirements for financial flows—size material incentives shunting managers and duty stations depending on complexity of railcar traffic flows that are processed at every station;
4. Choice of the optimal sequence of implementation methods for structural engineering. Definition of requirements for increased bandwidth and capacity elements of TTS necessary to fulfill the specified requirements, timeliness of freight traffic at a given (actual) intensity, structure and uneven cargo and freight and railcar traffic flows in the system;

5. Assessment of utilization of industrial railway stations of special railway tracks and calculation of optimal routes promotion of railcar traffic flows. Determine requirements for development of bandwidth capacity and processing capacity of stations and spans;
6. Structure optimization of railcar traffic flows in railway transport node, by redistribution of sorting volume (shunting) between stations junction. The evaluation of capabilities of information systems for collecting and processing data required for calculation of urgency coefficient of railcar traffic flows, and to coordinate reallocation of sorting work volumes in node, determining required investments in information system development;
7. Assessment of level of bandwidth and processing capacities of elements of transport infrastructure of region, the choice of methods to enhance throughput and processing capacity, effectiveness evaluation of chosen methods, their ranking in terms of efficiency and determination of the implementation stages;
8. Assessment and monitoring of socio-economic indicators development of regions location elements macrologistical TTS, choice of placement of elements TTS.

As can be seen from the presented sequence, developed method is based on idea of a priority implementation of less costly organizational and technological measures, essence of which consists in redistribution of existing reserves bandwidth and processing ability of the transport devices. Implementation of reconstruction activities carrying, according model of dynamic balance, only if it is impossible to achieve organizational and technological activities required level of service quality in terms of irregularity increasing and complexity of structure of jets of railcar traffic flows. Thus, implementation of the developed method of forming intelligent transport systems in industrial enterprises can provide consistent coordination of parameters of flow at different levels of organization TTS, as well as to justify targeted programs to improve the quality of freight transport in TTS, gain of bandwidth and processing capacity of the transport elements of TTS.

8 Conclusion

The proposed universal for all levels of organization TTS functioning approach to the formation and operation of intelligent transportation systems based on the using of a combined analytical and simulation models TTS combined with transport and logistics methods of functioning organization of the railway, industrial TTS improves the efficiency of interaction between production and transport in terms of patterns complexity of traffic flow and increase of requirements to quality of freight transport. The main difference between developed analytical and simulation models (Fig. 7) intelligent transport systems in industrial enterprises from famous concluding in different approaches using to simulation modeling (rough-cut—system-dynamic and detailed—discrete event) within the model TTS that allows to simulate operation of TTS at all levels of the organization of these systems, to develop strategies improving organization of TTS. Developed a combined analytical and simulation model allows to optimize the parameters of transport and logistics flows in TTS (Table 4), as well as to choose the optimal sequence of techniques and methods of functioning organization of industrial railway transport-technological systems.

Approbation of developed integrated (intelligent) transport systems and complex transport and logistics methods was carried out during the elaboration of "The Concepts and programs to enhance throughput and processing capacity of railway stations and spans special railway track of OJSC "MMK", and also with changing of work organization of industrial railway transport of Novotroitskiy and Ashinsky iron and steel works.

Implementation of developed transport and logistics methods made it possible to reduce the cost of transport infrastructure reconstruction of these enterprises on average 25 %. The total estimated economic effect of implementation of the development programme of the TTS for OJSC "MMK" amounted to 310 million rubles (10 million dollars). Maximum payback period of investments into realization of all complex of actions amounted to 35 months.

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European Rail Traffic Management System (ERTMS)

Jakub Młyńczak, Andrzej Toruń and Lucyna Bester

Abstract The article presents information about the European Rail Traffic Management System (ERTMS). This system is one of important components ensuring interoperability of the European rail system. The structure of the ERTMS has been discussed and its individual components have been described. Train control systems (TCS) are used in many countries in the world. However, for a long time, those were mostly national systems used in individual countries. The system is being implemented in individual European countries (as well as outside Europe), but it will take many years to reach full interoperability of the European rail system. Rail traffic management is an important element of rail transport systems. It contributes considerably to ensuring the expected quality and efficiency of rail services while retaining the required traffic safety level. To meet contemporary safety requirements and growing user expectations, rail traffic management systems are based on technologically and functionally advanced IT solutions. The strategic management system harmonizes all technical and organizational actions to ensure the assumed quality and the required level of rail traffic safety in the respective area.Of course, the ERTMS is not a system used only in Europe (the European Union) but also outside the EU and Europe. The ERTMS is an example of ITS system in rail traffic. It can be noticed that the ITS implementation only

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shows very good establishment of requirements for the system within the entire European Union. It is the standard best described within the ITS. There are no such accurate guidelines for the entire traffic control and management system in road traffic.

1 Introduction

Train control systems (TCS) are used in many countries in the world. However, for a long time, those were mostly national systems used in individual countries. They did not ensure interoperability between individual Rail Administrations. In addition, a lot of TC systems, which were completely incompatible with each other, often co-existed in one country (e.g. in France). Only work on the European Rail Traffic Management System resulted in unification of the system ensuring interoperability of the rail system in Europe. The system is being implemented in individual European countries (as well as outside Europe), but it will take many years to reach full interoperability of the European rail system. Poland, as a country, in which no TCS was commonly used, is in a comfortable situation, as the implementation of the ERTMS, in addition to ensuring interoperability, is also an opportunity to increase the train speed as regulations do not allow speeds over 160 km/h without a cab-signaling system [1–4].

Rail traffic management is an important element of rail transport systems. It contributes considerably to ensuring the expected quality and efficiency of rail services while retaining the required traffic safety level. To meet contemporary safety requirements and growing user expectations, rail traffic management systems are based on technologically and functionally advanced IT solutions.

A typical functional structure of a rail traffic management system is presented in Fig. 1. The strategic management system harmonizes all technical and organizational actions to ensure the assumed quality and the required level of rail traffic safety in the respective area.

From the technical point of view, the “life cycle” of the application and elements of the rail traffic management system is shorter than for other related systems, such as intensely used elements of rail infrastructure or the rolling stock. Therefore, the traffic management system is a key issue for short-term optimization of rail services. High costs of strategic traffic management systems are mostly influenced by the costs of devices and rail traffic control systems. They consist of several traffic protection devices, which are necessary to ensure the control of train movement and train communication systems installed on the side of the infrastructure and on moving trains.

As a result, to optimize the costs incurred for the operation of such systems during their entire “life cycle”, it is necessary to develop a consistent and planned strategy for the implementation of these installations and their maintenance in the future [5].

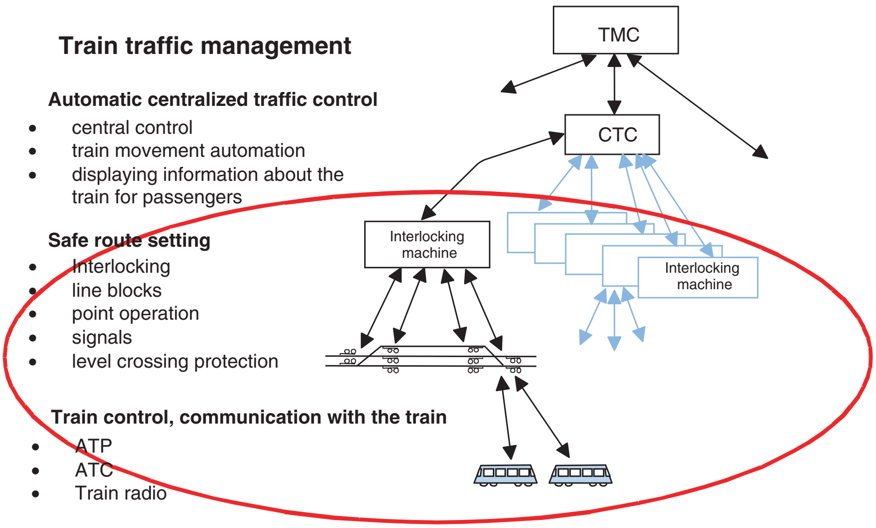


Fig. 1 Structure of the rail traffic management system

Following the development of management systems in other European Rail Administrations, one can notice that such systems were developed and used mostly in a given country under different conditions for each country. This resulted in reduced flexibility of the management process, mostly limiting it in one country, and sometimes to one Rail Administration.

In accordance with the idea of interoperability of the European railways understood as the ability of the rail system to ensure safe and continuous passage of trains, which meet the Community requirements for the rolling stock over the rail network, which meets the requirements for the infrastructure as described in EU directives, including 91/440/EEC, 96/48/EC, 2001/16/EC, 2004/49/EC, 2004/50/EC, 2008/57/EC [1–4, 17, 26] to improve international rail transport, it is necessary to combine and harmonize the actions of international management systems.

Considering the multi-layer division of broadly understood rail automation devices (rail traffic guidance and control systems), one can notice that the strongest need for the implementation of interoperability as regards to the control of train movement and train communication systems pertains to the lowest layer (basic control and communication with the train). It is a consequence of the fact that, in the past, uncoordinated development led to the creation of various technically inhomogeneous movement control systems, which, in fact, fulfilled the same functions.

Already Directive 96/48/CE, which results from the provisions of the Treaty on European Union, which includes, amongst other things, provisions concerning the trans-European rail network (Title XV, Art. 154, 155 and 156), defined legal conditions, which imposed, amongst other things, the obligation to use the

ERTMS system for all new high-speed lines and for all lines, for which rail traffic control systems are replaced. As regards conventional rail, they must be met within half a year after the decision entered into force on the use of the Technical Specification for Interoperability (TSI), which were adopted within the Directive 2001/16/CE. The ERTMS/ETCS system should be used for all newly constructed or modernized railway lines of particular importance for projects listed in decision 884/2004/CE.

Directive 2008/57/EC of the European Parliament and of the Council of 17 June 2008 on the interoperability of the rail system within the Community [6] clearly indicates that railway commercial activities over the entire railway network in the Community requires full compatibility of the infrastructure and vehicles and their effective connection as the efficiency of the transport system and the security level depend on this [6].

To achieve the required parameters, the Technical Specification for Interoperability approved by the *Decision of the Commission of 22 July 2009* amending Decision 2006/697/CE as regards TSI implementation in the control subsystem [7].

This means that the joint work of railways and industry has been implemented for 20 years in relation to the development of a technical description and a strategy for the implementation and development a new harmonized train control system—European Rail Traffic Management System (ERTMS), which is to ensure interoperability of rail transport, i.e. the possibility of free train movement within rail networks of individual countries (infrastructure owners) without the necessity of stopping at borders or changing the locomotive or train drivers. The introduction of the system is aimed at increasing the attractiveness of trail transport and increasing its share in intra-European transport [5].

These actions resulted in issuing directives by the E.U. for interoperability and Technical Specifications for Interoperability (TSI), which harmonize actions in these area among EU countries, at the same time assigning high priorities to guidance/control and information transfer for the train using radio communication, EU actions also impose taking specific actions by individual countries, which have prepared or are preparing necessary strategies for national migrations to ETCS. These strategies have to be harmonized and coordinated with European ones, especially for applications and implementations connected with traffic in transport corridors. Depending on the technical equipment, individual countries have different priorities for track-side installations and the rolling stock. Programs and strategies for ETCS implementation vary, depending on the country. In some countries, full applications are implemented on a large scale, while in other countries, it boils down to pure planning. However, in all national rail administrations, a very great interest can be noticed in gaining knowledge pertaining to these systems, especially as regards exchange of information about good and bad experiences. In addition, required information about the short and long-term potential market for ETCS components is provided by the industry on a regular basis [8, 9].

The European Rail Traffic Management System (ERTMS) is a modern system for rail traffic control and management. It is also consistent with EU attempts to create a unified European rail transport system. It should be noticed here that it does not involve the creation of one "European Rail" organization, but the existence of numerous infrastructure administrators offering an inter-operative rail route to numerous rail carries for providing transport services using inter-operative rolling stock [10].

The word "inter-operative" is of key importance here. Interoperability is broadly understood compatibility of:

- the infrastructure (tracks, engineering structures, platforms…),
- power supply (overhead contact lines, on-board energy meters…),
- control (train control systems, train radio communication, driver warning systems AWS…),
- traffic management principles (traffic rules, end of train device, personnel competences…),
- rolling stock (the gauge, axle loads, resistance parameters…).

In the light of EU legal regulations, interoperability does not only pertain to newly constructed lines, but also to existing ones, e.g. modernized or included in the Trans-European Rail Network (TEN or TNT), and, in accordance with Directive 2008/57/CE of the European Parliament and the Council of 17 June 2008 clearly identifies not only the trans-European railway system, but also the railway system in the Community as the area for TSI applications (which is also indicated by the reference in the title of the Directive) [11].

As regards the control system, broad implementation of the European Rail Traffic Management System is planned to ensure interoperability in the European Union [12].

2 European Rail Traffic Management System (ERTMS)

The European Rail Traffic Management System (ERTMS) originally consisted of:

- the European Train Control System (ETCS),
- the Global System for Mobile Communications—Railway (GSM-R),
- European Traffic Management Layers (ETML).

ETCS and GSM-R were fully defined in the specifications established by Decision of the European Commission 2008/386/EC of 23 April 2008.

The ETML layer, on the other hand—traffic management—was abandoned due to considerable differences between the expectations of individual Rail Administrations. Finally, it was decided that the ERTMS will include the possibility of storing information and its transfer using the interface and its use has remained the responsibility of individual administrations; therefore, the ETML was excluded from the ERTMS and included in non-structural TSI, i.e. TSI TAF and TSI TAP.

Considering the ERTMS in its current shape, one needs to take into account only ERTMS/ETCS (divided into the CCS—track-side infrastructure and CCO—on-board devices in the TSI) as well as ERTMS/GSM-R—a digital radio communication system [10, 13].

2.1 European Train Control System ERTMS/ETCS

The ETCS is to complement and, in the future, largely replace the differentiated Train Control Systems (TCS) with one common system. As since the beginning of the work on the ETCS, it was assumed that the system must be fully acceptable, certain general principles were adopted, which can be summarized in the following way: [26]

- The ETCS must make available all functions fulfilled by the currently used Train Control Systems, while some of the basic functions will apply to all lines equipped with the ETCS and other functions will be used on an as-needed basis.
- The ETCS will need to ensure the possibility of cooperation with various structures, both on the part of the vehicle and on the part of the infrastructure so that its use is acceptable from the economic point of view.
- The ETCS is to ensure traffic management in accordance with the requirements and regulations of individual rail administrations and to ensure high safety levels, not lower than the existing ones.

It is also necessary to make it possible to cross borders smoothly (borders between individual rail administrations) without longer stopovers to change the locomotive; reduce investment and operation costs by increasing the market and to introduce market principles of competition between manufacturers of control systems for railways by making available to potential manufacturers full documentation of interfaces between system modules as well as functional and systemic requirements pertaining to individual modules [10, 11, 14].

These objectives are implemented by far-reaching modularity of the system structure and functions, open hardware and software architecture and mechanisms for taking into account national and local traffic regulations.

The ETCS is based on digital signal transmission between the tracks and the vehicle. The signal can be transmitted via Eurobalise, Euroloop, digital radio channel and specialized transmission modules (STM) enabling cooperation with national systems of various infrastructure administrators. Data about the infrastructure describe the route and data about the train describing the vehicle (e.g. the train weight, braking effort, etc.) are used for calculating static and dynamic speed profiles, which will be described in a further part of the article. The calculated dynamic profile is continuously compared with the current speed as a function of the location. The tracking function, which is necessary to this, is based on unambiguous distinguishable (owing to unique numbers) and precisely tracked spot transmission devices—Eurobalise.

Control and supervision functions are always implemented according to the same principles, regardless of the channel which received information from the tracks.

The division into track-side devices, track-vehicle transmission and on-board devices is a classical division which always occurs in train control systems, based on track-vehicle transmission. However, attention should be paid to the fact that for the ETCS the majority of functions can be fulfilled by both track-side devices and by on-board devices.

The ETCS is basically devices into three levels (level one, two and three) and into two auxiliary levels—level zero and the STM level. Track-side devices are only prepared for the fulfilment of the specific scope of functions depending on the level. This scope is defined at the design stage of the ETCS for a given line, considering, amongst other things, the needs of the line (expressed by e.g. the required throughput or allowed speed) as well as the investment and operation costs.

Each vehicle equipped with ETCS devices, depending on the level, is capable of fulfilling all functions on the side of the ETCS on-board equipment. Whether individual functions are used or not depends on the content of the information received from the track, i.e. on the level of the ETCS use and the configuration of road-side devices. However, this does not mean that each vehicle equipped with the ETCS is capable of moving along each line equipped with the ETCS (e.g. a vehicle equipped with level 2 devices certainly can move along a line equipped with level 1, while the reverse situation is practically impossible).

It is necessary to distinguish clearly between the level of track devices and the level of devices on the vehicle. For example, a vehicle equipped with level three devices can move along lines equipped with ETCS level one, two and three track devices, but a locomotive equipped with ETCS level one devices can only move along lines equipped with ETCS level one devices, while it will not be able to move along a line equipped with ETCS level two or three as it will receive the “STOP” signal from the first encountered Eurobalise [13].

2.1.1 General ERTMS/ETCS Architecture

The specifications for ETCS requirements describe the so-called ETCS kernels with its interfaces to:

- the GSM-R radio system,
- line systems,
- on-board train equipment.

The general functional structure with connections of the system kernel and interfaces is presented in Fig. 2 [10].

On-board devices, i.e. the so-called Eurocab, include transmission devices and antennae for exchanging data with field locations: antennae for reading information from Eurobalise, Euroloops and GSM-R digital radio devices with an Euroradio connection devices.

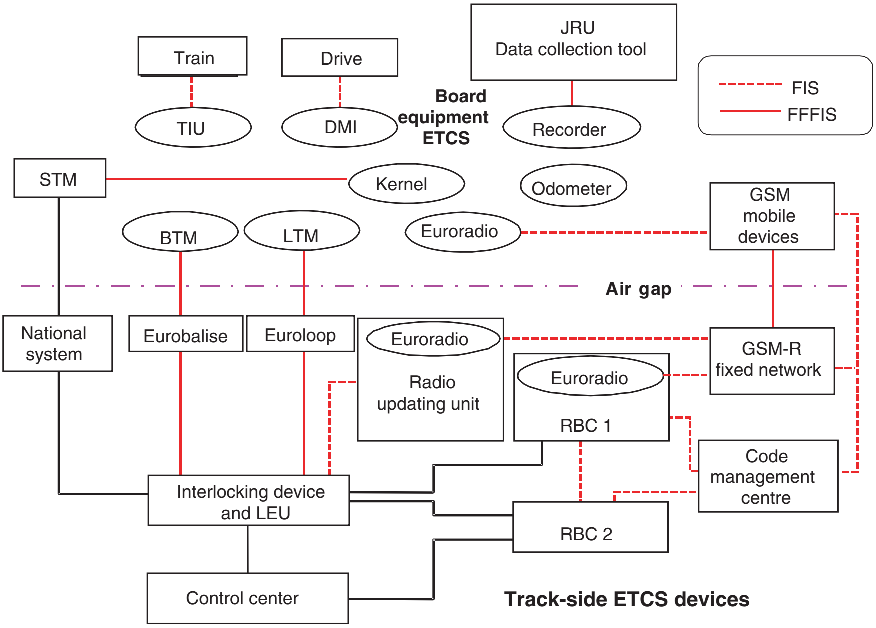


Fig. 2 ETCS functional structure

ETCS track-side devices contain data transmission devices using balise, loops or GSM-R and, additionally, various types of individual interface connection with permanent rail traffic control installations.

Two types of interface specifications are distinguished in the ETCS:

- FIS (Functional Interface Specification)—it is used to achieve logical interoperability.
- FFFIS (Form Fit Function Interface Specification)—it is used to ensure both logical and physical interoperability.

The FFFIS ETCS specification includes the interfaces listed below:

- (propagation) break for data transmission using Eurobalise or Euroloop;
- (propagation) break for data transmission using Euroradio/GSM-R;
- interface for adding a Specific Transmission Module (STM) to the Eurocab;
- interface for downloading data for the Juridical Recorder Unit (JRU);
- and the following FIS interfaces:
- Train Interface Unit (TIU);
- Driver-Machine Interface (DMI);
- interface between radioblock sections (Radioblock-Radioblock);
- interface for the key management centre.

The selection of these interfaces was justified and it resulted from the necessity to maintain proper operation for lines and traction vehicles equipped with devices by various manufactures and from the necessity to ensure interoperability. It needs to be emphasized that no full interchangeability of various subassemblies has been achieved, which is necessary to ensure a proper process of keeping devices in the required technical condition [10].

The construction of ERTMS devices in accordance with the description presented above allows for the fulfilment of a range of functions. However, system functions occur, which are largely independent of the transmission route (Eurobalise, Euroloop or GSM-R with an interface unit to Euroradio) used by ERTMS/ETCS. These functions include:

- Balise/radio transmission support;
- determination of the train location and report preparation;
- authorization for train movement;
- description of route properties;
- dynamic speed monitoring;
- special actions (timing, auxiliary operations etc.);
- external functions (operation of the Radio Block Centre RBC).

The basic operation of the system is based on calculating and controlling braking curves or, in other words, calculating the safe speed, its control and a safe response of the system if it is exceeded. The aforementioned curves depend on numerous factors. While the system was being designed, it was assumed that these factors can be divided into infrastructure- and vehicle-dependent ones. Sets of information about the train include data, such as: vehicle weight, maximum load on a single axle, maximum allowable speed, braking system parameters, etc. This information are introduced by the driver before the beginning of the trip together with the driver's ID. These data are not required for shunting movements. Sets of information, which remains unchanged for a given on-board ETCS devices, e.g. due to the vehicle structure and which can be read into the main memory from mass memory. The manual provision of data by the driver using the DMI (Driver–Machine Interface)—an interface used for cooperation of the driver with the ETCS system must be indicated as the simplest solution.

Data about the vehicle are provided once, before the commencement of the trip, while information sets about the route change both in time (depending on the traffic situation) and in space (depending on the vehicle location). This information mostly includes authorization for train movement, which consists of the maximum distance which the vehicle can travel and the allowable speed as a function of the distance from the reference point. In other words, the vehicle is informed about the fact that it received authorization to travel n1 metres at a speed of v1, n2 metres at a speed of v2, etc., after which it needs to stop if it does not receive a subsequent authorization for train movement before it achieves the location resulting from the valid authorization.

Together with the authorization for train movement, the vehicle also receives other information, which determine factors dependent on the infrastructure, which influence braking curves calculated by the system. Such information includes, for example, the track profile (rises and falls), permanent and temporary speed limits, distances from the neighbouring Eurobalises or information about other track-vehicle transmission channels [10].

On the basis of the information set about the vehicle and data about the route, the statistical speed profile is calculated. The static speed profile is a step graph of the allowable speed as a route function. It is called statistical as stepwise changes of the speed (without changing the position) are physically impossible—they do not take into account movement dynamics.

Numerous static speed profiles are distinguished in the ETCS, which can be seen in Fig. 2. Some of them are an integral part of the data set on the route and some must be calculated on the basis of data about the vehicle and information about the route.

Basic ETCS functions also include data registration. Two recorders are provided for in the ETCS. One of them, called the "legal recorder", is subject to full normalization at the European level. This recorder is supposed to collect all data necessary to reconstruct events, e.g. in a post-accident procedure. Both collected data, their storage format and the interface allowing for reading these data are defined.

Legal registration includes the following data:

- data introduced by the train driver,
- data exchanged between the vehicle and track-side devices,
- traffic events (e.g. changes of the operation mode),
- vehicle-driving parameters,
- system interventions (e.g. implementation of braking).

