Lecture Notes in Networks and Systems 2

Elżbieta Macioszek
Grzegorz Sierpiński *Editors*

Contemporary Challenges of Transport Systems and Traffic Engineering

13th Scientific and Technical Conference "Transport Systems. Theory and Practice 2016" Katowice, Poland, September 19–21, 2016
Selected Papers

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Janusz Kacprzyk, Polish Academy of Sciences, Warsaw, Poland
e-mail: kacprzyk@ibspan.waw.pl

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Editors
Elżbieta Macioszek
Faculty of Transport
Silesian University of Technology
Katowice
Poland

Grzegorz Sierpiński
Faculty of Transport
Silesian University of Technology
Katowice
Poland

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Preface

Contemporary transport systems require new decisions pertaining to planning, organization and control of traffic to be made on an ongoing basis. These decisions entail the necessity of seeking increasingly efficient solutions. The main challenges faced in this respect include increasing availability and quality of the transport services rendered, improving safety and reducing the negative environmental impact of transport.

This publication, *Contemporary Challenges of Transport Systems and Traffic Engineering*, provides an excellent opportunity to become familiar with the latest trends and achievements in the field of contemporary transport systems as well as traffic engineering challenges and solutions. It has been divided into four parts:

- Part I Quantitative and Qualitative Determinants of the Development of Transport Systems,
- Part II Optimisation of Transport Systems,
- Part III Safety Analysis in Advanced Transport Systems,
- Part IV Advanced Systems of Traffic Engineering and Travel Models.

The publication contains selected papers submitted to and presented at the 13th Scientific and Technical Conference "Transport Systems. Theory and Practice" organized by the Department of Transport Systems and Traffic Engineering at the Faculty of Transport of the Silesian University of Technology (Katowice, Poland). The topics addressed include the current problems of transport systems, among other subjects discussed. Using numerous practical examples, authors have analyzed various opportunities for improvement of the current state of matters, bearing the well-being of people, sustainable development of transport systems and protection of natural environment in mind.

We would like to use this occasion to express our gratitude to the authors for the papers they have submitted and their substantial contribution to the discourse on the multiple challenges facing transport systems and traffic engineering in the contemporary world as well as for rendering the results of their research and scientific work available. We would also like to thank the reviewers for their insightful remarks and suggestions which have made it possible to ensure high quality of the publication.

And to all readers, we wish intellectually stimulating reading.

Katowice, Poland
September 2016

Elżbieta Macioszek
Grzegorz Sierpiński

Organization

Thirteenth Scientific and Technical Conference "Transport Systems. Theory and Practice" (TSTP2016) is organized by the Department of Transport Systems and Traffic Engineering, Faculty of Transport, Silesian University of Technology (Poland).

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Part I
Quantitative and Qualitative Determinants of the Development of Transport Systems

Competition Tools in Passenger Transport in Urban Areas

Zofia Bryniarska

Abstract Growing transportation needs of passengers in cities and urban areas around them are satisfied by walking, cycling trips or by traveling by means of public transport. The use of competition tools (competing on price, competing on quality, competing on service, competing on communication and information) and increase in the attractiveness of public transport, particularly in relation to individual transport, can allow for sustainable development in urban areas, reducing emissions and saving energy resources.

Keywords Public transport · Competition · Urban area

1 Introduction

City functioning and development depend to a considerable extent on an efficient transportation system. The importance of the problem is strengthened by the fact that more than 60 % of people live in cities and it is predicted that by 2050 the share of city population will rise to 75 %. Depending on distances, inhabitants move by walking, cycling or by means of public transport and private transport. Modal split is dependent on many factors, including geographical, physical, economic, cultural, psychological ones, and others. A growing share of private motorization is observed in many towns. On the other hand, traffic conditions for both individual participants as well as public transport worsen, speed decreases and waste of time for passengers and drivers as a result of congestion grows.

Diverse technical, technological, legal, and cultural solutions, which would reduce the burdensomeness of transport, facilitate the movement of passengers and improve the quality of citizens' life, are sought.

The competition tools used in collective public transport in urban areas, entities who use them in practice and effectiveness of individual tools as well as the need

Z. Bryniarska (✉)
Cracow University of Technology, Krakow, Poland
e-mail: z_bryn@pk.edu.pl

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to consider their interdependencies to reinforce the positive impact of the tool have been presented in the article.

2 Literature Review

The problem of growing transportation needs of residents in urban areas and the ineffectiveness of activities involving only an increase in the size and capacity of the transportation infrastructure has been known for years [1]. Additionally, a sense of unease about the growing external costs of transport [2] and threats to the environment caused by transport [3] is observed.

In recognition of the existing threats and the need for transport services in cities, EU documents [4–6], formulate recommendations for the sustainable transport development, which will provide efficient, safe, effective mobility, and simultaneously guarantee the economic development of cities and access to them, the improved quality of life and environmental protection. Solutions are found in a more accessible, intelligent, safe and reliable urban transport, where the participation of walking and cycling and collective public transport will be increased. The vision of a competitive and sustainable transport system, the need to support integrated mobility while achieving the target of reducing emissions by 60 % is emphasized even more strongly in the subsequent White Paper 2011 [7].

It is stated in the Polish legal documents [8] that the obligation to meet the collective needs of the community in the administrative borders of the municipality, including with respect to local transport, should be the obligation of the municipality. Another document [9], which implements an EU regulation [10], assumes a form of public transport organization based on regulated competition with the needs of sustainable development taken into account. In addition, it is stated that the management of collective public transport includes tasks related to ensuring appropriate conditions for the operation of public transport, determination of quality standards, testing and analyzing transportation needs for different user groups, the control of the implementation of contract terms, the current correction of the transportation system and schedules, passenger information system administration.

The need to integrate transport systems of the city (municipality) and the neighboring suburban municipalities is reflected in the following documents [11, 12]. They formulate the recommendations to solve transport problems in an over-municipality scale i.e. functional areas or metropolitan associations, assuming that the problems of transportation and public utilities must be addressed in a coherent and integrated way in the city and the areas around it characterized by a high density of the population living an urban lifestyle.

3 Description of Research Object

The object of the research is the city and the urbanized area around it, where the transportation needs of residents are solved in the form of walks, bicycle trips or journeys by means of motorized transport. The organizer of public transport in this area is the competent body of the local government i.e. a municipality (city), an inter-municipality union, a metropolitan area, a district or a province. Its tasks include planning, organization and management of collective public transport.

Competition in urban transport manifests itself in the form of competition for market entry and competition in the market. In the model of regulated competition, an organizer of transport is a monopsony in relation to transport operators and a monopoly in relation to public transport passengers. As a monopsony, it is the only recipient of services, which are provided by multiple carriers-operators. It controls the entire market and can dictate its terms to suppliers (e.g. related to standard, age, equipment of vehicles). It prepares and carries out the procedure leading to the conclusion of a contract for the provision of services in the field of public transport, signs the contract and controls its execution. Competition in the sphere of transportation services provides the organizer who purchases transport services with the verification of the level of service costs [13]. All carriers functioning within a public transport system operate under the brand of the organizer. On the one hand, this means the loss of self-recognition and the necessity to meet the quality requirements of the transport service and rolling stock imposed in the contract, but on the other hand, it implies no need to acquire buyers of services. Quality criteria in the contract for the provision of services usually include monitoring the punctuality of departures from stops, reliability of services, quality of vehicles (equipment, cleanliness) and service quality (driving technique, the way of stopping at bus stops, politeness of service staff) [14]. The verification of these criteria is carried out by the organizer at a high frequency [15, 16] in accordance with the requirements specified in the contract for the provision of transport services.

But in the sphere of the operations of transport organizer, recipients of transport services (passengers) may also choose travelling by means of individual transport and due to the kind of transportation needs served, a passenger car is the main competitor to collective public transport [17]. Organizer's activities should aim to fulfil the most important transportation-related postulates of passengers (directness, punctuality, frequency, availability) [18] and meet the expectations of the recipient in the best way possible [13].

4 Applied Research Methods of Competitive Struggle

An appropriate modal split in cities is a big challenge as regards high quality of life, environmental and natural resources protection [7]. In this process, the competition between collective public transport and individual transport is of utmost importance. Both forms apply for access to the same resources: infrastructure and energy. The rivalry against individual transport can take four basic forms: price competition, quality competition, service competition, competition by communication and information [19, 20]. The entity which may use these tools is the organizer of public transport, although it must be supported by the units responsible for planning transportation systems. The aim of such cooperation should be to acquire as many buyers of public transport as possible.

4.1 Competing on Price

In the conditions of urban transport, competing on price has a limited impact. The organizer prepares a proposal for tariffs for transport services, it is responsible for the organization of these (which fall under its competence), but the proposal is subject to approval by the city council and is also a tool of social policy of the city authorities.

Besides the level of the fares for public transport services, it is the transparency, fairness and clarity of tariff structure that are of great importance to passengers. The tariff should be structured in such a way as not to raise doubts concerning the choice of the type of ticket fare. Fares are also important for people who usually use cars when they have to decide whether to use the services of public transport.

Additional facilities are addressed to groups of people who use the services of public transport on a regular basis (season tickets), who are entitled to municipal or statutory discount for transport or entitled to free transport (discount tickets), groups of people travelling together (group tickets), families at weekends (family tickets), job seekers (activation tickets) or people who change means of transport within the designated time of the ticket (rule of correspondence). In such cases, a single journey is considerably cheaper than a single ride by car and the level of benefits for the passenger against the travel by car is much higher.

Another advantage for car drivers is an ability to use the "P & R" car parks within a season ticket for public transport.

Integrated tariff-ticket systems provide an even greater level of amenities for passengers. On the one hand, such systems require the organizers and carriers to solve the problem of mutual settlements, but, on the other hand, they give passengers the convenience of using a single ticket offered by multiple carriers, without the need to become familiar with their tariffs and the consequences when choosing the wrong ticket, without the need to validate the ticket in the next means of transport. Furthermore, they facilitate the use of different transport systems operating in the large area, break the barrier of fear against public transport. Additionally, they provide financial benefits, since the price of the integrated ticket is lower than the sum of the partial ticket prices for individual means of transport [21].

Free public transport (zero tariff) is a proposal that goes far ahead in the direction of reducing the cost of using the public transport services in the city. It was introduced in several cities in Poland (Zory, Lubin, Swierklany, Nysa, Goleniow and Mlawa) and worldwide (Tallinn, Sydney, Miami, Seattle, Cardiff, Bangkok) [22]. The evaluation of this system and the benefits of increasing the number of people using public transport are not clear [23].

The development of tariff schemes can be expected in the near future, when metropolitan associations are set up [11]. The scope of their powers include the establishment of an integrated system of tariffs and ticketing in force within the boundaries of the system [9].

4.2 Competing on Quality

Competition in terms of quality includes compliance with high quality characteristics of the transport service, and especially the elimination of an identified quality gap, offering innovative products, flexible and environmentally-friendly transportation offering. In competition with individual transport, the journey duration, travel speed and comfort of movement are of particular importance for passengers. With the use of a variety of priorities for public transport vehicles (dedicated bus, tram or tram-bus lanes, privileged traffic lights, determination of zones of limited access to other users) [24], it is possible to reduce journey duration and increase the speed of public transport vehicles on crowded routes of the core part of the public transport system. However, travel time includes also the time for getting to/from the bus stop. To shorten this time to such an extent that it is attractive for passengers and inclines passengers to make a decision about using the public transport services, the network of public transport routes must be dense enough, and the pathways to bus/tram stops must be short, of good quality, comfortable, safe, without a need to pass obstacles, aesthetic and ergonomic. This aspect is rarely of interest to transport organizers, yet it belongs to the obligations of the municipality [8].

The convenience of travelling means much more than just the comfort of ride. The comfort of ride depends on the quality and technical condition of the vehicle, its equipment, the number of seats, the level of congestion, the driving technique of the driver. The number of passengers in vehicles is affected by the organizer's decision on the size of vehicles used, the number of rides on the line, regularity and frequency of communication lines. The size of vehicles can be easily adapted to the size of passenger flows. More and more often, even in large cities (Vienna), small buses are used on routes in the city center or in the suburbs and multi-articulated buses or trolleybuses (24 m Hess—Hamburg and Zurich bus) on the core routes of primary importance are used as well as multi-articulated tram vehicles (43 m Pesa 2014N tram in Krakow, 54 m—Siemens Combino in Budapest, 65 m—Alstom Citadis in Casablanca). The use of the tram is determined not only by the purity power but also by higher capacity of vehicles. Other attractive vehicles are trams on tyres (Translohr system in Clermont-Ferrand) providing high capacity and quiet driving typical of the bus. There are also other noteworthy solutions in which the overhead catenary is abandoned in favor of powering the tram from the ground, using a special "track" placed as the third track between the guide rails near the tram (Orleans), or using a power system consisting of supercapacitors and lithium–ion batteries to cover some sections of routes autonomously, which seems to be great in the historical city centers (Bordeaux, Seattle, plans for Krakow).

On the one hand, environmental performance of vehicles results from better and better engines which meet EURO 5 and EURO 6 standards or engines fueled by natural gas, biogas, hybrid buses, and on the other hand, vehicles using electric power from the traction battery or from more and more modern batteries. Electric buses, whose batteries are loaded in the depot or in a special charging station in the street, are also increasingly used. Their other undeniable advantages are the flexibility of routing, quiet ride, the ability to recover energy during braking, ride comfort for passengers.

The standard vehicle equipment includes a low floor, number and width of the doors for easy entry and exit, comfortable and ergonomic seats, handles for all standing passengers, space for transporting prams and wheelchairs, and even bicycles (inside or outside the vehicle), monitors broadcasting program in the form of current news, curiosities, advertising, Wi-Fi or Internet communication, USB socket, air conditioning or heating, security cameras inside and outside the zone of the vehicle.

In addition to vehicles which are modern in technical, technological, energy, or ecological terms, their attractiveness is increased by aesthetic design, workmanship, details of adaptation to the specifics of the city, and at the stage of operation to maintain the efficiency and cleanliness.

4.3 Competing on Communication and Information

Information on traveling by collective public transport plays an important role at every stage of the journey: while planning, while at the bus/tram stop or in the vehicle and when reaching the destination [25].

When you are planning a journey with the use of the available sources of information about the routes and timetables of communication lines in the form of traditional schedules (paper ones and those at stops) or modern information technology (websites, search engine of connections and mobile applications), you can easily decide if you can make your move by means of public transport, at what time and at what cost. This information allows the passenger to largely reduce uncertainty and discomfort due to the risk of not achieving the destination on time.

The level and scope of information at the bus stop changes as well. In addition to traditional forms of information on timetables, tariffs and transport regulations, there is also other useful information particularly appreciated by passengers [25]. This information includes pictograms indicating the place where the door stops in order to enter a wheelchair or a pram, site maps of the interchange, QR codes allowing passenger to use mobile devices and browse through the invariably up-to-date timetable of the line, dynamic passenger information boards, which display information on the actual arrival time of vehicles or transmit it in the form of voice. The information on the disruption of services and the projected time of solving these problems is desired and expected by passengers. Multimedia passenger information display systems are another innovative feature. In addition to a modern attractive form of presentation, among others, they provide the ability to customize the font size to the needs of the user or display additional information about the state of the air, weather forecasts, cultural events and other important objects or monuments.

The necessary information on the vehicle (and inside the vehicle) relates to the communication line number and direction of the vehicle destination, the doors designed for wheelchairs and prams or doors closest to the ticket machines. The additional information inside the vehicle includes the route of the line, journey duration at sections between bus stops, the current place where the vehicle is located, displaying information and a voice calling a stop to which the vehicle is approaching.

4.4 Competing on Service

Competition by service covers many aspects of the service provision, beginning from the availability of time and space, through the accessibility of the functional diversity of distribution channels, and ending with the complexity of the operation. It gains more and more importance as service competition allows the organizer to use many small elements, which were mentioned with regard to competing on quality and communication and information in the whole system of supplying public transport services that are competitive in relation to private transport.

Public transport time availability covers the time of the greatest activity of inhabitants (4:00 a.m.–12:00 a.m.) and continues services at night [26]. The spatial availability covers at least the area of the city and the area around the city, and it is increasingly being extended to the functional (metropolitan) area of the city. However, the intensity of communication services encounters difficulties arising from insufficient planning of communication systems at emerging areas or improper scheduling tasks of long-term investment plan (Gorka Narodowa in Krakow).

The efficient use of resources in both infrastructure and means of transport allows the organizer to increase the functional availability and integration of different modes of transport and strengthen an attractive, varied transport offering. Rail transport (rail, metro, tram) is most commonly used within the core transport network, supplemented by bus and trolleybus transport, and in the specific field conditions also funicular, rack railway, water tram, ferry or a multi camp in rail transport (Karlshruhe, Nordhausen).

Directness expected by passengers can and often due to technological reasons must be replaced by the combination of journeys using different lines on the itinerary, but under conditions of maximum ease during transfers for the passenger.

This rule includes provision of high frequency of trips on the core routes of the transportation network, the convenience of changing vehicles, coordination of schedules. The convenience of changing trains can be improved by proper design of interchanges, respecting their compactness, clarity, quality of basic infrastructure within the platforms and passages between them, accessibility for disabled and elderly, personal security and safety (when crossing the road), passenger information, additional equipment (pergola, ticket machines, small architecture) [27]. Another solution convenient for passengers covers also common tram and buses stops on dedicated tram-bus lanes or location of bus stations next to (at the ends or at other levels [tunnel, wharf]) rail transport line (trams, subway, commuter rail) in such a layout that it saves the passengers from a long passage.

The integration of public transport and individual transport also applies to a comprehensive treatment of the problems of “P & R” and “P & B” car parks. Those car parks located on the inlets to the city can stop the movement of vehicles on the outskirts of the city, but they also need to be communicated with public transport stops (regional railways, agglomeration (S-Bahn), urban underground (U-Bahn), metro, tram and bus services), which will offer travelers convenient and fast transport to the city center [28]. It is worth noting that “P & R” car parks are often created spontaneously along the lines of urban and regional railways [29], and supplemented with high frequency (every 30 or 60 min) and constant-bar timetable of trains contribute to multiplying a number of passengers on railway agglomeration lines [30] and reduce traffic on the roads.

The diversification of distribution channels is to facilitate the methods, ways and place of purchase of public transport tickets. The traditional way of buying tickets in kiosks or from drivers is replaced by ticket machines (for coins, banknotes—with change, payment cards) selling single tickets or season tickets available around the clock, located at bus stops or in vehicles. The form of a ticket is also changing from a paper ticket to an electronic card with a chip or e-wallet which has numerous additional features for passengers, but also functions as the transport organizer. Tickets can also be purchased via mobile devices.

5 Presentation of Analysis and Discussion

An extensive set of different competition tools is constantly being developed together with the emergence of new innovative technical and technological solutions in infrastructure and vehicles, new ways of communicating and sharing of information provide many opportunities to facilitate the planning of trips and commuting, and reaching other destinations, reducing the uncertainty associated with the journey, shortening the duration of travels, ensuring comfortable conditions also for passengers at an older age, with movement dysfunctions and visually impaired.

Competition tools referring to price, quality, communication and information, and service have to be used together, simultaneously on many different levels of passenger services, at many stages of the journey, in order to strengthen the impact and achieve synergy of action.

The modern, fast and well-equipped vehicles are not enough when they waste time in overcrowded streets or while passing through the intersection. Organizational measures must relate to the integration of various technical and technological means of transport operating in the area, with varying coverage (local, regional), and, at the same time, to the development of traffic control systems and systems of passenger information. Tram tracks require to be modernized and properly maintained. “P & R” car parks must be linked with fast public transport systems operating with high frequency. Considerable attention should be paid to the development of integrated tariff schemes.

Moreover, the stage associated with the arrival to and departure from the bus/tram stop is also an important stage of journey for passengers. Pathways are often excessively elongated, and if not, the quality of these roads, aesthetics, and safety do not encourage passengers to use means of public transport.

6 Conclusions

A variety of competition tools available in the collective public transport, in addition to the observed cultural changes among young people, their loss of interest in owning a car and a constant need for interpersonal contacts in social networks let us hope to meet the recommendations of the White Paper 2011 and to increase the share of public transport in the passenger transport in urban areas, and at the same time, decrease CO_2 emissions and save non-renewable energy resources.

Competition tools should, however, be used on many levels at a time. If they are used selectively, they lose their impact. This requires the involvement in the competitive struggle of not only transport organizers and operators but also city and suburban area (functional area of the city) authorities, planners and urban planners as well.

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The Method of Hierarchization of Public Transport Lines and Evaluation of Their Adaptation to the Users Needs

Ryszard Janecki and Grzegorz Karoń

Abstract Paper presents a synthetic discussion of the issues connected with public transport as an instrument of transport policies in the cities of urban agglomerations that create sustainable mobility and help achieve its goals. The theoretical investigations were supported with description of the results of empirical studies carried out by the authors. They concern the problems of using the methods of hierarchization of public transport lines and evaluation of the level of their adaptation to the customers' needs.

Keywords Public transport · Urban mobility · Transport modelling

1 Introduction

The results of theoretical investigations and empirical studies carried out by the authors in 2012–2015 in selected agglomerations of the Silesia region in the south of Poland concern the problems of creating suitable informational base for the decision-making process, where proposals of activities aimed at sustainable mobility are formulated. These decision-making processes use methods of hierarchization of public transport lines and evaluate the level of adaptation of public transport services according to the customers' needs, taking into account public transport vehicles with electric drive (buses with electric battery drive).

R. Janecki (✉)
University of Economics in Katowice, Katowice, Poland
e-mail: ryszard.janecki@ue.katowice.pl

G. Karoń
Faculty of Transport, Silesian University of Technology,
Katowice, Poland
e-mail: grzegorz.karon@polsl.pl

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2 Specific Nature of the Region

Silesia is a region in the south of Poland. On the basis of occurring in its area raw materials was formed the biggest industrial district, which plays a strategic role in the national economy as the basis of the national fuel and energy balance, developed many branches of industry, including the automotive industry.

Upper Silesia region covers 12.3 thousand km^2, which represents 4 % of the Poland. It is inhabited by 4.6 million people, which is over 12 % of the total population of the country. The population density is 372 people/km^2, and is more than three times higher than the average in Poland. Considering the built-up and urbanized area, the rate density is 3010 people/km^2 (Poland 2354 people/km^2) [1].

Silesian Region has a specific settlement structure on the background of the country. Its characteristic feature is the large number of cities—there are 71, forming a network with a density of 58 cities/10 thousand km^2 [1], twice the national average.

The results of the analyzes contained in numerous works and projects carried [2, 3] out by the authors of the article, concerning the diagnosis of the current state of transport in the region, also confirm its specificity. In describing the current situation in the environment of urban transport should therefore be indicated on such phenomena as (see [4, pp. 87–88], [5–8]):

- lifestyle changes, and thus needs of mobility, which is influenced by rapidly increasing incomes of households; it is presented on Fig. 1—showing dynamics of growth of average monthly gross salary in Silesia in the decade from 2004 to 2013. This growth reached 61.6 %, and the average salary is now (2013) in Upper Silesia higher by 3.6 % than the average in Poland,

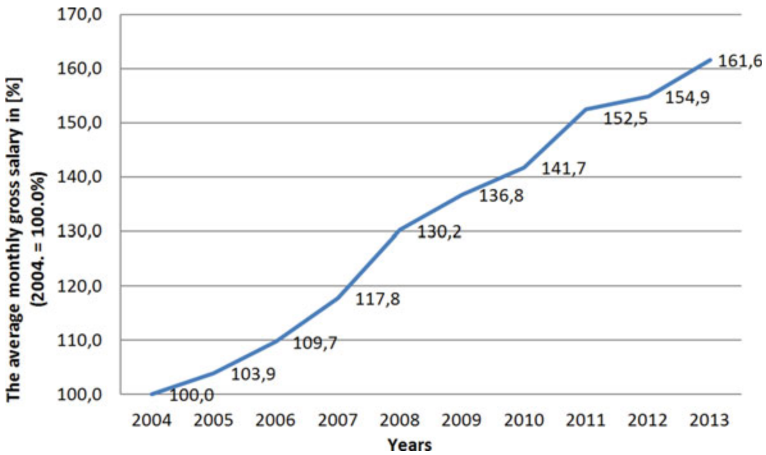

Fig. 1 Average monthly gross wages in Silesia in 2004–2013 in [%] (2004 = 100 %) (*Source* Own study calculations based on data from [1])

- deterioration in quality of citizens life due to the increase in traffic congestion, alarming levels of air pollution, deterioration of "acoustic climate",
- development of suburbanization generates the distributed demand for traveling, which requires different solutions for the transport service than in the case of areas with a high concentration of demand,
- unsatisfactory effects of actions in the development of metropolitan (agglomeration) and urban development, such as: the regularity of distribution of foci of activity, application of the "tree of availability", the harmonization of building, balancing the intensity of use and the centrifugal forces,
- underdevelopment of logistics channels causing disruption in the flow of goods in the agglomeration or cities in the region.

Many problems are identified also in transport systems of individual agglomeration or cities. In this case should be quoted, among others (see [4, pp. 87–88], [5–8]):

- a sharp rise in individual motorization (Fig. 2) causing adverse effects in the modal split, expressed by the dominance of a passenger car; Table 1 shows the changes that occurred in the five-year period in the region of Upper Silesia,
- inadequate to the needs of quantitative and qualitative functioning of collective public transport,
- the need to implement the investment program in infrastructure and fleet to make up years of neglect and delinquency,
- the need to improve the transport offer and make it more attractive,
- ineffective activities related to the integration and balancing transport technologies, utilizing strengthening the position of public transport,
- the lack of integration of transport policy with spatial policy and selected public policies.

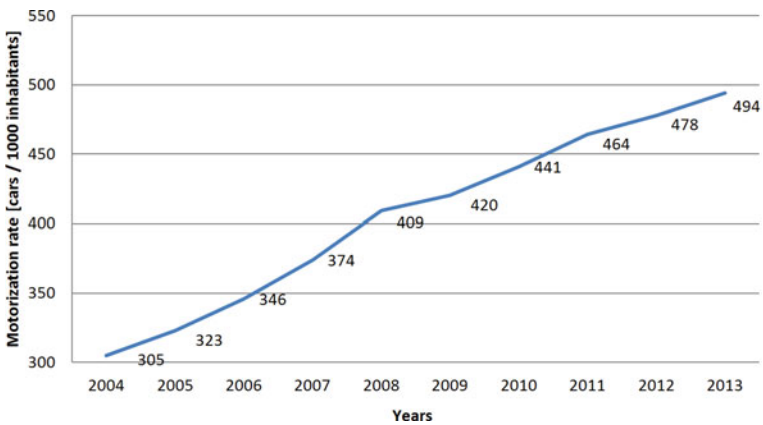

Fig. 2 Motorization rate in Silesia in 2004–2013 (*Source* Own study based on data from [4])

Table 1 Citizens activity in travels generally and non walking travels in (%) in selected agglomerations of Upper Silesia region (*Source* [6, 7])

Means of transport	The Upper Silesian Metropolis (2009)		The Bielsko-Biała agglomeration (2014)	
	Rate in (%)			
	Travels in total	Non walking travels	Travels in total	Non walking travels
Walking	28.8	–	10.1	–
Passenger car	29.3	41.2	61.6	68.5
Public transport	40.2	56.5	20.8	23.1
Other	1.7	2.3	7.5	8.4

Observed in the Silesia adverse developments in urban transport and the environment require effective actions. Due to the nature of these phenomena, a significant contribution to their overcoming, reducing the impact and elimination may have projects related to sustainability urban mobility. The current state of urban transport in cities and agglomerations of the region, especially in terms of infrastructure and fleet, requires programming and implementation of activities aimed at the modernization and expansion of these resources, and therefore the hard action [9]. However, it should be integrated into the relevant soft actions, so as to attain the horizontal objectives in the field of sustainable urban mobility. In the case where taken actions are characterized by soft actions, efforts should be made to make them having the form of integrated packages of actions.

3 Activities Leading to Changes in the Public Transport

One of the most important instruments that can be used in the process of sustainable urban mobility [10] in agglomerations and cities of the industrial region, are activities leading to changes in the public transport. It is expected at this first and foremost strengthen its role, which is reflected as the increase in the number of people benefiting from this way of movement in urban transport.