These data should be stored by the legal recorder for at least 15 days. At the same time, it is allowed and even recommended that additional "technical recorders" should be used by ETCS manufacturers for collecting technical data, including, for example, result information concerning the self-diagnosis process of an on-board device [10, 14].

2.1.2 Levels and Configurations of the ERTMS/ETCS System

The levels of the ERTMS/ETCS application, called briefly the "ERTMS/ETCS levels", as well as configurations available within various levels, can be presented using the functions discussed above. Three basic ERTMS/ETCS levels can be distinguished:

Level 1—train protection is limited to speed control. In practice, level 1 is an overlay on the station and linear devices, which retain the dispersed character of rail traffic control. Level 1 ETCS devices ensure that the train does not go beyond the place limiting the set and established route of passage and that it will not exceed the allowable speed at any section of the route. A locomotive equipped with ETCS Level 1 devices is equipped with: a safe on-board computer (meeting the requirements for SIL 4) (European Vital Computer—EVC), a Maintenance Computer—a computer-managing device on a vehicle (e.g. the odometer), the Driver Machine Interface—DMI, the recorder, the route and time-measuring device (unit) (the odometer) and an antenna for receiving information from

Eurobalises laid on the tracks. All these equipment elements are connected to an ETCS-bus, to which also other devices can be connected, if needed [10, 11].

A Level 1 locomotive may, but does not have to, be equipped with devices for reading Euroloop information and in GSM-R digital radio devices or specialized transmission devices.

A track equipped with Level 1 devices uses switchable and non-switchable Eurobalises. Additionally, it can be equipped with anEuroloop or radio used for updating information transmitted via Eurobalises or for bi-directional track-vehicle communication for preliminary information processing by track-side devices.

ETCS Level 1 can be implemented with or without data updating. The simplest configuration presented in Fig. 3 is Level 1 without updating. ETCS operation in such a configuration involves transmission via Eurobalises, authorizations for train movement issued by displaying a signal allowing for movement over colour light signals. To simplify it a little, it can be said that using an encoder (Lineside Electronic Unit—LEU), a switchable Eurobalise is connected to the signaller, which transmits authorization for train movement to the on-board ETCS device, depending on the signaller indication. The ETCS on-board device, based on the information received, controls whether the driver drives the vehicle in accordance with the signaller indication. Such a version of the system is cheap, but it limits the throughput of the line and requires the knowledge of the signalling system used on a given line. Level 1 is mostly intended for secondary and low-traffic lines, where no international or high-speed trains will be used and not line-throughput problems are expected. In practice, Level 1 is used in Europe not only on primary lines, but also on high-speed lines with traffic at speeds of up to 350 km/h. For lines with low traffic loads, the implementation of economically justified, cheaper, simplified Level 1 ERTMS/ETCS—ETCS Regional, ETCS LS (limited supervision).

S.A, ERTMS/ETCS Level 1 was implemented on the E-65 Warszawa—Katowice main-line as the basic system allowing for increasing the speed above 160 km/h. [25, 26]

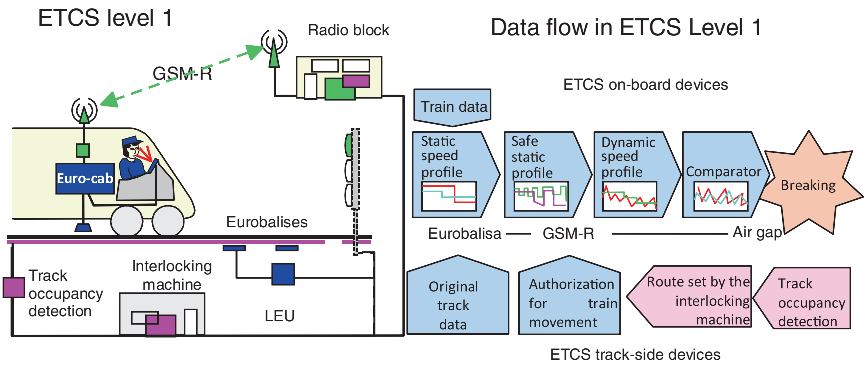


Fig. 3 ETCS level 1

Level 1 with updating can be implemented in various equipment configurations, while updating can be performed on a point basis (e.g. updating by additional Eurobalises) or on a sectional basis (e.g. updating via anEuroloop). It is also possible to update information via Special Transmission Module (STM) from the national system in the case of the Polish railways. The STM is intended for the automatic train braking and RadioStop area braking.

Level 2—ERTMS/ETCS involves traffic control based on continuous, digital, bi-directional radio transmission. A Level 2 locomotive, apart from devices, such as level 1 locomotives, must be additionally equipped with devices for the GSM-R digital radio channel.

Apart from Eurobalises, the tracks are additionally equipped with Radio Block Centres (RBC). At the same time, semaphores can be removed from the tracks as their functions are taken over by continuous digital transmission. Variable information can be easily transmitted via the radio channel, owing to which Eurobalises do not have to be switchable. However, they cannot be removed as they are the basis for confirming the vehicle location and constitute an element of on-board odometer calibration.

Level 2 is based on the GSM-R radio connection to issue authorizations for train movement and on the conventional track occupancy technique for prepared authorizations for train movement based on existing basic layer rail traffic control devices. Figure 4 presents the diagram of data transfer and processing at Level 2. Level 2 configurations are distinctly more expensive than Level 1 as serious costs connected with the GSM-R system are added. It should be emphasized, however, that GSM-R will also be used for other purposes, e.g. to ensure calling channels for train radio communication. Level 2 does not limit the line throughput and the driver does not need to know the signalling system for a give railway. It is mostly intended for international lines, high-speed lines and other lines of primary importance.

Level 3 is an extension of Level 2 by transferring the track occupancy control from track-side devices to vehicle devices. It allows for controlling the sequence

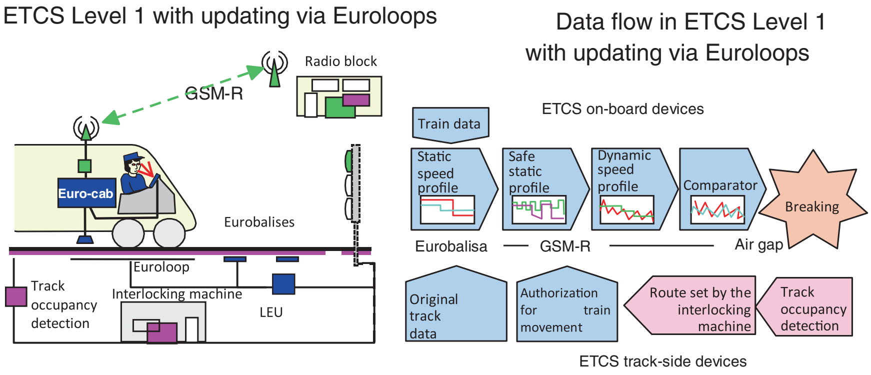


Fig. 4 ETCS level 1 with updating

of trains according to the moving block principle and allows for giving up track circuits and axle counters.

A level 3 locomotive, apart from equipment typical of level 2, must be additionally equipped with a safe and reliable Train Integrity Unit, which is why it will be mostly used in compact traction units. Apart from Eurobalises, Radio Block Centres (RBC), although occupancy control functions are fulfilled in a slightly different way [10].

Such a configuration allows for maximum use of the line throughput, however, it prevents mixed traffic, understood as the use of the line for passages of trains with and without ETCS on-board devices. Level 3 significantly increases the throughput of a railway line, on which it will be installed. It is possible to shift from Level 1 to Level 2 and from Level 2 to Level 3. ETCS Levels 2 and 3 are also called ATC (Automatic Train Control). The diagram of data transfer and processing for Level 3 is presented in Fig. 5.

For Level 1, the entire process of data processing takes place in the on-board device, while in the configuration for levels 2 and 3, the information processing partially takes place in on-board devices and partially in track-side devices, i.e. in the Radio Block Centre (RBC) For Levels 2 and 3, depending on the configuration, certain data processing steps can take place both in on-board devices or in the RBC. As it can be seen, communication at Level 2 and 3 of the ETCS is based on two track-vehicle communication channels which are used simultaneously. The first of these is a digital GSM-R radio channel and the other one is transmission using Eurobalises. The radio channel is a very good transmission medium; however, it does not offer the possibility of determining the current train position on the basis of information received. However, reliable, safe, accurate and current determination of the train position is necessary to control its movement. For this purpose, anEurobalise chain has been used, which constitutes an integral part of the ETCS. Theoretically, the Eurobalise chain can be replaced with a positioning

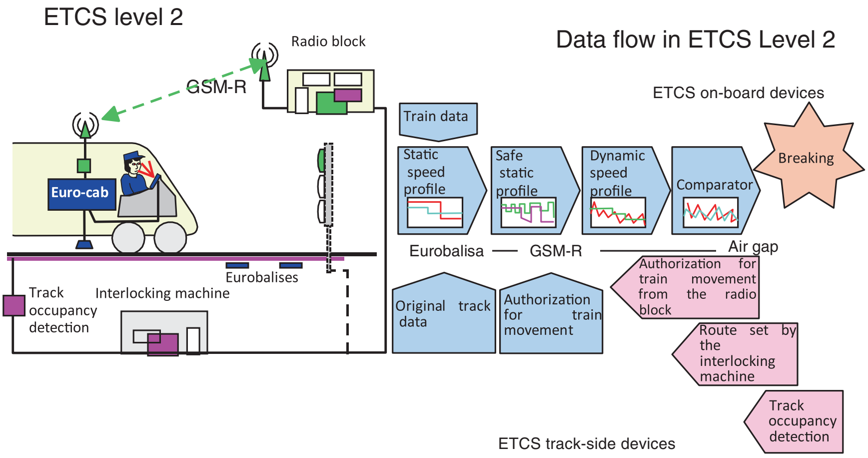


Fig. 5 ETCS level 2

system (GPS); however, today, this idea encounters technical and formal obstacles, however, specifications for the so-called “virtual balise” was prepared. Therefore, the use of Eurobalises and an odometer is assumed for determining the position on a standard basis (an on-board system for the route and speed measurement). The GSM-R system is used for sending all other information [11, 13].

On-board ETCS devices allow the driver to drive the train in various traffic situations without the necessity of switching off or disconnecting the system, by adapting its operational algorithms to various traffic conditions, e.g. for manoeuvring or passing a broken semaphore. As a result, various modes of operation have been distinguished, some of which can be initiated by the driver (e.g. passage to the manoeuvring mode) and some are initiated by information received from the tracks (e.g. running on sight).

2.2 Traffic Operation Methods

Regardless of application levels, the ETCS specifications distinguish several traffic operation methods. Three basic, typical methods for train traffic operation on a line are presented in Figs. 6, 7 and 8 [10].

2.2.1 Full Supervision Mode

In the Full Supervision Mode, the driver does not rely on information on the track-side signallers. The ETCS displays information on the DMI about the actual speed as well as about the maximum speed allowed for a given road section. If the actual

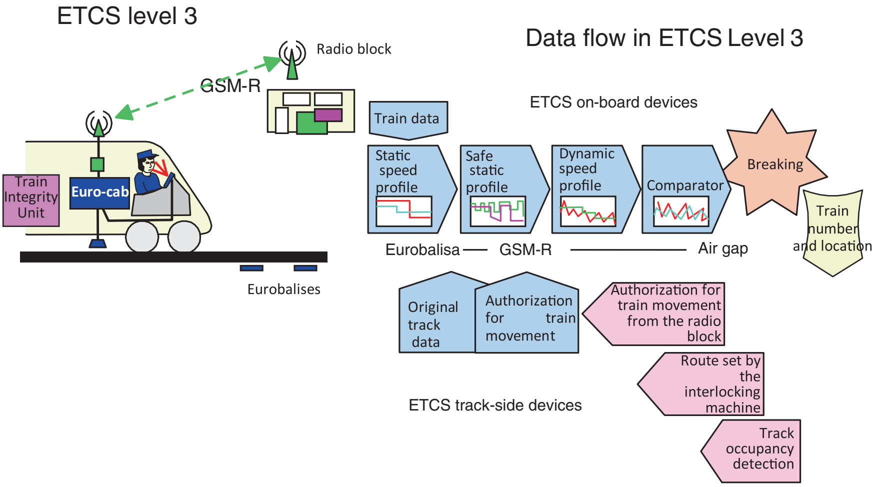


Fig. 6 ETCS level 3

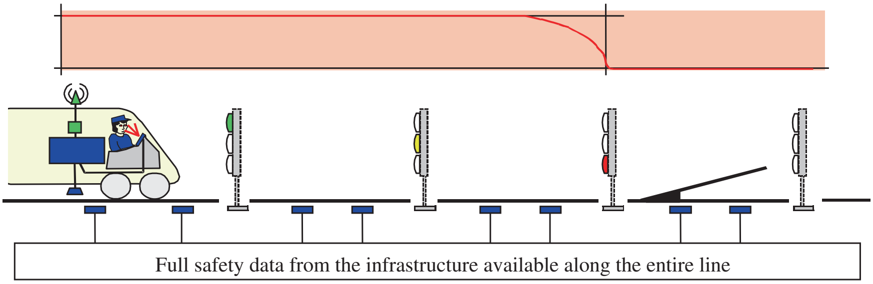


Fig. 7 Traffic operation method—full supervision—continuous supervision of the allowable speed along the entire length of the line

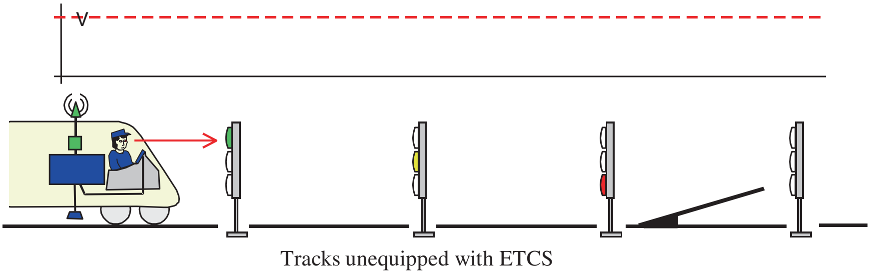


Fig. 8 Traffic operation method—unequipped supervision of the maximum allowable speed, no warning or train protection

train speed exceeds the critical value of the allowable speed for this road section, the ETCS acts on the brakes automatically.

The Full Supervision Mode is necessary on lines, where high speeds or high throughput is required. The Full Supervision Mode is also economically justified on lines, where the existing traffic protection devices are obsolete and where the ETCS with full supervision will create a possibility of full dependence on cab signalling and, thus, resignation from track-side signallers.

In the Full Supervision Mode, the ETCS operates using complete data from the infrastructure. These data are received from Eurobalises during the passage along the entire line and are sent to the ETCS in a safe format.

Figure 6 presents the Full Supervision principle in configuration with Level 1 ETCS with data transmission using Eurobalises.

2.2.2 Unequipped Mode

In the unequipped mode, there is no linear ETCS equipment. The driver proceeds (drives the train) in accordance with the indications on the track-side signallers. DMI ETCS only displays indications pertaining to the actual speed. The ETCS supervises the maximum (structural) speed of the train, but it is not capable of fulfilling any further train protection functions or supervising the speed as it does not obtain information form track-side devices (if the allowable speed is exceeded, the vehicle does not brake automatically).

In the Unequipped Mode, the ETCS may not practically contribute to increased train traffic safety.

2.2.3 Limited Supervision Mode

As presented in Fig. 8, the driver essentially drives the train based on indications from track-side signallers. The ETCS is a protection system indicating only the actual speed. At dedicated sections of the line with a higher potential risk, the track-side device provides all data necessary for continuous speed supervision. At sections with a low risk of exceeding the speed or collision, the track-side equipment provides only warnings, which may be connected with the spot speed control after travelling a specific distance. Other available simple functions include the speed trap—limiting the top and bottom speed or stopping the train.

In the Limited Supervision Mode, it is not necessary to safely provide complete data from track-side devices placed along the entire line to the ETCS. At selected line sections, it is considered to be sufficient to place Eurobalises transmitting permanent data (e.g. about a speed limit) in a simplified format. They are characterized by low costs of Lineside Encoder Units (LEU). Therefore, this mode, as regards to track-side devices makes the ETCS more scalable, which allows for its implementation in a shorter time and at a lower cost. Such a solution is recommended for lines which are already equipped with complete classical train traffic protection devices and where the existing traffic control systems ensure the functionality of the Limited Supervision Mode. In reality, such a condition exists on a larger part of the European conventional and regional rail network. The Limited Supervision Mode allows for adapting the rail traffic control devices on the line to ETCS Level 1 at the lowest possible costs. It also allows for meeting the interoperability needs at the same time.

3 Global System for Mobile Communications—Railway (Gsm-R)

GSM-R is another version of the GSM system (R—Railway) operating in the 900 MHz band. GSM-R corresponds to the functional version of GSM 2+, which makes available to users, apart from the calling channel, a digital radio channel for sending data, group calls, defining call priorities, functional addressing (e.g. using train numbers) and other specialized functions intended for services, such as railways or the police [5, 10, 15].

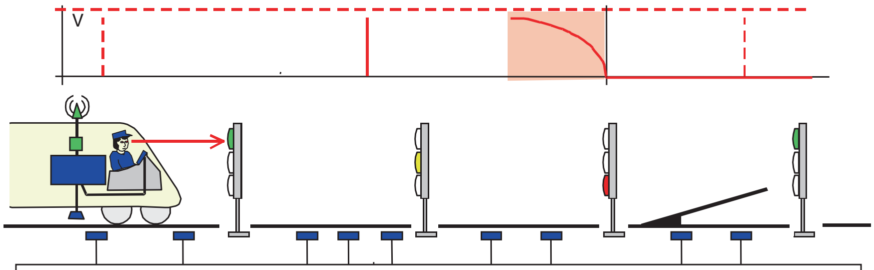
The GSM-R system architecture is a typical GSM mobile network and it consists of the main Network Switching Subsystem—NSS) and the Network Management Subsystem—NMS at the main level—and the Base Station Subsystem—BSSconsisting of peripheral groups of Base Station Controllers—BSC and peripheral groups of Base Transceiver Stations—BTS.

From the point of view of the ETCS, the GSM-R constitutes a transmission channel, which allows for sending authorizations for train movement by the Radio Block Centre—RBC to individual trains located within the entire area of the RBC. The GSM place in the ERTMS/ETCS system is presented in Fig. 9.

However, the GSM-R is not only a transmission channel for the ETCS system. GSM-R as an advanced communication platform finds a lot of applications both in the area of speech and data transmission.

EU legal regulations require that the GSM-R system should ensure the calling connectivity including train radio, manoeuvre, rescue and area connections as well as all other kinds. Individual infrastructure administrators, who are advanced in the implementation of the GSM-R system (e.g. DB Netz), are planning on using a unified communication platform for various applications supporting rail services (in the area of safety, travel information, data collection, settlements, carriage and shipment tracking…). For various radio connection specialists, the ETCS is one of such applications.

The GSM system was introduced into public use in 1992, as the second generation of mobile systems (1st generation mobile systems—analogue ones—were introduced in Europe in the 1980s, NMT-450i is an example of such a system in Poland). Rail radio connection systems in Europe are going through a similar evolution: from the first pioneer systems operating at various frequencies available in a given country, through systems developed more methodologically, e.g. operating in the 150 MHz band, to the most popular systems based on the UIC 751-3 standard (450 MHz). They were all analogue systems designed for the implementation



Full safety data from the infrastructure available at selected sections including the following functions: warning, speed limit, and stop.

Fig. 9 Traffic operation method, limited supervision—supervising the maximum allowable train speed, continuous speed supervision (ss) at selected sections, warning (w), speed trap (st) or stopping (s) can be used at other sections of a basic service: point-point voice connection and they were also characterised by a low degree of mutual compatibility (they did not ensure interoperability).

The current necessity of modernizing rail radio networks results from developmental needs and European rail integration (the introduction of faster and faster trains, increasing safety, interoperability requirement, etc.) as well as for economic reasons under growing competition conditions (higher management efficiency, lower costs). The existing means of communication proved insufficient for this purpose; hence, the International Union of Railways (UIC) undertook work aimed at creating designs of a modern train traffic control system. A system is based on the GSM-900 public digital mobile system marked as GSM-R in the railway application. Requirements for the system were developed at the UIC within the EIRENE project (European Integrated Railway Radio Enhanced Network). For the needs of this system, the ETSI reserved two frequency bands "adjacent" to appropriate bands of the public GSM system. To coordinate verification actions in practice, the MORANE Group (MObileRAdio for Railway Networks in Europe) was established, consisting of experts from European rail organizations and the industry, which developed, launched and practically examined prototypes of the GSM-R system at the test sections. These actions allowed for obtaining the final versions of functional (FRS version 7.0) and system requirements (SRS version 15.0) for the EIRENE system. At present, rail administrations in countries from the existing EU area are at various stages of implementing these projects [12, 16, 27, 29].

3.1 Basic Information About the GSM-R System

The following main functional characteristics, which distinguish mobile systems from traditional cable telephone connectivity, can be listed:

- the use of the radio as the transmission medium between the central unit and the user terminal.
- building-in mechanisms in the system allowing mobility of the user terminal,
- separating information about the user from information about the equipment.

One of the basic requirements of the GSM-R includes the necessity of serving a large number of subscribers using limited spectrum resources. It is achieved in three ways:

- by using 19 different carrier frequencies (multiple access with frequency division).
- at each of the channel carrier frequencies, multiplication of available channels was obtained using the TDMA method (Time Division Multiple Access), i.e. by establishing eight time gaps (8 calling channels),
- specific resources (carrier frequency and time gap) can be shared by many users separated by space, i.e. staying in various areas, cells that are not adjacent.

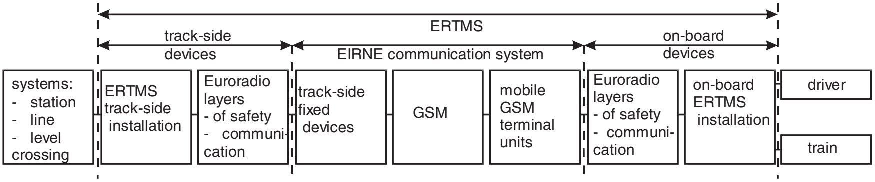


Fig. 10 GSM place in the ERTMS/ETCS system

The cell sizes (radii) range from approx. 30 km on a flat area outside cities up to several hundred meters in city centres. In places with a large number of subscribers, such as shopping centres, railway stations or airports, the so-called picocells with sizes of 100 m or smaller. Basic elements of the GSM-R are shown in Fig. 10. These include:

- subscriber stations (MS—Mobile Station) including a transceiver and a subscriber card (SIM card);
- The permanent radio transmitter serving the cell or, in other words, the BTS—Base Transceiver Station ensuring communication with mobile stations in this area. The BTS may include several transmitter-receiver units, the so-called TRX and it can serve several frequencies at the time. Under rail conditions, route base stations (linear, covering) and station ones (area-based, capacitive).
- The BSC—Base Station Controller ensuring control of many base stations and acting as an intermediary in the connection with a radio station. Base stations together with their controllers form a subsystem of base stations.
- The MSC—Mobile Switching Centre fulfilling commutation functions (connections between subscribers), access to the services as well as essential monitoring and control functions in the systems. For this purpose, the commutation subsystem includes, apart from the central unit itself, appropriate registers with necessary databases. Several MSCs usually exist in a given operator's network. At least one of them (GMSC) ensures connection with other telecommunications networks, also including the public telecommunications network.
- The HLR—Home Location Register)—a database containing information about a given operator's subscribers, together with information about their current location.
- The VLR—Visitor's Location Register—a database about subscribers travelling in the MSC area. It includes, amongst other things, information about the condition of each terminal device, ID of the call area, the address of the HLR, parameters of subscriber identification areas and transmission encryption. The appearance of a mobile station in a new area of location begins a registration procedure.
- The AuC—Authentication Centre—a database allowing for subscriber identification, which is aimed at preventing the connection of unauthorized subscribers and abuse on the part of subscribers.
- EIR—Equipment Identification Register, a database which allows for identification, e.g. of stolen or damaged transceivers or the ones with no approval, etc.
- The GCR—Group Call Register—a database about created subscriber groups supporting the group connection service.