Programming the development of transport falls within the scope of transport policy and transport development strategy, documents prepared by the relevant agencies of local authorities of a particular level [11–14]. Their construction, which is a multi-step decision-making process, requires adequate information base. These are resources of knowledge concerning:

- mobility needs and transportation preferences of urban transport users,
- the functioning of the urban public transport system.

The formulation of the transport policy program or building development strategy as a decision-making process and uses the accumulated resources at the disposal of knowledge [15–19]. From a morphological point of view it is defined sequence of steps including:

- identification of the existing system of the public transport, in the case of this project, organized by the Public Transport Authority (PTA) in the city,
- diagnosis and evaluation of the conditions of the urban public transport system,
- formulating solutions propositions being solutions of undertaken problems in terms of public transport, so—the constructing the policy agenda,
- implementation of the program of transport policy,
- monitoring and evaluation of taken actions.

Based on above point of view the multi-step decision-making process consists of the following steps:

Step 1. Identification the set of objects, which are bus lines.
Step 2. Identification the set of characteristics/variables of the objects from Step 1.
Step 3. Constructing a bus line pattern adapted to the identified needs of users of public transport.
Step 4. Ordering the set of characteristics/variables describing all the analyzed bus lines in the initial matrix of observation.
Step 5. Constructing a synthetic index *SILA* (Synthetic Index of the Level of Adaptation) of bus lines to the identified needs of users of public transport.

In order to determine the level of adaptation of bus lines to the identified needs of users of public transport in the area served by Public Transport Authority (PTA) in the city, were used the principles of taxonomic methods. This tool gives you the ability to describe the studied phenomenon by a single synthetic indicator instead of using many variables. Procedure in used method was as follows:

Step 1. Identification the set of objects, which are bus lines.

$$[L_1, \ldots, L_i, \ldots, L_n], \quad i = 1, \ldots, n \;\; n = 40 \tag{1}$$

Step 2. Identification the set of characteristics/variables of the objects from Step 1.

$$\left[x_{i1}, \ldots, x_{ij}, \ldots, x_{im}\right], \quad j = 1, \ldots, m \;\; m = 40 \tag{2}$$

Variables x_{ij} and their importance determined were on the basis of proposals of experts and members of the project team, based on their research experience. The examples are in Table 2.
Step 3. Constructing a bus line pattern adapted to the identified needs of users of public transport.
The bus line—variable X_0 is a vector of the form:

$$X_0 = \left[x_{01}, \ldots, x_{0j}, \ldots, x_{0m}\right] \tag{3}$$

Table 2 Features describing bus lines of Public Transport Authority (PTA) in the city (Rybnik)—selection of variables to synthetic measure (*Source* [6, 7, 20])

A variable name—feature describing the bus lines in Rybnik	The variable marking	The nature of variable: (N)ominants, (S)timulants, (D)estimulants	Adopted variable importance (weight)	Evaluation of reference dimension of variable
Running days of the line per week (Mon–Fri, Saturday, Sunday or holiday)	x_1	N	0.15	5.0
The time of line operation in a day of working in (h)	x_2	S	0.10	
Important traffic generators handled by the line	x_3	N	0.20	
The average number of seats in the buses used on weekdays, during periods of peak traffic attributable to 1 passenger	x_4	S	0.15	
Scheduled transportation speed of the line on a working day	x_5	S	0.15	
Average scheduled frequency of running of the line during transport peaks on working days	x_6	D	0.15	
Average scheduled frequency of running of the line during the noon (10–13) hours on Saturdays	x_7	D	0.05	
Average scheduled frequency of running of the line during the afternoon (14–17) hours on Sundays or Holidays	x_8	D	0.05	
Total	–	–	1.00	

The individual components x_{0j} will create the best dimensions [the maximum for variables with stimulant nature (S), the minimum when it comes to destimulants (D) or terminal for variables of a nominant nature (N)], which relate to the analyzed lines. These values were determined among experts and presented in Table 3.

Step 4. Ordering the set of characteristics/variables describing all the analyzed bus lines in the initial matrix of observation.

Its character is as follows:

Table 3 Pattern of a bus line adapted to the needs of public transport users in terms of the of Public Transport Authority (PTA) transport system in the city (Rybnik)

The variable name describing bus line in Rybnik—evaluation criteria of the line	Component of X_0 pattern marking	X_0 pattern of bus line	
		A reference value of the variable and its evaluation	The weighted value of the reference evaluation of variable dimension
Running days of the line per week	x_{01}	The line runs weekdays, Saturdays and Sundays or holidays (5.0)	0.75
The time of line operation in a day of working in (h)	x_{02}	>17 o'clock and after 22:30 (5.0)	0.50
Important handled traffic generators	x_{03}	Handling the area generating a large and continuous transport needs (5.0)	1.00
The average number of seats in the buses used on weekdays, during periods of peak traffic	x_{04}	≥3.0 (seat/lane) (5.0)	0.75
Scheduled communication speed of the line on a working day (km/h)	x_{05}	≥27.0 (5.0)	0.75
Average scheduled frequency of running of the line during transport peaks on working days (min)	x_{06}	≤30.0 (5.0)	0.75
Average scheduled frequency of running of the line during the noon (10:00–13:00) hours on Saturdays	x_{07}	≤45.0 (5.0)	0.25
Average scheduled frequency of running of the line during the afternoon (14.00–17.00) hours on Sundays or Holidays	x_{08}	≤45.0 (5.0)	0.25
Total weighted evaluation of the reference dimension of variables			5.0

$$X = \begin{bmatrix} x_{11} & \dots & x_{1m} \\ \dots & x_{ij} & \dots \\ x_{i1} & \dots & x_{nm} \end{bmatrix} \tag{4}$$

where

x_{ij} the value of the jth variable for the ith bus line in the city (Rybnik).

Then was constructed the observation matrix taking into account the results of the evaluation. The method of evaluation uses comparison for each assessed line the value criterion of the constructed X_0 pattern of bus line tailored to the needs of residents, which was shown in Table 3. In situation, where:

- criterion value of the line is more advantageous than the reference value, take rating of 5,
- value criterion for the line is close to the reference value or its equivalent, this assessment should be 3 or 4,
- value criterion for the line is unfavorable in relation to the reference value, take a rating of 1 or 2.

It is convenient to use the matrix taking into account the results of the assessment of the line, because it has the character of the standardized matrix, and thus released from various titers of characteristics of the tested bus lines. Table 4 shows the character of this matrix for several selected examples of bus lines in Rybnik.

Step 5. Constructing a synthetic index *SILA* (Synthetic Index of the Level of Adaptation) of bus lines to the identified needs of users of public transport.
Firstly was calculated the synthetic measurement (*SM*) of the line adjustment, which is constructed as a linear combination of the values of the proposed evaluation variables. Hence:

$$SM = \sum_{i=1}^{m} x_{ij} \quad m = 1, 2, \ldots, 8 \tag{5}$$

While the value of synthetic index of the level of adaptation (*SILA*) was calculated using the formula:

$$SILA_i = \frac{MS_i}{\sum_{j=1}^{m} x_{oj}} = \frac{MS_i}{MS_0} \tag{6}$$

where

$MS_0 = \sum_{j=1}^{m} x_{0j}$ synthetic measure of the level of adaptation X_0 pattern for MPT bus lines in Rybnik to the identified needs of users of public transport.

Table 4 Observation and assessment of individual variables which characterize these lines

No. of bus line in Rybnik city	The value of the variable (features) describing a given bus line taking into account its evaluation							
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
1	0.75	0.50	1.00	0.75	0.45	0.30	0.10	0.05
2	0.15	0.20	1.00	0.60	0.30	0.30	0.10	0.05
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
26	0.75	0.50	1.00	0.60	0.30	0.75	0.25	0.15
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
51	0.75	0.30	0.80	0.15	0.30	0.60	0.10	0.05
52	0.75	0.50	0.60	0.60	0.75	0.75	0.05	0.05

Table 5 Dimensions of (*SM*) and ($SILA_i$) for example selected bus lines in Rybnik

No. of bus line in Rybnik city	Dimensions	
	SM	$SILA_i$
1	3.90	0.78
2	2.70	0.54
⋮	⋮	⋮
26	4.30	0.86
⋮	⋮	⋮
51	3.05	0.61
52	4.05	0.81

Normalized values $SILA_i$ belong to the interval (0, 1). The closer the unity, the bus line better suited to your needs. Table 5 shows the results of synthetic measurement and synthetic line adjustment factor for example selected line.

4 Conclusions

Analysis of the obtained results can be noted that the maximum value of assessing the degree of adjustment of Public Transport Authority (PTA) bus lines in Rybnik city according to established criteria to the needs of users is 5.00 (pattern of bus line). 75 % of this value (synthetic measure equal to 3.75) has reached 12 bus lines, including 6 of the 7 main lines (lines no. 3, 26, 29, 48, 48 and 52) and 2 of 9 basic lines (lines 28 and 45).

The results allowed for variant defining and analysis of the operation of the bus lines. From the point of view of the balancing of urban mobility, the most useful was the variant maximizing the level of functional alignment the line system to the needs of public transport users. This variant presents a wide range of activities corresponding to the principles of sustainable mobility. The most important ones include:

- distinction of bus lines with strategic importance for Public Transport Authority (PTA) as the organizer of transport (main lines) and lines which task is to ensure a high level of accessibility to areas which are currently with the lowest attractiveness of transport (leading lines),
- extension of the working day for certain bus lines,
- increasing the frequency of courses on selected lines,
- the introduction of new connections—mainly direct, especially between districts with high demographic potential and movable,
- increasing the immediacy of routes lines serving the connection of selected districts to the city center,
- introduction to transportation on selected lines of modern fleet,
- increasing the availability of urban public transport in the individual districts of the city (reduction of areas “excluded” of the public transport).

Implementation of these measures should contribute to improving the attractiveness of the Public Transport Authority (PTA) transport system, and consequently, to increase the number of journeys undertaken by collective public transport in the Rybnik agglomeration.

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Qualitative and Temporal Determinants in Integrated Supply Chains

Maciej Mindur

Abstract The paper addresses the matter of relevance of an integrated supply chain for attaining high efficiency in operations of individual businesses. What proves to be decisive of the success is how businesses handle individual problems under the supply chain. Furthermore, optimum organisation of the supply chain is often a serious challenge for enterprises forced to function with growing efficiency and deliver products matching individual customer needs. Integration of the supply chain is inextricably linked with the concept of time management, since objectives of the supply chain integration are compatible with those of the time based competition strategy, such as lower costs, higher quality, larger product diversity, higher flexibility and sensitivity to customer needs as well as shorter response time. The paper provides a discussion on the universal concepts which prove to be most suitable for solving multi-faceted challenges and addressing newly emerging trends, oriented towards quality, time and flexibility. The problem of time management strategies, being crucial elements of an integrated supply chain, has also been addressed.

Keywords Integrated supply chains · Transport systems development

1 Introduction

A supply chain comprises extraction, production, trade and service companies cooperating in different functional areas as well as their customers between whom products, information and funds flow in streams [1] (Fig. 1).

All businesses operating in the market, i.e. production, trade and service companies, seek opportunities for reducing prime costs in order to attain the best competitive position, since customers search for cheap products and services which, at the same time, offer sufficient quality. Consequently, businesses must seek new

M. Mindur (✉)
International School of Logistic and Transport in Wroclaw, Wroclaw, Poland
e-mail: mmindur@vp.pl

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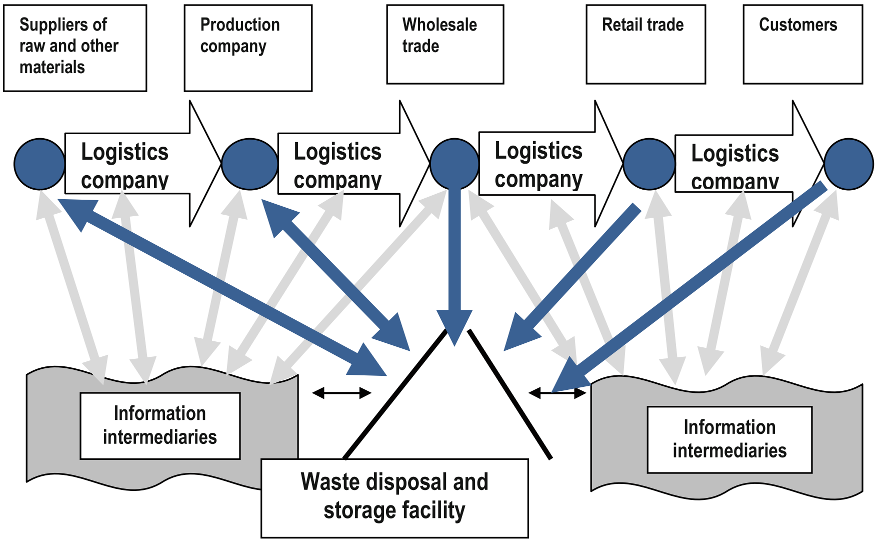

Fig. 1 Supply chain links (*Source* Based on [1, 3])

methods for streamlining of their costs, for instance, by undertaking joint partnership-based activities under an extended enterprise, such as an integrated supply chain.

In the literature of the subject, one may find multiple definitions of an integrated supply chain, and all of them emphasize a certain group of elements decisive of the former's specificity, namely cooperation of businesses with the purpose of attaining high efficiency of operations, both of individual enterprises and the entire supply chain [2, 3]. The foregoing is possible owing to shared identification and elimination of barriers in the flow of products, information and funds.

Sołtysik [4] defines an integrated supply chain as "flow of raw materials, auxiliaries and cooperation elements in the sphere of supply, production and sales, which requires suitable coordination activities."

It is the integrated supply chain which currently decides whether one can successfully maintain their position in increasingly demanding markets. Optimum organisation of the supply chain is often a serious challenge for enterprises forced to function more and more efficiently and deliver products matching individual customer needs. What matters particularly in this respect is the accuracy and precision at every stage as well as the ability to respond quickly to changes of demand, customers' predilections and economic conditions. What decides of the success is how businesses handle individual problems faced in the supply chain, such as:

- implementation of strategies ensuring the highest customer perceived value,
- understanding of how costs develop and are interconnected, and using potential sources of diversification,
- reaction to demand changes without having to accumulate excessive stock,

- organisation of collaboration with suppliers for purposes of rapid change of plans,
- utilisation of resources, capital and means of transport in order to improve service,
- rate of introducing new products into the market and preparing the enterprise to satisfy the increasing demand,
- supply chain efficiency, ensuring a wide selection of products to customers and completing supplies faster than the competition,
- satisfying customer demands in cases when the given order cannot be completed by the preferred supplier.

In order to meet the said conditions, one is required to escape the framework of a traditional supply chain, such as sequential, linear transfer of information from one partner to another, being too slow, inaccurate and costly.

Establishing communities of cooperation, combined into a supply chain system, where suppliers, manufacturers, distributors and customers share information, is a means to overcome the said problems, since in the contemporary economy, it is not businesses that compete against one another, but rather the supply chains the former comprise.

2 Qualitative Determinants of an Integrated Supply Chain

The turn of the 20th and the 21st century was a period of abrupt transformations triggering increasingly demanding requirements being faced by businesses (Fig. 2). The foregoing was, on the one hand, related to globalisation trends resulting in an ongoing increase in competition, complexity of systems and rate of innovation, and

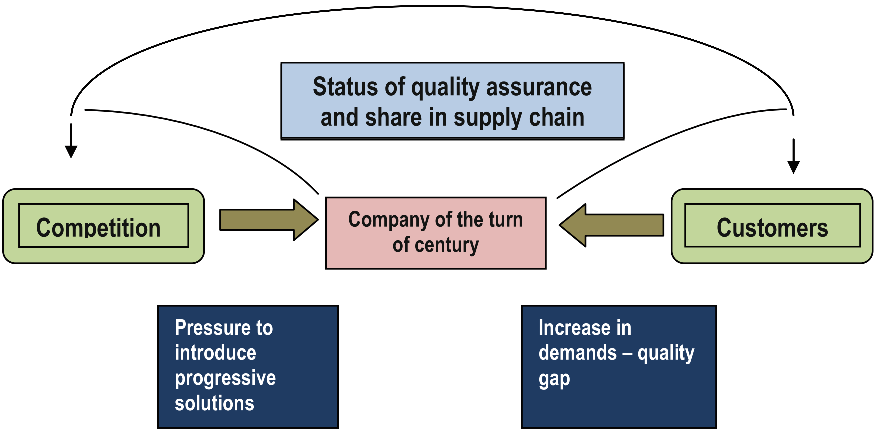

Fig. 2 Company’s response to challenges of the 21st century (*Source* Based on [3])

on the other hand, with customer expectations growing as the demands for production individualisation were becoming more and more common. One must not also disregard the cyclic decline of activeness of enterprises due to the economic crisis.

Therefore, the market situation forces businesses to shorten times of response to changes in the environment and to display more and more flexibility in operations. Enterprises willing to hold their position in the market must face up to multifaceted challenges and newly emerging trends oriented toward quality, time and flexibility. The universal concepts being most suitable for solving the aforementioned problems are logistics and quality management (TQM).

The interpretation of the Total Quality Management concept may be perceived from the perspective of three components of the notion of TQM [5]. The term "Total" refers to integration of all supply chain partners, where all structures, spheres and processes of management in the chain constitute the source for creating quality. The term "Quality" is customer-oriented. The products delivered to the customer must not only meet specific requirements in terms of quality, but their quality must account for the continuously growing expectations of buyers. The final term, i.e. "Management", highlights the very nature of TQM as a managerial concept which may be implemented in the supply chain by developing subsystems of the quality sphere management, i.e. functional subsystems for policy making, planning, controlling, organisation and development of all supply chain links.

Offering products of high quality features, extended with logistic advantages from the customer service area creates opportunities for the supply chain participants to behave in a strategic and competitive manner in the market. Not only does it enable them to win over the competition, but also satisfy or even exceed customer expectations.

It is commonly assumed that the prerequisite of the supply chain creation and growth is partnership, which should be interpreted as the way to manage economic relationships between the chain links on the grounds of mutual trust, division of the market and benefits, triggering additional effects of synergy and competitive advantage.

Bearing the time criterion in mind, partnership may be divided into short-term (operating) and long-term (strategic) relationships. Short-term partnership occurs when in the course of repeatable transactions concluded between enterprises, contacts are established between employees responsible for sales as well as distribution and those employed in the recipients' purchasing departments. In time, these relationships also begin to cover functions related to product design and manufacture. In the case when long-term (multiannual) partnership exerts significant impact on the content of and the manner in which the partners pursue their objectives, it is recommended that it should be referred to as strategic partnership. Consequently, strategic partnership in a supply chain should be understood as important and long-lasting collaboration between its participants, based on mutual trust, sharing risk and benefits, which consists in undertaking joint investment and organisational projects in the pursuit of diversified individual

Continuity	high	**Type II** Routine, simple supplier swapping, if needed.	**Type III** Efficiency improvement through continuous mutual adjustment, leading to benefits attained in terms of both costs and revenues.
	low	**Market exchange** Efficiency increase through price pressure Limited requirements in terms of continuity and commitment.	**Type I** Occurring when purchasing complex systems and installations.
		low	considerable
		Commitment	

Fig. 3 Commitment and continuity of cooperation versus partnership types depending on the situation in the sphere of purchasing (*Source* Based on [1, 3])

objectives serving the purposes of common goals oriented at winning competitive advantage and value creation.

When not only time but also intensity and scope of economic interconnections between the supply chain links are taken into account, one may distinguish between three types of partnership (see Fig. 3) [1, 6]:

- type one—usually short-term and limited cooperation in the scope of coordination of activities, and planning undertaken only in a single facility or the partner's functional area,
- type two—transition from coordination to integration of activities between multiple facilities and the partners' functional areas in a long, but typically strictly defined time horizon,
- type three—operational integration which leads to perceiving a partner as an "extension" of one's own organisation, without strictly defined time limits for the cooperation completion.

In order for the integrated supply chain and the system functioning under its framework to perform their functions properly, one should design a product made of raw materials and prefabricated units of suitable quality, and envisage highly advanced level of information flow and customer service.

Both the aforementioned types of activity are closely interlinked and interdependent. A high-quality product will not deliver the expected benefits without being effectively introduced into the market, and even the best organised logistic service will not improve the quality of products. Therefore, it is important that understanding of quality should be uniform. Any potential discrepancies in the understanding of quality-related problems among the supply chain participants may cause numerous perturbations in the flow of goods, consequently leading to deterioration of logistic integration. In order to ensure compatibility between quality-promoting activities of enterprises and quality-related demands of their customers, the International Standardisation Organisation proposed and developed the ISO standards. In 1986, ISO 8402 standards were introduced, providing quality-related terms and definitions, whereas in 1987, a series of ISO 9000 standards pertaining to quality management was deployed. The ISO 9000 system does not define technical parameters of a product or a service, but rather the manner in which enterprises operate, owing to which they are capable of furnishing their customers with products or services of specific quality.

Enterprises conforming with requirements of the ISO 10005 (guidelines for the quality) and ISO 100011 (guidelines for quality system auditing) standards are awarded the ISO certificate which ensures them a high competitive position, an increase in reliability and an opportunity to reach the network of suppliers for well-known manufacturers.

Quality may affect the manner in which a supply chain functions in three ways: activity-related, subject-related and procedural [1].

The activity-related effect pertains to the influence of the concept of total quality management on the improvement of all processes, and consequently also the activities exerting decisive impact on the efficient functioning of the supply chain, such as packing, reloading, transportation, storage etc.

The subject-related impact of total quality management on the supply chain efficiency consists in the activities undertaken in the sphere of quality and logistics being focused on the same raw materials, materials, semi-finished products and ready-made products, the only difference being that TQM determines these features, whereas logistics coordinates their flow (Fig. 4).

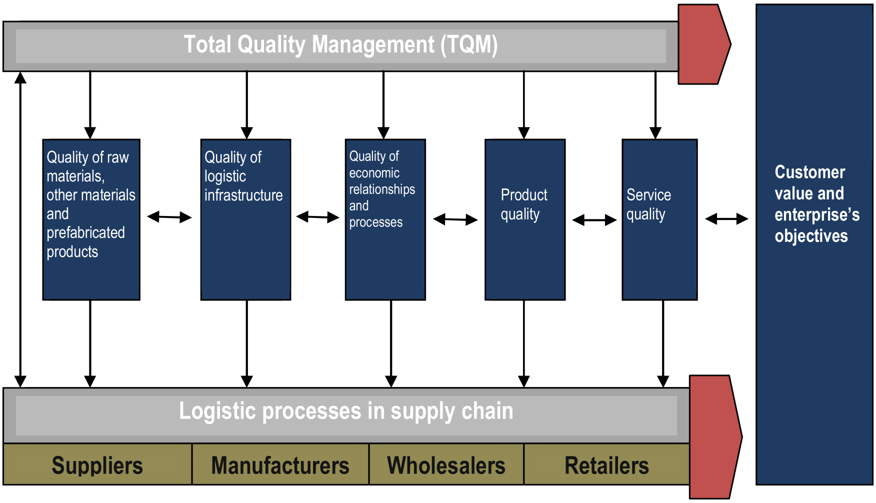

Fig. 4 Impact of TQM on the supply chain (*Source* Based on [3, 7])

Consequently, on a certain level, quality is the prerequisite of an operationally effective supply chain.

The procedural dimension pertains to the fact that logistic processes should be subject to streamlining activities undertaken as a part of quality management (procedures, methods, tools, documentation).

Under advantageous conditions, companies are capable of functioning in the market by selling products of very poor quality which, however, is impossible in the supply chain, because it causes numerous conflicts as well as loss of mutual trust among partners, which precludes efficient cooperation between individual chain links and intensification of integration.

Applying quality standards translates into numerous benefits for the supply chain participants. Bonds between businesses develop, since their collaboration is improving. The probability of production disorganisation resulting from material flaws and the necessity to process complaints is reduced. Higher quality of goods increases their economic transport susceptibility which supports application of better technological solutions in the transport process. The foregoing manifests itself in the fact that rapid transport reduces the level of frozen funds, punctual transport means less delays, reliable transport reduces inventory, and rhythmical transport enables reduction of storage area and the related warehousing costs, whereas flexible transport allows for quick supply chain adaptation to variable market conditions. Consequently, it becomes possible to attain specific synergy effects: cost reduction, lead time reduction, customer service quality increase, developing more beneficial market offer, obtaining competitive advantage, market share increase, technological development of the supply chain and many other goals significant from the perspective of mutual collaboration.

3 Time Management in Integrated Supply Chains

One of primary differentiating indicators decisive of the supply chain's competitive capacity is the time factor. Under current market conditions, businesses which are incapable of adapting to the changes taking place in the environment not only cannot count on success, but even on mere survival.

The importance of the time factor stems from the function it performs while innovative products and customer service strategies are prepared. Compression of time in the sphere of research and development enables enterprises to enter the market with a new product, whereas in the sphere of supply and distribution, it ensures rapid response to market demands and makes it possible to deliver products for which the demand is currently at its peak.

Therefore, time is a factor of strategic relevance, decisive of the success of operations, both with regard to flexibility and promptness of decision making, which implicates the enterprise's high market share.

Growing importance of time perceived as one of crucial factors in the struggle against the competition has contributed to the emergence of a new managerial concept, namely Time Based Management (TBM). This concept is characterised by more efficient use of time, which decides of the improvement of the process implementation efficiency and relationships between partners and with customers, since rapid responding to the signals incoming from the market exerts crucial effect on the features which cause diversification of the competitive level, such as: customer service quality, cost level, quality of the products manufactured and the way in which the entire supply chain of enterprises is perceived, this being decisive of market success.

Companies aspiring to join the group of enterprises achieving market success as a result of their quick response to customer needs should abide by the following principles:

- time expenditure (time consumption) is considered to be the basic strategic and managerial factor,
- capacity for responding to customer demands determines the level of and the efficiency with which customer loyalty towards the enterprise is triggered,
- promptness in the innovation process constitutes the target criterion of efficient allocation of new products on the market before the competition,
- capability and promptness of response make it possible to constantly adapt the benefit schemes functioning in the enterprise to the customer groups perceived as most attractive from the market perspective.

Integration of the supply chain is inextricably linked with the concept of time management, since objectives of the supply chain integration are compatible with those of the time based competition strategy, such as [8] lower costs, higher quality, larger product diversity, higher flexibility and sensitivity to customer needs as well as shorter response time.

The supply chain concept makes it possible to attain the synergy effect, owing to which implementation of time based strategies delivers better results compared to their implementation in individual companies. In this respect, one should mention such systems of quick reaction, also referred to as quick customer service systems, as QR (Quick Response), ECR (Efficient Consumer Response) and VMI (Vendor Managed Inventory). These systems considerably decrease the time of material, information and money flow in the integrated supply chain. The original premise for the logistics of quick response in terms of commercial activities was and still is competition.

The QR system assumes that there is an information network connecting enterprises from the supply chain, and the manner in which this system functions is as follows [8]:

- selling goods at a supermarket and scanning a product,
- sending information about sales of the given article to the store's computer,
- sending information about the volume of daily sales of individual products to the manufacturer,

- placing an order with the manufacturer via the JIT (Just-in-Time) system,
- manufacturer supplementing the range of goods using the JIT system,
- store confirming the shipment receipt in the computer system.

Enterprises functioning in the QR system must conform with numerous requirements. One of them is the necessity to establish partner relationships between enterprises, which involves overcoming mutual distrust in relation to information sharing. Moreover, it is necessary to reconfigure logistic systems, deploy an efficient IT system as well as production technologies and systems ensuring that changes proceed in a rapid manner, and improve products in accordance with the requirements of customers, and all these tasks may only be performed by a well-trained and flexible personnel.

Implementing the QR strategy makes it possible to significantly reduce the time of commodity stock supplementing, thus decreasing the actual stock levels, and this, in turn, triggers reduction of the costs incurred by the supply chain participants, enables quicker response to orders placed by customers and eliminates "unavailability" of products currently in demand.

According to Chaberek [9] and numerous other authors, the strategy of efficient customer service (ECR) is based on solutions resulting from a combination of the QR strategy and the JIT system. Similarly to the QR and JIT solutions, ECR requires implementation of an electronic data processing system, since efficient flow of information up- and downstream the supply chain translates into a more efficient flow of products between the chain links, this being a priority.