- The OMC—Operation and Maintenance Centre—equipment for ongoing management and supervision of the network operation, allowing for identification of damage and reconfiguration.
- The SMS—Short Message System.

Radio connection always takes place between the subscriber station (MS) and the base station (usually the nearest one, i.e. serving the cell in the area where the subscriber is). To ensure the optimal quality of connection and the lack of interference in the adjacent channels, distortion measurement and power regulation mechanisms are used for both base station transmitters and mobile ones. Generally, direct radio connection between GSM transceivers is not possible. The direct mode, optional for the GSM-R system, which can be used if the equipment is out of range or if the network is damaged [10] (Fig. 11).

The connection between the BTSs and the BSC can use various techniques: landline, digital communication network or a radiolink, when no network is available. Further connection on the BSC—MSC route should use the skeletal telecommunication network ensuring appropriate throughput (in practice—an optical fibre network).

An important advantage of GSM systems, as compared to analogue systems, is a higher level of information protection against eavesdropping or interference with their content. Measures used for this purpose include:

- access to the network is possible on the basis of the subscriber's confirmed authenticity, but without sending an authentication key (Ki) by the network (Kis can be found on the subscriber's SIM card and in the HLR register).
- encoding information sent from and to the subscriber.
- using the Temporary Mobile Subscriber Identity (TMSI) within the network.

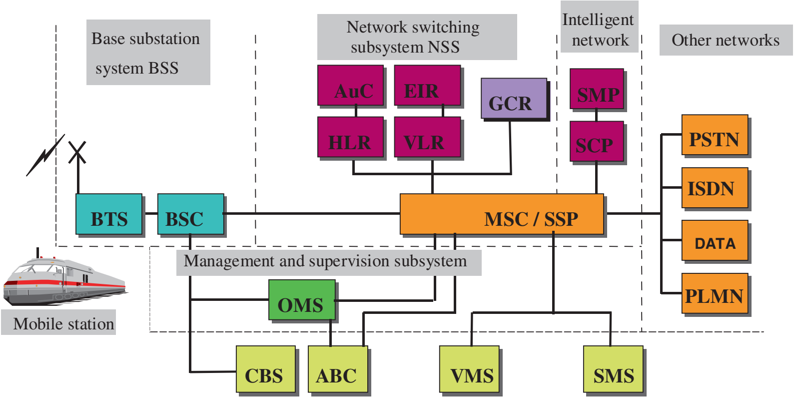


Fig. 11 GSM-R network diagram. *ABc* Administration and billing centre; *AuC* Authentication centre; *BSC* Base Station Controller; *BTS* Base station; *CBS*Broadcasting services; *EIR* Equipment Identification Register; *HLR* Home Location Register; *MSC* Mobile SwitchingCentre; *GCR* Group Call Register; *SCP* Service Control Point; *SMP* Service Management Platform; *SMS* SMS services;*SSP* Service Switching Point; *VLR* Visitor Location Register; *VMS* Voice Mail Service

After the transceiver is turned on, the subscriber is automatically verified and registered in the network on the basis of data contained in the subscriber's SIM card. The network accepts its own subscribers (who have an agreement, an account with a given mobile operator) or subscribers of their operators (in the so-called roaming, i.e. subscribers of other networks, which have a roaming agreement with a given operator). The GSM network will make connections to and from the registered subscriber within the scope of its authorization (i.e. in accordance with the scope of services contained in the subscription agreement with the operator).

The network checks the subscriber status on a cyclic basis, i.e. it verifies whether it is possible to connect with them or the subscriber's transceiver is switched off or outside the radio range of the network. The subscriber transceiver, on the other hand, receives cyclic information sent by the network base stations, which contains the operator's ID, information about the so-called call area and other necessary data.

A change of the call area (e.g. going from city to another or leaving the country) makes the terminal device connect with the network automatically and informs about its new location.

Connections to and from the subscriber involve a range of complex procedures. The terminal device reports a connection request in a special signalization channel in the current cell and if the connection is made from the network, the call is made in a special calling channel for all base stations in the call area, in which the subscriber is located. Next, connections are made in the signalization channel between the subscriber's terminal device and the network (Mobile Switching Centre—MSC), during which the subscriber is identified, connection parameters are established and the working radio channel is assigned for proper connection. Connections can be made both between mobile subscribers and subscribers of other telecommunications network. The transmission always takes place over the fixed network. During a connection, the network controls the quality of transmission in the radio channel and adjusts the power of radio transmitters appropriately or switches connections between base stations—cells (the so-called handover operations when a mobile subscriber moves from one network cell to another during a connection).

The network can also transmit short text messages (SMS) in a special signalization channel without making a regular connection. An extended control system allows for the provision of various additional services connected with switching calls between subscribers, arranging conference connections, creating groups of subscribers, etc.

The GSM-R network allows for data transmission using various techniques. The original technique, which used one channel, the so-called call channel, i.e. through circuit switching, limited the transmission speed to 9600 b/s. The HSCSD technology (High-Speed Circuit Switched Data) is a development of this technique, which allows for increasing the throughput by assigning several call channels to data transmission (throughput of up to 7.6 kb/s). However, these channels are only used for the needs of a given connection throughout its duration. The GPRS technology (General Packet Radio Service) is more efficient as it uses packet switched data. In theory, it offers transmission speeds of up to 115 kb/s, but in practice to approx. a half of this value.

3.2 Features and Services Characteristic of GSM-R

Features of GSM mobile radio communications are characteristic of the railway version of GSM-R.

Frequency: Frequency ranges assigned for the purposes of the railway GSM system are 876–880 MHz for connectivity from mobile to base stations and 921–925 MHz in the reverse direction. The interchannel distance is 200 kHz and the distance between frequencies for the "top" and "down" direction of the duplex system is 45 MHz. It allows for setting 19 channel with different frequencies.

As it is required that mobile terminal units should also work in the public GSM band, the practical range of operation for GSM-R terminal devices includes the following bands, 876–915 MHz and 921–960 MHz.

Values of group and collective voice calls: All devices should provide these services in accordance with the definition in the 2+ phase GSM standards. Services should be mostly used for:

- dissemination of messages from officers on duty to a specific group of trains in the area a given officer is responsible for,
- guiding group calls between train drivers and officers on duty in pre-defined areas,
- managing group calls between track workers, members of the manoeuvre team, station personnel and similar groups in local areas.

Multi-level hierarchy of importance and priorities: This service of the GSM-R standard allows assigning priority to specific calls to enable connections with a higher priority (related to danger, emergencies) at the expense of not serving (or even disconnecting) lower priority connections.

Transfer of the address and information about a place: A lot of railway employees should be addressed in accordance with their function and not by using their personal number. Function numbers can be changed on a regular basis. Train drivers are a typical example of such a change as they should be addressed, using current train numbers, which, in turn, can be changed for each passage. To overcome these difficulties, translation mechanisms should be provided, which will allow to send functional numbers to the majority of personal numbers at a given time.

Remote updating numbers remembered in the SIM: train drivers should have a possibility of connecting with officers on duty and other personnel after pressing one button. Additionally, train devices and other mobile devices must have a possibility of recognizing whether they are participants of group or collective calls that were made or not. To provide these properties, appropriate principles are stored in the SIM card. For example, when the train driver presses the "Officer on Duty Call" button, the number of the local officer of duty is selected from the SIM card and the connection is automatically assigned to this number. As the train moves, the current officer on duty number keeps changing. Thus, it is necessary to remotely update numbers on the SIM card in accordance with the current location of the train.

As information exchange between the officers on duty and train drivers is necessary, there exists a group of standard text messages, which are often sent between these two groups of system users. Due to the standardization of the content of such messages, it is possible to use a short code sent, instead of the entire message content. This code is interpreted on the receiving side and the full text of the message is displayed in the recipient's language.

Direct mode: Each mobile rail device can (optionally) use the direct connection mode so that it can connect with other mobile rail devices in the local area without using the GSM infrastructure. Such a mode can be used where:

- there is no GSM infrastructure,
- the GSM infrastructure is damaged.

Attention should be paid to the fact that one of the main reasons for implementing the GSM-R system is its use as a transmission medium for the European Train Control System (ETCS). This application is connected with higher requirements regarding the reliability of radio cover as compared to radio communications networks used only for voice connections. Factors exacerbating propagation conditions can be permanent (e.g. the lie-of-the-land), systematically variable (e.g. depending on the season—leaves or no leaves on trees) or accidental (weather conditions, interference, damage). To reduce the influence of these factors, a greater density of base stations is used so that their ranges overlap distinctly. Their greater density is also advantageous if one station is out of operation (e.g. as a result of damage), so that the vehicle is within the range of another station located in the vicinity [10].

3.3 Possibility of Using Digital Data Transmission of the GSM-R System in the ERTMS/ETCS

Another system of GSM-R radio communications ensures digital data transmission apart from voice connections. This transmission can be used to satisfy various needs as regards connection both between fixed objects and for connections with devices on vehicles. Digital data transmission made available by the GSM-R system can be used for:

- track-vehicle transmission for the purposes of the ERTMS/ETCS European control system,
- connections between the basic layer national signalling system (interlocking machines, blocks, passage protection devices) and the Radio Block Centre (RBC),
- applications connected with shipment tracking
- connections for the needs of virtual transcriber networks between train despatch offices and field transcribers and dispatchers.

- track-vehicle transmission for the purposes of the on-board information system for travellers,
- RBC communication with traveller information devices at stations included in the remote control,
- transmission of rolling stock diagnostic data,
- data for purposes of other applications which has not been defined yet.

As mentioned above, data transmission based on General Packet Radio Service (GPRS) is more advantageous than data transmission using the call channel as it allows for better use of radio spectrum resources. Among 13 European railways under analysis, the majority of them (8) declare that the GPRS system is used, only Norway declares that it does not use GPRS and other railways, despite the fact that they are not planning on using it now does not exclude such a possibility in the future.

4 Driver-Machine Interface

For the ETCS and GSM-R systems, the International Union of Railways proposes a joint Driver-Machine Interface—DMI.

The proposed interface device includes a touch screen divided into areas where icons are displayed. Main DMI areas are presented in Fig. 12. Each icon appears in a specific place on the screen in a color appropriate for the situation. The white icon means a normal situation and no need for the driver's response. The yellow icons still means a normal situation, but this time, the driver's response is required. The orange icon is an exceptional situation indicating an urgent need for the driver's response. If the icon turns red, it means that the system intervention has occurred and the system has replaced the driver, who did not drive the vehicle in accordance with the provided information. Colors are used for both classically understood icons and for the speedometer arrow and bar [11]. DMI areas:

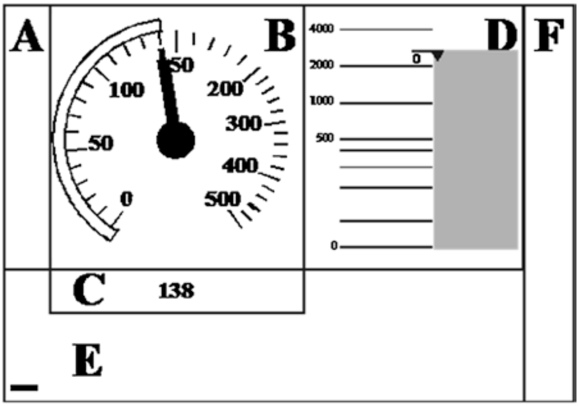


Fig. 12 Main areas of DMI common for the ETCS and GSM-R

A (braking data), B (speedometer) and C (speed values) pertain to the ETCS system, while D areas (planning—route description), E (supervision—vehicle device operation) and F (the driver's keyboard) are used by both the ETCS system and the GSM-R system. For example, the F area on the right side of the monitor the driver's keyboard. It contains the ETCS buttons, such as the "locomotive operation mode", "passage next to a signaller indicating 'Stop'" or "entering train data" as well as GSM-R buttons, such as "on-board radio functions", "call the first operator", "call the second operator", "call power supply supervision" and "urgent warning for all trains in a given area". The last button can be considered to be on the borderline between the ETCS and the GSM-R system [13].

5 Summary

In this chapter, an important element connected with train traffic operation within the European railway system has been discussed. Of course, the ERTMS is not a system used only in Europe (the European Union) but also outside the EU and Europe. The ERTMS is an example of ITS system in rail traffic. It can be noticed that the ITS implementation only shows very good establishment of requirements for the system within the entire European Union. It is the standard best described within the ITS. There are no such accurate guidelines for the entire traffic control and management system in road traffic.

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Intelligent Transport Systems in Aerospace Engineering

Anatoliy Kulik and Konstantin Dergachev

Abstract The tendencies of intellectualization in aerospace engineering are considered. The aircraft's intellectualization subsystems for various purposes are described. The types of intelligent systems in the infrastructure of aerospace engineering for pre-starting procedures and launch of an aircraft, air traffic control, airfield vehicles control are considered. Special attention is given to the intellectualization logistics of air transport.

1 Introduction

Progress of vehicles development is accompanied by number of negative impacts. Among them may be: an unacceptable level of human being losses, the growth of energy consumption of non-renewable sources, the negative impact on the environment, passenger and freight flows delay, etc. So, there is a number of harmful effects on the environment along with the need to improve transport means. Obvious contradiction between these two problems gives rise to seek for new ways of solving relevant scientific and technical problem providing for the vehicle safety. Currently, the solution of this problem can be found in intellectual vehicles implementation.

Continuous improvement of transport systems efficiency is achieved by constructing an integrated system that involves man, a transport infrastructure, vehicles as such, with maximum use of the newest information and control technologies.

Among transport systems, aerospace systems occupy a significant place. Aerospace systems use and integrate an aircraft or a spacecraft (flight vehicles, FV) for the purpose of things and passengers transportation. Today it is particularly important to improve exploitation efficiency of such systems.

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In aerospace systems, flight vehicle are used to perform functions of transportation which can bring us to new goals of FV functioning with taking into account various factors of environment and FV motion characteristics. Aircraft control is carried out through the use of control systems. In the past, they were building the FV control system with using a prior knowledge about the environment. Then the system operation was to work out a signal that has been preprogrammed; a need to adopt the system to certain conditions that could change happened. Recently an intelligent part of the control system performance was carried out by a crew along with a dispatcher; this led to simply implementation of fixed algorithms in the control system. The real situation requires alternative approaches for system design. In practice, environment conditions change, hence proper system parameters change. It is impossible to take into account all these changes prior to. Such a function may be implemented by using of a new class of control systems—intelligent transport systems (ITS).

Hither to, intellectual functioning of aerospace systems was possible at the macro level. The main control link of the system was the operator, i.e. a pilot, a navigator, an astronaut, a dispatcher skill of which affected the aerospace system and depended on. During the last decade a significant step in the development of computations, navigation, avionics, algorithms and software development, and advanced artificial intelligence occurred. This will result in reducing the human impact on effectiveness of the aerospace system.

It is clear that aerospace techniques intellectualization is an actual problem of scientific and technical research. This is expressed in extension and improvement of many functions of aircraft control and crowding man out of the control loop through the use of artificial intelligence.

Aerospace technology intellectualization will result in:

- effective solving navigation tasks without dispatchers and navigators assistance; e.g. the concept of 4-D navigation and free-plan flights (out of routes flights);
- carrying out profound diagnostics and workability recovery without ground services participation, during both flight and preflight;
- implementation of a number of other complex facilities requiring intelligent support.

Implementation of intelligent support is a prerequisite for the creation of the fifth generation aerospace systems. Intelligent support aims to reduce information overload, to deliver automation of aviation complex control, to supply a crew with situational awareness, to help making decision in a complex environment.

Intellectual support structure can be presented as the three types of automatic operations:

- missions being performed without informing the person;
- missions being performed with the help of informing the person;
- recommended tasks which the system should carry out after information confirmation.

Intellectualization of aerospace systems is the constructive way to improve safety of aerospace system operation, due to the fact that the human factor is often a reason of flight incidents and accidents. The solution of this problem can be achieved by full automation of the FV control. Ensuring information support for decision-making will become possible if you obtain the opportunity to collect, process, and display information that is carried out in the frame of the concept associated with a perspective CNS/ATM global system (communication, navigation, surveillance/air traffic management), developed by the International Civil Aviation Organization (ICAO).

Up-to-date technologies of elements production, e.g. the MEMS technologies, make a real opportunity to design an intelligent control systems that obtains properties of multi-level self-organization.

So new concepts like “the pilot new opportunities”, “smart body”, “distributed intelligence”, “active promoted environment”, “intelligent agent” can be implemented on the basis of intersystem integration of three kinds of medium: physical, information-type and virtual.

Actuating and sensor systems operate in the physical environment. Cognitive agents are members of information-type environment. A pilot and his professional surrounding occupy the virtual environment.

Aerospace systems intellectualization must be considered along with the associated infrastructure. The infrastructure embraces a number of tasks dedicated to the intelligent aerospace system control.

The following subsystems illustrate infrastructure functions:

- air traffic control;
- ground traffic control and guidance;
- weather conditions control;
- carrier missile control;
- satellite control;
- space stations control;
- logistics.

The paper describes basic trends intended to intellectualize a control system of a flight vehicle of various purposes.

2 Trends Intellectualization Objects Aerospace Engineering

Under intelligent information process mean combined aggregate of hardware and software that works in conjunction with a person or autonomously, that can based on the use of information and knowledge in the presence of motivation to synthesize the target, producing a decision on the action and find rational ways of achieving it.

Traditional understanding intelligence as artificial or natural, is associated with behavioral properties of systems, reaches a predetermined target in terms of active dialogue and counter.

Intelligent Transport Systems (ITS) in aerospace engineering are considered as intelligent systems that use information and communication technologies in the management of aerospace and infrastructure facilities, focused on improving the safety and efficiency of the transport process, comfort for transport users.

Research on artificial intelligence started from the middle of the last century and developed in parallel with the development of the theory of automatic control. "Artificial intelligence (from Latin intellectus—knowledge, understanding, reason)—the section of computer science, studying techniques, methods and techniques of modeling and playback on a computer sensible human activities associated with the solution of problems" [1]. Since the 80s of the last century began to use the ideas and methods using artificial intelligence in theory and practice of management. These artificial neural networks in problems of identification and the control, genetic evolutionary algorithms in problems of learning systems based on knowledge in the diagnostics. Artificial intelligence methods are applied to these control problems in which the control object cannot be adequately described by the equations of dynamics, such as differential equations, finite difference, transfer functions etc. [1].

The impossibility of adequate, accurate description depends on the a prior incomplete initial data about the object. An incompleteness of initial data caused un-certainty modalities of the object, its changes during operation, the uncertainty of destabilizing influences such as indignation, failures, malfunctions, and other factors, the characteristics of which cannot be obtained in advance and can be assessed only in the operation in real time. Thus, the intelligent control must be able to receive the information about the object, the destabilizing effect of varying operating conditions, to form conclusions, make decisions, and to stabilize the control and train.

As the basic objects of control in aerospace engineering are considered

unmanned aircraft (aircraft);
- piloted aircraft;
- spacecraft;
- group of aircraft (piloted and unmanned, space);
- ground complexes of start, tracking and landing.

As infrastructure aerospace engineering in the ITS considered airport and the center where flight control system implemented in which the air traffic control systems, control weather conditions, control traffic at the airport, motion control systems rockets, satellites, control systems, control systems space stations, logistics systems.

When considering piloted aircraft, ideas ITS basically already practically implemented on a global scale under the supervision of the International Civil Aviation Organization ICAO (ICAO) aviation. Thanks to the Standards and Guidelines management of international flights, airport operations and passenger services using information and communication technologies harmonized. All piloted aircraft have the means of communication, autonomous satellite navigation, automatic piloting, prevent collisions in the air, landing control etc. A ground service has the technology of continuous monitoring and the control in heavy traffic and echeloned.

Characterize the main features of the ITS in aerospace engineering, which have developed by now.

1. In world practice ITS recognized as a common transport ideology—the integration of telemetric advances in all transport activities to address economic and social nature—the reduction of accidents, improve the efficiency of public transport and freight, providing total transport safety, improved environmental performance [2].
2. The development and deploy of ITS—a potentially effective competitive business innovation and the development of new high-tech incentive industry sector, which is an important factor in crisis management [3].
3. Key components of intelligent transportation systems aerospace engineering are the same in almost all the existing systems. In the presence of the concept of development of ITS, all countries have their own national concepts and priorities to deploy of ITS programs in the aerospace transport, as recorded in the various regulatory documents [4].
4. Implementation of ITS in the aerospace field is strategic, in general defines the competitiveness of each country in the world market. Coordination and promotion of national programs in the aerospace field of ITS is carried out by the authorized government—the leader in the development of general policy and system-architectural, technical and functional standardization [4].
5. The key to the successful development of ITS in the aerospace area is the partnership of government, business, science and the public. This is implemented by creating a business company of open type, for example "ITS-Japan", "ITS-America", "ERTICO" in Europe, etc. [2].

Necessity of ITS applications in the aerospace field is dictated by the need to increase the volume of traffic and transportation services that cannot be achieved by the use of traditional planning methods based on the fragmentation air space and outer space [2].

ITS in the aerospace field is used to ensure efficient flight operations aircraft and spacecraft safety, national security, economic efficiency, environmental protection and unification projects.

Increasing the efficiency of operations associated with the increase in the number of flights that can be executed on the optimum profile, the trajectory and orbit of flight.

Improved safety is characterized by a reduction of the total number of incidents in the air, in space and on Earth, regardless of growth in aviation and space flight and starts.

Compliance national security associated with national security requirements, as well as the requirements of flight of space objects, both manned and unmanned aerial vehicles.

Environmental objectives associated with a decrease in the influence of the use of space systems and aircraft to pollution.

The main objectives of ITS in the aerospace area is the

- developing of modern technical solutions for the implementation of the procedures of forecasting and optimization of traffic flows;
- development of intelligent methods of digital information on the characteristics of the movement aircraft and the surrounding real picture space;
- effective use of modern avionics for optimizing flight paths aircraft;
- centralized planning of the use of aircraft in the interaction of the elements of the system the air traffic control (ATC) (ATM).

At ITS aerospace imposed the following functions:

1. Prevention of collision aircraft in airspace and outer space.

There are two levels of conflict prevention [5]:

- the first level consists of three stages of conflict prevention—strategic, tactical and short-term;
- the second level is provided as a safety net automatic alarm system, short-term intermittent conflict alert.

2. Prevention collision aircrafts on ground.

The ability of modern aircraft to take off and land in low visibility conditions increase the scale of the problem of ensuring the safe operation of their movement on the ground in conditions where visual recognition capabilities within the aerodrome maneuvering areas of the aircraft is low or reduced to zero.

3. Preventing collisions aircraft with Earth.

In strategic terms, this function is performed by a flight plan, defining the transition level and minimum altitudes on routes ATC safe landing trajectories of spacecraft.

4. Ensuring optimum performance of each aircraft flight.

Attention should be paid to needs to make flying with a minimum number of restrictions on the scheduled flight time, routes, paths, orbits, the vertical profiles of flight and time of arrival.

5. Providing crew piloted aircraft actual flight information.

Availability of aircraft's crew to date information is an important factor of safety.

6. Identification of aircraft for defense purposes

In accordance with national requirements ground services should assist services and missile defense in identification aircraft.

7. Activities associated with the rationalization of air traffic flow.

Service organization the air traffic control, flight control center should provide relevant information on the capacity of the air traffic services in the airspace, route, and in areas of airports, as well as the capacity of the relevant airports, spaceports, and all changes, wearing a temporary and permanent nature.

8. Ensuring alerting service and assistance during events for search and rescue.

Putting into operation reliable satellite systems and new onboard emergency beacons will affect the efficiency of emergency notification and assistance during search and rescue.

The main trends in the development of ITS in the aerospace area are

1. System and deep automation preflight preparation aircraft.

Preflight preparation is the most important stage of the flight of the aircraft. During preflight preparation necessary to process a large amount of diverse information and decide to take off.

The main factors affecting the decision are the take-off weight aircraft and weather conditions at the aerodrome of departure, destination (replacement) and route.

Based on the requirements set out in the regulations [6] main tasks implemented with preflight using the intelligent processing of data should be the following:

- determination of compliance actual take-off weight aircraft to permitted;
- determination of compliance meteorological conditions at the departure aerodrome to established;
- detecting the presence of dangerous weather phenomena on the route of flight;
- determination of compliance weather conditions at the destination to aerodrome established.

2. Expansion of application conditions preflight preparation aircraft.

Preflight preparation can take place under time pressure, so the solution of problems of preflight preparation is advisable to entrust the preparation of automated system preflight information, including intelligent decision support module to take off.

As an example of preflight preparation can be considered automated system navigational calculations, implemented on many aviation companies. Its purpose—calculation options for the air navigation navigator logbook to the particular situation prevailing prior to departure. For the implementation of the automated system of navigation calculations can be used on-board computing means for deciding to take off, based on the processing of information about the readiness aircraft for flight, on meteorological situation, information about the status of the controller and alternate aerodromes, air conditions and ensuring flight.

3. Increase the adaptability of aircraft control systems to expanding operating conditions.

The existing control system aircraft can operate at nominal flight conditions. In case of difference of flight conditions from the nominal values is a significant reduction of attainable implemented control system, compared with the region of possible maneuver aircraft. Intellectualization control systems aircraft in the direction of increasing adaptability will eliminate this drawback, on the basis of intellectual synthesis of aircraft flight paths for the current conditions and the management team on this trajectory. This approach extends the range of initial conditions, which can operate the control system and improve the efficiency of the existing control system. Intellectualization control systems aircraft in the direction of increasing adaptability will eliminate this drawback, on the basis of intellectual synthesis of aircraft flight paths for the current conditions and the management team on this trajectory. This approach extends the range of initial conditions, which can operate the control system and improve the efficiency of the existing control system. Usually such intelligent subsystem is performed as a standalone software module included in the computer system of piloting.

4. Improving safety of the aircraft.

An important and increasingly pressing concern is the issue of increasing the safety of aerospace systems. Creation and development of complex engineering systems present level, what is the aircraft, currently requires an approach based on the method of multicriteria analysis and design. Advances in computational methods and equipment requires the use of (creating) new algorithmic procedures based on parallelization processes. To solve the problems of multicriteria optimization is now relevant is the study and development of methods based on the use of systems with artificial intelligence (neural networks, evolutionary algorithms, fuzzy logic methods etc.).

There are four basic approaches to the construction of intelligent systems—a neural network, fuzzy logic, expert systems, and evolutionary algorithms. A distinctive feature of all these approaches is that unlike standard deterministic methods they use ideas simulation of the brain, the mechanism of decision-making rights and the principles of nature (evolution, natural selection).

Among the examples of intelligent safety systems aircraft, can be identified, the following system

- Proximity Warning System aircraft in the air (Traffic Collision Avoidance System—TCAS);
- Proximity warning system earth (Ground Proximity Warning System—GPWS) etc.
- Improving the comfort of using aircraft.

In the area of exploitation aerospace systems are aviation tendency to increase the level of comfort of passengers and flight crew members. For example number of activities both at the stage of designing aircraft and the operational phase and the entire aircraft, aerospace systems.

For example, at the design stage using intelligent aviaconstruction materials, as well as special propulsion, provides enhanced comfort of the crew and passengers—by reducing vibration and noise. In systems of aircraft the intellectual conditioning and heating system for microclimate on board aircraft is provided.

To provide comfort and convenience of passenger service uses intelligent logistics system:

- transportation logistics;
- inform passengers and carriers;
- ticketing system;
- system streamlining passenger and freight traffic etc.

3 ITS Objects

3.1 Background

The main controlled object in ITS is an aircraft in, which is a complex hierarchical system designed to purposeful control movement in the atmosphere or in space [6, 7]. However, the aircraft cannot be considered separately from that aerospace system in which it operates. Consideration of the aircraft in the scheme of “Air Launch” (Fig. 1) best describes the aircraft as part of modern aerospace systems.

The main features of the aircraft application with using such scheme:

– sloping aerodynamic descent;
– the low overload and a high level of comfort compared to other aircraft;
– precise landing of plane type to one of the aerodrome;
– minimization of the waiting turns number in the orbital motion.

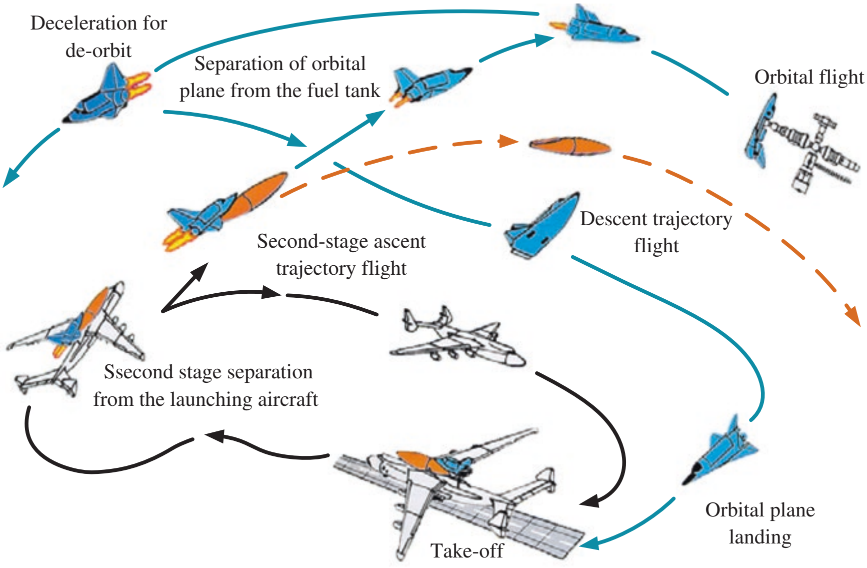


Fig. 1 General diagram of the aerospace system “Air Launch”

Procedure of this aerospace system operation provides satellites launching into Earth orbit with almost any inclination. This is achieved by the fact that the air-plane can implement missile launching at a distance of 4–4.5 thousand kilometers from the launching site. In this case the area of a missile launch while planning of each specific flight is selected on basis of providing a given satellite orbital inclination, location of flight path and areas of falling detachable part of the rocket. In the scheduled area of missile launching to create the most comfortable conditions for the initial flight, the launching aircraft performs a specific maneuver, which allows providing the flight mode, which is close to weightlessness.

At that moment the normal overload on the missile does not exceed 0.1–0.3 units. This solution allows increasing the launching mass of the missile compared with the ordinary launching in horizontal flight mode by 2–2.5 times, and hence improving its weight-lift ability.

At the moment when the launching aircraft at a mode “Pull-up” reaches the maximum flight path angle to the local horizon the missile ejected by a special launch container using a pneumatic ejection system, equipped with a powder pressure accumulator (Fig. 2). After the missile ejection procedure and the subsequent flight of its first and second stages, as well as a space booster, satellite separation and its output into the desired orbit are implemented.

It is noteworthy that the technology of heavy cargo’s dropping from aircraft, significantly exceeding the weight of loads that dropping in the normal horizontal flight, was implemented in the USSR in the 1987–1990 periods as part of a program “Energy-Buran”. This technology was developed under the rescue of reusable rocket units of the rocket “Energy” first stage and included the heavy cargo dropping in aircraft’s flight conditions close to weightlessness.

The structure and configuration of aircraft control system depend on the type, purpose and configuration of an aircraft as a control object. Aircraft is one of the units of closed-loop control system (stabilization), therefore, its characteristics and the specificity determine quality parameters of the overall system (Fig. 3) [6], during the process of design and analysis of control systems it is necessary to take into account the specificity and characteristics of the aircraft as the control object.

Therefore the classification of aircraft as the control object in intelligent transport systems can be performed by various characteristics:

- human participation in control process (manned and unmanned aircraft);
- type of aircraft aerodynamic configuration;
- mission or purpose of the aircraft;
- construction diagram of aircraft;
- creation of lifting force (wing, jet thrust, moving plane—helicopter blades);
- type of aircraft engine etc.

Based on of these criteria, a classification of aircraft can be made [8] (Fig. 4).

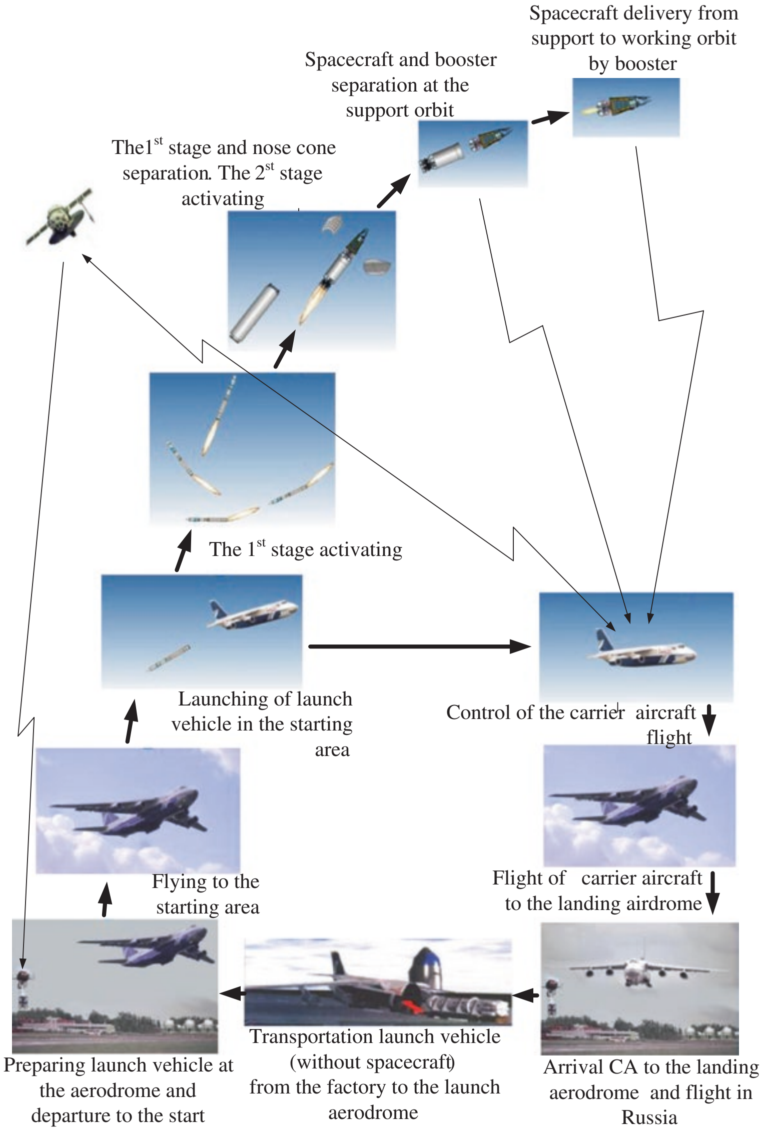


Fig. 2 Implementation of functioning aerospace system diagram “Air Launch”

In this paper the following objects are considered as ITS’ control objects:

- unmanned aircraft;
- manned aircraft;
- spacecraft;
- control of objects’ group;
- launching, tracking and landing ground complexes.

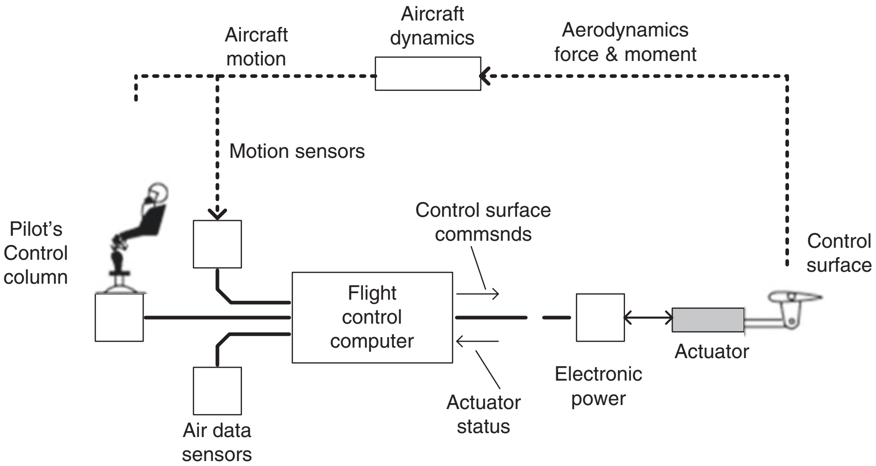


Fig. 3 The integrated functional diagram of aircraft control system

3.2 *Manned Aircraft*

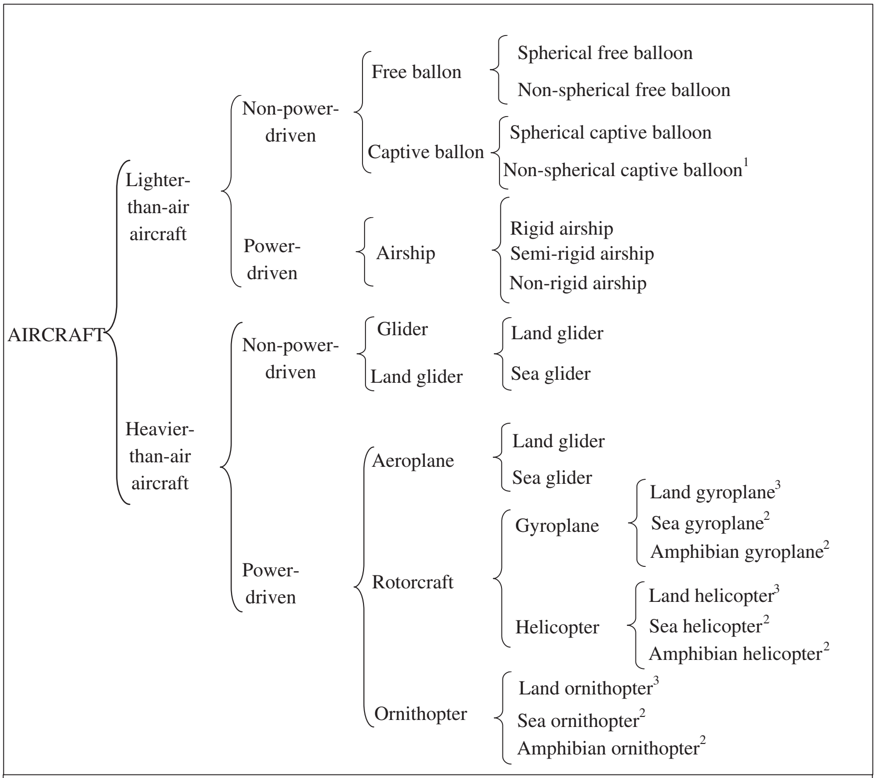
Manned aircraft is a complex dynamic system with variable mass and moment of inertia, time-varying number of freedom degrees, mechanical links, power and other interactions with the launcher and the other elements of the ground equipment and buildings [6].

At the same time the aircraft is a complex physical system, and vehicles which are controlled by human are also a biophysical system.

In this system, that are subordinated by control and monitoring algorithms, interconnected physical processes, complex movements of structural elements and moving elements of ground equipment, fuel components in the tanks, pipes, engine cooling jacket, movement of compressed gases, supersonic gas jets, and others occur. The movement of the aircraft and the movable elements of its configuration is the external demonstration (reflection) of these processes and begins before the aircraft lift-off from the Earth.

According to the ICAO standards all aircraft are divided into 5 categories by speed characteristics. The aircraft landing minimum and parameters of approach are determined based on this classification. Speed (indicated speed) classification of aircraft (Aircraft Approach Category ICAO) for the approach procedures calculations is presented in the Table 1 (the upper value is indicated in bold in kilometers per hour, lower—in miles per hour, knots).

One of the most important systems of the aircraft is a system of space traffic and the operation of all its components and subsystems control. The main tasks of the aircraft traffic control which are solved by control system are stabilization, navigation and guidance [9].



1. Generally designated “kite-balloon”.
2. “Float” or “boat” may be added as appropriate.
3. Includes aircraft equipped with ski-type landing gear (substitute “ski” for “land”).
4. For the purpose of completeness only.

Fig. 4 Classification of aircraft used in the ICAO

There are three modes (methods) of the aircraft traffic control:

- manual;
- semiautomatic;
- automatic.

A control system must be used to implement any of these methods. On modern manned aircraft it was transformed from a tool, only facilitates the process of the aircraft pilot control, in an intelligent system that provides the efficient operation of the aircraft:

- traffic control under any conditions;
- propulsion power plant and other units control;
- the aircraft system control;

Table 1 Classification of aircrafts used in the ICAO

Aircraft category	VAT, km/h knots	Range of speeds for initial approach (and reversal and racetrack procedures)	Range of final approach speeds	Maximum speeds for circling	Maximum speeds for missed approach	
					Intermediate	Final
A	<169 <91	165/280 (205[a]) 90/150 (110[a])	130/185 70/100	185 100	185 100	205 110
B	169/223 91/120	220/280 (260[a]) 120/150 (140[a])	155/240 85/130	250 135	240 130	280 150
C	224/260 121/140	295/445 160/240	215/295 115/160	335 180	295 160	445 240
D	261/306 141/165	345/465 180/250	240/345 130/185	380 205	345 185	490 265
E	307/390 166/210	345/465 180/250	285/425 155/230	445 240	425 230	510 275

VAT Speed at threshold based on 1.3 times stall speed in the landing configuration at maximum certificated landing mass

[a] Maximum speed for reversal and racetrack procedures

- monitoring, diagnosis and recovery of machines and systems technical status;
- preflight control, life support and maintain comfortable conditions on board;
- automatic implementation of extreme flight modes (approach, landing, take-off, missed approach, and others);
- reconfiguration of functional systems structure in the case of failure, etc.

Such intelligent control systems are digital and are developed based on the use of onboard digital computing systems. With their help intelligent algorithms for solving control problems are implemented. Development and debugging of the onboard digital control systems algorithms is one of the major tasks of the aircraft control system design.

3.3 Unmanned Aircraft

In the literature, the term “UAV” is commonly understood as remotely piloted (RPV) and automatically controlled aircraft. The difference between these two types of UAVs is due only with a degree of an operator participation in implementation of unmanned aircraft complex (UAC) task. In the future, all considered unmanned aircrafts will be denoted by the generic term “UAV”, without dependence from automation of their operation.

The term “UAV” shall mean an aircraft without crew on board, equipped with a motor driven autonomously or remotely controlled, able to carry the load for the implementation of its task [10].

Classification of UAVs can be made for different features. The most commonly used features are purpose, principle of flight, an aerodynamic configuration, weight, duration of flight, engine type, control principle (Table 2) [11].

This classification is only a sketch caused by tribute to tradition, since the UAV is only an active part of unmanned aviation complex (UAC). Another its part is ground segment, including preparation facilities, support services, reception and processing of information. Use of UAC has several advantages:

- absence of crew on board;
- high maneuverability;
- mobility;
- low cost of operation;
- ability to work in dangerous conditions;
- significantly high rate of “cost—effectiveness”.

Rapid progress in development of UAVs for different purposes are caused largely by two factors (economic, scientific and technical):

- significant increase in price and operational costs of manned aircraft in peacetime and wartime;
- the general scientific and technological progress and development of computer technology.

Table 2 Classification of UAVs

<table>
<tr><td colspan="7">Purpose</td></tr>
<tr><td>Manufacturing and environmental monitoring</td><td>Digital 2D and 3D cartography</td><td>Patrolling of objects, terrain and borders</td><td>Search and rescue</td><td>Chemical treatment of objects and grounds</td><td>Accurate delivery of cargoes</td><td>Retransmission for corporate organizations</td></tr>
<tr><td colspan="7">Flight principle</td></tr>
<tr><td colspan="3">Static</td><td colspan="2">Dynamic</td><td colspan="2">Ballistic</td></tr>
<tr><td colspan="7">Aerodynamic configuration</td></tr>
<tr><td colspan="3">Balloon</td><td colspan="2">Airplane</td><td colspan="2">Helicopter</td></tr>
<tr><td colspan="7">Weight</td></tr>
<tr><td colspan="2">Small-sized</td><td colspan="2">Middle-sized</td><td colspan="2">Large-sized</td><td>Huge</td></tr>
<tr><td colspan="2">micro to 5 kg</td><td colspan="2">mini 5–200 kg</td><td colspan="2">2000–5000 kg</td><td>>5000 kg</td></tr>
<tr><td colspan="7">Flight duration</td></tr>
<tr><td colspan="3">Short duration,
t < 6 h</td><td colspan="2">Middle duration,
6 < t < 12 h</td><td colspan="2">Long duration,
t > 12 h</td></tr>
<tr><td colspan="7">Engine type</td></tr>
<tr><td colspan="2">Electrical</td><td colspan="2">Reciprocating</td><td colspan="2">Turbine and turbopropellers</td><td>Turbojet</td></tr>
<tr><td colspan="7">Control principle</td></tr>
<tr><td colspan="3">Remotely-controlled</td><td colspan="2">Autonomous-manned</td><td colspan="2">Combined-manned</td></tr>
</table>

- These and other advantages of the UAC allow classification for a greater number of features that reflect new systemic effects resulting from integration of the UAC, payload and ground-based complexes.
- At the same time UAVs have disadvantages compared with manned aircraft, in particular :
- Lower flexibility in the implementation of a given task.
- A significant increase in requirements to the information component of the onboard equipment and to the UAV's avionics complex control in the implementation of a given task.
- The difficulties of creating high-performance communication channels between the operator and the UAV (or between several UAVs when performing of a given task in group flight). Now such communication is possible only on the distance of direct visibility. Radio relay stations or other air (space) platforms are needed to achieve greater range.
- Difficulties in flights over densely populated areas in peacetime, particularly in airspace seriously saturated with civil aviation

These drawbacks are largely compensated by the advantages of UAVs [12, 13, 14]. Therefore, almost all developed countries in a varying degree takes part in the development of UAVs for military and civilian purposes [13].

Number of problems solved UAVs for civil use is very wide and has a tendency to further rapid expansion. For given UAVs backgrounds of development are:

- high potential to development of catastrophic situations due to abnormal and emergency situations in numerous industrial objects and technological infrastructure and natural objects necessary in connection with this rapid response and control the output of such situations;
- extent of natural and technological objects, their distance from the developed technology centers;
- expansion of the technological objects and expanding the range of control objects.

Target functions define such technical characteristics of UAVs as take-off weight, the multiplicity of application, flight range and duration, launching and landing techniques, the level of "intelligence". The essential bounding characteristic is the cost of UAC (composed with UAVs), as well as cost and ease of operational service [13].