Inventory management by the vendor (VMI) consists in planning of material flows conducted by the vendor. In this system, the recipient does not place orders but shares information with the vendor as regards the actual sales of the latter's products, the current stock levels and the promotional activities currently being undertaken. Ongoing access to information on the customer's stock levels is possible owing to the continuous flow of information from electronic points of sale (EPOS), by means of which the vendor is capable of forecasting demand and optimising the utilisation of production and logistic capacities more accurately.

In order to successfully deploy the time competition strategy, it is required that partners from the supply chain be fully involved and undertake close collaboration consisting in mutual information sharing. Such collaboration between the supply chain partners enables faster identification and easier elimination of reasons for too high stock levels, too long response time across the entire supply chain and considerable reduction of operating costs. Monitoring the entire path of this process corresponds to the actual scope of logistic management of order processing (see Fig. 5) [10].

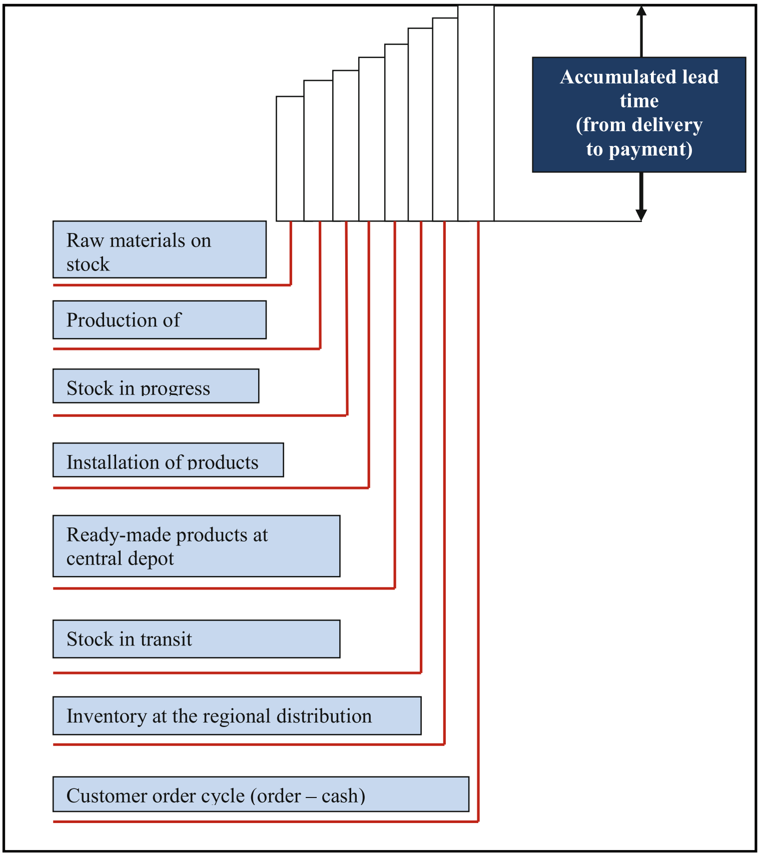

Fig. 5 Strategic lead time management (*Source* Based on [3, 10])

4 Conclusions

Implementing the concept of Total Quality Management (TQM) in an integrated supply chain is connected with the pursuit of what is referred to as logistics excellence. This notion was coined by the American A.T. Kearney's logistics agency while conducting a survey aimed at assessment of the quality level in the sphere of logistics [6]. A supply chain is logistically excellent when it entails all elements of this quality assessment concept. Implementation of the logistic quality concept is preceded by identification of comprehensive and solid relationships between supply chain partners and customers, ones which simplify defining shared goals owing to understanding of mutual needs. Then, through planning, integration of all the supply chain participants' activities, technological progress, personnel motivation and stimulation to pursue the common goal, the integrated information system as well as implementation of criteria and indicators for measurement and assessment of logistic quality, the supply chain may attain logistics excellence.

Companies' experience in the sphere of application of the time management strategy implies that the promptness of response of enterprises and optimisation of values across the entire chain of logistics increasingly often prove to be the factors conditioning the former's survival in the market. Even where a dedicated time competition strategy has been deployed in individual businesses, various efforts aimed at the time compression are undertaken more and more commonly. Faced with the demanding and highly variable economic reality, only those businesses which successfully master the art of quick response and embed the time compression concept in the strategies they deploy will survive.

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Structural Aspects of Airfield Runways with Concrete Pavements

Andrzej Więckowski and Alicja Sznurawa

Abstract The increasing weight of aircraft enforces engineering enforced runways. As a result, the volumes of concrete and steel built into runways are currently very large. Reduced consumption of such materials allows for application of improved concrete and abrasive prestressed slab pavements, which are much thinner than other concrete slabs. For the purpose of the study, solutions for the new runway have been analysed in two structural variants, namely runway of prestressed concrete, and dowelled concrete runway at the Katowice-Pyrzowice airport. Forces in bottom fibres have been defined based on Westergaard method, while for slab corners, extended force interdependencies have been applied according to Pickett. Fundamental benefits from constructing abrasive concrete runway surfaces in prestressed technology, as compared to dowelled structure, include: possibility of reducing thickness of the bearing system by about half, greater runway resistance to overload and cracking, better durability of the pavement.

Keyword Dowelled runway · Prestressed concrete

1 Introduction

Civilization development systematically changes the needs of the society, particularly as regards transport. One can observe a tendency that people want to travel increasingly quicker and cheaper. The emergence of “cheap airlines” on the market has evoked significant demand for air transport services. An increasingly greater popularity of purchases via the Internet and import of goods from abroad has also

A. Więckowski (✉)
AGH University of Science and Technology, Krakow, Poland
e-mail: awiecko@agh.edu.pl

A. Sznurawa
Faculty of Civil Engineering, Cracow University of Technology, Krakow, Poland
e-mail: alisznurawa@gmail.com

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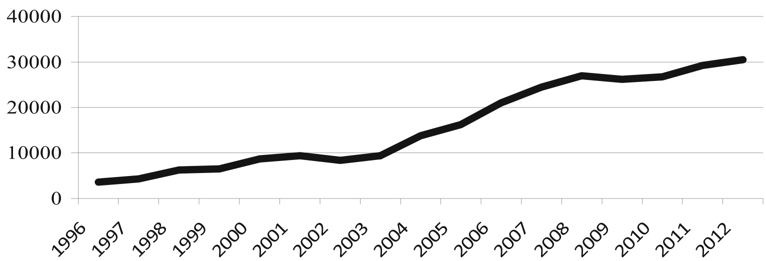

Fig. 1 Airline operations at the Katowice-Pyrzowice airport in the years 1996–2012 (*Source* Own study on the basis of [8])

enforced the development of cargo fleets. In most countries, significant growth in the number of passengers and cargo is observed. Some deterioration in air transport popularity occurred after the attack of 9/11 in 2001, but air transport soon regained passenger trust. As a result, also the number of airline operations increases. In Poland, e.g. at the Katowice-Pyrzowice airport, in the period from 1996 to 2012, the number of operations increased over eight times, Fig. 1. Such a high demand for services and, therefore, the need to increase the number of operations, have caused the need for many modernisations, extensions and construction of new airports.

Among the presently modernised airports in Poland, there is the Katowice-Pyrzowice airport (KTW), where a new runway is to be built. Most literature items, e.g. [1–4], indicate that runways with a prestressed structure can be much more expensive and more difficult to build than when applying other solutions, with traditional concrete structures. According to [3–7], the application of prestressed structures allows for favourable reduction of the thickness of the bearing structure and for increasing the length of elements between joints, or for increasing permissible load without changing the geometry of the structure. In such a case, however, as compared to structures of reinforced concrete, more complex and accurate execution is required. This is caused by the need to prestress slabs, and by high actual forces in the structure.

Prestressed pavements have been applied for airfield construction since 1946, yet presently they are rarely executed, giving way to dowelled concrete structures [5]. Below, at the example of modernisation of the Katowice-Pyrzowice airport, the effectiveness of runway structural solutions has been analysed in two variants, namely considering prestressed structure and dowelled structure.

2 Development in Airfield Surface Structures

Runways, taxiways, and parking slabs constitute the fundamental parts of airports. They can have following structures of pavements: of non-reinforced concrete, of reinforced concrete, of prestressed concrete, asphalt, and grass. There are also mixed pavements, where the concrete structure is covered with an abrasive asphalt layer [4–7].

Continuous increase in aircraft weight (with culmination upon the emergence of the giant Boeing 747-400 JumboJet with maximum weight upon landing of over 400 tonnes) forced engineering of reinforced runways. Strengthening of the structure was achieved particularly by increasing their thickness and bearing strength of subgrade.

As a result, the volumes of concrete and steel built into runways are currently very large. Reduced consumption of such materials is rendered possible by the application of pavements of prestressed slabs, which are much thinner (by approximately 50 % [4, 5]) than other concrete slabs. The first runway with prestressed structure was made at the Orly airport near Paris in 1946, Fig. 2. That runway had the dimensions: 60 m × 420 m, and thickness of 18 cm. Each slab was divided into triangles, with joints situated at the angle of 45° against the longitudinal axis of the runway. Cross prestressing was applied. This solution was problematic, as contemporary machines for laying (“spreading”) concrete mix did not execute triangular elements. Moreover, during long-term use, increased corrosion of bars was observed at joints [5].

Another prestressed runway was built eight years later, at the Maison-Blanche airport in Algeria, Fig. 3. This was a prestressed runway with dimensions of 60 × 2.430 m. It involved bidirectional prestressing with 12-tendon system, spaced every 1.75 m (in both directions). At the edges of the runway, under the slab, there

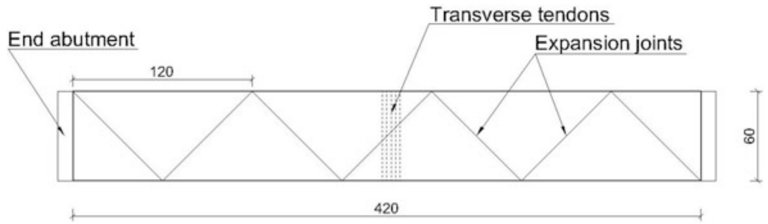

Fig. 2 Prestressed surface of the runway at Orly Airport near Paris, description in the text (*Source* Own study on the basis of [5])

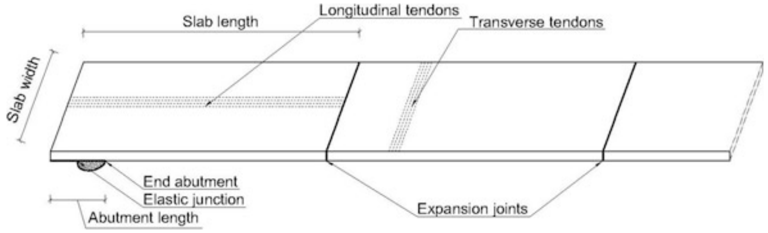

Fig. 3 Prestressed surface of the runway at Maison-Blanche Airport, description in the text (*Source* Own study on the basis of [5])

were flexible retaining blocks of predefined length, ballasted with the weight of backfill and slab. Additionally, every 300 m, there were expansion joints with permanent readjustment devices. Such a solution allowed for additional readjustment during runway use. This solution, however, is feasible exclusively in a balanced climate (with small temperature amplitudes), hence its application was not possible in most European countries. Increase in the temperature increasing contraction forces, which exerts significant load on retaining blocks, and the repeated high temperature fluctuations can result in structure damage [4, 5].

3 Assumptions for the Designed Runway at KTW Airport

Due to the intensely increasing number of airline operations (by over eight times in the years 1996–2012), there is a need to modernise the Katowice-Pyrzowice airport in the aspect of new runway construction.

Below is the analysis of the runway structure in two variants. Runway (27-09) with PCN classification number 64/R/B/W/T, for airfield with reference code 4E, is to be 3.600 m long and 45 m wide, with shoulders of 7.5 m width on each side (the actually built runway will be 3.200 m long, with the possibility of its extension to 3.600 m). Therefore, runway width with the shoulders totals 60 m. Code 4E means that the reference length of aircraft take-off exceeds 1.800 m, while aircraft landing there have wing span within the range of 52–60 m, and total track width setting of main landing gear wheels of 9–14 m. The new runway, marked in red in Fig. 4, has been located 195 m to the north of the existing runway (in white below).

For the purpose of the study, have been analysed the solutions for the new runway (27-09) in two structural variants, namely runway of prestressed concrete,

Fig. 4 Satellite photograph of the Katowice-Pyrzowice Airport with new runway marked (*Source* On the basis of [9])

and dowelled concrete runway. For this purpose, have been developed a structural design of the newly constructed runway at the Katowice-Pyrzowice airport (excluding taxiways and auxiliary infrastructure). The following engineering assumptions have been applied (it was impossible to obtain the original design from the investor).

Load capacity of the runway was assumed for Boeing 747-400 JumboJet, with maximum weight while landing of 414.130 kg [10], 90 % of which is transferred via four main items of the landing gear, pressure in the tyres was adopted as 230 psi (1.6 Mpa). Subgrade was assumed with Winkler soil reaction coefficient equal to 110 MPa/m. Traffic intensity was adopted as more than 100 operations per day.

For comparative purposes, calculations for two runway structure variants have been performed:

- variant I: runway of prestressed concrete,
- variant II: runway of dowelled concrete.

In both variants, runway is set 1.20 m below the land surface (namely 20 cm below the soil freezing level; in this case, acc. to [11] for climate zone II, freezing depth totals 1.00 m).

Subgrade of the runway has been designed of three layers. First layer of gravel, the second of sand and gravel mix, while the third of base concrete (class C15/20). Thickness of subgrade layers for variants I and II totals, respectively: 50, 25, 25 cm, and 30, 25, 25 cm, according to vertical cross-sections through the designed runway layers, as presented in Fig. 5. In the case of prestressed runway, subgrade layers are separated from the surface slab with a sliding layer of PE foil (three layers of 0.2 mm thickness each), while in the case of dowelled runway, there is additionally bituminous mass (Fig. 6).

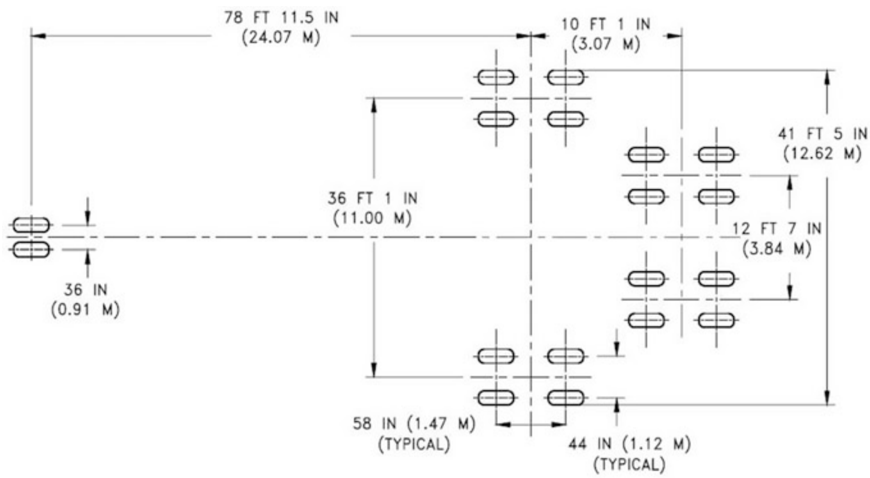

Fig. 5 Aircraft wheel location (*Source* [10])

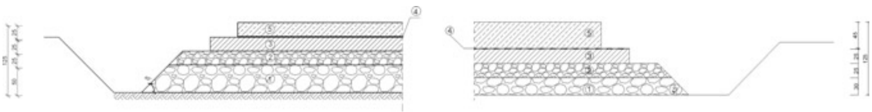

Fig. 6 Fragment of cross-section of prestressed runway—variant I and dowelled concrete structure—variant II: *1* gravel, *2* sand-gravel mix, *3* concrete subgrade, *4* sliding layer, *5* surface layer (*Source* Own study)

Pavement slab has been designed of concrete: compressive strength of C45/55, flexural strength F6.5, freeze resistance F150 and absorbability below 5 %. Concrete mix is one of the most important elements affecting the quality of the structure, thus it must meet significant requirements. Major parameters include flexural strength of concrete [12]. In the USA, there are many studies on this parameter. The studies, among others, referred to concrete made of fly ash. Results were obtained in the range of 6.0–7.0 MPa [13]. Exposure of XF4 has been adopted. Covers amount to 60 mm for surfaces adjacent to external environment, and 30 mm for surfaces on the side of base concrete.

3.1 *Variant I—Prestressed Slab*

Thickness of prestressed slab totals 25 cm, and this is the lowest possible value due to the adopted prestressing technology. The entire runway of 3600 m was divided into 30 slabs, of three types (2 slabs type I, 6 slabs type II, and 22 slabs type III), Table 1. Type I includes slabs with dimensions of 119 m × 45 m and maximum load capacity. Type II includes slabs with dimensions of 118 m × 45 m and also maximum load capacity. Type III includes slabs with dimensions of 118 m × 45 m and load capacity reduced by 15 % (central part of the runway). Between the prestressed slabs, there are jacking gaps with the width of 2 m. The gaps (executed

Table 1 Division of the prestressed slab into sections

No.	Type	Slab measurement	No.	Type	Slab measurement	No.	Type	Slab measurement
1.1	I	119 m × 45 m	3.1	III	118 m × 45 m	5.1	III	118 m × 45 m
1.2	II	118 m × 45 m	3.2	III	118 m × 45 m	5.2	III	118 m × 45 m
1.3	II	118 m × 45 m	3.3	III	118 m × 45 m	5.3	III	118 m × 45 m
1.4	II	118 m × 45 m	3.4	III	118 m × 45 m	5.4	III	118 m × 45 m
1.5	II	118 m × 45 m	3.5	III	118 m × 45 m	5.5	III	118 m × 45 m
2.1	III	118 m × 45 m	4.1	III	118 m × 45 m	6.1	II	118 m × 45 m
2.2	III	118 m × 45 m	4.2	III	118 m × 45 m	6.2	II	118 m × 45 m
2.3	III	118 m × 45 m	4.3	III	118 m × 45 m	6.3	II	118 m × 45 m
2.4	III	118 m × 45 m	4.4	III	118 m × 45 m	6.4	II	118 m × 45 m
2.5	III	118 m × 45 m	4.5	III	118 m × 45 m	6.5	I	119 m × 45 m

after prestressing) allow for post-tensioning of the cables, and as a target, joints compensating for elements' expandability will be made on their edges.

3.2 Variant II—Slab with Dowelled Concrete Structure

In variant II, simplified calculations were carried out, with the assumption of runway structure with dowelled concrete pavement (without compression anchorage). In such a case, subgrade is 80 cm thick, with layers according to Fig. 5. Here, the structural layer is made on a layer of bituminous mass. The slab has been divided into sections with dimensions 45 m × 45 m, and then into slabs of 9 m × 9 m. Concrete as for prestressed slab has been applied. In the course of calculations, slab thickness was optimised due to the value of loads and economics of construction so as to maximally reduce flexural forces in bottom fibres, while at the same time trying to keep the runway slab thickness as small as possible.

4 Engineering Method

Identification of the forces in the runway cross-section is the core element of structural calculations. At present, there are many types of software on the market to allow for engineering airfield pavements and many analytical methods using empirical formulas and monograms. Methods applied include FAA, AASTHO, ACI and other [14].

Forces in bottom fibres have been identified based on Westergaard method, which is also applied in dedicated software. According to Westergaard method, forces have been calculated on the basis of the following formulas [15]:

- load at the centre of the slab:

$$\sigma_r = \frac{0.275P}{H^2}(1+v)\left[\log\frac{E_{cm}H^3}{kb^4} - 0.436\right] \tag{1}$$

- load at the edge of the slab:

$$\sigma_r = \frac{1+v}{3+v}\frac{P}{H^2}\left[8.8\ \log\left(\frac{l}{a}\right) - \frac{4v}{\pi} - 0.290 + \frac{3}{\pi}\left(\frac{1-v}{2} + 1.18(1+2v)\frac{a}{l}\right)\right] \tag{2}$$

- load at corners:

$$\sigma_r = 0.529(1+0.54v)\frac{P}{H^2}\left[4\log\left(\frac{l}{b}\right) + 0.359\right] \tag{3}$$

Moreover, for slab corners, extended force interdependencies have been applied, according to Pickett [15]:

- for dowelled corner:

$$\sigma_r = \frac{3.36P}{H^2}\left(1 - \frac{\sqrt{\frac{a}{l}}}{0.925 + 0.22\frac{a}{l}}\right) \quad (4)$$

- for non-dowelled corner:

$$\sigma_r = \frac{4.2P}{H^2}\left(1 - \frac{\sqrt{\frac{a}{l}}}{0.925 + 0.22\frac{a}{l}}\right) \quad (5)$$

where:

$l = \sqrt[4]{\frac{D}{k}}$, $D = \frac{E_{cm}H^3}{12(1-\nu^2)}$,

E_{cm} concrete flexibility module (MPa),
ν Poisson coefficient,
H slab thickness (m),
K soil reaction module (N/mm^3),
P load applied (kN),
a equivalent radius of wheel contact with the surface (m),

$b = \sqrt{1.6\,a^2 + H^2} - 0.675\,H$, when $a < 1.724$ H,
$b = a$, when $a > 1.724\ H$.

Additional forces occurring in the pavement include forces from load with uneven temperature:

$$\sigma_{st} = \frac{\mathrm{E_{cm}}\alpha\Delta_{\mathrm{t}}}{2}\frac{\mathrm{C_x} + \nu\mathrm{C_y}}{1 - \nu^2} \quad (6)$$

and shrinkage stress. Forces from other vehicle's wheels have been omitted, as in normal operating conditions, there are no other vehicles on the runway, just one aircraft.

5 Calculation Results

The forces in the slab depend on its thickness. Table 2 presents the values of forces in the slab, less calculated flexural strength of concrete. Additionally, change was determined to the volume of built-in concrete with the change of system

Table 2 Change of forces from load with aircraft wheel in the prestressed slab depending on slab thickness (*Source* Own study)

Slab thickness (cm)	Forces at the centre of the slab (MPa)	Forces at the edge of the slab (MPa)	Forces at the corner of the slab (MPa)	Increase to element volume against the slab with 25 cm thickness
25	3.807	6.035	8.667	1.000
30	2.449	4.246	6.195	1.200
35	1.647	3.143	4.749	1.400
40	0.938	2.191	3.488	1.600
45	0.429	1.493	2.591	1.800
50	−0.016	0.857	1.802	2.000
55	−0.342	0.398	1.232	2.200
60	−0.613	−0.017	0.723	2.400
75	−1.037	−0.672	−0.074	2.800

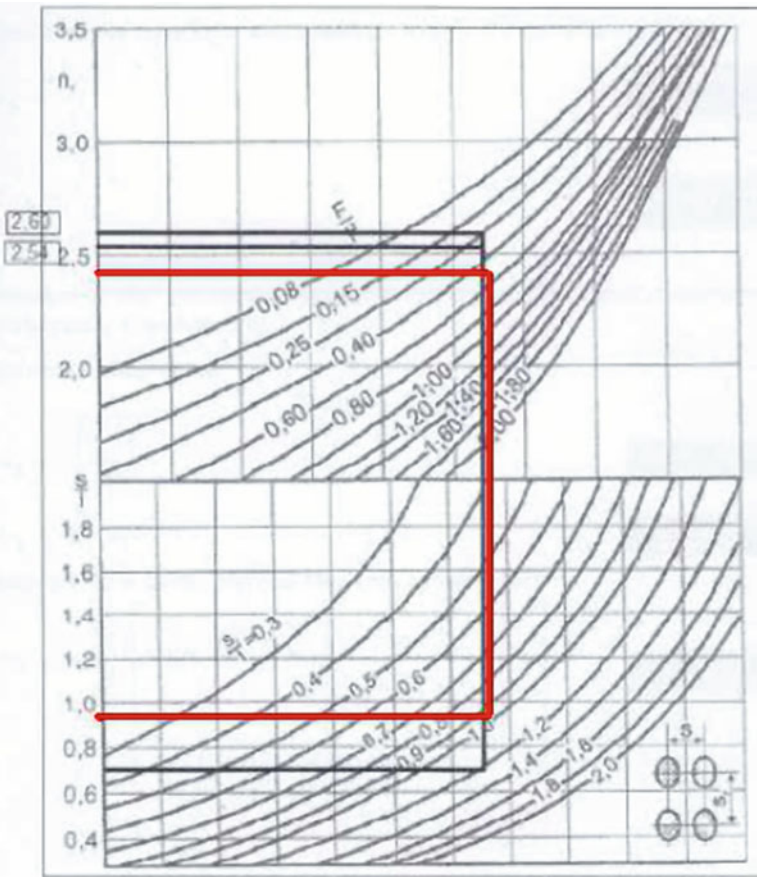

Fig. 7 Nomogram for setting reduction coefficients (*Source* [3])

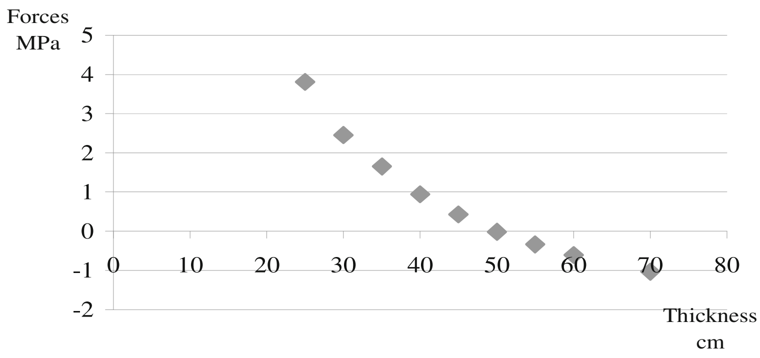

Fig. 8 Dependence of forces at the centre of the slab on its thickness (*Source* Own study)

thickness, in reference to the slab with 25 cm thickness. Moreover, Fig. 7 presents the nomogram for setting reduction coefficients, whereas Fig. 8 presents the dependence of forces at the centre of the slab on its thickness.

5.1 Variant I—Prestressed Slab

On the basis of detailed calculations according to formulas (1–6) for the slab of 25 cm thickness, concrete flexural strength is not sufficient, and significant forces must be transferred through prestressing [6], Tables 3 and 4.

After determining forces that need to be transferred by prestressing and considering the size of the investment, designed durability and safety of passengers and the staff, prestressing has been designed to meet the conditions for bottom and top

Table 3 Forces from load with aircraft wheel in the prestressed slab (*Source* Own study)

Forces from load with aircraft wheel	Type I (MPa)	Type II (MPa)	Type III (MPa)
Force at the centre of the slab	5.271	5.348	4.708
Force at the edge of the slab	7.352	7.458	6.660
Force at the corner of the slab	9.513	9.651	8.483

Table 4 Forces in slab types to be transferred through prestressing (*Source* Own study)

Forces remaining to be transferred through prestressing	Type I (MPa)	Type II (MPa)	Type III (MPa)
Force at the centre	3.716	3.807	3.039
Force at the edge	5.907	6.035	5.077
Force at the corner	8.644	8.667	7.264

fibres tensile strength with the reserve of 1 MPa. Therefore, a prestressed slab has been designed with the thickness of 25 cm. Prestressing tendons of φ 75 mm in HDPE jackets have been applied (fpk = 1860 MPa) grouped by four strands laid in both directions. The tendons have been placed on supports of φ 6 rods with spacing not greater than 100 cm. The slab features circumferential reinforcement of rods φ 12, of RB500W steel, with spacing of 25 cm and spacer bars φ 8 with spacing of 45 cm. Dowelling of slab edges has been applied with φ 20 dowels of 90 cm length, placed between anchorages of prestressing tendons, with spacing from 30 to 50 cm.

5.2 Variant II—Slab with Dowelled Concrete Structure

A runway slab has been designed with thickness of 45 cm, divided into sections of 9 m × 9 m. Due to insufficient load capacity, calculated according to formulas (1–6), Tables 5 and 6, the slab requires additional reinforcement.