Use of UAVs for civil purposes provides the following results:

- the possibility of obtaining comprehensive information about the parameters of the natural environment, industrial-technological complex created by man, about the state of the urban (i.e. man-made) living environment of modern man;
- minimization the probability of occurrence and shortening the time for elimination of anthropogenic and natural disasters;
- improving the efficiency of technological of human activity;
- creating conditions for operational forces and means resources maneuver;
- stability of human industrial activity information support.

Achieving the above results requires creating a variety of sensors to obtain information applicable to a wide geographical range and in a variety of climatic and operational conditions.

Therefore, UAC based on UAVs civil purposes must be mobile; their number should provide capacity of dense informational networks. In this case a significant number of staff is required. Note that this staff does not necessarily have high professional skills.

3.4 Spacecraft

Considering the intelligent control of the spacecraft, it should be noted that its movement is performed in specific, significantly different from the "terrestrial" conditions [15, 16]. This difference is expressed by the complete lack of an environment, which causes a number of specific properties of the spacecraft—no friction, air resistance, which leads to the effect of the "deceleration" absence.

Intelligent control of the spacecraft must provide its maneuvering, trajectory correction, performing operations of rendezvous spacecraft to the orbital station, the desired orientation of the spacecraft relatively external reference points and other similar operations.

Tasks of the spacecraft intelligent control can be summarized to three main types [17]:

- obtaining the required trajectory (center of mass traffic control);
- orientation control, i.e. obtaining the desired position of the spacecraft body relatively external reference points (control the rotational motion around the center of mass);
- a case where these two types of control are implemented simultaneously.

It is known that the desired orbit of spacecraft motion is formed by launcher rocket. Spacecraft separates from the rocket at a predetermined point of space and with the specified size and direction of the velocity. However, the characteristics of speed, and the point of separation from the launcher vehicle cannot be realized exactly. The required speed is achieved only with some technically possible accuracy, and this technically unavoidable error can lead to unacceptable deviations from the calculated trajectory.

Hence there is a problem of intellectual orbit correction, actually acquired by the spacecraft, and its proximity to the orbit required to perform the flight tasks.

Orbit correction may be required when orbit insertion by launcher rocket was performed with the desired accuracy. Small forces that gradually change the orbit of the spacecraft act on the spacecraft over time, the evolution of the orbit happens. There is a need for correction after the evolution of the orbit leads to unacceptable deviation from the predetermined one.

Sometimes maneuvering in space due to uncorrect errors or removing the effects of the natural evolution of the orbit, but with other problems: the transition to rendezvous orbit with another spacecraft, orbit of descent to Earth, and so on.

Spacecraft maneuvering can be considered as a special case of the intellectual trajectory correction task.

The task of the flight control system is implementation of the control algorithm.

At various stages of flight this general problem is decomposed into a number of specific problems by type of maneuvers (orbiting, interplanetary trajectory correction at the stage of passive flight, rendezvous and docking, landing, change of orbits, etc.). However, more appropriate to divide the general problem solved by control system on functional purpose into:

- spacecraft center of mass control;
- traffic control respectively the spacecraft center of mass.

The first type of motion refers is the long-period (because of relatively large time control interval), the second type is in this sense is the short-period.

Spacecraft control is a change with a certain accuracy parameters of the spacecraft center of mass motion and the parameters of motion around the center of mass in accordance with predetermined (or formed during the motion) laws.

Intelligent control of spacecraft motion is performed by control systems, which represent a set of automatic control systems, each of which solves a particular problem.

Center of mass traffic control system (TCS) consists of the navigation and guidance systems. Program device that implements intelligent control algorithms will act as TCS.

Motion control system relative to the center of mass or angular motion control system, consists of orientation and stabilization systems.

The above division of control tasks is presented in the following diagram (Fig. 5). The following notation SSC-system of starting coordinates, BCS-base coordinate system are used in Fig. 5.

Let us consider the individual issues of intellectual control of spacecraft.

Consider in more detail in particular tasks of spacecraft intellectual control.

The main task of the navigation is definition of real current kinematic parameters of spacecraft motion (its position and velocity in the inertial CS) based on the measurement of available navigational parameters characterizing generally perturbed trajectory.

Together with the main task a number of additional tasks can be solved:

- determination of the spacecraft actual orbit parameters;
- calculation of current deviations from the spacecraft programmed trajectory;
- prediction of the motion kinematic parameters to a coming time period;
- determination of spacecraft route: the current coordinates of the spacecraft center of mass projection on the surface of the Earth, etc.

The main task of the guidance is the definition of the required control actions that will ensure bringing the spacecraft to a specified point in space at a given speed, at a given

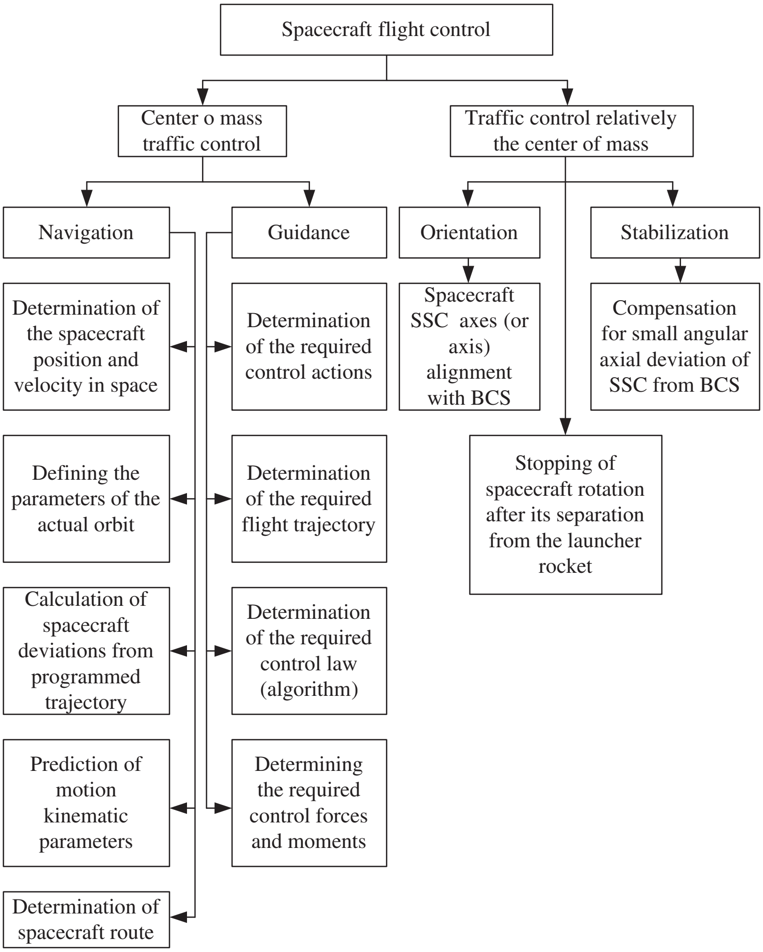


Fig. 5 Spacecraft control tasks

time according to the current kinematic motion parameters obtained by solving the problem of navigation known to the dynamic characteristics of the object and control systems, and specified constraints (energy source, the maximum engine thrust, etc.)

When solving the basic problem of guidance, you may need some additional solution of problems:

- determination the desired flight trajectory to the terminal point from a given position in space;
- determination of the necessary forces and moments for the maneuver of transition from the actual orbit to the desired orbit;
- determination of the law of control action change depending on the current motion parameters, etc.

Orientation of spacecraft is spacecraft angular motion control to impart a certain angular position relatively to the celestial bodies, the lines of magnetic force and gravitational fields, as well as other selected directions, called the reference or base frame of reference.

The control system which lead to an angular position of the spacecraft to the desired is called n orientation system (OS). It performs coordinatization on board the spacecraft base reference system, its storage and generates signals for turning the spacecraft for a given program around one or more axes.

Spacecraft stabilization is an angular movement around the spacecraft center of mass control, during which inevitably arising in flight angular deviation of the axes associated with the spacecraft from the respective axes of the reference ystem are eliminated. Control system that supports a predetermined angles (or angular velocities) value is called stabilization system (SS).

Given values of angles can be equal to zero, can be set by orientation system or entered by programming device.

3.5 Control of Objects' Group

Modern airspace and outer space is full of lots of aircraft and spacecraft that have intelligent control systems. For efficient use of a group of objects and prevent dangerous situations the problems of behavior planning of intelligent mobile objects that can act as a fully autonomous as well as collectively, by joining in a group or team ("swarms") must be solved.

These problems include, for example, problems in the area of robots swarm control, designed for remote sensing of the Earth or in the field of controlled aircraft motion near the airport.

To solve this problem it is possible to use artificial intelligence methods, namely, multi-agent technologies as well as technologies for knowledge representation (ontology), which allows creating self-organizing interacting intelligent objects teams, that are able to make their own decisions and then harmonize and coordinate them.

Intelligent control system of the aircraft's group control is a distributed network whose objects make movement in near-Earth space.

The designed intelligent system based on the method of coherent interaction of mobile agents groups in which the intermediate aircraft as agents perform functions of relay and signal delivery for other aircraft to a specified place of problem solving, and the aircraft approaching to the zone of action dynamically form a team consisting of a spacecraft cluster and single spacecrafts distribute among themselves the task and solve it in parts, depending on their position and capabilities of on-board equipment, and other parameters. Tasks and roles of each object in the group are determined dynamically in distributed collaboration in real time, at that they can adaptively vary with situations [16].

The main components of the architecture and technology platform of intelligent systems of collective moving objects control are the modules of ontology and scenes creation, as well as dynamic scheduling module, forming a plan of input events stream treatment (applications for target detection, failure of equipment, etc.) and performing dynamically adaptive change in created plan.

3.6 Launching, Tracking and Landing Ground Complexes

Launching, tracking and landing ground complexes can be considered as objects of ITS. These complexes are high-tech and should ensure a clear and consistent on-time and purpose fault tolerant service operations of aircrafts and space-crafts.

Ground launching complexes are an integral part of the space (air) system, designed for the prestarting preparation of space (aircraft) launch vehicles objects and implementation of their launch. Launch complexes differ in the following characteristics [7]:

- the class of launcher vehicle;
- a method of assembling and transportation;
- a method of a space rocket preparation;
- a place of dislocation;
- the possibility of moving in space;
- the number of launchers;
- the degree of universality.

Creating universal high-launching complexes for rocket launches various classes and types allows for quick adaptation to the new generation of launcher vehicles. Universal launch complex in comparison with the system of specialized launching complexes has the following advantages:

- lower costs of development and operation;
- simplified overall infrastructure of the spaceport;
- smaller total number of payments and service staff;
- higher intensity of launches;
- high capacity for rapid modernization of the launch complex.

Flight Control Center performs functions of aircraft and spacecraft escort, its controls missions of various spacecraft: manned orbital complexes, spaceships, automatic interplanetary stations and satellites.

Tracking and landing complex is an intelligent transportation system that implements the following functions:

- measurement of the navigation parameters for the aircraft coordinates correction;
- measurement of the orbital ship navigation parameters in range of radio landing systems for automatic flight on final approach and aircraft landing;

- radar control of aircraft's trajectory, translation and display this information in the Flight Control Center (FCC);
- develop an operational guidance for target designation systems of ground antennas telemetry, television and FM radio;
- control of air space in order to solve problems of air traffic control, ensuring safety of spacecraft and television-optical observations aircraft guidance.

To solve these problems, complex tracking and landing includes [18]:

- radio navigation system as part of a three-coordinate distributed radio rangefinder system, azimuthally ranging beacon and appropriate avionics, navigation parameters defining on board the spacecraft;
- radio systems for all-weather automatic landing;
- radio systems of aircraft trajectory and air traffic radar control which consisting of:
- en-route radar complex and airfield surveillance radar, landing radar system;
- airborne radar transponder;
- aircraft traffic control tower—ATC;
- system of vehicles technical condition;
- technical control complexes and control of terrestrial radio systems.

4 Aircraft Intellectualization Subsystems

Modern development of production aircraft elements technology (airframe, engine, avionics, airborne measurement and actuators) cannot increase its technical characteristics of so that to get a significant gain in efficiency of use.

To achieve substantial growth of efficiency of aircraft application it is necessary to improve the intellectual component ("system kernel") of aerospace systems, i.e. that totality of onboard algorithms implemented by aircraft on-board computer and algorithms of its crew's activities, who create a functional integrated system "crew—board equipment—aircraft" from disparate onboard equipment.

Classification of aircraft intelligent systems performed on a functional basis is presented in Fig. 6.

Off-board intelligent systems for pre flight training provide aircraft crew and technical tools training to perform specific flight mission of planned flight.

These intelligent systems perform:

- analysis of pre-flight information about the area over which the flight will take place;
- the development of rational route of flight;
- preparation of flight documents and initial data to board (in board equipment, the pilot card);
- preparation of the flight (ground) technical documentation providing preparing departure.

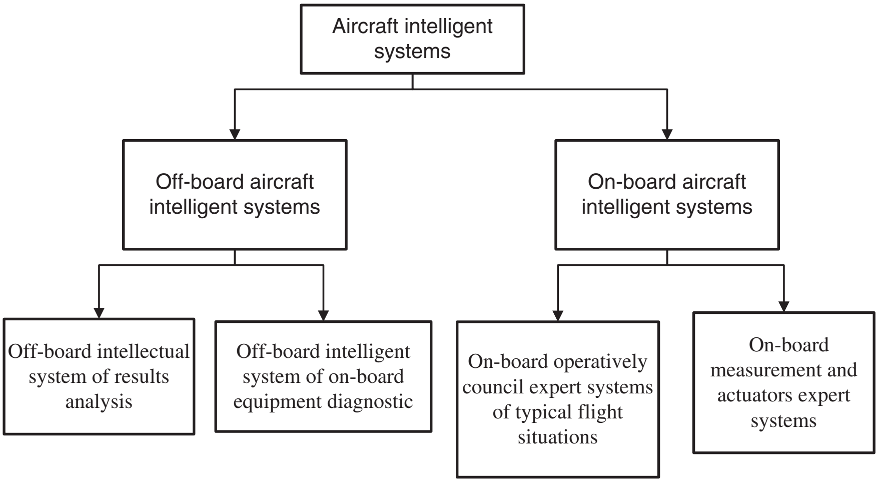


Fig. 6 Classification of aircraft intelligent systems

The results are learnt by preparing crew and recorded in the onboard systems of the aircraft.

The second group of intelligent systems consists of onboard systems including

- on-board operatively council expert systems of typical flight situations;
- on-board measurement and actuators expert systems.

On-board operatively council expert systems are designed to operatively develop recommendations to crew by solving the problems which can occur in the current situation model.

On-board measurement and actuators expert systems provide the fullest currently obtain the necessary information of the external environment and status of the on-board equipment and the most accurate execution of decisions. They work closely with the on-board operatively council expert systems.

Off-board intelligent system of flight results analysis operates with information from the onboard system of objective control, embedded control system and installs along with the crew the quality of done work by the system "pilot—on-board equipment" and its impact on the effectiveness of the flight.

Off-board intelligent system of on-board equipment analysis on information from on-board systems, regular check-recording equipment provides, together the technical staff analyzing of the onboard equipment in flight, the localization of its faults and determines the technology to debug them.

Intelligent technical status of avionics control systems are developed to compensate for incomplete information presented to the crew by detected failures of on-board equipment.

Currently available on airplanes of the 4th generation onboard systems of automatic control at best only can fix faults. Tasks of estimating the impact of failure on the possibility of continuing the successful execution of the task of departure, including the problem of determining the efficiency of the remaining board equipment, the problem of the impact of failure on the possibility of continuing the current flight stage and rational method of determining the localization (eliminating) the problem have to be solved by the crew. In this case the crew doesn't receive any assistance from airborne computation algorithms.

Currently there are intelligent aircraft on-board systems, which allow diagnosing and repairing of the aircraft technical status. Known intelligent system [19] is presented for self-repairing aircraft control system, work on which proceed with the end of the 80s. It also gives information about the onboard equipment and airframe status control system created by the USA.

Consider a special type of intelligent system—Automatic piloting systems that relieve pilots from routine tasks and provide him the opportunity to focus more on navigation and piloting [20].

In general, there are the following systems of automatic piloting:

- the flight control system;
- the engine control system;
- the automatic flight control system;
- the piloting computing system.

Automatic piloting systems interaction is shown in Fig. 7. Automatic piloting systems control is performed by using appropriate panels in the cockpit.

Flight control system (Fly-By-Wire—FBW) provides position control of the airplane in the air with the help of mechanically deflectable portions (elevator, rudder, ailerons, flaps, slats) [21].

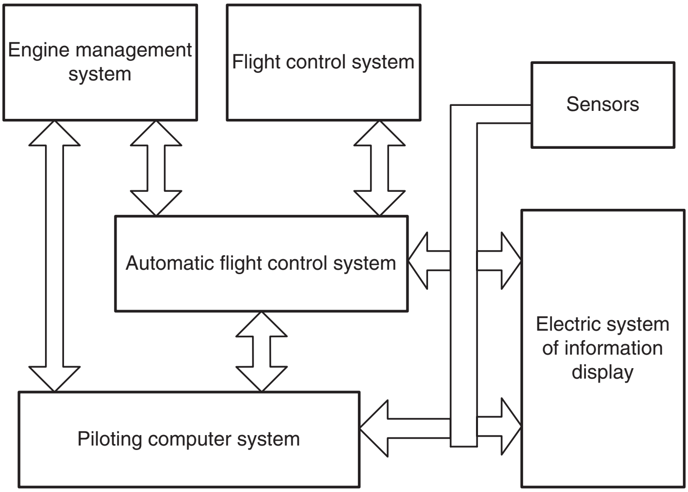


Fig. 7 Intellectual system of automatic piloting

The FBW system ensures the position control of the aircraft in the air. The main functions of the FBW:

- pitch, roll, course control;
- ascension power control;
- deviation of the interceptors in accordance to the position of the ailerons;
- evaluation of the maximum permissible deviations and preventing their occurrence;
- torque reduction in case of one engine failure;
- reducing the influence of the turbulence;
- automatic change of the aileron effectiveness depending on airspeed and others.

The automatic flight control system (Autopilot/Flight Director System—AFDS) insures the automatic control of the trajectory flight of the aircraft. It controls the speed, the height, the flight path of the aircraft and guarantees maintaining this flight values in certain limits by dint of connection to the FBW.

The AFDS system controls the flight of the aircraft through the speed, height and course control, and together with ILS or MLS system provides takeoff and landing of the aircraft in an automatic mode. AFDS consists of computing unit, making calculations in parallel (Fig. 8). Thereby, reservations and necessary reliability of the system is reached. Through the control panel pilot selects the necessary AFDS modes and sets parameter values. In addition, the buttons of the emergency shutdown of the automatic control modes are placed on the steering wheel, and the buttons of autothrottle shutdown are located on the traction controls.

AFDS provides flight parameters control through three control channels: traction channel, longitudinal and lateral channels. Traction channel issues control commands to the engine management system. The longitudinal channel assures elevator control, lateral channel—ailerons and rudder through the flight control system.

By setting a specific value to one of the flight parameters, AFDS affects the engine management system or the FBW, whereupon the aerodynamic condition

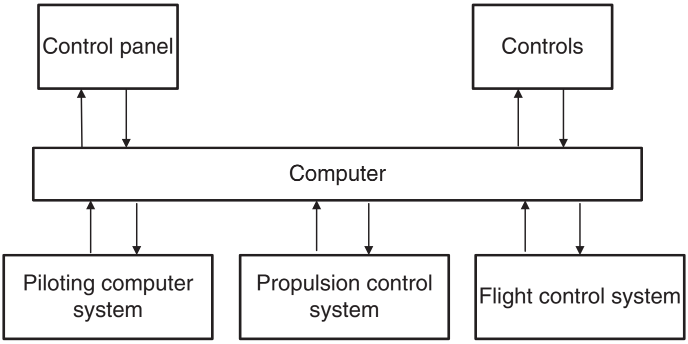


Fig. 8 System of the automatic flight control

of the aircraft changes, controlled by certain acceleration, velocity and positional sensors. Thus, the AFDS proves the value of a specific parameter to the required value.

The input information about the state of the flight parameters AFDS gets from:

- Control system of the aircraft;
- Radio altimeter;
- Landing system;
- Inertial navigations system;
- System of altitude and speed parameters;
- FMS;

AFDS provides in the automatic mode:

- Stabilization of the aircraft relatively to the center of mass;
- Stabilization of the pressure altitude;
- Stabilization of the course;
- Flight controlling of the aircraft according to the FMS signals;
- Management of the aircraft during the approach before the decision height;
- Stabilization of speed and Mach number;
- Warning about the derivation of the speed, overload parameters, roll and pitch angles out of range and others.

Flight management system (FMS) helps pilot to execute navigation functions. It indicated the next position of the aircraft according to the plan of the flight for AFDS.

The effect of all those systems is controlled with the help of a numerous amount of sensors, which measure the flight parameters of an aircraft, and reflects their values with the use of the electronic indication system.

At various stages of flight, the pilot of aircraft requires a variety of flight and navigation information from fundamentally different navigation systems. For example, during the landing the most important information is from the landing system about the deviation from the glide path, and during flight on the route—orientation at ground beacons and satellite navigation. Modern navigation systems are very complex to use (the pilot of an aircraft can lose a lot of time while using them).

Flight Management system (FMS)—a computerized system that allows the pilot to control the aircraft and manage systems for safe operation. The FMS accomplishes all technical, routine operations with aircraft systems used during flight, enabling the pilot to devote more time to the flight management rather than configuring systems.

In general, the FMS consists of two calculators (computers) and two multi-functional control and display units (Multifunction Control and Display Unit—MCDU).

The FMS provides:

- display of flight and navigation information, necessary for piloting on a particular phase of flight through the electronic indication system;
- changing radiofrequency of navigation and communicative equipment through the control unit for communication equipment;
- the issuance of the deviations from the predetermined path of movement for automatic piloting system and information for engine management system.

Using the global bases of the aeronautical information and information from the avionics, FMS performs three main functions:

- navigation;
- evaluation of the optimal parameters of the flight;
- governance.

Navigation. Before the flight, pilot of an aircraft chooses the needed plan of the flight from the corresponding database, which was made by the airline, or creates a new one.

During the flight FMS reflects the necessary aeronautical information from the databases on the navigation display of the pilot. Moreover, during the flight FMS according to the set trajectory in the piloting plan changes the setting of the radio navigation equipment.

FMS assesses the current position of an aircraft, using the information given from the satellite navigation system inertial and beacon systems.

The FMS counter uses the information of the global databases for the computation of the optimal trajectory and flying modes of the aircraft. The results of evaluation of the actual position of the aircraft are compared with the planned trajectory and are reflected on the aeronautical maps through the navigation display.

Evaluation of the optimal parameters of the flight. In a specialized FMS database the mathematical model is stored, taking into account the effect of the engines, and the necessary parameters of action flight simulation.

The FMS uses this information for computation:

- optimal, the most thrifty flight velocity;
- the optimal height of the flight;
- marginal parameters of flight.

Such data depicts on the pilots display, on the bases of the rated data FMS predicts the time when the navigation span points are reached and depicts the time arrival at the destination airport.

Management. The FMS is connected to the digital control system of the flight and autopilot. Estimated coordinates of an aircraft are compared with the planned trajectory movement for detection unplanned deviations. The values of such deviations are redirected to the automatic flight control system for correcting the flight path.

According to the estimated optimal velocity and time arrival FMS generates information to the propulsion control system for withstanding optimal trajectory movement and timing. Moreover, FMS controls the settings of the radio frequency of all the radio navigation receivers of different beacon systems and radio frequency of the air connection with the help of communication equipment control unit.

The following functions allows you to use the FMS:

- navigation in the horizontal plane;
- navigation in the vertical plane;
- 4-D navigation;
- navigation, based on the maximum utility.

Four-Dimensional Navigation (FDN)—it is the navigation in the horizontal and vertical planes taking time into account. In the modern laden air space the time parameter is very important. According to this, FMS must assess the time flying over certain waypoints. This information is quite important for a pilot and dispatcher for managing in the case of the airways overload and safety of the air movement.

The emphasis for the safe flights is Traffic Collision Avoidance System (TCAS), which are intended to help pilot of the aircraft to avoid collision in the air or outer space [22].

There are four types of the TCAS:

TCAS 1.Informs pilot about the air movement around the aircraft (TA). The TCAS 1 presents itself like a system of the remote surveillance, and from time to time emits the request signals, which are taken by the other aircrafts. The plane respondents of the “S” mode process the received signal and direct the answer-signal, which consists of the information about the aircraft. This information is taken on board of the aircraft, where it is operated and reflected on the pilot’s display.

Moreover, parameters of the trajectory movement and the possibility of collision are assessed, what is more, they are displayed with the certain encoded symbols.

Modern TCAS 1 systems are oriented on the concepts of using ADS-B for informing a pilot about the aircraft, which are located nearby and can pose a threat of collision.

TCAS I is widely applied in avionic systems of easy aircraft. In particular it is mandatory for means of light aviation of the USA (with number of passengers from 11 to 30). In total easy aircraft applies the integrated systems and usually the TCAS I function is executed by an onboard computer system. The use of the combined system executing flight navigation functions allows to reduce the cost, overall dimensions and mass of the equipment.

TCAS II. Provides the visibility of surrounding air space in case of detection of other aircraft with on-screen display (THAT). Besides, TCAS II evaluates potential possibility of collision in the air with other aircrafts and in case of existence of such threat creates the message (RA) for both pilots, which allows to part aircrafts in the vertical plane and to avoid collision.

TCAS III. The TCAS III project in addition to consulting information about air traffic (THAT) shall provide recommendations about preventing the threat of collision (RA) in the vertical and horizontal planes.

The task of collision preventing in the horizontal plane is tightly connected to the accuracy of determination of a location of the clashing aircrafts. The applied principles of distant observation in creation of TCAS systems don't provide required accuracy of determination of the relative angular coordinates. Therefore in order to avoid the conflict by execution of maneuver in the horizontal plane is very risky.

Since it appeared technically difficult to create and implement this TCAS type, the project was rejected.

TCAS IV. The project of TCAS IV system provides the use of GNSS with the functional additions of EGNOS (WAAS) and inertial system of navigation for obtaining exact information on location of the aircraft [23]. On the basis of exact location coordinates it is possible to generate a path of maneuver for avoiding a conflict situation in the horizontal and vertical planes (Fig. 9).

The TCAS IV project is based on the use of the concept of ADS B and digital networks of data transfer for information exchange between the clashing aircrafts. One of the possible options of implementation of the concept of TCAS IV is creation of a warning function of collisions of the aircrafts as a part of the computing system of air navigation (FMS).

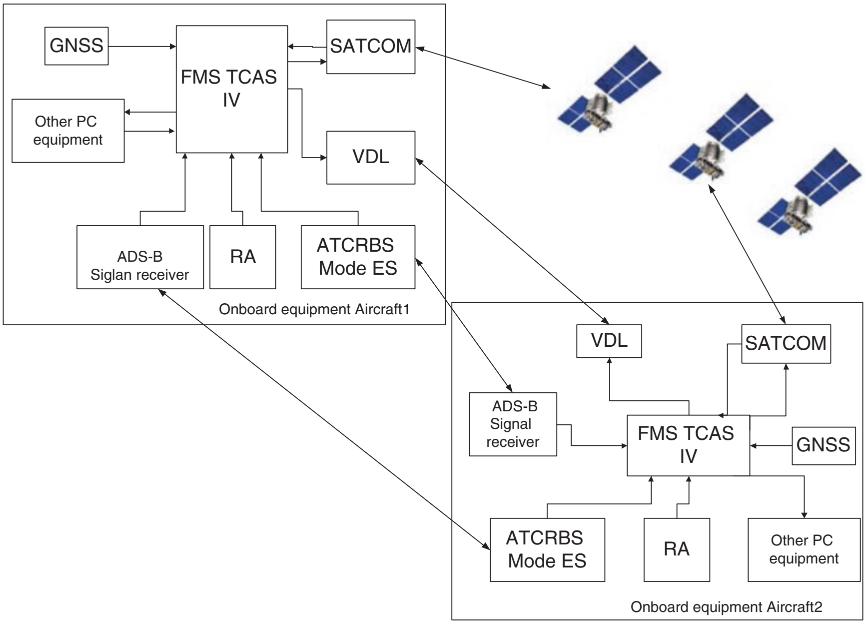


Fig. 9 TCAS IV project

During the flight ADSBA aircraft radiates information about its location. The onboard equipment ADS-B accepts these signals and after their decoding provides information about the location of the aircraft which is nearby to the FMS. Further FMS reflects tags of adjacent aircrafts in the display of electronic indication system. Besides, warning function of convergence consists of the continuous tracing of a movement path of an aircraft and check the possible intersection with own scheduled path of movement.

In case of detection of such a fact, FMS automatically communicates with the FMS of other conflict aircraft through digital data circuits, such as VDL, SATCOM or others, for comparing the scheduled paths of movement. In case of such intersection of scheduled 4D paths of movement of the aircraft, warning algorithms of collisions take into account specific features of aircraft and adjust to it. New paths of movement are provided to pilots for acquaintance and approval. Thus, early warning and solutions of possible conflict between aircrafts is solved.

Due to the unavailability of aero navigational support of flights this concept remains for the requirements of TCAS IV in the project form. Besides implementation of available digital links of a data interchange, global deployment of the concept of ADS-B and reduction of errors of system of the global satellite navigation which requires considerable expenses of time connected to placement of terrestrial infrastructure of stations of differential corrections is necessary.

Early warning system of approximation of the earth.

The first systems of warning of approximation of the earth (Ground Proximity Warning System—GPWS) appeared in the early eighties. Warning of the pilot about the possibility of collision of an aircraft with an earth surface owing to fast lowering was basic functions of GPWS.

Development of information technologies promoted the considerable enhancement of the basic function of GPWS. Development of satellite navigation systems gave the chance to determine location coordinates, and also to use ultra-precise electronic cards of an earth surface. All this led to appearance of a new class of early warning systems of approximation of the earth (Enhanced Ground Proximity Warning System—EGPWS).

The Swedish FAA entered designations of these types of systems (Terrain Awareness and Warning System—TAWS) and standardized three main classes TAWS [23].

Class B. The equipment TAWS shall signal in such cases

- reduction of distance to an earth surface;
- obviously expressed future collision;
- fast lowering;
- insufficient speed of ascent after take-off;
- lowering of an aircraft is lower than 500 feet over an earth surface.

As application TAWS B can reflect a card of the spreading surface on the special display.

Class A. TAWS of this class shall include warning in all cases of a class and provide a signaling in case of:

- exceeding of maximum allowable speed of convergence;
- flight near an earth surface with unissued chassis;
- an excessive deviation from the line of a glide path in case of aircraft landing.

Besides, TAWS of a class A shall reflect a map of the spreading surface or position concerning the landscape in the vertical plane.

Class C. To TAWS of this class the requirements are much lower and include only the most necessary functions of warning. TAWS of a class C is intended for aircrafts of light aviation, where quantity of passenger seats is less than six.

In the whole TAWS is intended for timely provision to crew of the aircraft a preventive language and visual signaling in case of occurrence of such situations in flight where development can lead to inadvertent collision of aircraft with an earth surface, and also for increase of awareness of aircraft crew on elements of an earth surface and location of artificial hindrances that are in a database of system and constitute potential danger on its present or the predicted way. Besides, the system provides output of:

- speech messages when passing the caused fixed heights;
- signaling in case of exceeding unacceptable value of a roll;
- a preventive signaling in case of premature lowering in case of landing approach.

Correlation of system with other systems of an aircraft is provided in Fig. 10.

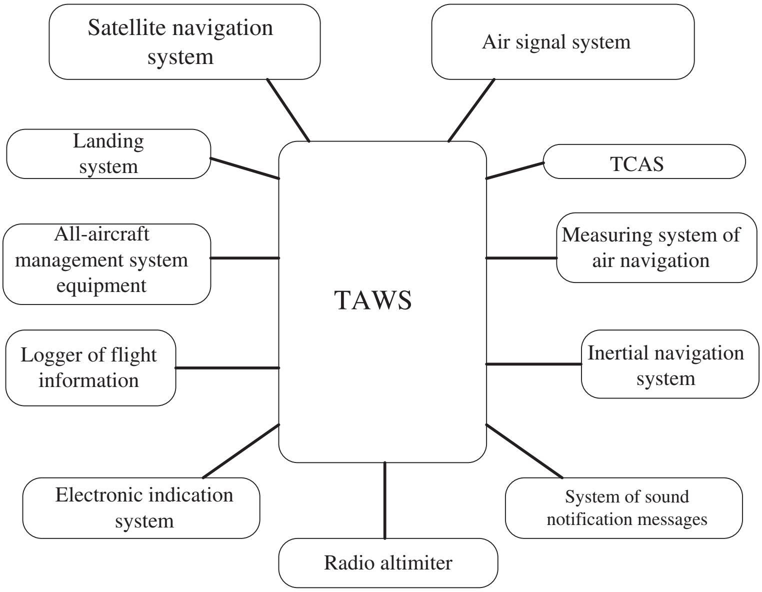


Fig. 10 Diagram of correlation of the TAWS system with systems of an aircraft

The TAWS equipment continuously analyzes the current parameters of aircraft flight, position of the chassis and flaps, a relief of the spreading surface and existence of artificial hindrances on a surface. In case of detection in the direction of flight potentially dangerous situation beforehand warns the pilot by means of visual and speech messages. Preliminary warning of possibility of collision allows the pilot to orient and start executing maneuvre for deviation of an aircraft from collision, without violating the rules of piloting.

Distinguish three basic functions of TAWS:

- function of the warning systems of approximation of the earth (SWAE);
- function of the early warning of approximation of the earth (EWAE), including a signaling about premature lowering;
- formation of preventive speech messages. The SWAE functions provide output of preventive messages in case of an output of certain parameters of flight for admissible values.

The SWAE functions provide output of preventive messages in case of an output of certain parameters of flight for admissible values:

- drift-down speed exceeds the set restrictions;
- closing speed to the earth exceeds the set restrictions;
- loss of height on take-off or leaving on the second circle;
- flight of the airplane is lower than admissible height in not landing configuration;
- a deviation down from a glide path in case of landing approach by radio engineering means of the landing exceeding the set restrictions;
- exceeding of a threshold of distinction between the relative barometric height and the valid height.

In the mode of early warning of TAWS on the basis of a database of a relief of the spreading surface, the current coordinates of a location of LA, parameters of flight and air status, tactical technical characteristics of an aircraft, the international standards about minimum admissible flight heights over an earth surface and hindrances on it, and also the standard rules of piloting the system creates in a work space two zones of a signaling—preventive and abnormal.

Hit of the spreading surface in the appropriate zone leads to actuating of the preventive or alarm signaling in the form of language and graphic messages.

For increase of aircraft crew awareness about the terrestrial situation the system gives out information on an electronic display system about the spreading relief. Besides, in case of preventive signaling operating the system allocates on the indicator screen with the bright yellow color the section of the spreading surface which caused actuating of a preventive signaling. In case of actuating of the alarm signaling the system allocates on the indicator screen the appropriate section with the bright red color.

Basic functions of early warning of TAWS:

- early warning of insufficient height over a hindrance in the direction of flight;
- warning of premature lowering in case of landing approach;

- output on the screen of the device the display of a visual situation about the spreading relief in a zone of the review and artificial hindrances.

When aircraft is lowering in the TAWS algorithm the possibility of an output of speech messages of passing by the aircraft is laid in advance stipulated fixed heights over the spreading surface in case of:

- intersections of height of decision-making;
- achievement of height of 150 m when lowering:
- passing of a row of the caused fixed heights; exceeding of the set limit value of a roll.

5 Intelligent Infrastructure Systems

5.1 *Air Traffic Management Systems*

Aero navigational service of aircraft flights is provided within system which consists of [22]:

- air traffic service (ATS);
- service of aviation electric communication (SOM);
- meteorological support of air navigation (MET);
- retrieval services and rescue (SAR);
- service of aero navigational information (AIS).

These types of service are provided at all stages of aircraft flight in air space during airfield dispatcher service, the dispatcher service of approach, region dispatcher service and flight-information service (Fig. 11).

Air traffic control includes some types of actions for safety of flights (Fig. 12):

- the dispatcher service (ATCS);
- flight-information service (FIS);

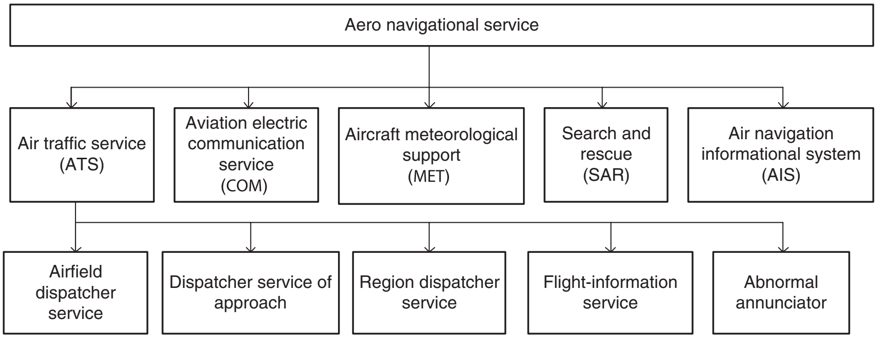


Fig. 11 System of aero navigational flight service

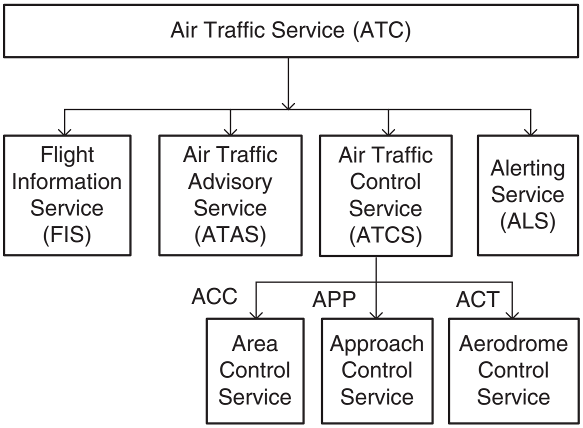


Fig. 12 Management air traffic system

- – consulting service (ATAS);
- – abnormal service (ALS).

Types of the applied service depend on many factors: relief, intensity of air traffic, equipment, weather conditions etc.

Management systems air traffic use intellectual solution algorithms of the following main objectives:

- Warning of collisions of an aircraft.
- Preventing of collisions of an aircraft which is in the region of maneuvering, and hindrances.
- Regulation of an air traffic flow in the dispatcher zones.
- Provision of consultations and information necessary for safety and effective implementation of flights.
- The notification message of appropriate authorities about an aircraft needing help and rescue, and also rendering necessary assistance.

The structure of perspective ATM/CNS OATA system (Overall ATM/CNS Target Architecture) is provided in Fig. 13. Feature of this structure is that intellectual systems of avionics of the aircraft becomes part of ATM/CNS system. The equipment of a digital data interchange creates a digital layer between structural elements, integrating the onboard and terrestrial equipment.

According to the concept of ATM/CNS OATA the main efforts of EuroControl are directed on enhancement of intellectual systems of aircraft avionics. Experts of Boeing and AirBus are engaged in this direction.

Further development of tracking systems provides development of infrastructure of the concept of automatic dependent tracking of ADS-B which functioning depends on certain conditions:

- – existence onboard of every aircraft the ATRSB Mode S or UAT equipment;
- – extension of stations of the differential corrections GNSS to increase the accuracy fix of an aircraft position;

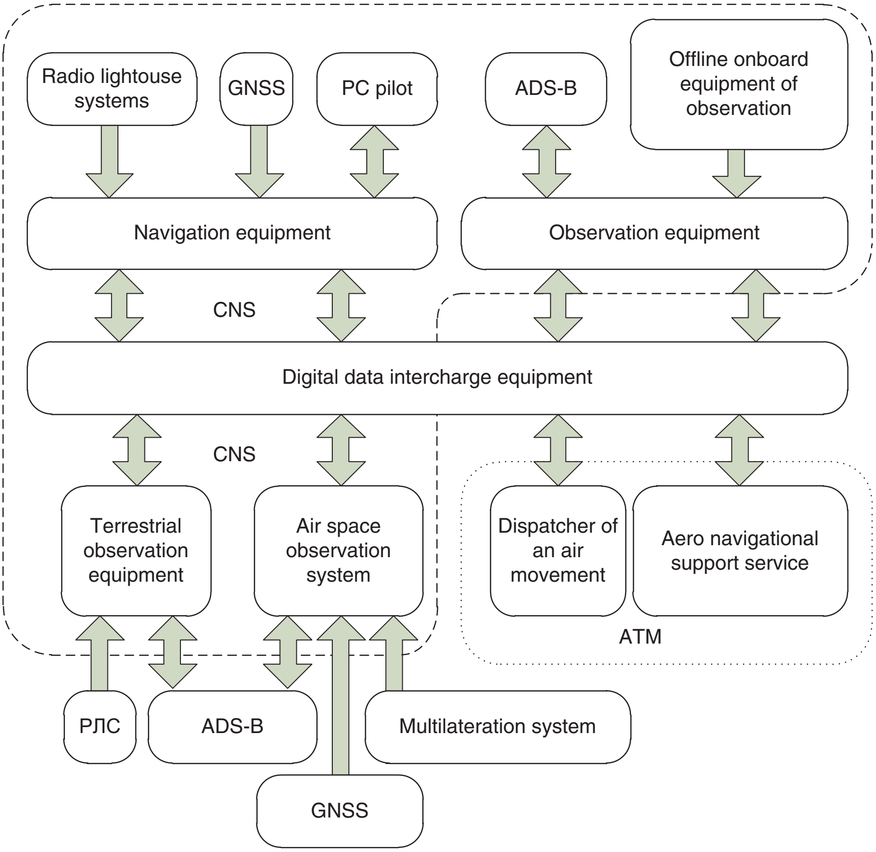


Fig. 13 Structure of perspective ATM/CNS OATA system

– creation of an expanded network of receiving stations.

The information received from ADS-B allows to refuse from the use of secondary radar stations and to provide with information on movement over surfaces of oceans and remote mountain regions.

The intermediate link of ADS-B systems are the Multilateration System (MS) of the airports. For information mapping in tracking systems intelligent displays are used.

5.2 *Meteoconditions of Monitoring Systems*

Process of maintenance of the aircraft equipment is directly connected to interaction of aircraft with an external environment. From all range of impact on an aircraft of an external environment it is necessary to select those meteorological phenomena under the influence of which origin of aviation incidents is possible. These phenomena are classified as the dangerous meteorological phenomena (DMP) which include:

- strong atmospheric turbulence;
- wind shift (WS),
- frosting of an aircraft;
- thunderstorms;
- electric discharges;
- showers;
- snow, fog;
- existence in the atmosphere some outside subjects (birds, probes, etc.).

According to ICAO, from total number of the aviation incidents connected to weather conditions. 62 %—are caused by a reduced visibility, 11 %—the strong bumpiness, 7 %—frosting, 9 %—other reasons, 11 %—the storm phenomena, [24]. Among other reasons which cause the collision of an aircraft-birds are on the most highest position on the list. The principal danger is constituted by the limited visibility connected to the low height of clouds, fogs, snowfalls and sharp shifts of wind, and also frosting of VS and its engines. In case of execution of flight along a route the most probable are AP connected to hit of an aircraft during a thunderstorm which is followed by hail, considerable convective turbulence, an intensive rain and lightning.

In 1998 ICAO published “The global aero navigational plan for CNS/ATM systems”. According to it the Coordination group EANPG at the 18th meeting developed the European plan of transition to CNS/ATM system. As the part of this plan is designated “Meteorological strategy” which defines tasks of meteorological support of air navigation for the next 15 years, actions for their execution, and also the related dates of execution and the responsible organizations. The finite form of submission of documents are maps of ways with certain milestones which shall satisfy future operational needs for CNS/ATM field of activity for Europe.

The ATM system will remain as an object of the same various influences of the weather phenomena, as well as the present ones. In difficult weather conditions can cause time delays or transfer of flights, the direction of airplanes on spare airfields, the appropriate influence on opportunities, profitability and efficiency of flight execution. As an example, the Executive commission of Eurocontrol in the report testified that 40 % of time delays of flights at the airports are caused by weather conditions.

Historically meteorological support was aimed at safety execution of flights, but in the context of future ATM it is, also, necessary to consider the influence of meteorological support on efficiency and throughput of ATM systems.

It is defined that future structure of Meteorological support shall be defined by complex technical requirements of ATM systems, but not internal solutions of national weather services. It shall envelop from rather simple requirement in concept “State”, to very difficult user requirements air and space surface of Europe and the Northeast air passage of the USA. The countries shall estimate the current opportunities against the nature, opportunities and the ATM level of operations to develop the evolutionary investment plan respectively.

"ATM strategy Eurocontrol 2000+" (ATM Strategy) defined strategic frames for absorption of future increase of air traffic in Europe according to the concept of CNS/ATM ICAO. It defines improving and development of Aero navigational information, including also meteorological part, for the countries, that are members of EKGA (where also Ukraine enters) for support of the harmonized and coordinated delivery of high-quality information to future ATM systems at all 7 stages of flight. The tasks of the ATM Strategy in relation to Meteorological support are the following:

- safety, that is improving of the security level by lowering of number of incidents and other aviation incidents;
- profitability, that is lowering the prime cost of outlay on unit of ATM operations;
- conducting opportunity, that is support of service during peak periods, without causing the considerable economic and ecological penalties;
- ecology, that is assistance to reduction of influence of aircraft on ecology;
- national security and defensive requirements that means provide military services the access to execution of defensive jobs through the specialized ATM procedures;
- homogeneity;
- quality that means to promote and expand the use in system maintenance quality of the ISO 9000 standard;
- human factor and duties which guarantees the presence of the person and his duties during execution of procedures in future ATM.

Meteorological combining (within VMO) will remain a basis for delivery of meteorological data and products, but within the countries of EKGA control of meteorological support will be improved by the centralized coordination, that is through the executive structure of EKGA EUROCONTROL and the relevant Ministries of transport and EKGA.

This meteorological strategy claims that its main process will be focused on effective and high-quality support of such ATM concepts as SWIM (Systems of broad information control) and CDM (Collective decision-making). Meteorological data in real time from terrestrial stations and onboard sensors of airplanes, and also prognostic data from a certain number of prognostic centers will be used by all stakeholders in case of acceptance of the joint decision for flight execution. Integration of meteorological data and other aero navigational information in European ATM system will be carried out through SWIM. SWIM will allow to provide the significant increase of informational exchange between service providers and users. The manual of their use and contents of meteorological data in SWIM will be provided in Standards and the Recommended practice of ICAO.

Meteorological information will have the accruing role in determination of the functional capabilities of future ATM system through its contribution to safety of flights, their regularity and efficiency of flights. At a context of ATM service safety is a guaranteeing echeloning of an aircraft so that flights were carried out freely, both one from another, and guaranteeing safety of rather unfavorable weather. Regularity and efficiency of flights depends on meteorological information especially.

The European air space will represent the continuous environmental space where the personal and coordinated actions of staff, systems and aircraft create a template of incidents at all levels and define how system will function owing to unplanned incidents at all levels, such as weather conditions, it is necessary to make changes or to interrupt the flight plan.