In order to meet the condition for forces in bottom fibres, slab reinforcement has been proposed according to [3, 4], and reinforcement degree has been adopted within the range of from 0.25 to 0.4 %. Therefore, the slab is reinforced at the bottom with the rods of φ 16 every 20 cm along, and every 25 cm across. At the top, structural reinforcement φ 12 every 25 cm in both directions bent so as to assure appropriate reinforcement of the edges. Dowelling is done for slabs with dimensions 9 m × 9 m spaced every 30 cm.

Table 5 Forces from load with aircraft wheel in the dowelled slab

Forces from load with aircraft wheel	MPa
Force at the centre	2.532
Force at the edge	3.673
Force at the corner	4.588

Table 6 Forces remaining to be transferred

Forces remaining to be transferred	MPa
Force at the centre	0.429
Force at the edge	1.493
Force at the corner	2.591

6 Analysis of the Results

According to the results of calculations in Sect. 5, it must be pointed out that, for the assumptions adopted, it is only the application of a concrete slab of 75 cm thickness that allows for complete transition of operating forces. However, apart from additional costs of concrete, such thickness generates costs related to the specificity of executing such a thick system. However, forces at the centre of the slab are fully transferred via the system of 50 cm thickness. In such a case, consideration of additional reinforcement just at the edges and corners is a disputable issue and generates similar costs as execution of fully reinforced slab of 45 cm thickness, which is not related to additional problems with preparation and distribution of untypical reinforcement.

It was also observed that change of forces at the centre of the slab as compared to the change of slab thickness is best illustrated with approximation with the polynomial function of degree 2.

In the structural aspect, it is possible to limit the thickness of prestressed bearing slab (pavement) to 25 cm.

At the same time, application of a 45 cm thick dowelled slab requires additional reinforcement with regular steel. The designed prestressing transfers forces of at least 9 MPa at the corners and edges, and 7 MPa at the centre of the slab, where the force is less frequently distributed. In the case of a dowelled slab, sections are so small that practically the entire slab can be considered an edge or corner zone. Therefore, even reinforcement was applied in the whole slab field, but assuring additional reinforcement at edges to secure the connections against damage.

Non-prestressed concrete structure, after application of a load exceeding its load capacity, will suffer permanent damage. In turn, application of an actual compressive strength to the prestressed slab, causing possible system overload which may occur during the need to accept a larger aircraft or during incorrect manoeuvers, will not cause structural damage. In the case of prestressed structure, temporary overload may cause damage, yet after load removal the structure will be flexible and return to the condition similar to the condition before overload—this is because compressive forces will occur in the cross-section, causing closure of cracks and reduction of bents.

According to [6], application of prestressing in the runway limited total joint length to 1.305 m (not considering shoulders). For a dowelled runway, total expansion joint length totals 3.555 m, while other joints—28.800 m at slabs of 9 m × 9 m (with slab division into 7.5 m × 7.5 m, this would be, respectively, 3.555 and 36.000 m). This approximately 25 times reduction in joint length is very important for later runway operation. Airports face major problems with joints [blog]. In the case of normal use of the runway, mainly the exhaust of gases from engines causes losses in mould compounds and concrete erosion at joints. Concrete pieces are often pressed into the mould compound by aircraft wheels or wheels of maintenance vehicle. Such joints do not behave as they should. In a further degradation stage (unless the losses are continuously repaired), concrete elements can be sucked by engine turbines, causing their accelerated wear [16]. For these reasons, reduction to joint length is much recommended.

7 Conclusions

On the basis of calculations performed for the newly built runway at the Katowice-Pyrzowice airport in two variants: with prestressed structure, and with dowelled reinforced concrete pavement, the following conclusions can be drawn.

Basic benefits from constructing concrete runways in prestressed structure against the traditional dowelled structure include:

- possibility of about double reduction to thickness of the bearing system, and thus concrete consumption lower almost by half,
- greater runway resistance to overload and cracking, while the occurrence of such unfavourable phenomena may not necessarily result in damage to the bearing system,
- better durability of the pavement, and smaller number and length of the joints, which significantly reduce the scope and volume of repairs.

Naturally, execution works are more complicated, and a higher quality of the works is necessary than in the case of traditional solutions. Moreover, in order to be able to present more general conclusions, further analyses are required, for other runway types, including at airports with lower reference codes. It also seems necessary to carry out technological-organisational analyses and construction economics, as well as operation of airport runways for various execution variants.

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Determination of Congestion Levels Using Texture Analysis of Road Traffic Images

Teresa Pamuła

Abstract The paper discusses the application of texture analysis of road traffic images for determination of congestion levels. The capability of mapping congestion is investigated using such texture features as: energy, entropy, contrast, homogeneity, dissimilarity, correlation, captured by co-occurrence matrices. No single feature distinctly represents congestion. An optimal combination of features is chosen for classification of congestion levels. Three levels of congestion are correctly differentiated using the proposed texture model of road traffic images. The model is validated using images registered by UAV (Unmanned Aerial Vehicle) flying over a traffic junction.

Keywords Texture features · Congestion · Traffic density classification

1 Introduction

The problem of congestion detection and description is vital for determining ways of limiting its negative impact on the functioning of transport systems. Current solutions of integrated traffic control systems, such as ITS, use a wide range of traffic monitoring devices. Video based monitoring systems gain on popularity and become important sources of information on road traffic. Image processing technology is used for determining traffic data such as: vehicle presence at junctions, vehicle counts and vehicle movement characteristics [1].

Several approaches for the determination of traffic congestion using video data can be distinguished. In [2] a motion analysis method is proposed to detect three typical traffic states—congestion, slow and smooth. The states are classified based on MOFV (macro optical flow velocity) value, calculated using feature optical flow vectors, and edge density values evaluated using Sobel algorithm for extracting vehicle edges. Thresholds of the values are determined and are used to discriminate

T. Pamuła (✉)
Faculty of Transport, Silesian University of Technology, Katowice, Poland
e-mail: teresa.pamula@polsl.pl

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the traffic states. The solution can be incorporated into existing video surveillance systems.

The authors of [3] use Haralick features for evaluating the level of traffic congestion. Energy and entropy features are calculated using four GLCM matrices representing horizontal, vertical and diagonal textural characteristics of the image. A composite measure, a linear function of the calculated values, is defined to represent traffic density directly related to congestion. In order to reduce the computation burden the gray scale of the pixels is reduced from 256 to 32 values. The performance of this solution is limited to detection of congestion that is determination of a very high density of traffic in the observed scene.

Qiao and Shi [4] propose to use image edge and texture features for extracting traffic parameters related to congestion that is the length of queue and lane occupation at junction approaches. Traffic lanes are defined as ROI (Region of interest) where Canny edge detection is applied to obtain vehicle contours and local binary pattern textures are computed to describe the vehicle and road surfaces. Morphological processing is used to enhance the presence of vehicles and reduce the background noise. Inter-frame difference is taken to segment the moving and stationary vehicles. The result is analyzed to extract the end of queue and the number of vehicles in the queue. Lane occupation is defined as the ratio of the pixel number of vehicles which are both static and moving to the pixel number of the ROI.

Bi in [5] proposes an average intensity of background subtract image to describe the number of moving vehicles, and proves a linear relation between this image characteristic and the occupation ratio. Traffic states related to congestion are classified based on the characteristics and additionally on illumination characteristics represented by Gaussian group histogram of the background. Mean speed of vehicles and scene classification is also incorporated into the classifier. The classifier differentiates traffic states during the day, in the evening and at night. Three states are defined: non blocked, slow and jammed.

Asmaa et al. [6] use a global motion estimator in the video scene to classify the road traffic in three categories: light, medium and heavy. The estimator is defined as the length of block motion vector having a minimum matching error, 16×16 pixel search window is used. The vector together with such extracted parameters as occupancy, mean speed of vehicles, traffic flow, traffic density parameters are applied to classifiers, the K Nearest Neighbor (KNN) and the SVM (Support vector machine). The best performance is obtained by using SVM with the vehicles mean speed and the density macroscopic parameters, based on block motion vectors.

The authors of [7] use a combination of Haralick texture features and sum and difference histograms for extraction of urban regions from aerial images, which is useful for assessing the range of traffic areas in transport management systems.

This paper presents a method for determination of congestion based on image texture features defined by Haralick [8]. Images are extracted from a video stream every 100th frame, this gives an image of the changes of traffic situation every 4 s. A 40 m stretch of a three lane road is observed and the images are appropriately cropped. The resultant observation sequence is converted into test sequences with different mappings of pixels. The test sequences are: 256 gray level images, 8 gray level images and binary images containing object contours. These are the basis for investigation of the texture feature properties and for the design of the congestion model. Results are presented in section four of the paper. Section 5 gives a summary of the work and proposes ideas for future research.

2 Image Texture Properties and Traffic Density

Texture is a visual characteristic of images. It is a sort of description of the statistical properties of image patches. This may include a set of specific features having similar shapes and sizes. The size of these and their mutual position define the texture description. The texture may map sets of objects of similar size and shape in the image. The change of the texture indicates the change of the contents of the image, for instance the number of objects their size and mutual positions. In the case of monitoring road traffic, vehicles become the elements of the texture and thus the texture maps the traffic density. The rate of change of texture features likewise represents traffic flow [4]. Vehicles have rectangular shapes of different sizes, which define distinctive features of the texture.

Haralick [7] proposed a set of texture features which became widely used for analysis of images and with success applied for image content description. The features are calculated using GLCM (Gray Level Co-occurence Matrix). This approach is used in this work.

GLCM is a square matrix GLCM = $[P_{i,j}]$, $i,j \in N$ where N is the number of pixel values, contains frequencies of occurrence $P_{i,\,j}$ of pixel values which lie at set distances from each other. A matrix is generated for each distance. For instance for a distance defined by the vector (1, 0) the table contains entries which are the sums of pixels with the value i which lie to the right of pixels with the value j. The size of GLCM is determined by the square of N. In the case of 256 gray level images there are 65,536 elements of the matrix. 8 level gray images require 64 element matrices, while matrices for binary images have just four elements. A texture description consists usually of several matrices, commonly 4 vectors are used which represent texture “directions” 0°, 90°, 45°, 135° that is horizontal, vertical and two diagonals. This directional description is useful for classification of contents with movement, where the change of values in the corresponding to movement matrices will indicate the direction of change of position. The test sequences contain only horizontally moving vehicles so only the matrix is used in examinations.

The generation of GLCM is very expensive in the sense of memory and processor resources, it is advisable to reduce the size of it, in the case of real time calculations, that is to use the least number of pixel values. The reduction of the pixel value resolution can lead to diminishing the sensitivity to noise, but may also result in loosing objects which are similar to the background.

Table 1 Texture features (*Source* [8])

Feature	Calculation formula
Energy Angular second moment	$\sqrt{\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} P_{i,j}^2}$
Entropy	$\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} P_{i,j}(-\ln P_{i,j})$
Contrast (Inertia)	$\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} P_{i,j}(i-j)^2$
Homogeneity Inverse difference moment	$\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} \frac{P_{i,j}}{1+(i-j)^2}$
Dissimilarity	$\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} P_{i,j}\lvert i-j\rvert$
Correlation	$\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} P_{i,j}\left(\frac{(i-\mu)(j-\mu)}{\sigma^2}\right)$ μ—mean values σ—standard deviation of values

Preliminary tests show that the reduction of the number of pixel values from 256 to 8 retains the characteristics of vehicles. Vehicles are mostly represented by homogenous patches of pixels, which constitute the features of the texture. Too high a resolution of the pixel values leads to deterioration of the homogeneity of these patches resulting in a more complicated description of the texture.

Table 1 represents the texture features set used for the design of the optimal model of congestion classification.

Energy and entropy are measures of arrangement of objects, homogeneity describes the perception of "smoothness" of the image content, contrast indicates the amount of local variations present in the image, correlation is a measure of linear-dependencies in the image. Energy reaches high values for pixels of constant or repeating values. High values of entropy are obtained for complex pixel patterns in the image.

3 Test Sequences

Road traffic video was registered using a 4k camera carried by an UAV. The road situation is observed from the height of 100 m. The view of the road is not stable due to wind and imperfect stabilization characteristics of the UAV. Figure 1a presents a sample image cut from the original video stream. The following images 1b–d illustrate the results of reducing the space of pixel mappings. First the RGB color space is converted to 256 gray levels, further the gray levels are binned to form an image with 8 "gray" values (Fig. 1c). In order to diminish the influence of ambient light variation and increase the visibility of low contrast objects the image is adjusted using histogram equalization.

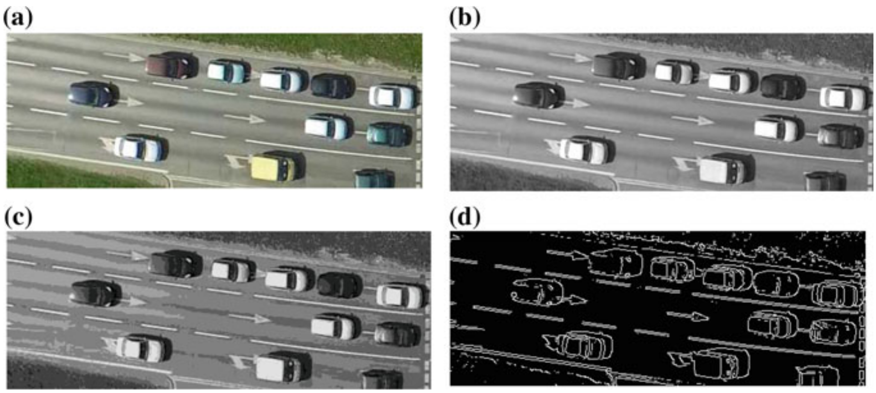

Fig. 1 Image samples: **a** original colour image RGB colour space, **b** converted to 256 gray levels, **c** converted to 8 gray levels, **d** edge map (*Source* Own Research)

The last conversion is aimed at obtaining a binary representation. Image thresholding requires a threshold value which is very sensitive to the contents of the image. To alleviate the problem of finding an appropriate threshold for extraction of objects relevant for processing, edge detection is proposed. Canny with an adaptive binarization threshold is used for detecting edges (Fig. 1d).

4 Texture Based Model for Congestion Classification

In all six texture features are used for the description of the contents of the test images. GLCM matrices are calculated for video observations lasting for a number of minutes, which gives sequences of tens of images showing the evolution of the traffic situation. Three levels of congestion are defined for the observed stretch of road:

- level 1—no congestion, image contains only a few vehicles,
- level 2—medium congestion, vehicles cover 50–70 % of the image,
- level 3—congestion, over 70 % of the image contains vehicles.

Table 2 presents texture feature values, the results of processing the test sequences. The values are normalized to enable efficient comparison of the results. Eight gray level images are processed and prove to provide the best performance in differentiating the levels of congestion.

In the next stage of the model design the number of texture features is optimized to reduce complexity. Ranking is used to find a set of three most sensitive texture features for determining the levels of congestion. All test sequences are processed. Table 3 presents the results. For all pixel mappings texture contrast is the member of the discrimination set. Energy and dissimilarity equally play an important role in discriminating congestion.

Table 2 Mean normalized values of texture features calculated for proposed levels of congestion with samples of traffic images (*Source* Own Research)

Congestion level	Sample images (8 gray levels)	Energy	Dissimilarity	Contrast	Homogeneity	Entropy	Correlation
1		1.000	0.423	0.321	1.000	1.000	0.652
		0.869	0.599	0.510	0.980	0.964	0.818
		0.903	0.599	0.514	0.980	0.970	0.820
2		0.826	0.742	0.696	0.964	0.949	0.881
		0.797	0.812	0.786	0.957	0.940	0.911
		0.742	0.866	0.836	0.950	0.931	0.936
		0.734	0.847	0.797	0.952	0.931	0.929

(continued)

Table 2 (continued)

Congestion level	Sample images (8 gray levels)	Energy	Dissimilarity	Contrast	Homogeneity	Entropy	Correlation
3		0.661	1.000	0.991	0.935	0.914	1.000
		0.656	0.999	1.000	0.936	0.914	0.996

Table 3 Discrimination sets of features (*Source* Own Research)

Test image sequence	Texture features
256 gray levels	Contrast, energy, entropy
8 gray levels	Contrast, energy, dissimilarity
Edge map	Contrast, correlation, dissimilarity

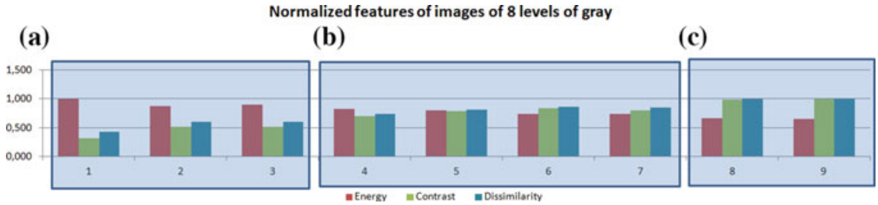

Fig. 2 Texture feature values for discrimination of congestion: **a** level 1, **b** level 2, **c** level 3 (*Source* Own Research)

Table 4 Congestion levels (*Source* Own Research)

Congestion	Energy	Dissimilarity	Contrast
Level 1	Above 0.90	Below 0.70	Below 0.60
Level 2	0.75–0.90	0.70–0.95	0.60–0.95
Level 3	Below 0.75	Above 0.95	Above 0.95

Figure 2 illustrates in the form of bar graphs the results of congestion classification using the optimized discrimination set of texture features. Sample images from Table 3 are processed.

The shapes of the graphs are distinct for the different congestion levels and are significantly different from each other.

Based on the examination of all 8 gray level images test sequences the following thresholds are determined for classification of congestion levels—Table 4.

5 Conclusions

The proposed model of congestion classification based on texture features correctly determines congestion levels for all the tested sequences. The determined discrimination thresholds are defined as ranges of values. These ranges cover at least 5 % of the total span of values and in most cases it is more than 15 %. This characteristic signifies a measure of robustness of the model.

The influence of the change of the observation view due to wind and imperfect stabilization characteristics of the UAV proves to be marginal. The position shift is too small to give significant changes of the texture features values.

The proposed model is suitable for real time evaluation of traffic congestion. Its application for processing video from road side cameras requires further research. Road side cameras provide highly distorted views of the traffic lanes especially when installed on low posts. The problem of occluding vehicles may also corrupt the interpretation of the image contents. A perspective solution of the problem of road side observation may include a neural network for resolving the complex impacts of different factors on congestion representation.

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Part II
Optimisation of Transport Systems

Technologically Advanced and Responsible Travel Planning Assisted by GT Planner

Grzegorz Sierpiński

Abstract Sustainable development of transport triggers changes targeting reduction of emission of harmful substances and noise, and by that means also fostering more eco-friendly solutions. Particularly with regard to urban areas, these changes must not be limited to the "hard" (i.e. infrastructural) activities only. Emphasis is mainly placed on two aspects, i.e. development of modern supporting technologies (including ITS) and changes in habits of the travelling population. Behaviour patters of travellers constitute a particularly important element in the process of appropriately shaping the future of transport systems. This article highlights the matter of responsible travel planning understood as a more environmentally aware approach to the effects of transport. Contemporary tools known as trip planners provide assistance for planning of travels as well as for appropriate flow of information about alternative travelling modes to the travelling person. The requirements typically applied to similar planners have been discussed using the example of a tool developed for research purposes, namely GT Planner. The trip planner described in the paper is a universal platform enabling transfer of information on the available travel options, using additional criteria which make it possible to travel in a more eco-friendly manner.

Keywords Trip planner · Urban travel · Sustainable transport · Green travelling

1 Introduction

Contemporary trends of changes in transport systems are predominantly assumed to prevent negative environmental effects of transport. At the same time, mobility limiting is a concept clearly being abandoned. For instance, the EU communication [1] stresses that minimisation of negative environmental impact of transport cannot be pursued through mobility limiting, but rather through efficient utilisation of

G. Sierpiński (✉)
Faculty of Transport, Silesian University of Technology, Katowice, Poland
e-mail: grzegorz.sierpinski@polsl.pl

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natural resources. The foregoing implies the need for changes in the modal split of traffic and further evolution of technologies reducing energy consumption and emissivity of transport, at the same time providing the travelling population with alternative travelling solutions. Such an approach is supposed to trigger improvement of the current state of matters, maintaining mobility on unaltered level at the same time.

People who travel (particularly in relation to work and education) often do not consider alternative ways to arrive at the destination. They tend to use the same travelling mode they originally chose. And frequently, it is a passenger car. It should be noted that such a conduct may be founded on diverse grounds, yet the most typical of them are a habit, unawareness of the negative environmental effects of transport and lack of full information on alternative travelling modes. With regard to transport systems, flow of information has become particularly important. There are numerous ITS-based solutions applied in contemporary towns, ensuring direct transfer of information to a travelling person. The most popular of them include variable-message signs informing drivers in due advance about obstacles which have occurred in the given road (accident, road works, congestion etc.) and suggesting a detour. For users of collective transport, dynamic passenger information systems, used at stops, deliver more factual information on departure times of incoming means of collective transport (as per the current status of the transport network, taking potential en route delays into consideration). Even though they are very efficient, all these solutions operate on a point basis, after the choice of the travelling mode has already been made, and they do not provide comprehensive information about the transport system. Solutions which prove particularly useful in such a case are trip planners, i.e. web-based or even mobile applications enabling route planning with multiple factors taken into account (pertaining to both the user and the transport system). This article addresses the problem of responsible and informed planning of routes, which is possible when using contemporary trip planners. The subject matter has been discussed using the example of GT Planner, a tool developed under an international research project.

2 Project Idea and GT Planner's General Route Planning Algorithm

The changes triggered by technological and organisational evolution must be transparently communicated to the travelling population. In light of the orientations defined by the EU for the urban transport system changes, an idea has germinated that a set of tools should be developed, supporting the travelling persons and educating them about environmentally friendly solutions applicable to travelling, on the one hand, and on the other hand, assisting local authorities in making appropriate decisions on the functioning of the transport system in the given area. This idea is pursued under the international project entitled “A platform to analyze and foster the use of Green Travelling options (GREEN_TRAVELLING)” co-financed by the ERA-NET Transport III Future Travelling programme. The institutions involved in the project represent three countries: Saitec, Factor CO2 and DeustoTech from the Basque Country, the Silesian University of Technology from Poland and Mantis from Turkey. This article concentrates on only one of the project deliverables, namely the Green Travelling Planner (GT Planner). The most fundamental goal defined for the trip planner was to create a tool capable of providing a travel planning person with far more extensive information than other tools of similar type. It was also important to implement a criterion highlighting the impact of individual travelling modes (between specific points defined by the user in the given area) on the environment [2, 3]. Consequently, in this respect, the planner performs two functions, namely that of information and education, which may support the promotion of appropriate behaviour patterns among the travelling population in the future.

Trip planners are often limited to a single travelling mode, hence the planners dedicated to passenger cars or to public transport. As for the search criteria, the limitation basically applies to seeking the quickest or the shortest route. More expanded trip planners featuring a system of multiple criteria are far less popular. With reference to contemporary transport systems, also in terms of route planning, common expectations are much more demanding owing to the travelling persons' need for full knowledge on travelling alternatives, at the same time, targeting the possibility of moulding their travelling behaviour, for instance, by highlighting disadvantages of non-eco-friendly solutions. In more advanced tools, route planning requires of the user to enter specific input data depending on one's travel-related expectations. A general overview diagram of the route planning algorithm using the example of GT Planner has been provided in Fig. 1. General structure of the planner based on Open Trip Planner.

As shown above, route planning consists of several stages, the first one traditionally being the definition of the points of origin and destination of travel. Additionally, one must choose the date and time of the travel start planned. In the mobile application dedicated to devices featuring a GPS (Global Positioning System) receiver, it suffices to enter the destination point (assuming that the travel starts at the current location and time). As for the multimodal planner, in the second instance, the user must define one of the available travelling modes. The modes available in GT Planner have been described in the next section. For each mode, there are several additional parameters available which the travelling person can define. Moreover, on account of the need for the current traffic conditions to be taken into consideration, the user may include congestion-related information. Full information about the range of available alternative solutions for the route between

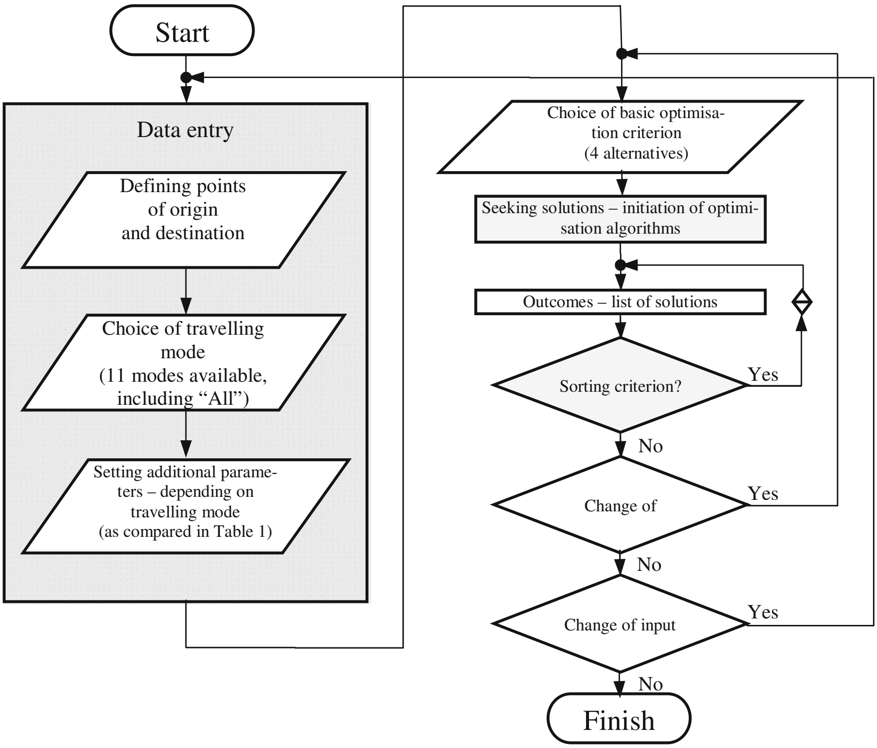

Fig. 1 Diagram of GT Planner's general route planning algorithm (*Source* Own research)

the pre-defined points is delivered to the travel planning person once the "All" mode has been selected. The last action preceding the initiation of algorithms seeking optimum routes and travelling modes is the choice of the primary optimisation criterion. The criteria available in GT Planner have been described further on the article.

A trip planner may be considered as one of the ITS elements. It supports dynamic traffic stream management systems and is capable of cooperating with them by providing users with data which include, for instance, current traffic conditions. One of the demands postulated towards ITS elements is their universal nature which, with reference to a trip planner, should be interpreted as a possibility of deploying them in any chosen area. Bearing the foregoing in mind, GT Planner was built on the grounds of such databases as the Open Street Map and the National Elevation Dataset [4] or the Shuttle Radar Topography Mission [5], which describe topographic features of land. Sample implementations of the planner in several European cities have been illustrated in Fig. 2.