Eurocontrol at the moment create a map of ways for creation of a strategic system and investment planning. The main concept of this virtual system is the meaning of Manager of Aero navigational information which will include the actual and prognostic data about weather as part of system. This system consisting of a network of databases which are connected by the general dialogue operating system of computers and software packages to provide such an environment where different levels of planning of flights will be executed.

Thus, in future ATM system, together with other information, meteorological information will be collected, compared and analyzed to provide delivery of the refined data for creation of the imitative layers of each stage of planning. Simulation will provide determination of the result of change in safety, throughput and efficiency of systems which will allow schedulers to solve a problem of leaving zones with adverse weather conditions on a route, TMA zones and at the airports.

5.3 *Terrestrial Movement Management System and Monitoring Over It*

The term “Surface movement guidance and control system” (SMGCS) is a system of the means, the equipment and procedures intended for execution of requirements to control and monitoring over terrestrial movement in specific operational conditions in a specific airfield. The SMGCS system is present at this or that form in each airfield [25].

The SMGCS system includes:

- visual means;
- not visual means;
- means of radiotelephone communication;
- monitoring and information aids.

Systems can be simplified at small airfields with small intensity of movement which is made in case of good visibility, or are complicated on the big and loaded airfields on which vehicles are exploited in the conditions of limited visibility.

The equipment of airfields with SMGCS systems intends, first of all, for support of safe control and monitoring over terrestrial movement in specific conditions of maintenance. For this reason the system needs to be projected so that to prevent collision of aircrafts among themselves, with land transport and hindrances, and also vehicles with hindrances and among themselves.

Basic SMGCS systems aren't always capable to provide necessary support of aircraft operations so that the required throughput of the airport without lowering of the security level, especially in the conditions of low visibility was withstood.

Use of the advanced terrestrial movement management system and monitoring over it [Advanced SMGCS (ASMGCS)], as expected, will be able to provide adequate throughput of the airport at the necessary security level taking into account specific weather conditions, intensity of movement and planning of specific airfield thanks to application of modern technology and high integration scale of different functions. In new technologies, possibilities of capacity growth in the conditions of low visibility in airfields with a difficult design and high intensity of movement should be considered.

The entity of A-SMGCS system lie in progressive development of the existing SMGCS systems which gives great opportunities for their maintenance. It is not an alternative system, which implementation required elimination of the existing SMGCS systems.

In the basis of development SMGCS systems lies a principle "to see and be seen" which was adequate for keeping of intervals between aircrafts and terrestrial vehicles in a movement zone. Permanently growing intensity of movement, complexity of identification of the given route of taxiing at airfields with difficult planning and weakening action of the principle "to see and be seen" in the conditions of low visibility-are factors which can lead to incidents and the accidents caused by incompatible exit on the runway (R).

Level of requirements to SMGCS system which is set at an airfield, should correspond to conditions in which it is supposed to exploit the system. It is necessary to understand that in difficult SMGCS system there is no need and it is economically not favorable where visibility conditions, planning of airfield and intensity of movement in total or separately don't create problems in the organization and implementation of terrestrial movement of aircrafts and vehicles. On the other hand, the failure from SMGCS system implementation with throughput which is properly coordinated with needs of the executed operations in airfield, will lead to restriction of speeds and can negatively affect safety.

All terrestrial movement management systems execute four basic functions:

- instructions to the movement directions—include the appropriate equipment, information and output of the controlling influences necessary for the continuous, single-digit and solid data for an aircraft and terrestrial vehicles during movement of an aircraft or vehicles along the routes specified to them on the earth.

- determination of a route—development and assignment of a route movement to specific aircraft and terrestrial vehicles for safe, fast and their effective relocation from the current location to the assigned place.
- control—consists in application of measures for preventing collisions and to inadvertent exits on a runway or a point of start, providing, thus, safe, fast and effective terrestrial movement.
- observations-allow to identify an aircraft, terrestrial means and other objects and to receive exact information on their location.

Instructions on the direction of movement and control of a large number of aircrafts and terrestrial vehicles which move in parking zones, represent a special problem in case of a choice of necessary level of equipment of the created SMGCS system. Solving this problem, it is necessary to recognize that a role of each specific parking lot changes from time to time. If an aircraft with operating engines stopped in a parking zone, moves on it or comes nearer to a parking lot, then the parking zone represents itself as a part of a zone of movement, and in this case appropriate means of SMGCS system are necessary. If the parking lot is taken, aircraft engines don't work or if the zone of the parking is free and aircraft doesn't come into it, now this zone isn't part of a zone of movement, and, therefore, there is no need to use the SMGCS system.

The tendency to use the advanced SMGCS system—A-SMGCS lies in reduction of loading the language telephone communication, extension of the application of control terrestrial movement and leadout a big role to the onboard aviation equipment, in assistance to the pilot of an aircraft to get on a runway or to leave it. For observation the aircrafts and terrestrial vehicles by service Department of Internal Affairs (ATM) the radio-electronic equipment will be use more, and escalating value for monitoring of dynamics of terrestrial operations is acquired by automation.

Detail project development of SMGCS system depends on the specific requirements of maintenance and restrictions dictated by features of an airfield. The skeleton diagram of a system in every case will have specific signs. However, users of the system in any zone of movement are provided with the homogeneous, standardized information, characteristic for the appropriate function of system operation. The example of the skeleton diagram of the system responding to concepts of A-SMGCS and suitable for application in airfields with a difficult design and high motion speeds is given in Fig. 14.

In Fig. 14 the method of integration of visual means is shown. Besides, in Fig. 14 correlation between different components of the equipment which needs to be provided is illustrated, so that such system will practically realize and use its every four basic functional aspects, i.e. instructions of the direction, determination of a route, traffic control along a route and observations.

Possibility of selective switching on lighting fires—one of the important aspects considered during practical implementation of A-SMGCS system. Necessary switching are carried out in case of visual observation over airfield

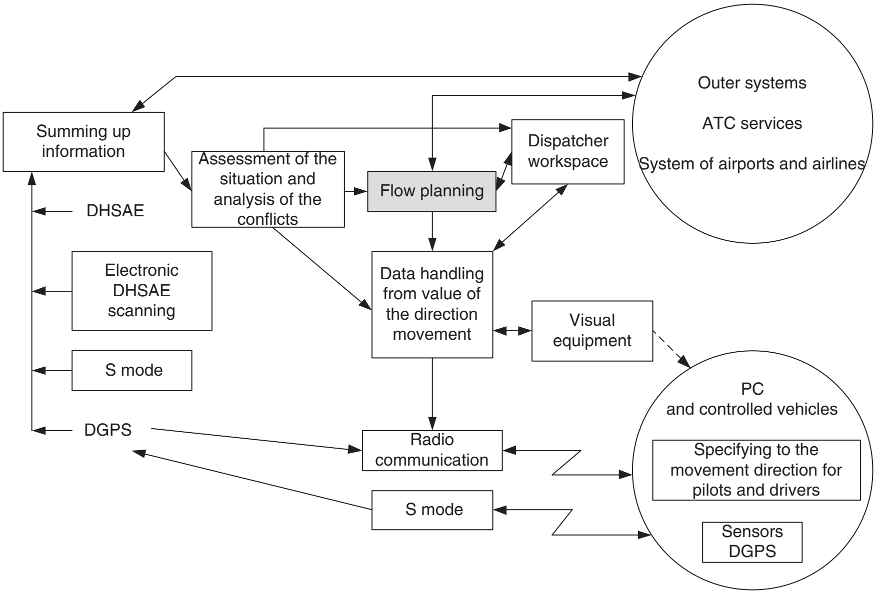


Fig. 14 Skeleton diagram of A-SMGCS system: DHSAE—the determination of hindrances on a surface of an airfield equipment

movement from the dispatcher tower. In certain cases for manual control by selective switching on of elements of the system it is possible to use different survey devices. In remaining cases this or that level of automation is allowed.

5.4 Control Systems of Carrier Rockets

Before separation of SC from the carrier rocket (CR) they represent the uniform aircraft, for its control, it is enough to have the general control system installed on SC. However in practice, considering the need of space experiments high reliability ensuring, consider obligatory to supply with own control systems, both the carrier rocket, and SC.

For the modern stage of the missile and space equipment development such approach is justified and is explained by the following reasons:

- flight conditions of the considered objects are significantly different: repeated overloads and the zero gravity changing in the wide range density of air and vacuum;
- because of flight conditions and specifics distinction of the solved tasks designs of the compared objects are different: tandem and package ligaments of the extended cylindrical form bodies with the strong case, on 80–90 % filled with

liquid, and the bodies of rotation varied in form belonging to the class of thin-walled covers and containing capacities, insignificant on volume, with liquid.

The specified reasons are a consequence of that a control system of carrier rockets and SC are also different from each other by hardware structure. It means that devices and units of the CR control system can be unnecessary in an orbit. Perspective reusable SC, for example, space planes with horizontal start and the same landing, should have the multifunctional control systems created on the basis of the most advanced achievements in the field of aviation and space equipment.

One of important problems of the carrier rocket (CR) start with the spacecraft is calculation of a program nominal trajectory of its movement on an active site. Creation of a flight trajectory is carried out for:

- estimations of payload removal possibility by means of CR into the set orbit, that is carrying out check of start-up problem realization possibility;
- obtaining of initial information by flight trajectory parameters for calculation of an onboard flight task coefficients.

Creation of the CR movement must be carried out with performance of conditions of:

- the movement optimality by criterion of maximization of weight launching by CR into the set orbit;
- falling of the separated elements of the CR design into set regions.

At the present time a number of essentially new conditions are shown:

- changes under the terms of start-up, first of all data of the wind systematization and specifications according to CR mass characteristics have to be considered;
- creation of the program movement has to be carried out taking into account restrictions by angles of attack, sliding and by angular speed of a turn of CR caused by minimization of cross overloads on an atmospheric site of flight and design features of the carrier;
- launching of SC into the orbits set by accumulating heights over a surface of an all-terrestrial ellipsoid;
- creation of the program movement and preparation of an onboard flight task have to be carried out operatively before start with use of the regular ground-based equipment of a control system.

The control system of the carrier rocket consists of several subsystems (Fig. 15).

The system of the masses center stabilization or the targeting system (TS) includes:

- RA—the removal automaton;
- SSRS—seeming speed regulation system;
- NSS—normal stabilization system;
- LSS—lateral stabilization system.

Work of TS is possible only if orientation of the propulsion system (PS) draft vector is known at any time.

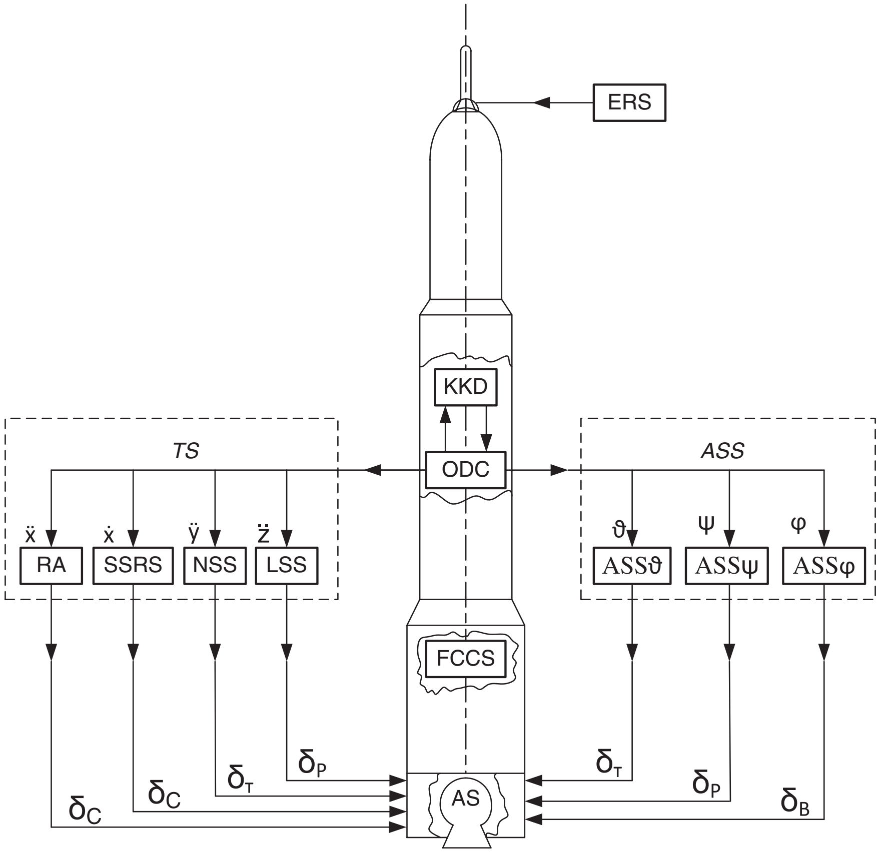


Fig. 15 Structural diagram of a control system of the carrier rocket

Tasks of stabilization and change of angular provision of the carrier rocket concerning the masses center are solved by the angular stabilization system (ASS) consisting of three channels:

- pitch channel of ASS υ—stabilizer of pitch angle ϑ,
- yaw channel of ASS ψ—stabilizer of yaw angle ψ,
- rotation channel of SUS φ—stabilizer of rotation angle φ.

The listed channels operate a deviation of the executive device of the pitch angle stabilizer by a tδ, of stabilization.

Information from the carrier rocket comes to all subsystems via the on-board computer from a complex of command devices. Projections of the masses center linear acceleration on axes of the chosen coordinates system measure accelerometers or gyroscopic integrators of linear accelerations, and angles of ϑ, ψ, φ, characterizing the provision of the carrier rocket concerning the masses center respectively by channels of pitch, yaw and rotation, gyroscopes of the direction or a three-axis gyrostabilizer.

Vertically starting carrier rockets need large reserves of liquid fuel. In relation to starting weight these stocks account for 80–90 %. For simplification of a control system work and reduction of guarantee reserves of fuel include the fuel consumption control system of (FCCS) in its structure.

For the purpose of the piloted flights safety the emergency rescue system (ERS) operating its own PS located over SC and rigidly related has to be provided. The command for inclusion of this PS arrives from special sensors of an accident condition

5.5 Satellites Control Systems

Generally for management and control of satellites from the moment of start and until the end of life cycle it is necessary to create the following organizational structure:

- technical and operational control center (TOCC);
- satellites control center (SCC);
- control and measuring stations (CMS);
- spectrum control stations (SCS). The technical and operational control center for each served region is responsible for planning and coordination;
- actions necessary for ensuring the correct use and functioning of the spacecraft;
- actions within maintenance of terrestrial stations which can influence on functioning of the spacecraft;
- communications availability for operational control;
- control of satellite segment using for realization of the translation plans or unforeseen plans and emergency situations.

The control center of satellites is responsible for control of the spacecraft and its systems which aren’t connected with performance of the main function namely:

- orientation and deduction of an artificial satellite of the earth in an orbital point;
- maintenance of working parameters of the satellite;
- the analysis of the telemetry received from control and measuring stations;
- control of the satellite location;
- granting guidance for targeting to earth stations.

Control and measuring stations are in each served region. They trace position of the spacecraft, accept from it telemetry and transfer to it control teams in interests of SCC, and also control a condition of an artificial satellite in interests of TOCC.

Control and measuring stations are equipped with means of accumulation and processing of certain volumes of telemetry data and data of vision angle and distance to the satellite, level the pilot-signal, identifications the pilot-signal and its frequency for transfer in SCC. Spectrum monitoring stations are usually combined with means of control and measuring stations and form uniform system. They closely interact with TOCC and generally answer for:

- help to earth stations and satellite operators in check on compliance of certain obligatory parameters of earth stations;
- measurement of EIRP of the spacecraft, central frequency deviation of the bearing, extra band noises and frequency of power dispersion;
- spectrum frequency control;
- carrying out of certain measurements according to the instructions of SCC and TOCC.

Regardless of a start place, type of the carrier and restrictions of payload start into a geostationary orbit is usually carried out in four stages:

- satellite launching into a low circular orbit
- transition to an elliptic orbit;
- transition to a circular equatorial orbit in apogee of a transitional orbit;
- drift in a final orbital point.

Each of stages demands the highest accuracy of maneuvers execution. Management and control during launching is exercised by means forces placed in a place of start-up and/or along a trajectory. These stations can use the same frequency ranges, as the main control and measuring complexes, or S range. Functions of stations—control of range and angles, telemetry and control. In a phase of position control of the SCC satellite:

- determines satellite height;
- performs calculation of transition optimum parameters to a circular orbit and the subsequent maneuvers;
- defines the actions which are necessary for exact orientation of the satellite in space on a transition stage;
- operates and controls maneuvers as a result of which the satellite reaches the estimated position.

Tracking of the satellite position and its control, removal of telemetry are carried out by special control and measuring complexes. During the entire period of the satellite existence the complex has to provide the solution of two tasks in the simplified look:

- the satellite is in the set point;
- antennas of the satellite look at Earth in the correct direction.

Radio contact with the satellite is provided by means of one or several CMS while information processing and formation of control teams are carried out by SCC. Though the satellite also “hangs” over one point on Earth surface, for bigger reliability it is recommended to use several stations carried in space.

There is a constant necessity to trace a condition of a large number of the satellite systems, to correct their work in case of a deviation from the standard mode and to operate work of the reserved equipment and payload. The systems of telemetry serve for the first, and for the second—control systems serve. The most important control objects are:

- operating mode of thermo control system;
- a power supply system operating mode (especially during the eclipse periods);
- operating mode of telemetry and control onboard system;
- work of an orbit correction system;
- work of payload;
- definition of the malfunctions location revealed as a result of program or random inspections;
- ability to immediate actions in case of the emergencies menacing to performance by the satellite of its main functions.

5.6 *Space Stations Control Systems*

Creation and operation of long-term orbital space stations during several tens of years can by the right be considered as one of the main achievements of astronautics. Development of the Universe by the person is impossible without his long stay out of the Earth's atmosphere. Technologies of long stay of the human in space which are one of key factors of mankind advance in space, were fulfilled on orbital space complexes.

Important aspects of such technology are:

- creation and tests of the life support systems allowing the human to be in space for a long time;
- the systems of a medical support and psycho physiological support of crew allowing to keep to astronauts health and working capacity in the conditions of hostile space environment;
- data exchange communication systems with onboard systems; control systems of the movement and navigation, etc.

However one of the most important results of the long-term orbital space complexes received during operation is the created control technology of their flight. This technology represents the unique control instrument of the difficult human-machine object separated from the control subject by considerable distance, and sometimes by temporary delays. System, in which and with the help of which this technology—an automated flight control system works.

Components of this technology are flight planning, control realization, the analysis of onboard systems work, full support of crew, various aspects of decision-making etc. [15].

It is obvious that all parts of flight control technology can harmoniously be implemented with the demanded efficiency level only if flight control process is appropriately organized.

The foundation of the long piloted flights was laid out by a series of orbital space stations “Salute”. At operation of these stations many elements of the flight control technology organization, such as creation of the full-fledged civil Main operational team of flight control which included representatives of various departments and the enterprises participating in flight control were created and realized; creation of multi-stage process of planning, etc.

The orbital stations flight control technology applied now is the unique product allowing to realize any very difficult space projects, to provide to Russia a leading position in the world in questions of space activity. It absorbed in itself all accumulated operating experience of orbital stations of the previous generations, grew in experience of the international cooperation and is in continuous development.

It gives the chance to operate successfully the space objects and complexes altered in the process of long continuous flight with the increasing complexity of control process, allowing the personnel of control to carry out in the conditions of the increased intensity of loading the control tasks assigned on them without decrease in reliability and quality of work.

Even in the mid-70s the main aims and the directions of world astronautics development were formulated, for example [16]. These directions are defined first of all by objective economic prerequisites of mankind’s use of space. It is possible to carry on in this direction:

The near-earth communication systems, data transmission and navigation formed by groups of Earth artificial satellites and a land segment of office boards control and target loading. Main target of such systems is considerable expansion of information space and efficiency of obtaining information by the interested users.

Land systems control by means of the space repeaters systems allowing influencing on control objects in territorially remote and inaccessible regions of a terrestrial surface.

Activity of these and other economically perspective directions can be carried out only by construction and functioning means of the corresponding space infrastructure [26]. The complex of such space infrastructure means includes:

- automatic spacecrafts for ensuring communication, navigation, meteorological supervision and remote sensing of Earth, research of planets, objects of Solar system and space;
- orbital and planetary elements of infrastructure near-earth space stations, independently flying ships, visited automatic platforms or large-size devices assembled in space, near-the-planet space stations, planetary bases;
- the transport space system providing delivery of infrastructure elements, and also people and goods in various points of Solar system;
- land complexes of preparation and start of spacecrafts, land complexes of control and management.

Key element of similar space infrastructure will be the intellectual transport space system as it is a link between other elements of space infrastructure, besides creation and functioning of space infrastructure elements without this system is represented to be extremely difficult.

One of the intellectual transport space system creation variants is the multilevel structure. At each level elements of system are integrated by the general signs: by the solved tasks, flight schemes, features of design etc.

It is obvious that the space infrastructure will consist of rather large number of non-uniform elements and only the coordinated work of all these elements can provide demanded level of infrastructure functioning efficiency. The demanded degree of coordination is provided as the coordinated collaboration of structural elements, and adaptive opportunities of these elements.

5.7 ITS in Logistics of Air Transport

Air transportation is generally used for delivery of valuable, urgent or perishable freights. Air transportations are especially in demand when it is not possible to deliver freight by other types of transport. It occurs due to the geographical position of the freight destination where transportation by air is the only way of freight delivery.

Air transportation—is a way of goods and passengers transportation by means of aircrafts. Advantages of air transportation are [27]:

- The highest speed of freight delivery;
- High reliability;
- Deliveries of freight to remote regions of the world;
- Opportunity to deliver freights practically to any distances;
- High guarantee of freight safety;
- The shortest routes of transportation.

The disadvantages of air transportation are [27]:

- High cost of transportations, the highest tariffs;
- Limited geographical availability;
- Dependence on weather and climatic conditions;
- Tough schedule of transportations.

Despite all the above listed disadvantages, air transportations are very popular and demanded type of transport, and often are the only ways of freight delivery. For many carriers companies air transportation is the main activity, and air transportations bring the most part of revenues.

The organization of air transportation demands from the company not only necessary specifications, but also the arrangement with various organizations and establishments. Therefore major carriers companies having sufficient financial means, a wide experience, having the stable income, and also necessary knowledge in this type of transport are often engaged in air transportations.

As this type of freights delivery is considered the most expensive, it would be actual to consider ways of decrease in cost of air transportation.

The correct calculation of weight and volume of freights will allow to optimum sort freight that as a result will cut down expenses. Other factor allowing to reduce expenses at air transportation—is an ergonomic arrangement of freights and high-quality packing.

In system of the international air transport, except the international carriers and the airports, the significant role is played by the states which are connected by the international airlines and provide this communication, and also the international organizations in the field of air transport which purpose of activity consists in ensuring its effective functioning and safety.

Air transport has three ways of regulation:

- national (by licensing of the air carriers working both on internal and on the international routes);
- interstate (when regular aviaroutes have the basis of the agreement between the governments of the countries);
- international (tariffs for regular flights establish (for members of airlines) on the basis of mutual contracts between airlines—participants by means of the International association of air transport (IAAT) or the third party).

One of types of the air transportation international regulation—is creation of the pools uniting the airlines operating on certain international routes. As air transport takes strong positions in world transport system, there was a need for its universal coordination and regulation. The international aviation organizations ICAO and IAAT are engaged in it. ICAO—International Civil Aviation Organization (International Civil Aviation Organization) which unites 183 states of the world. IAAT—the International association of air transport (International Air of Transport Association) uniting the international airlines (it was created in 1919).