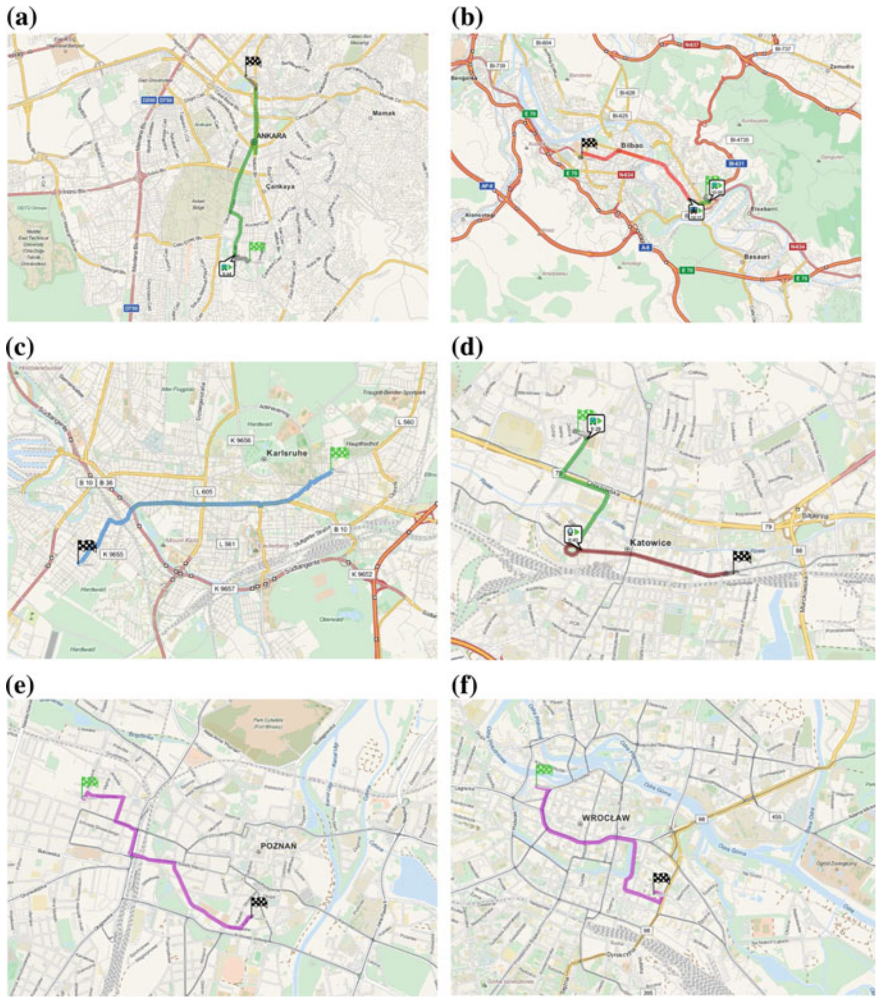

Fig. 2 Sample GT Planner implementations in different European cities: **a** Ankara (Turkey), **b** Bilbao (Basque Country, Spain), **c** Karlsruhe (Germany), **d** Katowice (Poland), **e** Poznań (Poland), **f** Wrocław (Poland) (*Source* Own research)

3 Organisational and Technological Changes Versus Urban Travelling Modes—A Challenge for Contemporary Trip Planners

Seeking and implementing technologically advanced organisational and technological solutions in transport systems requires suitable studies and simulations to be conducted. The studies undertaken at the planning stage are mainly focused on infrastructural features and vehicles. After implementation, a selected new solution is tested from the perspective of how travellers respond to it. This allows for estimating the extent to which the original assumptions conform with their interpretation among users as well as the actual effect on the travelling behaviour patterns among the travelling population triggered by such a change. Being so extensive, this spectrum of phenomena makes the assessment from a global perspective difficult, and therefore, one usually deals with studies limited to a more specific element of the infrastructure (e.g. roundabouts perceived as solutions improving the traffic flow [6–8] or devices supporting traffic management [9]) or a vehicle driver's behaviour (e.g. while performing specific manoeuvres [10, 11] or for purposes of creating a simulation model [12, 13]).

However, what is needed besides the implementation of new solutions is the transfer of appropriate information about such solutions addressing potential users. Lack of information causes lack of interest in a new technology or an organisational solution, even if the travelling person could consequently save time or reduce travelling costs. So far, when assessing a functioning transport system, a four-element modal split was referred to, distinguishing between a passenger car, public transport, cycling and walking. From such a perspective, the passenger car seems to be the only non-eco-friendly means of transport in this group, and so its share in traffic should be minimised. As further technological and organisational changes were implemented, new variations of the four basic travelling modes emerged. For example, one could refer to travelling by bicycle which, originally being an individual means of transport, evolved towards a shared system of urban bicycle rental services. A similar development can be observed in urban passenger cars (which the user can rent). On the other hand, the technological evolution has made it possible to introduce cars whose drive systems decrease the environmental nuisance to a considerable extent (by reducing noise and emission of harmful substances), e.g. electric cars. According to the EU guidelines, besides promotion of environment-friendly means of transport for direct travels, one should consider at least partial limitation of the passenger car use in travel, in a fraction of the route to be covered. Hence the Park&Ride and similar solutions, often to be encountered in towns, enabling travel to a dedicated spot with a passenger car, only to change for a means of collective transport. It should be noted that, as successive solutions are implemented, aimed at transport sustainability and promotion of travelling alternatives towards a conventional passenger car, it seems reasonable that the available trip planners should become more detailed.

Bearing the foregoing changes in mind as well as the need for using a broader range of travelling options, it has been proposed that trip planners should support a larger number of travelling modes. The tool addressed in the paper, i.e. GT Planner, features eleven available travelling modes which comprise one of the route search input parameters [14]. The last one, the eleventh, is actually an outcome of a review of all the remaining options. Each mode allows for entering additional parameters which can be defined by the travelling person (otherwise, these parameters assume average values characteristic of the given area and travelling mode). A detailed collation of additional parameters which should be defined by

Table 1 Travelling modes available in GT Planner, including the additional parameterisation capability

Travelling mode designation	Additional traveller-defined parameters
"Walk only"	Maximum walking distance (m)
"Bike only"	Maximum walking distance (m)
	Additional choice of the biker's preferences enabling priorities to be set from among the available alternatives of a "quick", "flat" and "safe" route
"Electric car only"	Maximum distance to be covered by an electric car at the given moment (depending on the battery charging status) (m)
	Energy consumption (kWh/km)
	Energy cost (EUR/kWh)
"Walk and urban bike"	Maximum walking distance (m)
	Maximum biking distance (m)
	Additional choice of the biker's preferences enabling priorities to be set from among the available alternatives of a "quick", "flat" and "safe" route
"Walk and urban car"	Maximum walking distance (m)
"Walk and public transport"	Maximum walking distance (m)
"Walk and urban transport"	Maximum walking distance (m)
"Walk and Park&Ride"	Maximum walking distance (m)
"Walk and Bike&Ride"	Maximum walking distance (m)
	Maximum biking distance (m)
	Additional choice of the biker's preferences enabling priorities to be set from among the available alternatives of a "quick", "flat" and "safe" route
"Car"/"motorcycle"	Average fuel consumption (l/100 km)
	Fuel cost (EUR/l)
"All"	All parameters characteristic of the above modes

those planning their travel depending on the chosen travelling mode has been provided in Table 1.

Individual travelling modes are defined as follows:

- "walk only": travelling on foot only, i.e. not using any means of transport. The planner suggests a route leading directly from the point of origin to the destination point, using sections of the transport network in which one can walk,
- "bike only": travelling by bicycle only. The planner suggests a route from the nearest point to the pre-defined origin to the destination point, using sections of the transport network in which one can use a bicycle,
- "electric car only": travelling by an electric car and on foot in the last stage of the travel. The planner suggests a route from the nearest point to the pre-defined

origin to a point where one can charge the vehicle located as close as possible to the destination point, using sections of the transport network in which one can move by car, and then walk to the travel destination,

- “walk and urban bike”: travelling by means of an urban bicycle (i.e. urban bicycle rental services) and on foot, depending on the distance which may complement the travel chain (the extreme case being a travel on foot without using the rental services). The planner suggests a route to be covered by walking from the point of origin to an urban bicycle rental point, then biking to a bicycle return point of optimum location against the destination point, at which one should ultimately arrive on foot. The planner uses all the available transport network sections appropriate for the pre-set travelling mode,
- walk and urban car”: travelling by means of an urban car (i.e. urban car rental services) and on foot, depending on the distance which may complement the travel chain (the extreme case being a travel on foot without using the rental services). The planner suggests a route to be covered by walking from the point of origin to an urban car rental point, then driving to a car return point of optimum location against the destination point, at which one should ultimately arrive on foot. The planner uses all the available transport network sections appropriate for the pre-set travelling mode,
- “walk and public transport”: travelling by means of collective transport and on foot, depending on the distance which may complement the travel chain (the extreme case being a travel on foot without using public transport). The planner suggests a route to be covered by walking from the point of origin to a collective transport system stop, then going to a stop of optimum location against the destination point (including an option of transition stops, changing and walking), at which one should ultimately arrive on foot. The planner uses all the available transport network sections appropriate for the pre-set travelling mode. As for collective transport, the planner makes use of a graph based on the route of the collective transport line (according to the GTFS standard),
- “walk and urban transport”: a combination of the three previous modes, i.e. travelling by collective transport, urban bicycle and car rental services and walking. The planner suggests a route to be covered by walking from the point of origin to a place where one can use the urban transport system, then going to a stop or a bicycle/car return point of optimum location against the destination point (including an option of transition stops, changing and walking), at which one should ultimately arrive on foot,
- “walk and Park&Ride”: travelling by means of the Park&Ride system, collective transport and walking. The planner suggests a route from the nearest point to the pre-defined point of origin (driving by a passenger car) to the nearest point to the P&R system’s start point, and then walking to a point where one can use the urban transport system and go to a stop of optimum location against the destination point (including an option of transition stops, changing and walking), at which one should ultimately arrive on foot,
- “walk and Bike&Ride”: travelling by means of the Bike&Ride system, collective transport and walking. The planner suggests a route from the nearest

point to the pre-defined point of origin (driving by one's own bicycle) to the nearest point to the B&R system's start point, and then walking to a point where one can use the urban transport system and go to a stop of optimum location against the destination point (including an option of transition stops, changing and walking), at which one should ultimately arrive on foot,

- "car"/"motorcycle": travelling by one's own passenger car/motorcycle only. The planner suggests a route from the nearest point to the pre-defined origin to the nearest point to the destination, using sections of the transport network in which one can move by car/motorcycle,
- "all": seeking possible routes using all the above modes in the comparative analysis.

4 Responsible Travelling Versus Route Optimisation Criteria

Responsible travelling in contemporary transport systems is inextricably linked with being aware of the negative environmental impact of transport. Although it is the external costs associated with transport processes on which the media often focus, not before such effects are highlighted with regard to a specific route, planned by and familiar to the travelling person, can one actually influence the latter's travelling behaviour. Under the Green Travelling project, the trip planner in question was expanded beyond the traditional criteria of the quickest ("quicker" criterion) and the shortest ("shorter" criterion) route with two new ones, i.e. "cheaper" and "greener". The first one ("cheaper") allows for seeking the cheapest routes. The travelling person is often unaware of the fact that a connection by means of public transport proves more attractive in terms of this criterion exactly. While initiating the optimum solution search mechanism (functionally based on a hybrid approach combining Dijkstra's algorithms and the A* algorithm), the aforementioned three criteria take the following premises into account, respectively:

- "quicker"—unit time required to cover individual sections of the transport network,
- "shorter"—unit distance of individual sections in the transport network,
- "cheaper"—unit cost of covering the given transport network section.

In each case, the unit parameters depend on the manner in which one travels (on foot, by bicycle, passenger car, public transport). As for the time-related optimum route criterion, some additional periods of time are also taken into account, e.g. time required for parking, urban bicycle rental etc. The "greener" criterion is of major importance as far as external transport costs are concerned. While working upon this criterion, more than a dozen emission-related indicators were defined [15], including those to which other authors from Europe and all over the world most usually refer (including at [16–20]): CO (carbon monoxide), HC (hydrocarbons), NO*x* (nitrogen oxide), PM (particulate matter), CO_2 (carbon dioxide), Pb (lead), SO_2 (sulphur dioxide), CH_4 (methane), Benzene, N_2O (nitrous oxide), NH_3 (ammonia), NO_2 (nitrogen dioxide), PN (particle number) as well as FC (fuel consumption) and WH (energy consumption in the case of electric cars). Eventually, two interchangeable indicators were assumed to be applied under this criterion, namely a criterion connected with climate change (CC), interpreted as global warming (in degrees Celsius) caused by emissions, and disability-adjusted life year (DALY) [14]. The former reflects the environmental costs, and the latter—the social ones. When used to estimate emission values, these indicators entail several parameters connected with the transport infrastructure as well as current traffic conditions:

- vehicle type—for public transport, types defined in the OSM (Open Street Map) standard, and additionally, those used in individual transport. The planner does not entail transport with lorries, since the Green Travelling project applies to passenger transport only. It should also be noted that bicycle and urban car rental systems as well as electric cars were taken into account in this respect,
- road types—similarly to vehicle types, directly derived from those defined under the OSM (i.e. more than a dozen different road types),
- gradient—it determines topographic features of the land and is estimated based on the information contained in such databases as the National Elevation Dataset [3] or the Shuttle Radar Topography Mission [4],
- the last two parameters are related to speed with reference to organisational limitations, i.e. the permissible driving speed and the traffic flow indicator, estimated based on the current average running speed of vehicles using individual sections of the transport network.

A person using GT Planner to plan the expected transfer receives a list of suggested travel solutions. The said solutions constitute a group of most advantageous options corresponding to the search criterion defined by the user. At the same time, for each solution, values of time, distance, cost and environmental impact are established. This makes it possible to broaden the travelling person's awareness in terms of the negative environmental impact of transport. The planner user is also capable of applying any chosen secondary criterion (Fig. 1) in order to create a

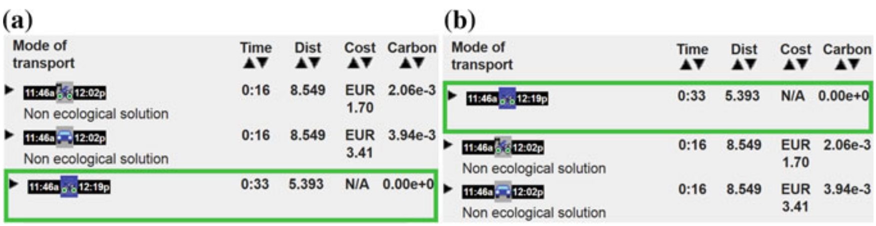

Fig. 3 Example of a secondary criterion being applied in order to create a new ranking list of the solutions found: **a** list of solutions in line with the "quicker" criterion, **b** solutions from the first list sorted according to the "greener" criterion (*Source* Own research)

ranking list based on the solutions originally proposed. This, in turn, allows for finding the most eco-friendly solution among those, for instance, which were established on the grounds of the quickest route criterion (Fig. 3). Consequently, it is possible to foster responsible travelling by making small steps towards improvement of the modal split and triggering changes in the behaviour patterns displayed by the travelling population.

5 Conclusions

Travelling in contemporary times requires awareness of the negative environmental impact of transport and making responsible decisions, so that future generations can also be offered opportunities to develop in line with the sustainable development principle [21]. In light of the necessary changes, oriented by different directives and guidelines (e.g. [22]), threats may be reduced by seeking new technological and organisational solutions [23]. Intelligent Transport Systems enable control of traffic streams in towns. However, stimulating a complete change requires appropriate transfer of information about alternatives towards transport-related habits. In this aspect, expanded multimodal trip planners provide reasonable grounds for the relevant demands stipulated in guidelines to be satisfied. For they do not reduce mobility, but rather supply information on different solutions and enable their users to make the final decision on the manner in which they are about to travel. However, such a choice is an informed one. Therefore, it can be claimed that trip planners provide a complementary solution to infrastructural investments, supporting the promotion of transport behaviour patterns oriented at eco-friendly travelling.

Owing to the possibility of comparing different travelling modes (using the "all" mode), in terms of time, travelling distance, cost and environmental impact, GT Planner, i.e. the tool discussed in the article, performs an information function. It should also be noted that the most environment-friendly travelling mode (irrespective of the criterion chosen) is always additionally highlighted in the list of the available options found. Because in many cases a solution only slightly inferior in terms of time, and sometimes even more advantageous in terms of cost, may prove to be more eco-friendly.

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Solutions for Agglomeration Railway Integration—Case Study of the Line Wieliczka—Krakow Airport

Aleksandra Ciaston-Ciulkin and Sabina Pulawska-Obiedowska

Abstract Today agglomerations are faced with a number of transport issues related to the increasing mobility, especially by car. Growing congestion and environmental pollution are forcing to search for solutions to encourage changes in travel behavior. One of the effective tools supporting public transport is the integration of different transport systems in urban areas. The case study of the railway line Wieliczka—Krakow Airport operating within Krakow agglomeration area can be presented as an example of good practice for integration of rail with other transport systems. The article presents the solutions in the field of infrastructural, organizational, financial and economic together with informational integration. It also presents the dynamics of the passenger flow volume as an effect of transport systems integration.

Keywords Agglomeration railway · Krakow · Transport system integration

1 Introduction

The scope of the approach for transport integration is worldwide very broad. The integration is understood and used as one of the main tool for improving the operation of public transport in urban areas. The definitions of the integration from transport system point of view were presented in many publications [e.g. 1–8]. One of the most popular is the definition of [3]:

> The organization process through which elements of the passenger transport system (network and infrastructure, tariffs and ticketing, information and marketing etc.) are, across modes and operators, brought into closer and more efficient interaction, resulting in an overall positive enhancement to the overall state and quality of the services linked to the individual travel components.

A. Ciaston-Ciulkin (✉) · S. Pulawska-Obiedowska
Faculty of Civil Engineering, Cracow University of Technology, Krakow, Poland
e-mail: aciaston-ciulkin@pk.edu.pl

S. Pulawska-Obiedowska
e-mail: spulawska@pk.edu.pl

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In the literature one can identify different approaches to the classification of the urban public transport integration. Many different solutions supported the integration of urban public transport systems are presented in the literature (e.g. [9–15]). These solutions are focused mainly on: facilitating interchanges for passengers, design services provided by different transport modes with coordinated timetables, a common tariff and a multimodal passenger information. All the solution for the urban public transport integration are leading to improve the quality of public transport.

Based on a review of literature (e.g. [4, 16, 17]) one may indicate the scope of the public transport integration in five crucial areas: infrastructural, informational, organizational, economic/financial and spatial.

Infrastructural integration refers to all elements of the transport network, in particular elements such as location of stops, stations, convenient interchanges for the passenger taking into account the changes between transport modes. Organizational integration refers to all levels of the transport services that support the movement within the agglomeration. The integrated organization of transport services should ensure the continuity of travelling as soon as possible. The most popular tool for organizational integration is the timetables coordination for minimizing the time losses related to change of transport mode. Economic/financial integration refers to the solutions providing the best conditions for economic and financial multimodal journey (regardless of used vehicle). The most popular tools for economic—financial integration is fare integration (common tariff for different operators and different modes). Informational integration refers to the common solutions allowing undisturbed movement within entire the transport network, regardless of the vehicle and transport mode of transport. Spatial integration refers to urban planning linked to the existing transport network and allows to improve the accessibility.

In the further part of the paper different solution for the integration in the first four areas on the basis of the rail link Wieliczka—Krakow Airport are presented.

2 The Railway Line Wieliczka Marketsquere Salt Mine —Krakow Airport

The railway connection Wieliczka Marketsqure Salt Mine—Krakow Airport has been operating since September 2015, however it had been existing also earlier—as two independent lines:

- to Wieliczka from Krakow Central Station,
- to Krakow Airport from Krakow Central Station.

The passenger traffic on the first line was carrying out already in the second half of the nineteenth century, what had affected the dynamic development of the Wieliczka. The electrification of the rail line conducted in 1960 improved the offer and a significant increase of passengers number. The connection was used by approximately 15,000 people per day, and from 4.5 to 5 million per year. This trend started to turn around dramatically from the moment of social, economic and political changes that occurred since 1989 in the country [18]. In addition, because of slumping mining the final stop in Wieliczka has been closed, what resulted in a further decline in the railway offer and a decrease in the amount of users. The modernization of railway truck in 2012 did not produce a significant increase in the competitiveness of the connection—the rail was used by an average of 1.5 thousand passengers per working day. A significant change in the volume of passengers was recorded only in 2015, when the attractive (in relation to other transport modes) offer of rail service has been provided. The attractiveness of this offer is not only due to the high frequency, regularity, punctuality, or the attractive ticket prices and travel comfort, but also to the integration of rail with other transport modes.

The history of second line is very short. First service on the line Krakow Central Station—Krakow Airport was conducted in May 2006. The connection was based on the existing non-electrified, single-track siding. The line had only one station—Krakow Balice. The station was situated far from the airport terminal, so the additional free shuttle bus service was required.

Despite the short travel time (18 min), the railway connection, had been not played such a big role in commuting to the airport as was expected. Frequently happened delays, unreliability of rolling stock, the high price (19 PLN) had resulted only in 1.3 thousand passengers per day [19]. The growing role of Krakow Balice Airport together with EU guidelines [20] for increasing airports accessibility caused the decision of a significant modernization of the line (02.2014–09.2015). At that time, the line has been fully electrified, new stops has been developed, the frequency of service has been increased and, what is the most important, the end station has been located directly in the building integrated with the airport terminal.

Since the end of September 2015 the two mentioned above lines has been combined into one connection. A total route length is 25 km and includes 13 stops. The main generators of traffic are final stops (Krakow Airport and the Wieliczka Marketsquere Salt Mine and Wieliczka Park) together with Krakow Central Station (which is also the largest public transport hub in the city). The total travel time takes 45 min, from Krakow Central Station to the Airport—18 and 22 min to Wieliczka. The remaining five minutes difference is a stop of the train at the Krakow Central Station.

The current offer includes 39 courses on the section Krakow Central Station—Krakow Airport, and 35 courses on the section Krakow Central Station—Wieliczka Marketsquere Salt Mine. The service is characterized by regularity and high frequency of running—the trains run at regular 30 min intervals.

In the case of the first section of the line, the passengers are mainly commuting from Wieliczka to Krakow (daily journeys related to jobs or school). The line has also big importance related to the touristic character of Wieliczka (Wieliczka Salt Mine is listed on UNESCO World Heritage). However, one may easily indicated the pick of flows related to the commuting to Krakow in the morning and to Wieliczka in the afternoon. In a different manner is formed the flow on the second section of the line—there is no clearly-marked traffic peak on the section From Krakow Central Station to the Airport. In this case, the passenger flows are generated mainly by airport users and employees. Large flows are therefore correlated with the arrivals and departures of aircraft.

The attractive offer of rail service resulted in the dynamic growth of passenger volume relatively quickly. Number of passengers on the section Krakow Central Station—Wieliczka Marketsquere Salt Mine has increased in a one year (XI. 2014–XI. 2015) 2.5 times [21], while on the section Krakow Central Station—Krakow Airport two months after the opening of the new line, the number of passengers was almost twice higher than in 2008. The improvement of the railway service offer was related to the regularity and the frequency (frequency has increased by approx. 140 % on the section Krakow—Wieliczka and approx. 20 % on the section Krakow-Airport), reduced fees (the price for a single ticket approx. 25 % lower on the section Krakow—Wieliczka and more than half lower on the section Krakow-Airport), better comfort of travelling (low-floor, air-conditioned fleet equipped with dynamic information, monitoring, wi-fi, a toilet and a lift for disabled users).

3 The Solutions for Integration of the Line with Other Transport System

The popularity of the railway line is resulted also by its significant integration at various levels. Infrastructural, organizational, economic and financial, informational integration has been applied, what has improved the transport accessibility level.

3.1 Infrastructural Integration

A wide range of solutions for infrastructural integration between different transport modes has been developed. Most train stops on the route are integrated with other transport modes. In particular, one may easily continue the journey by other transport modes at the final stops (Wieliczka Marketsquere Salt Mine and Wieliczka Park and Krakow Central Station). The train stop and stations, where have been applied solutions for infrastructural integration, are presented in the Table 1.

Most solutions for infrastructural integration is located at Krakow Central Station—the biggest passenger transport hub on an international, national, regional and local scale in the region. In the area of the Krakow Central Station different infrastructural elements for integration are functioning:

- the railway station, where approx. 330 international, interregional, regional and agglomeration trains are operating every day,
- the main bus station, where approx. 1.8 thousand of international, interregional, regional buses and coaches are operating every day,

Table 1 Elements of infrastructural integration of transport modes on the Wieliczka—Krakow Airport line

Name of the stop/station	Integrated transport system	Parking for cars	Parking for bikes	The extent of the integration
Krakow Airport	Air connections, urban buses	Commercial	–	International, National, Regional, Local
Krakow Mlynowka	Urban buses	–	–	Local
Krakow Lobzow	Urban buses, bike system	Municipal	Bicycle racks, station for urban bikes	Local
Krakow Central Station	Urban buses/trams, bike system, long-distance trains/buses, private operators (regional buses)	Commercial, Kiss&Ride	Bicycle racks, station for urban bikes	International, National, Regional, Local
Krakow Plaszow	Urban buses/trams	Planned	Bicycle racks	National, Regional, Local
Krakow Biezanow Drozdzownia	Urban buses	Unformal	–	Local
Wieliczka Bogucice	–	Unformal	–	Local
Wieliczka Park	Bike system, private operators (regional buses)	Park&Ride	Bicycle racks	Regional, Local
Wieliczka Marketsquere—Salt Mine	Bike system, agglomerational buses dedicated for local inhabitants using the rail line	Commercial	Bicycle racks	Regional, Local

- three tram stops, where 13 day lines and four night lines are operating,
- three bus stops, where 10 urban day lines, 8 night lines, 6 agglomeration day bus lines and 2 night lines,
- two final stops of private operators (regional transport buses), where nearly 2.6 thousand courses are operating,
- Commercial parking for private cars,
- kiss & Ride—4 stands,
- two parking spaces for bicycles,
- the station for KMK bikes (urban bike system) equipped with 16 stands for bikes,
- taxi stop,
- pedestrian areas, walkways, escalators and moving ramps, elevators.

Wide infrastructural integration in the main passenger transport hub allows to interchange in an easy and convenient, and above all quick way.

Well integrated is also the station Krakow Airport. The main users motivation to make a journey to Krakow Airport station is a job at the airport or further journey by aircraft. Accordingly, the location of the station at the airport terminal is suitable. Trains are departing from the covered platform, that is directly connected to the terminal through the moving ramp and the internal corridor. This solution allows to move to the correct part of the airport even for passengers having a large luggage.

Good possibility for the convenient multimodal interchange has been provided at two final stops in Wieliczka. The rail stop Wieliczka Park has been dedicated to the trips linked to individual transport by car or bicycle. The stop is located quite far from big traffic generators so directly near, the large Park&Ride parking has been created.

Park&Ride is consist of 264 parking spaces for passenger cars (186 spaces on the parking just at the station and 78 spaces on the parking located on the other side the street). Additionally, at the area of Park&Ride 13 spaces for buses and bicycle racks for 112 bikes has been developed. The degree of parking space usage is very high—during working days the parking is completely full before 8 a.m.

Completely different solution of the infrastructural integration has been implemented at the second final stop in Wieliczka (Marketsquere Salt Mine). At the station one may use a commercial parking or stop of agglomeration lines together with a special space just at the platform for the stop for two regular bus lines (line R1 and B1). These lines are dedicated for inhabitants of municipalities around Wieliczka, who want to use train line do Krakow.

The infrastructural integration of other stops is mainly based on ensuring convenient transfers to other public transport systems (buses, trams). A good example of such kind of solution is the railway station Krakow Plaszow. Good access to public transport become possible thanks to thanks to the new tram flyover running just above the station. One may use one of the very frequent tram line, using one exit from the platform directly to the tram stop. Improving the integration of the Krakow Plaszow station to other public transport resulted in significantly increase of the rail passenger number. Before opening the tram flyover, the average number of passengers using the analyzed line and getting on and off at the Krakow Plaszow station was approx. 420 people/day [21]. As a result of the integration, exchange of passengers at the Krakow Plaszow station has been increased by more than 75 % (750 passengers a day) [21].

Another important station is Krakow Lobzow. Travellers have access to public parking, bike racks, station for urban bikes (with stands for 16 bicycles) and bus lines operating also to large tram terminus. The arrangement of other non-integrated stops are mainly dedicated the users from the immediate surroundings. However, passenger behavior indicates that also people living outside of walking distance area of the train stop are interested in the line. In the area of the Wieliczka Bogucice and Krakow Biezanow stops the informal car parks started to appear. The dynamics of changes in the number of train stop users are shown in Table 2.

Table 2 Usage of railway stop/station on the route Krakow Airport—Wieliczka Marketsquere Salt Mine (thousands of passenger per year)

Name of the stop/station	Year of the research		Dynamics of change (%)
	2008 (Krakow-Airport) 2014 (Krakow-Wieliczka)	2015	
Krakow Airport	490.26	691.05	141
Krakow Olszanica	–	35.87	–
Krakow Zakliki	–	88.51	–
Krakow Mlynowka	–	67.40	–
Krakow Lobzow	9.17	168.48	1838
Krakow Central Station	487.40	679.19	139
Krakow Central Station	227.90	1079.06	473
Krakow Zablocie	57.00	–	–
Krakow Plaszow	92.03	222.45	242
Krakow Prokocim	42.31	103.71	245
Krakow Biezanow	49.52	152.63	308
Krakow Biezanow Drozdzownia	46.19	159.00	344
Wieliczka Bogucice	8.50	43.09	507
Wieliczka Park	63.87	304.24	476
Wieliczka Marketsquere—Salt Mine	127.82	619.03	484

The traffic studies conducted before and after improvement of service offer show that better quality of transport service has influenced significantly the increase in the number of users. Therefore, the elements of infrastructural integration of train stops with other modes have played also the important role in the success of the line. The largest increase in passenger volume has appeared on stops and stations well integrated with other transport modes, particularly in Wieliczka and on Krakow Central Station.