The main function of IAAT—is the ordering of the international commercial aviamessages, introduction of uniform rules and procedures, coordination of tariffs for the international passenger air transportation.

The logistics of air transportation in transit of passengers demands the maximum coordination of logistic strategy and tactics of travel agencies and airlines. The logistic concept of passengers air transportation control provides, first of all, system approach to the organization of passengers and freights movement.

To the logistic scheme of airline interaction belong:

- block of organizational and legal support (ICAO, IAAT, bodies of state regulation);
- block of production providing (airports, enterprises of aero technical service, other airlines);
- block of service ensuring (customs, transport enterprises, insurance companies, banks);

- the block of air-transport production sales promotion (the automated systems of sale and tickets booking, own network of sales, sales through travel companies).

There is a logistic cooperation of transport firms and airlines which provides as the general coordination of passengers air transportation, such as cooperation in implementation of tickets to passengers. The last direction is rather in detail discussed in professional literature, in particular, define such forms of interaction:

- booking of places and repayment of air tickets through airlines agencies;
- booking of places and repayment of air tickets through booking systems;
- the contract with airline for a quota of places on scheduled airlines;
- the agency agreement, that is work as agency on sale of air tickets for the passengers;
- the organization of charter flights for transportations of passengers.

The purpose of ITS functioning in logistic systems of air transport—is an expansion of goods and passengers transportation logistic systems opportunities on the basis of intellectual algorithms application, navigation and information technologies in interests of demand satisfaction, taking into account safety of transportations.

Problem of ITS in logistics of air transport—is providing and maintenance of transport balance between demand for air transport and the real capacity of a transport network, taking into account its structural state. The main strategy of air transport ITS realization is full-landmark building and expansion of the existing systems:

- air traffic control and monitoring of transport streams;
- informing systems of transportations participants and passengers;
- rationalization of freight delivery systems;
- rationalization of passenger traffics and freight traffics;
- transport logistics of warehouses and Cargo.

Introduction of ITS in air transport logistic systems creates a necessary set of innovative tools for the solution of air transport effective control problems.

The basic structure of intellectual system of aerospace system logistics is presented in Fig. 16.

Each of subsystems in Fig. 16 at the first stage develops independently, irrespective of the others, for the purpose of development and association of the objects entering it:

- Monitoring of stationary objects directly depends on development of high-precision positioning of satellite navigation systems, and also application of technical vision technologies.
- Monitoring of mobile objects completely depends on equipment of mobile objects satellite controllers with means of communication. This subsystem, in view of presence of various hardware needs data centralization and standardization, data protocols on the uniform server of data collection.

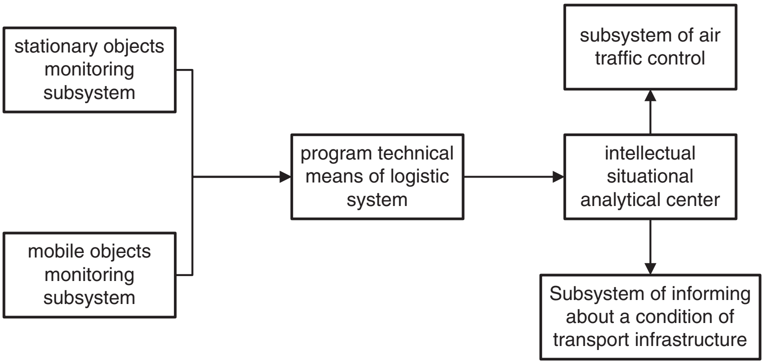


Fig. 16 Structure of intellectual system of aerospace system logistics

- Program technical means of logistic system provide reception, preliminary processing of monitoring results, and problems solution of images recognition, fixation and indexing of monitoring data.
- The subsystem of air traffic control provides logistic system elements control on the basis of 4-D navigation technologies.
- The situational center is created on the basis of the operating systems of stationary and mobile objects monitoring and makes formation of situations and the subsequent their analysis on the basis of artificial intelligence methods.
- Functioning of an informing subsystem is the final stage of information processing in ITS of air transport logistic systems, it is connected with the central storage of data on the ITS server and resources of monitoring hardware subsystems.

As the main functional subsystems within the intellectual system of ITS in logistics uniform control center it is possible to allocate the following:

- Intellectual control system of the AC movement;
- Control system of transportations safety by aircrafts.

The intellectual control system of the AC movement includes:

- the modernized means of AC avionics;
- system of the transport streams automated monitoring;
- monitoring of freights, passenger traffics on the basis of technical vision systems, and means of satellite navigation;
- system of transportation participants information support;
- intellectual system of an assessment of transport streams parameters.

Intellectual control system and safety of air transport transportations:

- system of mobile objects monitoring data collection;
- system of passenger traffics monitoring;

- system of informing passengers;
- intellectual calculation of passengers;
- systems of technical vision and assessment of the AC movement parameters;
- intellectual analysis of the transport streams movement parameters.

The subsystem of informing about a condition of transport infrastructure, can be presented in the form a complex of decisions on informing, presented in Fig. 17.

The logistic system of passenger traffic by means of AC, covers the following three links, as preflight, flight and post flight service.

The essence of preflight service of passengers consists, first of all, in providing sufficient and various information about possibility of a carrier, that is the passenger inform about a regularity of flights from the directions, interesting its existence determined by the AC type, privileges and a discount during buying of the tickets, on services which provide onboard according to a booking class etc. There is the first block of a preflight service link is directed on that the potential passenger became the client of a certain company. The important place is taken thus by technology of service sale in AC transportation which needs to be carried out quickly and accurately. In the course of sale there is a coordination of a route, i.e. a choice of compatible flights, convenient for the passenger, which can carry out other airlines, define a service class, the airport, date and time of departure and arrival. After payment the contract between the passenger and a carrier is fixed by the ticket for transportation. So the client becomes a passenger and it is included in a logistic chain of passenger traffic.

In the second part of preflight service it is provided arrivals of the passenger and his service at the departure airport. At this stage it is necessary to organize accurately control of passenger traffic on the way of the movement to the airport,

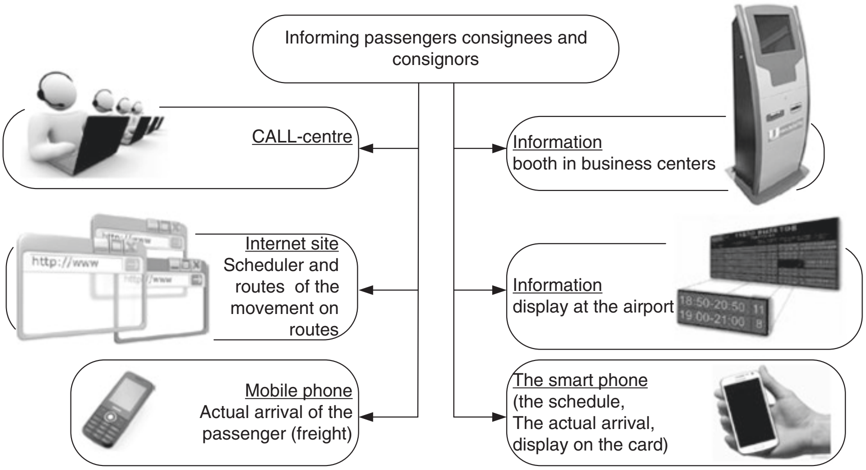


Fig. 17 Subsystem of informing about a condition of transport infrastructure

at registration of air tickets at the airport, and also passing by passengers boundary, customs, quarantine and other preflight types of control and formalities.

Flight service—arrival of clients in airports of destination with safety of flight, necessary comfort and service during travel.

Post flight service consists in ensuring comfort at the airport of arrival, and also providing additional services by airline, for example booking of hotel reservations, the order of a taxi, etc.

Therefore, for achievement of the maximum effect of system in general all three links have to function in coordination with uniform logistic chains of passenger traffic that, in turn, demands coordinated actions of all participants of logistic system. The majority of logistic system sites of passenger air transportation is, in fact, service institutions where services are directly connected with the passenger. Therefore rendering of services by means of an effective way from the point of view of expenses and passengers providing requirements has to become an assessment criterion of interaction level of all links of a logistic chain on service of a passenger traffic. For an assessment of services quality it is expedient to use comparison of the buyer expectations with actually provided aviaservices in such parameters as reliability, safety, a regularity, flexibility of tariffs, responsibility, convenience, politeness, aboard food, skill to communicate and knowledge of foreign languages, informational content, additional services. Such aviaservice quality indicators of the passengers who are often meeting in polls making various airlines to find out service level. The purpose of logistic system functioning of a passenger traffic service consists in the control organization so that to minimize distinctions between expected and actual levels of services quality.

Now broad penetration of logistics into the sphere of transportations by air transport perhaps thanks to a computerization of processing and providing data and automation of communication [31]. In this area the leading role in the global automated distribution systems (GASZ) of air-transport production, for example, play systems “Gabriel”, “Amadeus”, “Galileo”, “Siren-2000”. For today primary activity of these systems is directed on inclusion in the sphere of all complex of the services connected with air transport controlled by them, including sale of places in hotels, car rental, cruises and other tourist travels, trips by other means of transport, i.e. automation of airlines. For the purpose of air transportation electronic sale use the international computer Internet more often. One more factor promoting application of logistic methods on air transport, globalization of the world market of air transportation. In recent years this market was divided by the leading airlines of the world. To get on the new markets, airlines unite in alliances. Thus, they can increase production volumes (“economy of scale”), to order big parties of the equipment and materials at low prices, and also in common to order planes, flights under the general code, to use uniform forms of air tickets, etc., there is a possibility of standardization and rationalization of the equipment, reduction of auxiliary services. Example of international aviaalyans is the association “Uniform World” which is composed of eight airlines, namely “Ayer Lingusy” (Ireland), “American airlines” (USA), “British airways” (Big Britan), “Kezevey Pasifik” (USA), “Fineyr” (Finland), “Iberia” (Spain), “Foams of Chile” (Chile), “Qantas” (Australia) are.

6 Instrumental Tools of Intellectualization

6.1 Composition of Intelligent Transportation Systems

This part focuses on the development of architecture and technical solutions for implementation (ITS). The presented system will perform the following functions: monitoring the movement of an object collecting displaying information about the state warning of the approaching object to obstacles, routing, as well as control of movement and speed of the output parameters of the recommendations of the movement, the development of intelligent decisions about the choice of rational routes, intellectual analysis of data (IAD) of the style and movement, IAD on the technical parameters of the vehicle. Thus, it is advisable ITS divided into several subsystems, which are related but are responsible for one or more functional tasks. Consequently, the need for monitoring the movement subsystem, the database on the state of the object database on the location of an object, display subsystem, the subsystem of control, the engine safety (prevention of obstacles), the subsystem control parameters of movement, routing subsystem [28–30, 32].

6.2 The Subsystem Monitor Traffic

This subsystem is required to track the current location of the object, recording the location, monitoring the passage of a given route. To implement this system can be based on the AVL system, which uses global satellite navigation. The subsystem on-board set a system is shown in Fig. 18.

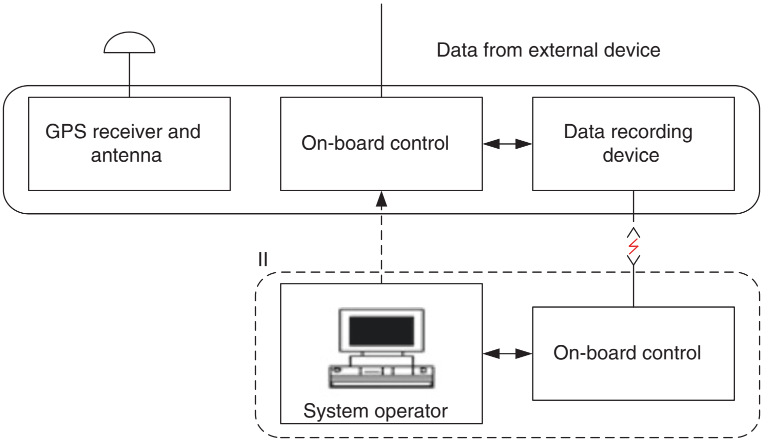


Fig. 18 Functional diagram on-board system

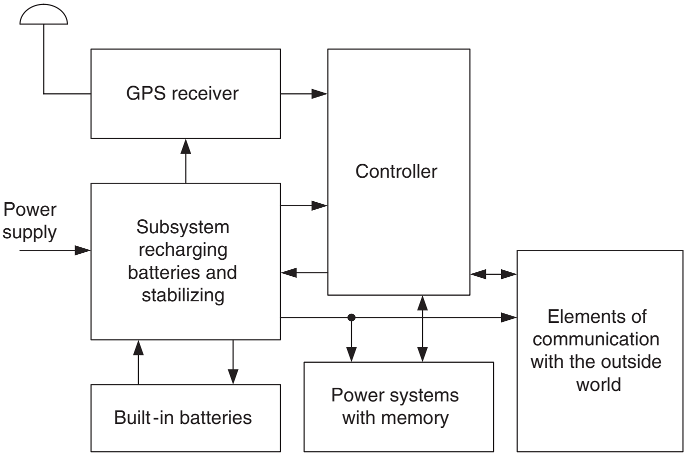


Fig. 19 Functional diagram of the board set

Board set the transport facility is designed to obtain information about its current coordinates the collection of information from external sensors, archiving, data transformation and conservation in non-volatile memory.

N-board kit consists of the following hardware:

- Navigation GPS receiver and antenna (one case);
- Intelligent controller.

Figure 19 shows a general functional diagram of the on-board kit.

6.3 Databases

For the Intelligent Transportation System to two databases. The first is a database on the state of the object, which will include online data obtained from the motion control subsystem, namely, speed, distance traveled, time, motion, time, motion, without stopping, the number of stops of the object. Also, this database will contain information on safety systems—the coordinates of obstacles and dangers on the route of movement, but also record messages and notifications that need to convey to the user system. The second database—the navigation database. It is formed by the monitoring subsystem. That is obtained from the device to write data reported by GPS navigation sensor in the format of NMEA, namely GPGGA, formed by a set of coordinates and time of movement of the object. These databases are used by virtually all the subsystems of intelligent transportation system.

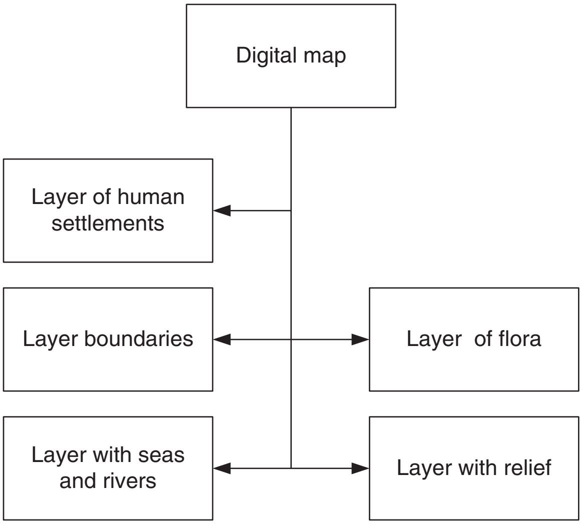


Fig. 20 The structure of the vector map

6.4 Display Subsystem

The system is designed to display the results of the system: the location on the map, the coordinates of obstacles and dangers on the road map of the route or movement of the program on the map, the map a route to overcome the subject, displaying messages from the security system. The work of this system can be divided into two types—work with cartographic information and work with messages. Working with messages based on the work with the database state. Working with Cartographic information implies the presence of a digital terrain maps. It is advisable to use vector maps, as they contain not only the image area, but also, primarily, a set of data about the objects areas, transport networks, topography, etc. The structure of the vector map is shown in Fig. 20.

Displays information from the navigation database is using real mathematical coordinate binding to the sheet maps and its size, the rate of one degree steps onscreen pixel.

6.5 Control Subsystem of the Way

The operation of this subsystem is to monitor the status of the satellite line in order to detect obstacles to free movement or of any hazards. Functional diagram of the control subsystem of the road is shown in Fig. 21.

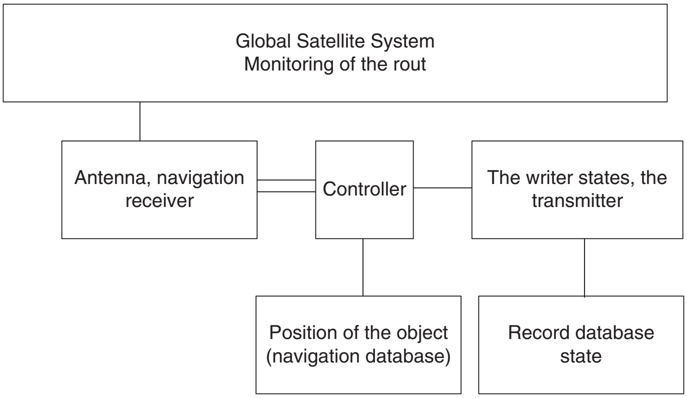


Fig. 21 Functional diagram of the control subsystem

6.6 Subsystem Routing

Subsystem routing is necessary for laying, constructing and displaying routes and best routes to save time, energy and economic resources. Implemented using software, based on the algorithms on graphs, in particular, depth-first search, Dijkstra's algorithm, I * and greedy algorithms.

Control subsystem is a subsystem of parameters of motion information processing in order to transform the data into the navigation database data in the database state by using mathematical calculation speed and distance from the known coordinates of time and movement.

6.7 Model of the Intelligent Transport System

The information model of ITS

Based on the analysis of the interaction of subsystems of intellectual ltransport system together can build an information system model. This model is presented in Fig. 22.

Functional diagram of ITS

To implement the ITS developed the following scheme (Fig. 23) [3].

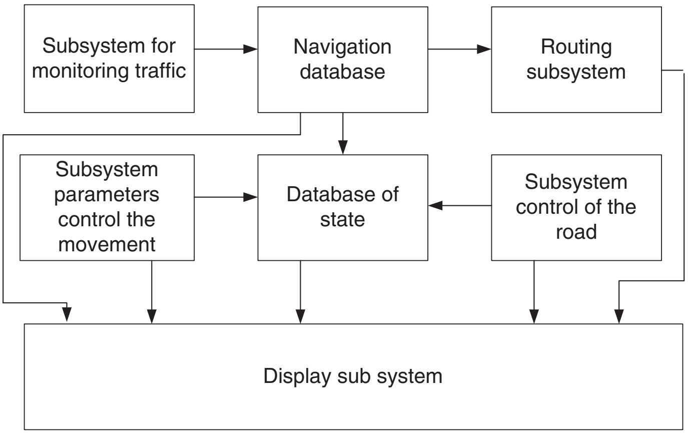


Fig. 22 The information model of ITS

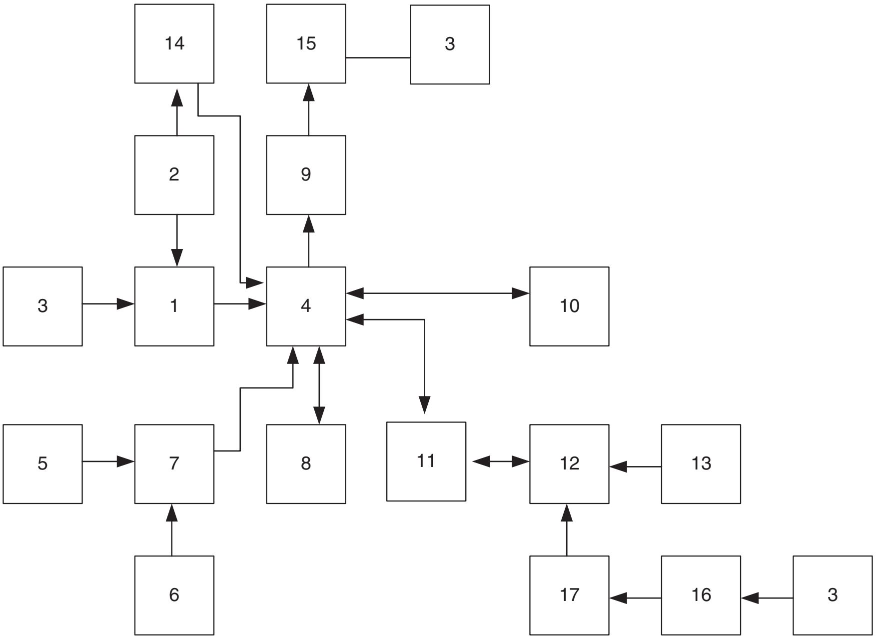


Fig. 23 Functional diagram of ITS. *1* The receiver of a moving object. *2* The moving object. *3* Global satellite system. *4* Managing controller. *5* Power supply. *6* Battery. *7* Subsystem stabilize supply. *8* Memory. *9* The device is displaying map information. *10* Nonvolatile information sohranitel. *11* Wireless transmitter of information. *12* Central station. *13* Cartographic information. *14* Power sensor motion parameters. *15* The device for calculating and recording data on the state of motion parameters and the state route. *16* The local radio. *17* Transducer terrain data

7 Conclusions

The current state of the main ITS in aerospace systems attempts to present in the paper. It should be noted that today it is practically impossible to analyze all existing set of intelligent systems in the area of interest. The analysis of systems allows the following conclusions.

Application of intellectualization in aerospace engineering gives rise to

- eliminate the influence of human factor when picked and implement solutions to modern problems of navigation—4-D navigation and free flights;
- transfer carry on numerous functions of ground services on aircraft board, such as deep diagnosis and restoration of working capacity, aircraft control systems, during both the flight and preflight;
- integrate aircraft avionics systems into air traffic control system;
- creating automatic intelligent hardware and software means at every levels and stages of the aircraft control.

The main functions of the ITS in aerospace engineering as follows:

- preventing collisions of aircraft in the airspace and outer space.
- preventing collisions of aircraft on the ground;
- avoiding collisions aircraft with the Earth;
- ensuring optimal efficiency of each flight of the aircraft;
- providing the crew manned aircraft actual flight information;
- intelligent identification of the aircraft;
- activity related to the rationalization of air traffic flow;
- ensuring alerting service accident on search and rescue.

In aerospace engineering, it is advisable to consider the ITS, in accordance to and consist of

- intellectual aircraft subsystem;
- intelligent aircraft infrastructures;
- tools of intellectualization.

Should be allocated the fact that many intelligent systems in aerospace engineering have been complex evolutionary path of development and appeared within individual intelligent systems, so today is the actual task of integration of existing intelligent systems into a single ITS.

In parallel with the subsystems of aircraft intelligent infrastructure systems, focused on the implementation of the preflight preparation of aircraft, traffic management, and logistic application of aircraft intellectualization were developed. Among intelligent systems infrastructure is particularly important following systems:

- air traffic management systems
- meteoconditions of monitoring systems
- terrestrial movement management system and monitoring over it

- control systems of carrier rockets
- satellites control systems
- space stations control systems

ITS in logistics of aerospace systems.

The tools allow you to implement subsystem of aircraft intellectualization jointly developed with infrastructure intelligent tools. Among the basic trends in the development of ITS in aerospace systems should be noted

- system and deep automation preflight aircraft;
- extension of the conditions application of the aircraft preflight preparation;
- improving the adaptability of aircraft control systems to expanding operating conditions.
- improve safety of use of the aircraft.
- improving the comfort of using the aircraft.

Significant increase autonomy and reliability perspective samples aerospace engineering, expanding their range of tactical and technical and operating characteristics will require a new generation of on-board intelligent control systems, providing an opportunity operation in a transience changing environment, in the presence of random perturbations of the environment, and other factors of uncertainty in an integrated the use of advanced intelligent technologies, as well as the integration of such systems in the global ITS.

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