3.2 *Organizational Integration*

The organizational aspects of the integration should be understood in particular as the coordination of schedules. In this area, many actions has been taken to encourage multimodal travelling minimizing the time losses resulting from transfers. In relation to analyzed rail line, the coordination of timetables is ensured for the transport on local, regional or long-distance level. Starting with the latter, a train schedule was built to handle the passengers of all flights. Hence, the first course of the train to the airport is carried out from the central station at 4 a.m. (before the first flight departures at 6 a.m.) and the last course from the airport is carried out after midnight to handle the passengers landing after 11 p.m. In addition, the timetable of trains to airport is also coordinated with the working hours of port employees.

The train schedule is also coordinated with timetable of two special bus lines R1 and B1 (see in Sect. 3.1) operating from Wieliczka Marketsqere Salt Mine station. The integration of train schedules with other transport modes one may also indicated for the Krakow Central Station and Krakow Plaszow. In these two cases, the good integration with other public transport infrastructure together with high frequency of buses and trams results in a very short waiting time for another vehicle.

3.3 Economic-Financial Integration

In terms of economic and financial integration the most common solution is fare integration. In relation to analyzed rail line, the fare offer by Malopolska Railways has been integrated with:

- individual transport,
- public transport in Krakow and Tarnow,
- special bus lines.

In addition to the basic types of normal and reduced-price tickets one may find a ticket integrated with individual car transport. Such kind of ticket allows to leave the car in the Park & Ride in Wieliczka. Both season and single tickets can be bought with the additional possibility of leaving the car on P&R. Prices of ticket integrated with parking Park & Ride are at present the same as the prices of non-integrated ticket.

Special lines R1 and B1 operating in the area of Raciborsko and Byszyce municipalities (in the neighborhood of Wieliczka) are also integrated with the analyzed rail line in terms of fares. The offer includes both season and single tickets. In the buses of line R1 and B1 one may buy a two-hour ticket for the section Byszyce/Raciborsko—Wieliczka Bogucice or six-hour ticket for the section Byszyce/Raciborsko—Krakow Central Station. Special season ticket called "Personal monthly Wieliczka Ticket" can be purchased in trains and it entitle to travelling on the route Byszyce/Raciborsko—Olszanica Krakow.

Integrated rail/urban transport fare enable also to travel by train and bus or tram supported by Municipality of Krakow. In the case of single tickets the number of transfers between the vehicles is not specified, however the duration of the ticket is set (70 min). The usage of integrated fare allows to the passengers saving from 0.40 to 1.40 PLN (depending on ticket that is replaced). In the offer of integrated season tickets one may find tickets entitling to unlimited number of journeys during all weekdays on one/two routes or whole network indicated by user. Integrated tickets are approx. 10 % cheaper than tickets bought separately.

Additionally, since December 2015 the so-called Malopolska Agglomeration Card (MKA) has been implemented. The holders of this special card have access to the services of Malopolska Railways, of other operator of rail regional transport and of public transport in Krakow and Tarnow. Furthermore, KMA card users have access to a service of urban bike rental system and Park & Ride parking located on routes of Agglomeration Railway. The offer is also available in a mobile version—for all integrated services one may pay through the mobile application.

3.4 Informational Integration

Passenger information is one of the most important elements of the entire transport system. Information plays an important role not only during the journey, but also at the stage of planning. Additional importance should be granted in the context of integrated information for many transport systems. Users of different railway service have access to a railway connection browser. When planning the multimodal journey passengers have access to a free web portal www.e-podroznik.pl. The portal enables to plan journeys through the Internet taking into account the time of interchange to different modes of transport.

In relation to the information during the journey, one may indicate the monitors inside the train that display the information on arrivals and departure of train from the central station. However, there is a lack of the solutions providing information about other transport systems. In particular, there is no information at getting to a Park & Ride about the free parking spaces or hours of departure of the train. Such kind of information could be delivered through variable message signs. Another desirable solution for multimodal journeys could be voice information in trains indicating the possibilities for interchange.

4 Conclusions

The growing number of trips made within urban areas is facing problems related to the ability to ensure the mobility for inhabitants. Growing traffic congestion affects the extension of travel time and increased travel costs. One of the important solutions that can reduce transport problems is the integration of different modes of public transport with car. The integration of different systems requires interchanges. The duration of the interchange should be as short as possible. Therefore, the effectiveness of transport systems integration depends on a number of infrastructural, organizational, financial and information solutions.

As shown in the example of Wieliczka—Krakow Airport railway line, the implementation of many solutions simultaneously brings good results, meaning the increasing share of multi-modal journeys. Multimodal trips made by car and train has a great share in total number of trips. Nearly 7 % of this type of trips are possible thanks to large Park & Ride parking at one of the railway station. Observing huge interest in Park&Ride parking together with creating of informal car parks near stations proves the high demand for this solution. An interesting and popular option are also special bus lines, dedicated for the inhabitants of rural parts of the agglomeration and provided with timetable integration and fare-integrated offer. The high interest among passengers in such a solution results in plans to expand the offer for another municipalities.

The presented example is not a prime example of integration with other transport systems. There are many other solutions encouraging to the multimodal travelling. Many of them could be also implemented into the analyzed line, in particular the solution for informational integration. In this field still many gaps may be indicated in the stage of the trip planning as well as during travelling.

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Bimodal Technology Based Concept of Road and Rail Cargo Transport

Leszek Mindur

Abstract The article provides an analysis of the essence of bimodal transport which may be brought down to using special semi-trailers, meeting requirements defined for road semi-trailers as well as railway cars, transported to terminals where they are combined with rail tractors and formed into a train. It also addresses the concept of a bimodal train, which consists in substituting certain subunits of a traditional train with elements of road vehicles, and explains what elements they are. Three groups of design solutions for the bimodal train set assembly have been discussed, these being distinguished by the manner in which semi-trailers are supported on bogies and how they are coupled. They include a system featuring dedicated adapters enabling a semi-trailer to rest on the bogie, a semi-trailer type coupling system and a system ensuring the semi-trailer support on the bogie by means of two independent torsion beams. Names of some of the bimodal transport systems used by individual European railway transport authorities have been collated along with distinctive technical and operating features of the bimodal road and rail transport systems compared. The article has been recapitulated with an analysis of advantages and disadvantages of the combined road and rail cargo transport based on the bimodal technology.

Keywords Bimodal transport · Technical means · Bimodal transport systems · Advantages and disadvantages of combined road and rail transport

1 Introduction

The article comments upon technical and operating problems as well as economic advantages of bimodal transport. It also addresses flaws of this transportation technology.

L. Mindur (✉)
International School of Logistic and Transport in Wroclaw, Wroclaw, Poland
e-mail: lmindur@vp.pl

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Achievements in civil engineering had contributed to the development of a new technique of combined road and rail transport, also referred to as bimodal transport.

The very essence of bimodal transport can be brought down to using special semi-trailers, meeting requirements defined for road semi-trailers as well as railway cars, transported with tractors to terminals where they are combined with rail tractors and assembled into a train.

The concept of a bimodal train consists in substituting certain subunits of a traditional train with elements of road vehicles, namely dedicated semi-trailers of special design, the load bearing capacity of which enables them to perform the function of rail car bodies once they are mounted on rail bogies equipped with special coupling pieces, referred to as adapters.

2 Bimodal Transport Concept

A bimodal train consists of specific repeating elements, namely [1]:

- an automotive semi-trailer (closed cargo van or tank),
- an adapter, i.e. a device providing indirect support for two semi-trailers on a single rail car bogie or coupling the set with the locomotive or the freight train,
- a two-axle car bogie equipped with a complete set of braking devices (Fig. 1).

Notwithstanding the fact that such a train set comprises all structural elements of automotive semi-trailers, it must also meet all the relevant technical requirements imposed on standard freight trains, i.e. the strength conditions specified in the UIC597 card.

Consequently, mass-produced automotive semi-trailers require being redesigned. First of all, their load-bearing structure must be strengthened so that it ensures sufficient transfer of static compressive and tensile force reaching 850 kN. However, it should not cause excessive increase in the semi-trailer kerb weight in

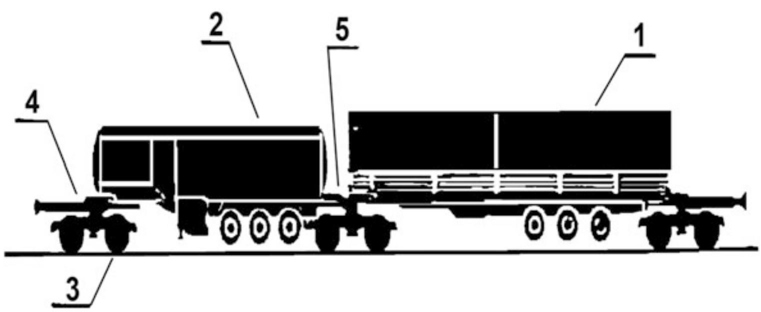

Fig. 1 Components of a bimodal train set section: *1* box-type road-rail semi-trailer, *2* tank-type road-rail semi-trailer, *3* standard rail car bogie, *4* terminal adapter with train buffer stops, *5* middle adapter (*Source* Own research)

order to prevent tare weight increase and excessive axle load. At the same time, all protruding elements of the semi-trailer as well as its general dimensions must fit into a kinematic gauge as per UIC. The foregoing requires numerous efforts, including bending the corners of the upper semi-trailer profile or reducing its height as well as lifting the semi-trailer road wheels for the time of transport by rail using pneumatic lifting devices. An automotive semi-trailer intended for operation in the bimodal transport system must have the main air tank and the brake hose mounted in such a manner that they are not exposed to damage, and each conduit must feature a hose coupling enabling tight connection between the main hose and the pneumatic system of rail car bogies. On account of the fact that the distance between the semi-trailers transported on rail bogies must not be larger than 450 mm, there is a necessity for furnishing the semi-trailer with a rear upward deflecting bumper featuring sufficient safeguards for the time of transport on rail bogies, so that the permissible distance between semi-trailers is not exceeded.

The aforementioned UIC597 card also comprises a selection of technical requirements pertaining to loads of rail bogies, adapters, elements of the coupling and adjusting mechanism, explicitly specifying the intended technical and operating parameters.

The above structure of subunits forming a bimodal train set implies that the means of rail transport have been reduced to standard two-axle bogies equipped with the aforementioned adapters and a complete braking system. The same applies to means of road transport, since this system only entails semi-trailers of a closed cargo van or tank type featuring their own load-bearing structures as well as typical tractor units.

What stems from the fact that semi-trailers are equipped with their own lift mechanisms is that assembling and disassembling a bimodal train is possible without having to use any specialised machinery and loading gear, since all the related activities can be performed by means of the aforementioned driver-operated lifts. The only prerequisite is a hardened yard with tracks laid and embedded in the ground in such a manner that rail heads are horizontally level with the yard surface, thus enabling unconstrained handling of the road set while the bimodal train is being assembled or disassembled. The foregoing requirements also arise from the possibility of using a tractor unit whenever rail car bogies must be moved within the terminal in the course of the bimodal train marshalling.

3 Bimodal Train Assembling Technology

The main premise for using bimodal transport is its economic and social efficiency as well as simplicity of the transport process. For these reasons, uncomplicated devices are designed for coupling of a road-rail semi-trailer with a rail car bogie, ensuring that the bimodal train set can be assembled by one person. However, it requires such engineering of auxiliary systems that, while the semi-trailer is being mounted on rail car bogies, one does not waste any time making sure that the "aiming" operation is accurate.

In terms of how semi-trailers are supported on bogies and coupled together, one may speak of three groups of design solutions.

The first one comprises systems featuring adapters for supporting the semi-trailer on the bogie, thus enabling all adjusting (mobile) devices to be placed on the bogie, which increases the train operating safety.

The second group includes a system for what is referred to as semi-trailer coupling, which consists in the semi-trailer rear section resting directly on a spherical bogie kingpin and side shoes, or on a special cross-beam supported on the bogie frame by means of the kingpin and the side shoes. The semi-trailer front, on the other hand, is directly connected with the rear section of the neighbouring semi-trailer by means of an articulated joint transferring vertical loads as well as longitudinal and transverse forces to the rear section of the adjacent semi-trailer and the rail car bogie. A disadvantage of such a system is the necessity of using two types of bogies (intermediate and terminal), and installing the coupling pieces in semi-trailer chassis.

The third group of design solutions comprises a system featuring semi-trailers supported on rail car bogies via two independent torsion beams mounted on the bogie by means of kingpins and side shoes. This system also requires using two types of rail car bogies, and furthermore, it does not ensure uniform distribution of load from wheel sets on the track.

The above characteristics imply that the most efficient design solution is the system featuring adapters used for supporting semi-trailers on bogies. The bimodal train assembly operations based on that system have been illustrated in Fig. 2.

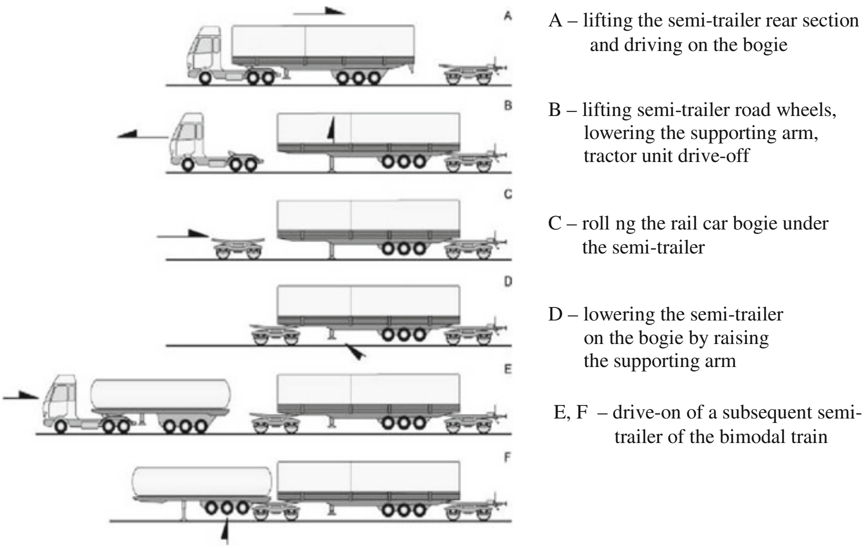

Fig. 2 Stages of the bimodal train set assembly and related operations (*Source* [2])

The bimodal train disassembly proceeds in a reverse sequence, however, the train can be uncoupled at any chosen location in order to disconnect the intended number of semi-trailers from the train set.

4 Basic Bimodal Transport Systems

The country with the most extensive experience in application of the bimodal system is the United States, this to be owed to more advantageous operating conditions compared to Europe. It is also there that the concept of combined road and rail transport system was born, with bimodal transport being just one of its variations (The Roadrailer system trains, representing the semi-trailer coupling type group of design solutions, have been used with much success for many years in USA).

It was for the advantages of the bimodal system that, at the end of 1980s, several design variants of the bimodal system were developed and introduced into trial operation in Western Europe. The names of some of the bimodal transport systems used by individual European railway transport operators have been provided in Table 1.

Each of the systems included in the table was based on a semi-trailer for road and rail applications, the differences primarily to be found in the structure of coupling pieces.

The systems of Kombitrailer, CODA-E, Kombirail and Semirail belong to the group of design solutions based on the adapter coupling, the Transtrailer and Roadrailer systems represent the semi-trailer coupling group, whereas the Railtrailer systems comprise the group of design solutions featuring two torsion beams (SMK).

The technical and operating properties of the aforementioned bimodal road and rail transport systems have been collated in Table 2.

Table 1 European bimodal transport systems (*Source* [3–6])

System name	Country or manufacturer	Railway authorities conducting trial system operation
Kombitrailer	RFN TALBOT ACKERMANN-FRUEHAUF	DB, NSB, SBB
Coda-E	THE NETHERLANDS STORK ALPHA ENG AAB HENSCHEL—Wagon Union	NS, SJ
Semirail	FRANCE REMAFER FRUEHAUF FRANCE	SNCF
Transtrailer	SPAIN	RENFE
Roadrailer	FRG	DB
Kombirail	FRG—FRANCE, TALBOT, FRUEHAUF	Presented for the first time at the 1992 exhibition in the Hague
Railtrailer	FRANCE, SAMBRE ET MEUSE, KAISER	No data available

Table 2 Comparison of bimodal transport systems (*Source* [7–9])

Feature	Adapter coupling systems		Semi-trailer systems		SMK system
	Kombirail	Coda-E	Roadrailer	Transtraile	Railtrailer
Body supported on bogies	Four-point type	Three-point type	Three-point type	Three-point type	Four-point type (rail car type)
Axial play in coupling pieces	Existent	None	Existent	None	No data available
Vertical load of intermediate bogie	Central	Central	Central	Central	Non-central
Wheel load—bogie (intermediate terminal)	Identical identical	Identical identical	Identical identical	Identical non-identical	Non-identical non-identical
Terminal bogies	Identical	Identical	Different (DB)/identical (SBB)	Different	Identical
Option of the intermediate bogie loading from both sides	Yes, but after adapter rotation	No	Yes	Yes	Yes
Horizontal loading with semi-trailer height adjustment	–	Horizontal + vertical	Horizontal + vertical	Horizontal + vertical	Horizontal + vertical
Semi-trailer suspension required	Pneumatic with height adjustment; road wheels lifted and interlocked	Pneumatic with height adjustment; road wheels lifted and interlocked	Pneumatic with height adjustment; road wheels lifted and interlocked	Pneumatic with height adjustment; road wheels lifted and interlocked	Pneumatic with height adjustment; road wheels lifted and interlocked
Interlocking pieces mounted on	Adapter	Adapter	Semi-trailer	Semi-trailer and bogie	Bogie

According to experts, the most advantageous design solutions are those which feature the adapter couplings, whereas the least favourable ones are the SMK systems based on the beam-type coupling piece.

5 Conclusions

Besides the typical advantages offered by road and rail transport, such as reduction of energy consumption of transport, environmental hazards, shipment time owing to elimination of holiday downtimes as well as customs clearance waiting time, bimodal transport ensures increased economic efficiency, mainly for the increase in the ratio of load capacity to the train weight compared with other forms of combined road and rail transport by more than 1/3. An additional advantage of bimodal transport may be found in the fact that it can be brought down to a small number of items (transport units) and means of transport, and that it does not require reloading equipment to be installed at terminals. At the same time, the system in question does not require any additional reloading personnel to be employed, since all the activities related to the bimodal train set assembly and disassembly can be performed by the road set driver using the vehicle's on-board lifting mechanism.

Advantages of bimodal transport have been compared with features of other combined road and rail transport systems in Table 3.

Table 3 European bimodal transport systems (*Source* Own research)

Conventional road and rail transport systems	Bimodal transport prospects
Load capacity to train weight ratio in percent	
Semi-trailers in pocket rail cars 50 % Swap bodies and containers 51 % Road load carrying sets 45 %	Road-rail semi-trailer 68 %
Transport units	
Containers for marine applications Containers for land applications Swap bodies Automotive semi-trailers Road sets	Road-rail semi-trailer: closed cargo vans tanks
Means of transport	
Road vehicles for transport of: containers and swap bodies automotive semi-trailers Rail cars for transport of containers, swap bodies, semi-trailers and road sets: container platforms pocket rail cars "Wippenwagen"	Tractor units, standard rail car bogies with adapters

(continued)

Table 3 (continued)

Conventional road and rail transport systems	Bimodal transport prospects
"Rolling Highway"	
Terminal unloading equipment	
Rail travelling cranes Outrigger vehicles "Reach-stackers" Hoisting vehicles "Lift-Trucks"	Redundant

There are also some disadvantages to bimodal transport, namely the bimodal train sets being too short and the speed possible to achieve when using standard rail car bogies—too low.

Based on the information provided in the materials of the 2nd All-Poland Conference on "Technical Means of Road and Rail (Bimodal) Transport" [10], there are sets composed of two, three or exceptionally even five semi-trailers in trial service conducted by certain railway operators, however, the studies and calculations conducted to date imply that standard rail car bogies enable a bimodal train to run at a speed not exceeding 100 km/h. Nevertheless, the foregoing are not obstacles which could veil the benefits stemming from application of the bimodal technique. The energy related savings achieved using the bimodal system are sufficiently high that locomotive transport of a set comprising merely one semi-trailer with the weight of 38 t is already profitable. It has also been proved that through minor structural modifications, namely application of a system for binding wheel sets in the horizontal plane outside the bogie frame, it is possible to increase the running speed significantly. Concluding, evolution of the bimodal technique is inevitable, particularly in terms of long-distance freight transport.

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Cost and Implementation Cycle of Concrete Runways

Andrzej Więckowski and Alicja Sznurawa

Abstract The aim is to evaluate the time and cost efficiency of constructing concrete runways and find optimal solutions. The analysis was carried out for a design of a 3600 m runway with set location considerations (Katowice-Pyrzowice airport). Reinforced and post-tensioned concrete runways have been compared. National standards were applied while calculating the costs. All cost estimates were obtained from local suppliers/contractors. Time schedules were prepared for the runways using network analysis. They were based on seven days a week, twenty-four hours a day work. It was assumed that work units were optimised. The following results have been obtained: cost calculation for post-tensioned runway was about 6.4 million € lower than for reinforced runway, which is 18 % of the total cost. Duration of construction of post-tensioned runway was estimated to require 10 months whereas reinforced takes with an 8 % more time.

Keywords Dowelled runway · Prestressed concrete · Technology and organization of construction

1 Introduction

At present, in the conditions of accelerated development of air transport, at most Polish airports, new runways are being built, and the existing ones are extended. The need for accepting and dispatching often intercontinental aircraft with wing span up to 65 m with heavy weights on touchdown, reaching over 400 tonnes (Boeing 747-400 or Airbus A340 [1]) causes a demand for reinforced runways [2, 3]. As a result, the volumes of concrete and steel built into runways are currently

A. Więckowski (✉)
AGH University of Science and Technology, Krakow, Poland
e-mail: awiecko@agh.edu.pl

A. Sznurawa
Faculty of Civil Engineering, Cracow University of Technology, Krakow, Poland
e-mail: alisznurawa@gmail.com

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very large [3, 4]. Reduced consumption of such materials, according to the calculations in [3–9], allows for application of improved concrete and abrasive prestressed slab pavements, which are much thinner than dowelled concrete slabs.

Two variants of such a runway have been analysed: in prestressed technology—variant I, and in dowelled technology—variant II. After the analysis of the occurring technological-organisational conditions at the construction site, and according to the even work method, work cycles have been determined [3–11], and on the basis of the developed investor's cost estimates the effectiveness of the analysed technical solutions has been assessed due to labour R, materials M, use of equipment S, as well as costs.

In the context of actual construction of the runway at the Katowice-Pyrzowice airport, the technology of prestressed abrasive pavement has been analysed, pointing to executive solutions, with the necessary specialist equipment for execution of core concrete works. For both variants of runway construction, the variability of outlays and costs has been analysed, and work cycle has been assessed.

2 Elements of Technology and Work Organisation

The intensity of traffic of various lorries (with total weight up to 40 tonnes) is very high during the construction, and on average amounts to 2.26 lorries per minute. Hence, on both sides of the runway constructed, temporary roads have been designed with the width of 6 m each, with extensions for pump stabilisation for the time of mix pumping. After removal of the vegetable earth layer, on the compressed sand mix levelled with cross-fall of 1 % and thickness of 10 cm, roads and extensions were made of reinforced-concrete slabs with dimensions of 300 cm × 300 cm × 15 cm.

On the basis of efficiency analyses, feeding of concrete mix has been planned with four mobile pumps. The pumps are located symmetrically against the centre of horizontal projection of the element built, Fig. 1. First, the pumps are set on workstations. Each two pumps begin mix pumping, starting from the edges of opposite sides. Two pumps opposite one another, on both sides of the slab, lay concrete mix within the same belt, from edges to the centre, coming closer to one another until they meet. After the first belt is completed (on the entire width of the slab), they commence and execute the following belts, from the edges of the slab (adjusting the width of the belts to the efficiency of the concrete pumping team [7, 8]). Therefore, the works approximate one another from opposite sides until they meet.

Therefore, in order to achieve monolithic connection, time t_w^k—completion of building in any portion of the mix k must meet condition [8]:

$$t_w^k \le \min\left(t_{pw}^k, t_{pw}^{k+1}\right), \quad k = 1, 2, \ldots, n-1, \tag{1}$$

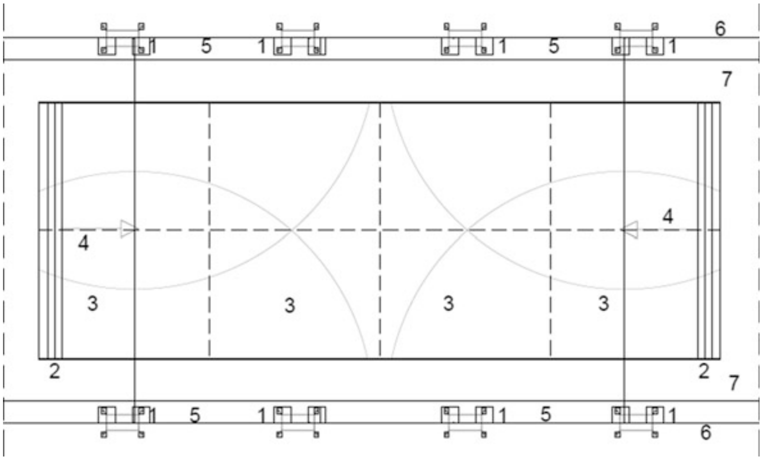

Fig. 1 Concrete mixture pumping plan: *1* concrete pump, *2* vibrating screed, *3* concrete pump radius, *4* direction of works, *5* stopping area, *6* temporary road, *7* lean concrete course (*Source* Own study)

where:

t_w^k, t_w^{k+1} times of commencement of cement setting, respectively, in portion k laid earlier, and in added portion $k + 1$.

While calling the mix working period τ_u^k—the time period calculated from moment t_0^k—cement working with water in the prepared portion k, until completion of all activities related to building in this portion of the mix as above until moment t_w^k, the following can be written:

$$\tau_u^k = t_w^k - t_0^k, \quad k = 1, 2, \ldots, n. \tag{2}$$

In contractor works, the working period τ_u^k refers to the entire portion k, formed by the supplied mix, e.g. in one concrete mixing vehicle. Therefore, the period is calculated from the moment of cement sprinkling with water in the first working mix prepared (upon mixing the first feed from the concrete mixing vehicle), and τ_u^k—comprises: period of mixing and loading of all mixes transported together, in one concrete mixing vehicle, next the transport duration, later total period of feeding and execution of all activities upon mix building-in, until natural completion, including the periods of awaiting and stoppages occurring in each of the aforementioned storage periods.

The application of pumps with horizontal reach of 36 m. The pumps are stabilised on supports placed on extensions of temporary roads, made of concrete slabs. The mix is compressed with poker vibrators, levelled and panned with a vibrating screed, with a platform for the staff, with modular length. The screed features a combustion engine that drives the shaft with deadweights placed off-centre. The screed is made of modular truss with triangular cross-section with dimensions of 100 cm × 200 cm, with total length of 46 m. It serves for finishing, compression, levelling and smoothing the surface of the concrete mix pavement. From the platform of vibrating screed, initial compression of the mix is performed using poker vibrators. The screed moves on the rails placed along the longer edges of the slab.

Initial prestressing begins after concrete has achieved compressive strength equal to 12 MPa in sample cubes or 10 MPa in sample cylinders (according to EN-206/2000). In practice, initial prestressing takes place after 24 h from completion of concrete pumping. First, tendons are compressed lengthwise, and then crosswise. Final prestressing is performed after concrete has achieved compressive strength equal to 24 MPa in sample cubes or 20 MPa in sample cylinders. After the end of tensioning, anchorages must be secured, dowels installed, and then jacking gaps must be reinforced and filled with concrete. Runway pavement is finished on the surface by grooving, with the application of cutters with diamond blades.

3 Construction Cycles of Structural Variants

When planning the organisation of teams executing particular works, in the context of methods and technological order of works, 8-h shifts have been planned with five days working week, from Monday to Friday inclusive, for all brigades except for prestressing teams. Such teams perform prestressing usually one to eight days after concrete pouring. Hence they have to work on Saturdays, and sometimes also on Sundays. No additional limitations have been considered, as may be imposed by the airport.

The volume of works is very large. Hence, the brigades usually have double numbers of the same types of the equipment. Similarly, when pouring concrete for prestressed slabs, in order to lay 1.350 m^3 of the mix during an 8-h working shift, as many as two vehicle-mounted conveyor belts or two pumps must operate simultaneously, feeding concrete mix supplied by 21 truck concrete mixers from concrete-mixing plant for the purposes of the site, and possibly from two standby concrete-mixing plants.

The works have been planned according to the uniform work method. Five operating plots have been applied, with section lengths of 600 m (each plot covers the area of 5 prestressed slabs with jacking gaps). In the plans for executing the whole investment, a uniform, three-week rhythm of work has been adopted (with five business days per week). The task execution cycle can be calculated according to the relation [10, 11]:

$$t^D = r(m + n - 1) \tag{3}$$

where:

r rhythm duration, $r = 3$ weeks,
m number of working processes executed, variant I—prestressed slab, $m^{I} = 9$, variant II—dowelled slab, $m^{II} = 8$,
n number of plots, $n = 6$.

After substitution of values to formula (3) and calculation, execution cycles amount to:

- $t^{I} = 42$ weeks (namely 294 calendar days),
- $t^{II} = 39$ weeks (namely 273 calendar days).

In the case of runway construction according to variant II, there is no prestressing process, hence $m = 8$. Then, the execution cycle is shorter by $r = 3$ weeks, namely by 7 % against the cycle of runway construction in the prestressed technology; compare schedule on Fig. 2.

According to the guidelines, before commencement of construction works, natural habitats present on the area of the planned runway must be removed and relocated into other places. The performance of such works prolongs the runway construction cycle by eight weeks (as only after completion and evaluation of works can the runway construction begin). Hence, total investment completion time $t^{C} = 50$ weeks. In the Polish climatic conditions, works must be commenced in the second half of September, so as to replant the bushes in autumn, while in early

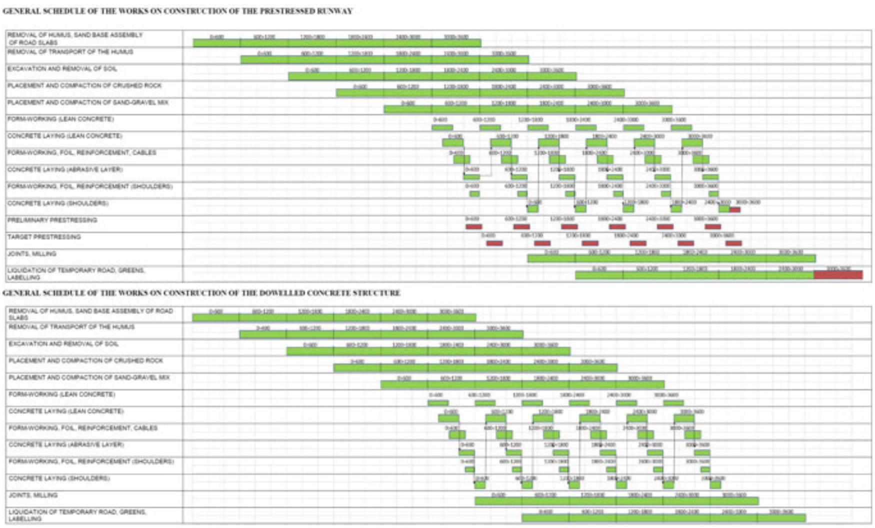

Fig. 2 General schedule of the works on construction of the prestressed runway and of the dowelled concrete structure

spring, immediately after defrosting of soil, to start preparation of temporary roads for the site, and if the temperatures permit it, to carry out earth works and other works.

4 Cost Analysis

Cost estimate prices of particular works, as regards the construction of each fragment, and next each complete facility, have been determined according to the relation:

$$\mathrm{CK} = \mathrm{R} + \mathrm{M} + \mathrm{S} + \mathrm{K_P} + \mathrm{K_Z} + \mathrm{Z} + \mathrm{P_V} \quad (4)$$

where:

R, *M*, *S* direct costs of, respectively, labour, materials and of equipment and technological transport, calculated as products of $L \cdot n \cdot c$, *L*—number of material units, acc. to bill of quantities, *n*—unit material outlays acc. to KNR [12] and individual calculation, *c*—unit prices of production factors acc. to Secocenbud for Q_3 of 2012 and individual calculations, assuming labour of 5 €/h,

K_P indirect costs, $K_P = w_{KP}(R + S)$, w_{KP}—indirect cost factor, $w_{KP} = 0.65$,

K_Z cost of procurement and external transport of materials, $K_Z = w_{KZ}M$, w_{KZ}—procurement cost factor, $w_Z = 0.12$,

Z calculated profit, $Z = w_z\ (R + S + KP)$, w_z—profit factor, $w_z = 0.1$,

P_V VAT tax, $P_V = w_V\ (R + M + S + K_p + K_z + Z)$, w_V—VAT factor, $w_V = 0.23$.

Total cost estimate price, VAT inclusive, for the execution of runway with pavement with prestressed structure, namely according to variant I, amounts to 35.3 M €, Fig. 3. In turn, the execution of the runway with traditional dowelled reinforced concrete structure, namely according to variant II, is valuated at 41.7 M €. High price difference, totalling 6.4 M €, results from the change of material outlays, principally as regards structural elements of the runway, namely subgrade and pavement.

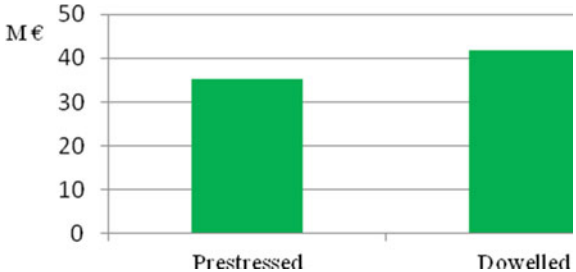

Fig. 3 Total cost estimate prices (VAT inclusive) for performance of the runway according to two structural variants (*Source* Own study)

4.1 Prices for Performance of Sub Base Course and Base Course

The price of crushed rock and sand-gravel mix layers in the case of pavement with dowelled structure amounts to 10.7 M €, and is lower by 2.4 M € than the price of such layers with prestressed structure, Fig. 4. This results from different thickness of such sub base course parts. In turn, over three times greater price difference than in the case of layers of crushed rock and gravel in sub base courses occurs between variants I and II of concrete sub base and concrete base course (with standard and prestressing reinforcement, applied in particular variants). In this case, the cost estimate price of concrete layers, sub base and pavement of the runway with prestressed structure amounts to 20.6 M €, and is lower by 8.8 M € than the price of such layers with dowelled structure. Such a large difference is principally due to concrete layer of pavement of the runway with traditional structure, which is by 20 cm thicker than the concrete layer of pavement with prestressed structure.

4.2 *Disbursements on Labour* R, *Materials* M *and Equipment Operation*

Labour consumption of the solution with prestressed runway amounts to 465,000 working hours and is greater by 20,000 working hours than in the case of traditional concrete structure, Fig. 5. Furthermore, greater precision is required, as well as strict timeliness of all works related to prestressing.

In turn, steel consumption is much lower, by 600 tonnes, while in the case of concrete mix by 43,000 m^3 as compared to dowelled structure, because for prestressed load-bearing structure it amounts to 3500 tonnes and 110,000 m^3,

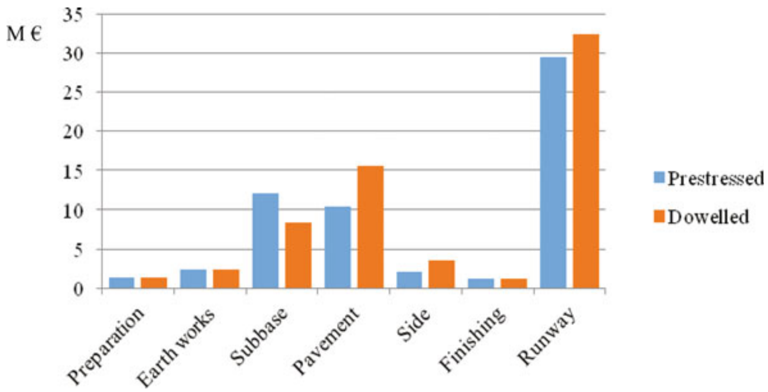

Fig. 4 Structure of work price components. Total disbursements (*Source* Own study)

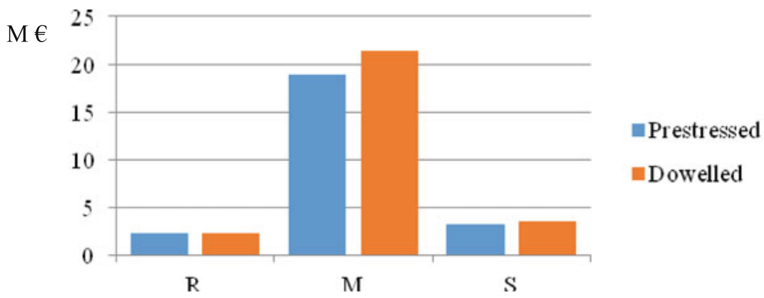

Fig. 5 Disbursements in the analysed variants of runway construction, *R* labour, *M* materials, *S* equipment operation (*Source* Own study)

respectively. Also, equipment operation is lesser, by 11,000 machine-hours, including the pumps, by 2000 machine-hours, than in the case of prestressed structure.

5 Conclusions

At present, the clearly increasing global demand for civil aviation services, there is a need for many repairs and modernisations, as well as construction of new runways for airplanes. On the basis of calculations performed for the newly built runway at the Katowice-Pyrzowice airport with prestressed structure, as compared to solutions with dowelled reinforced concrete pavement, the following conclusions can be drawn:

- fundamental benefits from prestressing include:

– about double reduction of the thickness of load-bearing structure and reduced consumption of steel by 14 % (whereas in this case this is principally extra-fine steel for prestressing),
– greater resistance to overload and cracking of the structure,
– operational profits resulting from greater pavement durability (without micro-cracks) and smaller number and length of joints,

- investment cycle is slightly longer, only by 8 %, yet execution of the processes requires greater precision of works and observance of work schedule (in particular in the case of prestressing works),
- cost estimate price of runway performance is lower by 18.1 %, principally due to lower cost of concrete layers by 42.7 %,

- disbursements on equipment operation are lower by 10 %, while particular difference is observed in the case of much lower volume of in-built concrete mix by 43,000 m^3 (namely the volume corresponding to capacity of 4050 truck concrete mixers), whereas labour consumption of the works is greater by 4.7 % (which includes specialist prestressing).

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Transport Network Parameterisation Using the GTAlg Tool

Ireneusz Celiński

Abstract This article discussed a method of the transport network parameterisation. Transport networks are typically parameterised by infrastructure administrators and competent organisations or by entities having an impact on the transport policy making and financing of transport infrastructure. Sometimes, transport networks are parameterised by public transport administrators. This process usually consists in defining certain synthetic measures for the given transport network area depending on the manner in which it has been delimited. In practical terms, in any case, such parameterisation is not directly linked with statistical transport network users and their individual needs. This article presents an approach towards parameterisation of transport networks from the perspective of their users. Describing the network in such a manner may contribute to the transport system's sustainable development. In order to achieve this goal, it is proposed that one should use trip planners (GT Planner) and other tools featuring a bidirectional information transfer channel.

Keywords GTAlg · Delimitation · Transport network · Supressed supply

1 Introduction

Parameterisation of the transport network is a common practice in the process of intentional determination (valuation) of specifically defined sections of the former. This process is usually preceded by the network delimitation, legitimate from the perspective of its parameterisation. Furthermore, assigning values to selected parameters (or their sets) of the network sections triggers some specific consequences. They result from the fact that network parameterisation serves multiple purposes, including statistics, accounting, financing of the infrastructure maintenance, traffic management and control etc. There are various indicators applied in

I. Celiński (✉)
Faculty of Transport, Silesian University of Technology, Katowice, Poland
e-mail: ireneusz.celinski@polsl.pl

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the process of transport network parameterisation [1]. Network density indicators are constructed in such a manner that the length of individual transport lines is principally divided by the surface area which they cover (the statistical unit referred to as a regime or a spatial territory). One may also encounter some other terminology in use, such as e.g. a cell, a transport district, a network section or the NUTS (Nomenclature of Territorial Units for Statistics). Network density indicators may be modified in various ways, for instance by subtracting the area of idle land from the area subject to analysis, or by introducing the transport work notion into the formula [2, 3]. Indicators of this type are examples of the means of quantitative assessment. If one applies any cost-related criteria in the numerator of the indicator, then it becomes an example of an evaluative assessment.

As aforementioned, the transport network parameterisation process is each time preceded by its area being delimited. Delimitation is a process of dividing the transport network area into pre-defined spatial territories (also known as regimes). It may concern the network area dividing in a homogeneous manner, using a fixed grid of transport network delimitation. In this case, the network is divided vertically and horizontally into a specific number of territories with invariable area (apart from the network area elevation profile, which is relevant when analysing transport-related problems). On the other hand, there are also inhomogeneous methods of the transport network delimitation which usually result from the division criterion applied, being most commonly a specific one and depending on the chosen network assessment methodology or the purpose of its assessment (e.g. administrative division, statistical division according to NUTS). What should definitely be stressed in terms of delimitation of transport networks is the fact that such a division usually adopts the perspective of the network administrator, the public transport operator (PuT), the entity financing transport infrastructure related projects etc. Therefore, it is a division which escapes the real influence of network users.

This article elaborates upon a different method of the transport network delimitation which may be implemented by taking transport-related behaviours of a decided majority of transport network users into consideration. Such an approach is assumed to ensure sustainable development of transport networks where it is the everyday users, and not only administrative bodies, that participate in deciding how those networks are managed. Among the useful tools supporting such delimitation, one will find all kinds of trip planners, road navigation systems, information systems and electronic timetables. They all make it possible to introduce the element of feedback between administrators and users into the process of transport system planning. These tools often feature a bidirectional transaction mechanism. Submitting a request for defining a route in the transport network is accompanied by parameterisation of the physical transfer in question and the relevant data are stored on the server offering such a service. The author of the article is convinced that, once combined with an option of geopositioning of characteristic points of such a transfer, this may be an efficient method of the transport network parameterisation.

2 GTAlg Tool

This article addresses one of such demand-oriented tools used for delimitation of transport networks, namely a trip planner named Green Travelling (GT Planner), based on the GTAlg transport route defining algorithm. Even though the tool is primarily used to promote eco-friendly modes of transport, owing to advanced data transaction mechanisms, it may well serve the purpose established in this article. Queries submitted in the planner may be processed against all queries pertaining to the area covered by the given planner. Such an area may then be divided on the basis of rational premises in line with the conclusions formulated with reference to the analysis of these data.

Figure 1 illustrates the Green Travelling trip planner. This tool enables travel planning in a transport network. Its basic functionality allows for routing a transfer in the transport network between any two points which belong to its structure. The road network structure is described as a network graph. However, in order to establish the transfer route for the sake of the trip being planned, irrespective of the start and the destination points defined, one must enter a number of additional parameters depending on the selected decision-making criterion.

While specifying the criteria for the route search in the network, depending on the chosen means of transport, one may set e.g. the maximum domain of a function for the given transfer or detailed data concerning the means of transport, such as fuel consumption (Fig. 2). One can also state the motivation for travelling. While using the trip planner, the information on the travel parameters (queries) is catalogued under queries sent to the server. The server's replies to the submitted queries

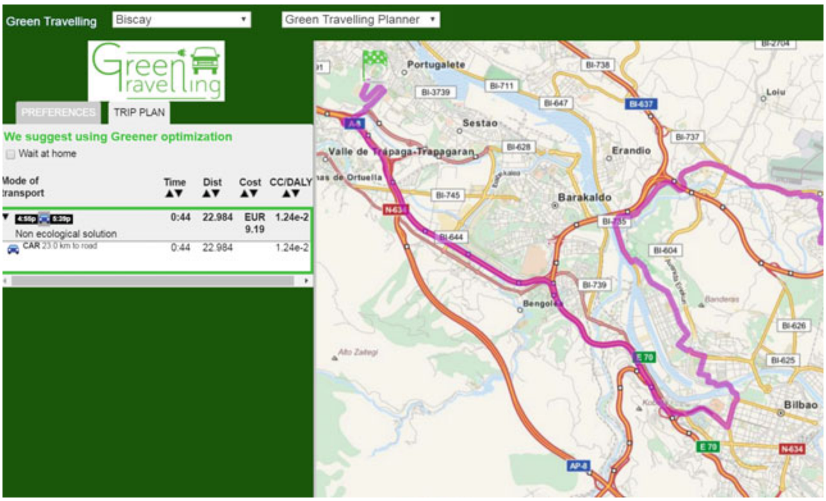

Fig. 1 GT Planner transport network parameterisation tool—Biscay area (*Source* [4–9])

Fig. 2 Transport network parameterisation tool—criteria review (*Source* [4–9])

(i.e. routes found) may also be archived. By that means, the planner server may store data concerning the parameters of travelling within certain areas. A trip planner such as GT Planner covers a certain physical section of the globe each time it performs its functions. At the current moment, there are data about several agglomerations from all over the world stored in the planner's repository. Theoretically, the entire global population may be covered by the planner's service. In practice, however, technical obstacles (computational capacity, server memory, available open format data) as well as the lack of other data developed in this respect (elevations) cause that tools of this kind service individual agglomerations or metropolises only.

In reality, when servicing the transport network functioning in the given area *S*, the trip planner is available to the entire population having access to a technology which enables using the tool (a computer or another device providing access to the Internet). According to authors of papers [4–10], the percentage share of those using trip planners is 38 % of the population (based on a sample of 14,000 persons). Therefore, the potential size of the sample one can create based on the group of trip planner users is optimistically estimated at ca. 38 %÷74 %. In practice, this value may be lower, considering only persons using a trip planner more than once a week. Publications addressing studies of traffic models provide an estimation that, for a town of up to 50 thousand inhabitants, a representative sample should correspond to ca. 5 % of the total population [11]. For an agglomeration (>1 million inhabitants), the size of a representative sample may drop to ca. 1 %.

3 Real Transport Network Versus Hidden Network

The manner in which people perform physical transfers in a transport network is referred to as transport behavior [12–21]. Transport behaviors one can observe result from the existing transport network structure as well as its organisation which one is given. They are described by the points of start and destination of travel, the travelling motivation, the chosen means of transport, the transfer time, the fact of combining means of transport (multimodal travelling) etc. [16]. A description of real transport related behaviors of people in the given area is in fact a breakdown of a certain objective picture of the existing status. And even so, people also display specific transport preferences which, however, for a certain reason, they cannot pursue (they want to, but are unable to do so for objective reasons). For instance, a supporter of the green lifestyle cannot perhaps afford an electric car, and as regards the transport connection he or she makes on everyday basis, the public transport is characterized by low availability. Another person would like to make use of railway while travelling to work, but the time required to reach the station is considered too long. Yet another would prefer to travel by tram only, but it is unavailable in the given neighborhood. Consequently, to some unknown extent, preferences of transport network users face certain objective and subjective obstacles preventing their accomplishment [18, 19]. Such preferences do not turn into transport related behaviors. They are usually suppressed by the existing structures or other transport network conditions of various nature [18, 19]. The foregoing results from the very fact that the fundamental structure of every transport network is developed in an evolutionary manner. Not only do the junctions it contains correspond to the contemporary points of traffic distribution, but also to those which emerged several dozen or even several hundred years ago. At the same time, age by age, decade by decade, the process of migration of traffic generators and absorbers functioning in the road network has been accelerating. Especially the last two decades of the 20th century could serve as clear evidence for the foregoing. There is a particularly strong migration of businesses observed in the sector of small and medium-size enterprises. Every month, about 25 thousand such companies are entered into Polish Central Registration and Information on Business, but at the same time, ca. 21 thousand are removed from Central Registration and Information on Business. In both cases, as different sources estimate (including persons who make living on real estate rental), the foregoing constitutes from ca. 0.5 to 1 % of all the registered SMEs (in accordance with the REGON business statistical records, the total number of businesses is ca. 3 million). It is difficult to estimate the exact percentage of companies having their registered offices at a different address than the owner's one. In any case, every business being officially closed may change its address, and a new one may emerge at any point of the transport network, which corresponds to a number from 10 up to 250 thousand changes of SMEs' locations within the Polish territory per annum. It is also difficult to estimate exactly what number of address changes in the traffic pattern of each municipality is directly associated with the phenomenon in question. Nevertheless, it is most certainly large, especially for individual transport. This process coincides with the phenomenon of suburbanization of urban areas. In light of the above data, it is questionable that, in terms of changes, the network structure should evolve in line with the dynamics of relocation of traffic generators and absorbers.

Consequently, there is an urgent need for answering the question how to describe differences between transport related preferences and the behaviours manifesting themselves in the existing road network, and furthermore, how one can adjust the development of the network structure in accordance with the dynamics of relocation of its generators and absorbers. The author of this article has been focused on the former problem.

A tool which may be used to adjust the transport network to the differences observed between transport related behavior and preferences is a trip planner. The transport related behaviors manifesting themselves in the road network can be described with matrix $OD^B = [od_i]$, whereas the preferences (including the suppressed ones)—in a form of a different source-destination flow matrix: $OD^P\left[od_j\right]$. However, the following is true: $OD^B \cap OD^P \neq 0$ (preferences being pursued). Consequently, while seeking travelling preferences, still the supressed ones (referred to as supressed demand), one should define $OD^S = OD^P - OD^B$.

4 Supressed Transfers—A Case Study

In order to illustrate the problem addressed, a specific case of suppressed transfer occurring in the Conurbation of Upper Silesia and Dąbrowa Basin (Poland) was studied. This case is marginal against the scale of such an important issue, but it provides an accurate picture of the phenomenon described in this article. The transfer in question is made between a large changing point located in the municipality of Mikołów (i.e. transport district A) and a transport territory hosting a housing estate, industrial facilities and a large commercial centre (transport district B). This network features an objective obstacle hindering the performance of all combinations of transfers between these districts, namely a regional railway line. In grey colour, Fig. 3 shows the only connection available in the existing network which enables travelling between these districts (under a railway overbridge) and which may be considered convenient in terms of time and, at the same time, legally

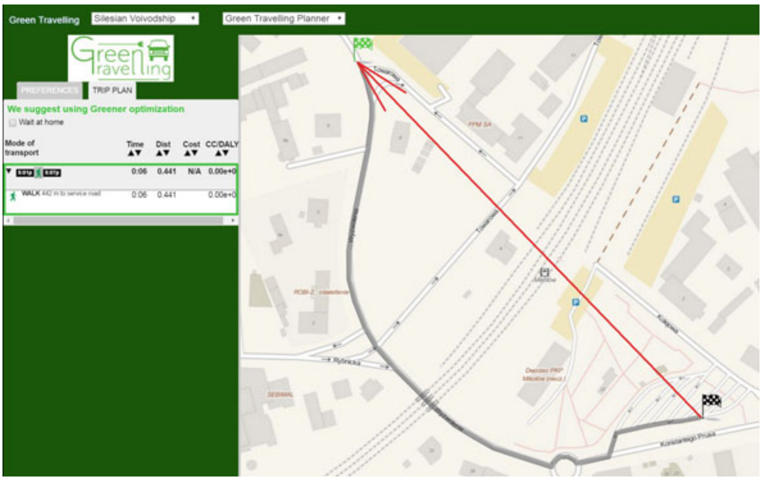

Fig. 3 GT Planner; suppressed traffic case analysed (*Source* [4–9])

permissible. The length of this transfer is ca. 460 m. However, a considerable number of people moving between districts A and B choose an illegal transfer crossing railway tracks marked in red colour in Fig. 3, which corresponds to a connection of ca. 350 m in length. The measured time difference between both transfer solutions is ca. 78 s. Realistically, it comes to ca. 2 min on account of inaccuracies in OSM (Open Street Map) data. For such an insignificant difference, persons choosing the quicker way risk being fined by the railway security services (SOK) at the very least.

For the last two decades, the case discussed has been connected with cyclic incidents of devastation of the signs warning people that crossing the tracks is prohibited as well as with systematic blockades by SOK patrols (there have been fatal accidents involving pedestrians related to this track section). In January 2016, the track crossing point was rebuilt, and at the current moment, there is only a warning about incoming trains.

5 Hidden Network Indicators

The case illustrated in Fig. 3 shows how transport preferences of inhabitants of a certain area are suppressed and in what way (illegally) these preferences are pursued as transport related behaviours, and consequently, how they are legalised under the existing transport network. The idea which appears in this context is that most of the identified supressed preferences should be introduced into the set of transport related behaviours:

$$\min_i (OD_i^S = OD^P - OD^B) \tag{1}$$

where:

i flows from matrix OD, $i \in (1, 2, \ldots, n)$,

n dimension of flow matrix OD.

Equation (1) represent the pursuit of such traffic organisation in the transport network, and such a structure of the latter which minimises the number of supressed flows occurring in the traffic network, and which also minimises the number of transfers in supressed flows which, for various reasons, cannot be completely eliminated.

$$\min_n \left(\sum_{i=1}^{n} od_i^n\right) \tag{2}$$

It should be noted that using a trip planner creates transfer vectors $\overrightarrow{AB}$ between every travel starting point A and destination point B of known modulus equalling the Euclidean distance between the points. The foregoing has been illustrated in Fig. 4.

Fig. 4 Transfer vectors in transport network (*Source* [4–9])

Therefore, in the transport network covered by the trip planner's functionality, as a result of having formulated Y queries, the $V = \{v_i\}$ set of vectors is created in limited space R^2. The planner's coverage area is divided into p perpendicular lines and s horizontal columns which delimit the area subject to analysis into $t = ps$ spatial regimes with the dimension of $S/(ps)$ each (for homogeneous delimitation).

By that means, for every spatial regime r_u, using GT Planner, a set of values is noted, namely the number of the regime intersections with travel vectors re_u, the number of travel completions rs_u, the number of travel starts ris_u, the sum of moduli of transit travel vectors ri_u, the sum of moduli of travels being started rss_u and the sum of moduli of travels being completed res_u. Recently featured variables was illustrated in Fig. 5. Each of the foregoing values may be modified by defining the tm means of transport to which the former apply, and so the following notation: ri_u^{PC} applies to a number of regime intersections with travel routes made with individual cars (HOV—heavy occupied car). Using the features of GT Planner, these values may be modified by applying the travelling motivation, and so the following notation: ri_u^{HO} applies to a number of regime intersections with travels made to satisfy the home-work motivation. GT Planner's functionality involves specific methods of indexation of spatial regimes. Notation ri_u^{xMM} represents the number of multimodal travels made through (alternatively started/completed in) a spatial regime. Moreover, applying the emission values defined in the planner for every transfer, one can note the ri_u^{ET} sum of emission of harmful substances attributed to transit vehicles in the given spatial regime. Harmful substances should be indexed independently on account of their diverse impact on human health and natural environment, which can be noted as follows: $ri_u^{ET^g}$. Since the foregoing notation applies to the Euclidean space vectors, these indicators may apply to regimes where, in reality, no such pollutants are emitted, vehicles of the given kind do not physically run across their area etc. But this fact is indeed linked with the restrictions imposed upon travelling preferences through evolutionarily developed structure and organisation of the transport network.

Without the knowledge of traffic conditions (traffic intensity level), the shortest route will always be considered the optimum one. Nevertheless, one may seek other ways of traffic optimisation by investigating traffic processes. This requires studies

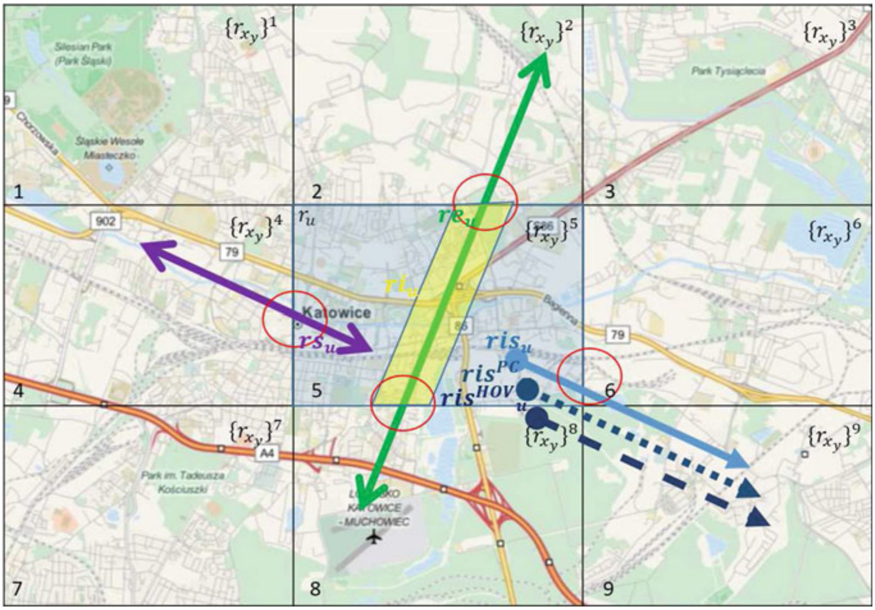

Fig. 5 Transfer vectors versus parametrisation variables in transport network (*Source* [20])

dedicated to various traffic engineering problems and modelling of transport processes in this area [22–34]. They may even involve problems so specific as bicycle traffic at roundabouts [32, 33]. In this sense, the indicators defined above imply the role performed by the given spatial regime in the transport system of a specific area. In this manner, by defining indicators for all spatial regimes in the given area, one may undertake reasonable actions aimed at building new sections of the transport infrastructure and introducing potential organisational changes. One may even attempt to change transport related behaviours [23]. Interpretation of the indicators may be ambiguous, and so it will be explained with reference to an example of indicator ri_u, i.e. the number of regime intersections with travel vectors. An indicator formulated based on the above grounds, i.e.:

$$ind_{s_u}^{ri_u} = \frac{ri_u}{s_u} \tag{3}$$

It shows the number of routes intersecting with the given spatial regime and being referred to the value of its surface area. This value indicates how potentially important the role performed by the given area is for the transport network. Such a value should find practical application, for instance, in establishing real estate prices for the given area, and should prove useful in planning the transport network expansion. It is also of relevance to collective transport operators with regard to siting of collective transport stops, which translates into improvement of potential accessibility. A reference between values of the indicators, as expressed in the form of Eq. (3), can and should be made against the parameters of the existing transport network:

$$ind_{s_u}^{ri_u} = \frac{ri_u}{l_{s_u}} \qquad (4)$$

where:

l_{s_u} e.g. length of the transit road network in the given spatial regime [km].

For every single indicator, the interpretation of its values is of major importance.

6 Conclusions

The article describes a method proposed for the transport network parameterisation based on features of a trip planner, namely GT Planner. With regard to certain parameters, one may also use other trip planners, however, their capabilities are limited, for instance, as regards estimating emission of harmful substances or calculating multimodal travel parameters. The discussion on the parameters addressed in this article as well as on their relevance for solving problems of supressed demand in the transport network will be continued in subsequent articles. Development of this kind of methodology has been stimulated by contemporary unresolvable problems affecting the sphere of traffic control and organisation in the scope of the existing infrastructure, primarily manifesting themselves in road traffic.

The indicators described in the article, calculated for travels completed and started in the given spatial regime, may be calculated as items directly derived from GT Planner's data, without a need for any further complicated processing. However, such processing is indeed required for the sake of all indicators based on intersections between the given regime and a transfer vector of the given travel. A similar tool will also be discussed in another independent article.

The use of the proposed methodology is based on the development and evaluation of such indicators as shown in Eq. 4. Equation 4 expresses the ratio of the length of all the modules travelling transit vectors across the spatial regime area related to the length of the transit routes in the regime area. Evaluation of such indicators allows adjust the spatial regime network to performed his function in the various aspects of the network utilisation. For high rate of Eq. 4 that means need to build new transit routes in the spatial regime. The analysis of indicators related to the above (Eq. 4) allows the identification of lacks in the transport network in the context of suppressed demand (Fig. 6).

The idea proposed in this paper has been strong supported by statistics, since 74 % of Poles have access to the Internet, and 38 % of them use trip planners [34]. The presented in this article methodology distinguishes from other methods of parameterization transport networks used tool for network analysis [35, 36].

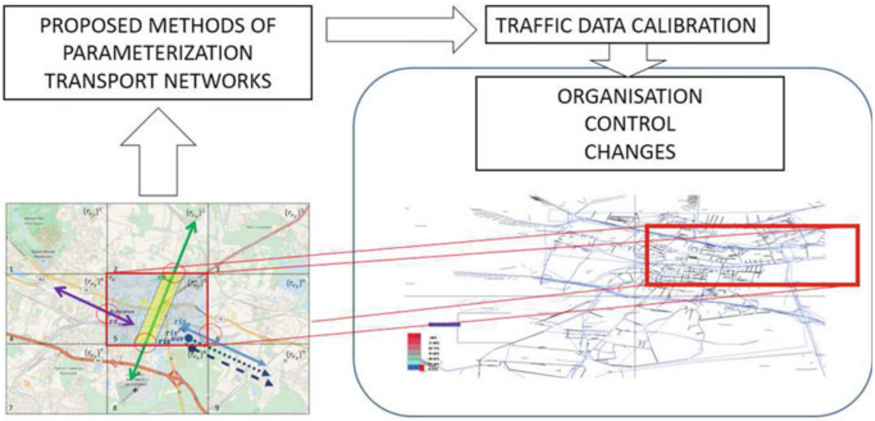

Fig. 6 Parametrisation variables as transport network changing criteria (*Source* Elaboration own, [20])

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Part III
Safety Analysis in Advanced Transport Systems

Analysis of the Relation Between Assessing Own as Well as Other People's Driving Skills and Causing Road Collisions and Accidents

Ewelina Sendek-Matysiak

Abstract This paper presents the study analysis regarding the relation between the assessment of own, as well as other people's driving skills, and the frequency of causing traffic collisions and accidents. The respondents have been divided into five groups, based on the replies which they provided as regards obeying the road traffic safety regulations. The first group included those drivers who viewed their skills as very good, followed by the group of good, average, poor and very poor drivers. In case of the first two groups, i.e. those, who assessed their skills to be at least good, the analysis has been carried out in scope of causing road collisions and accidents.

Keywords Driver · Self-assessment · Road collision · Road accident

1 Introduction

Transportation is one of the major sectors of economy which ensures employment and prosperity of population. The functioning of contemporary societies without this industry is difficult to imagine. However, it is increasingly more often associated with a potential risk. Of all methods of transportation, it is the road one which is perceived as the most dangerous and it brings the higher loss, expressed by the amount of people killed. It is estimated that more than 90 % of all fatalities in the transport industry is the outcome of road accidents. According to [1, 2] road accidents will become one of the three major causes of death in 2020, with the approximate 2 million people killed.

The year 2014 saw the improved safety on the Polish roads, with the national data suggesting a decrease in the number of accidents, fatalities and injuries. Compared with 2013, there was a 2.5 % decrease in the amount of car accidents, 4.6 % fewer fatalities and 3.4 % fewer injured people [3].

E. Sendek-Matysiak (✉)
Department of Mechatronics and Machine Construction, Kielce University of Technology, Kielce, Poland
e-mail: esendek@tu.kielce.pl

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Despite some positive trends and a few years of improving safety, the risk level on the Polish roads is still higher than the European average. Between 2011 and 2013, the average annual decrease in the amount of accidents in Poland reached 4.3 %, whereas in Europe it was 6.2 %. It means that during this period of time, the number of fatalities in Poland and in Europe lowered by 39 and 53 % respectively [4].

The level of road traffic safety, determined by the number of accidents and, more importantly, by their consequences, puts Poland at one of the last places in Europe. The causes for road accidents have a varied and often complex basis [5]. The first studies that analysed the issue of road safety were published as early as the beginning of the 20th century. Many years later, the reasons for road traffic accidents do not seem to have changed much and include:

- risky behaviour of drivers, in particular excessive speed, bravado, poor skills of drivers combined with wrong assessment of the traffic circumstances, drunk driving, inadequate level of using safety devices,
- lack of proper road infrastructure,
- poor technical condition of vehicles [3, 6].

Moreover, as emphasised in [7] other elements with a significant impact on the road traffic safety are motivation and attitude, i.e., the factors which influence and change drivers' behaviour. Among the ten most frequent reasons of traffic accidents, the third position is occupied by the high self-assessment [8]. There are numerous articles, in particular in English-speaking publication, which discuss the issue of drivers' excessive self-assessment and its influence upon the road traffic safety. However, those studies are focused on identifying the relations between the self-assessment and the behaviours, in particular the aggressive ones, of drivers on the roads [9–16]. In 2007, a survey was ordered by the Szkoła Jazdy Renault (Renault Driving School) and carried out by TNS OBOP, which concerned the links between the assessment of own driving skills and the number of road accidents. Given the fact that the study was conducted nearly ten years ago, the number of vehicles on the roads is larger and assuming that drivers' mentality may have changed since then, it is safe to say that this issue requires a new analysis.

2 Own Study

2.1 Study Material

The study material used in this paper was collected during the surveys conducted in November 2015 in the town of Kielce. For that purpose, a questionnaire was prepared with the questions about the elementary issues of road traffic safety, of which the participants were informed at the beginning of the study. The selection of respondents was random and the only prerequisite was to be a licensed driver (Fig. 1). The sample was divided into three groups: professional drivers, the students of the Transportation Faculty of the Kielce University of Technology, and other drivers. The study included 103 respondents (30 professionals, 53 students and 20 others) in the 20–70 age bracket, with 36 women and 67 men. More than a half (61 %) of the respondents have declared to be driving a vehicle on a daily basis, while 22 % said they do it a few times a week 8 %—once per week, and 9 % —less than once per week. Since two respondents failed to provide answers to all the questions, their questionnaires were disregarded in further analysis.

To determine how the surveyed drivers assess themselves and other traffic participants, they were asked several question about obeying elementary road safety principles. Table 1 presents the frequency of committing specific driving offences and the percentage of drivers who do it, whereas Table 2 presents the results of how other drivers are assessed by the respondents.

Each reply has been assigned a rank, i.e. 1—very often, 2—often, 3—rarely, 4—sporadically, 5—never, then the average has been calculated for each respondent, separately for the replies they gave about themselves and about other drivers. In addition, the following has been assumed—if the average for the replies provided by the drivers is found within the range <5.4) then it means such drivers assess their skills as very good, <4.3)—good, <3.2)—average, <2.1)—poor, and ≤1 very poor. Figure 2 presents the number of respondents divided into five, above-mentioned groups.

Of all the respondents, 42 % assess their skills as very good, whereas 47 % claim to be good, and 11 %—average. None of the respondents has obtained the average value of provided replies below 2.5. Thus, the amount of respondents in the groups “poor” and “very poor” was 0. In the group of “very good” drivers, one has obtained the average of 5, which implies that (s)he had never committed any offence included in Table 1. Still in the same group, 42 respondents have obtained the total average of 4.4, whereas in the group of “good” and “average” drivers it was 3.7 and 2.9 respectively. The driver who was the most critical about his/ her skills has reached the average of 2.625.

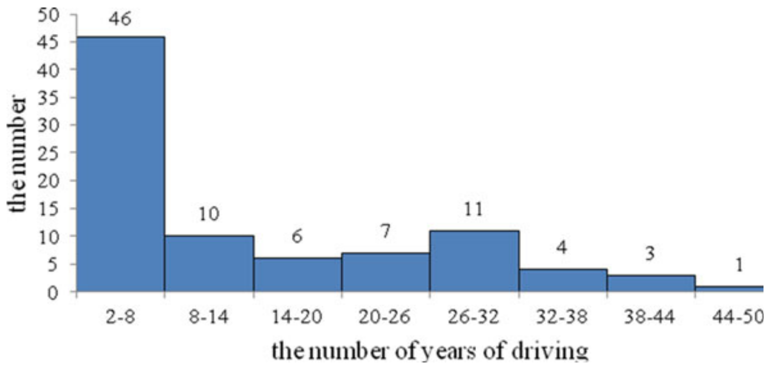

Fig. 1 The years of being a licensed driver

Table 1 The number of respondents committing specific driving offences, expressed as percentage

	Very often	Often	Rarely	Sporadically	Never
Rank	1	2	3	4	5
Driving on red light at crossroads (%)	0.00	0.99	9.90	39.60	49.50
Failing to stop at the 'STOP' sign (%)	1.98	9.90	20.79	32.67	34.65
Forcing the right of way (%)	0.99	7.92	17.82	41.58	31.68
Not fastening seat belts (%)	4.95	8.91	10.89	20.79	54.46
Overtaking in prohibited places (%)	0.00	3.96	15.84	44.55	35.64
Not using indicators (%)	0.00	3.96	11.88	35.64	48.51
Using mobile phone while driving (%)	2.00	18.00	18.00	34.00	28.00
Excessive speed (%)	15.69	21.57	35.29	21.57	5.88

Table 2 The amount of respondents indicating the frequency of committing driving offences by other drivers, expressed as percentage

	Very often	Often	Rarely	Sporadically	Never
Rank	1	2	3	4	5
Driving on red light at crossroads (%)	6.93	50.50	25.74	13.86	2.97
Failing to stop at the 'STOP' sign (%)	12.75	49.02	25.49	12.75	0.00
Forcing the right of way (%)	26.73	53.47	16.83	2.97	0.00
Not fastening seat belts (%)	15.15	32.32	28.28	17.17	7.07
Overtaking in prohibited places (%)	26.00	54.00	14.00	6.00	0.00
Not using indicators (%)	27.72	30.69	28.71	12.87	0.00
Using mobile phone while driving (%)	36.63	47.52	9.90	4.95	0.99
Excessive speed (%)	61.39	31.68	6.93	0.00	0.00

In terms of respondents' gender, 40 % of women and 60 % of men view themselves as very good drivers, 31 % of women and 69 % of men claim to be "good" and the "average" skills are admitted by 36 % of women and 64 % of men. As regards the type of respondents, the results are as follows: "very good drivers"—38 % professional drivers, 45 %—students, 17 %—others; "good drivers"—25 %, 58 and 17 %; "average drivers"—9 %, 55 and 36 %—others, respectively. The average age in the "very good" group was 34.5 years, in the "good" group—31.5 years, and in the "average" group—28.3 years.

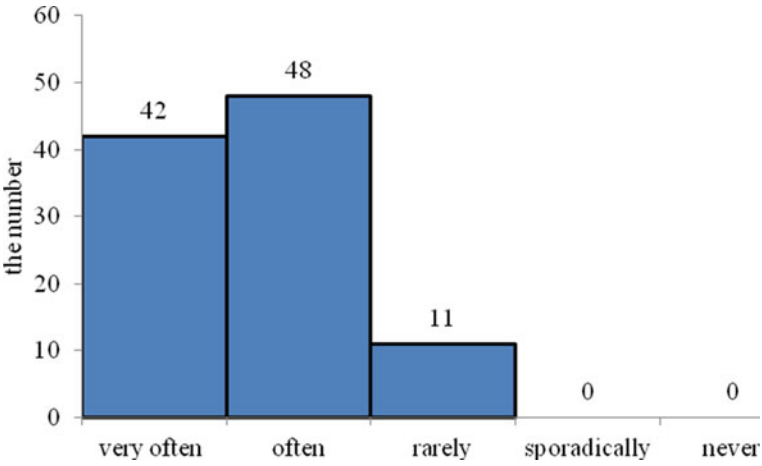

Fig. 2 The number of respondents assessing their driving skills, divided into five groups

As mentioned previously, the average was also calculated with regard to the respondents' replies about other drivers' skills. Since the assumed scale is the same as the one for assessing own skills, the higher average calculated for this case means that the given respondent perceived other drivers better, and the lower means the poorer assessment. Figure 3 demonstrates the number of the respondents who assess other drivers' skills as very good, good, average, poor and very poor.

None of the respondents has assessed other drivers' skills as very good. The majority—52 %—indicated the "poor" level, 38 %—"average", 7 %—"good" and 3 %—very poor. Men are more critical about others' skills, with 71 % claiming that other drivers are "average", 58 %—"poor" and 67 %—"very poor".

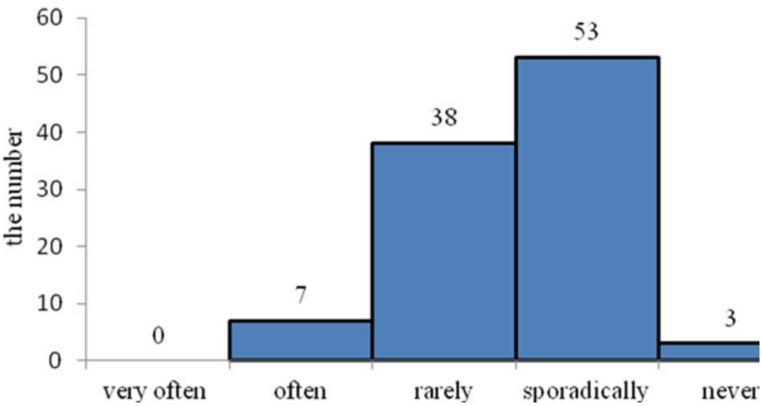

Fig. 3 The number of respondents assessing other drivers' skills, divided into five groups

In terms of the professional status, as much as 67 % of the professional drivers claim that other traffic participants are “very poor”, 32 %—“poor”; 21 %—“average”, 29 %—“good”. In the group of students, one-third thinks that other drivers are “very poor”, half of them assess that other drivers are “poor”, 61 %—average and 57 %—“good”. The respondents in the group of “others” were the least critical, with 14 % of them assessing other drivers’ skills as “good”, 18 %—average, and 21 %—“poor”.

The following question to be replied by the respondents referred to perpetration of road collisions and accidents. Of all study participants, 28 have caused road collision (28 % of all respondents), whereas five caused road accident (5 %).

Figure 4 demonstrates the quantity of drivers who caused road collision or accident and how many times it happened.

The highest number of respondents (17) caused one road collision, five caused two collisions, other five-three collisions, and one respondent was the perpetrator of five collisions.

Table 3 demonstrates the number of the respondents who caused at least one collision or accident, divided into groups of how they assessed their own driving skills.

The conducted analysis reveals that 24 % of the “very good” drivers, 27 % of the “good” drivers and 45 % of the “average” drivers have caused at least one road collision. One of the respondents was the perpetrator of five road collisions, and it was a professional driver who assessed his/her skills as very good. The average determined for this respondent was 4.75, while his/her assessment of other drivers’ skills was 1.75. He/she perceived him/herself as a very good driver, whereas the others were viewed by him/her as average. Two out of five drivers who caused three road collisions describe their own skills as very good, the next two of them—as good and one of them—as the average. In the group of the drivers who caused two

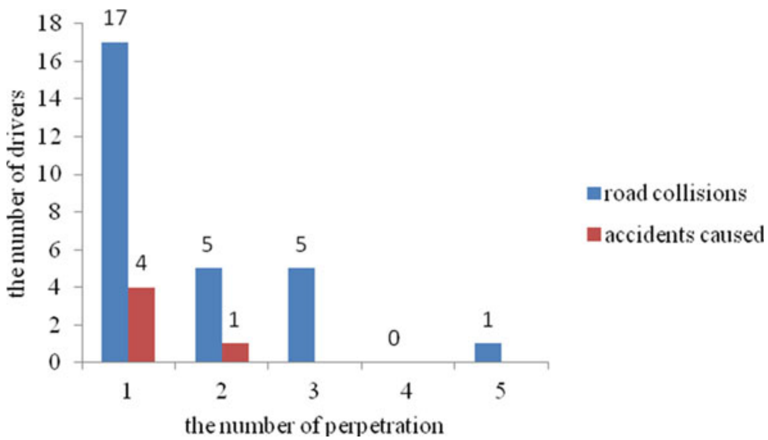

Fig. 4 The number of road collisions and accidents caused by the respondents

Table 3 The number of respondents who were perpetrators of a road collision or accident

	Number of respondents causing road offence	
Assessing own driving skills	Road collision	Road offence
Very good	10	1
Good	13	1
Average	5	3
Very poor	0	0
Poor	0	0

road collisions, one viewed him/herself as very good whereas four described themselves as good.

It must be emphasised that the respondents who caused more than one road offence have assessed other drivers in such a manner that the average calculated for them was 1.9, which means they perceived other drivers' skills as "poor". In this group, 73 % are professional drivers, 9 % are students and the remaining 18 % are other drivers.

Only one respondent has caused two road accidents, and four participants—one. The former respondent—a professional driver, assessed his/her skills on such a level, that the average determined for this person indicated that he/she belongs to a group of drivers describing themselves as very good. However, other drivers' skills were viewed by this person as poor. The other four respondents comprise two professional drivers, one student and one driver in the group of "others". All the respondents who caused a road accident were also perpetrators of a road collision, with one of them contributing to three collisions.

Table 4 presents the number of the respondents who caused at least one road collision or accident, divided into the groups assessing other drivers' skills.

The majority of the respondents who caused at least one road collision (57 %) have a poor opinion about other drivers' skills, 7 %—very poor, 32 %—average, 4 %—good. Those who caused road accident assessed other drivers as poor (60 %) and average (40 %).

Table 4 The number of respondent causing road collision or accident and their assessment of other drivers' skills

	Number of respondents causing road offence	
Assessing other drivers' skills	Road collision	Road offence
Very good	0	0
Good	1	0
Average	9	2
Poor	16	3
Very poor	2	0

3 Conclusions

The conducted analysis reveals that the respondents assess their own driving skills higher than those of other drivers. It may be confirmed by the scrutiny of the queries of the questionnaire. Having a similar scale of marks to choose from (disastrous, poor, average, good, excellent), the respondents were supposed to evaluate both themselves and, in another section of the questionnaire, other drivers. After determining the correlation coefficient [17] on the basis of the study results, a clear negative correlation has been found between assessing own and other drivers' road skills.

According to the study results, 89 % of the respondents claim to have at least good driving skills. In this group, 2 % view other drivers as very poor, 52 %—as poor, and only 8 % perceive other drivers as good. None of the respondents who evaluated themselves to be on at least a good level, has expressed a very good assessment of other drivers' skills. Out of 28 respondents who have caused a road collision, 23 viewed themselves as at least good. This group includes the driver who had caused five road collisions and viewed his/her driving skills as very good. Four other drivers in this group were perpetrators of three road collisions. In addition, another driver in this group had caused two road accidents, which is the highest number of road accidents caused by the study participant. Such a high self-assessment of own skill and poor evaluation of other drivers may lead to aggressive behaviours which often result in road collisions or accidents. It is not unusual to observe such behaviour on the roads, e.g. cutting other drivers off (overtaking one vehicle and braking in front of it), enforcing, "tailgating" (following other vehicle very closely), which are supposed to explain the other driver that his or her behaviour on a road is not consistent with road traffic principles. Drivers who do it are often described in the literature as "Mad Max syndrome drivers" or "Educators". However, it is the excessively high self-assessment of own driving skills which contributes to two-thirds of the road collisions and accidents [18]. It may be emphasised that every second respondent who evaluated his or her driving skills as at least good, could not indicate correctly the quantity of fatal car accidents in Poland during one year. It proves that such drivers have insufficient awareness, which, according to psychologists, contributes to ca. 30 % or road accidents.

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Assessment of the Safety of Microprocessor-Based Semi-automatic Block Signalling System

Zbigniew Łukasik, Tomasz Ciszewski, Jakub Młyńczak, Waldemar Nowakowski and Jerzy Wojciechowski

Abstract Qualitative assessment of the railway traffic control system is necessary to ensure railway traffic safety. According to CENELEC standards all railway applications are obliged to conduct RAMS (reliability, availability, maintainability and safety) analysis. This process should include the actions associated with design, production, installation, verification, as well as validation and the acceptance of the system. In this paper a safety analysis for the microprocessor-based semi-automatic block signalling was described. Provided analysis allows stating, if the risk is acceptable (and so further analysis is not necessary). If not, then additional protection measures should be implemented in order to keep the hazard and associated risk at an acceptable level. Methodology accepted in this analysis can be used for the evaluation of safety factors for other electronic railway traffic control systems.

Keywords Semi-automatic block signalling system · Safety assessment · MTBF · THR · SIL

Z. Łukasik · T. Ciszewski · W. Nowakowski (✉) · J. Wojciechowski
Faculty of Transport and Electrical, Kazimierz Pulaski University of Technology and Humanities in Radom, Radom, Poland
e-mail: w.nowakowski@uthrad.pl

Z. Łukasik
e-mail: z.lukasik@uthrad.pl

T. Ciszewski
e-mail: t.ciszewski@uthrad.pl

J. Wojciechowski
e-mail: j.wojciechowski@uthrad.pl

J. Młyńczak
Faculty of Transport, Silesian University of Technology, Katowice, Poland
e-mail: jakub.mlynczak@polsl.pl

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1 Introduction

The railway traffic control is a field of technology dealing with issues of efficient and safe providing the rail traffic [1–5]. Railway traffic control systems enable the accomplishment of this task [6, 7]. One of kinds of these systems is block signalling system which divides a railway line into a series of blocks. The system controls the traffic of trains between the blocks using signals. In the article the issues concerning the assessment of the safety for the microprocessor-based semi-automatic block signalling were discussed.

According to CENELEC norms recommendations of proving the compatibility of the system with safety requirements includes action associated with project, production, installation, verification and with the validation, as well as activities tied together concerning reliability, availability, maintainability and safety (RAMS) [4, 8, 9].

The risk analysis for the assessed system of the microprocessor-based semi-automatic block signalling was conducted including the principle of the risk acceptance consisting in estimating risk level. Estimating risk level allows stating, if the risk is acceptable (and so further analysis is not necessary). If not, then additional protection measures should be implemented in order to keep the hazard and associated risk at an acceptable level.

2 Safety of Railway Traffic Control System

Specific quality and technical requirements for railway traffic control systems result from the need of ensuring the high level of safety of the rail transport [10]. Basic documents containing recommendations in this area are Directives of the European Union, including Directive 2008/110/EC of 16 December 2008 on safety on the Community's railways (Railway Safety Directive), 2008/57/EC of 17 June 2008 on the interoperability of the rail system within the Community.

In the train industry CENELEC (European Committee for Electrotechnical Standardization): standards are a next group of prescriptive documents concerning quality and the safety requirements:

- EN 50126 Railway Applications—The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS)—Part 1: Generic RAMS Process [5],
- EN 50128 Railway applications—Communication, signalling and processing systems—Software for railway control and protection systems,
- standard EN 50128 is harmonised with directive relating to Trans-European High-Speed Rail network. It concerns principally software and defines Software Safety Integrity Levels [11–13],
- EN 50129 Railway Applications—Communication, signalling and processing systems—Safety related electronic systems for signalling,

- the standard EN 50129 includes safety life-cycle, safety management, provides an analysis of faults based on the FTA method (Fault Tree Analysis). The standard also shows the link which exists between the SIL and THR (Tolerable Hazard Rate) [14],
- EN 50159 Railway Applications—Communication, signalling and processing systems—Safety-related communication in transmission systems [15–17].

In the railway domain the standard EN 50159 defines a basic design of communication architectures for safety related equipment (railway traffic control systems). It also defines requirements for safety related communication in open and closed transmission systems.

According to the EN 50126 norm the producer of the railway traffic control system is obliged to conduct RAMS analysis. This norm defines following evaluation criteria:

- reliability—probability that the given product can perform a required functions under given conditions for the given time interval:

  MTBF—Mean Time Between Failures,
  MTTF—Mean Time To Failure,

- availability—Ability of the product to be in the state to perform a required functions under given condition at a given instant of time or over given time interval assuming that the required external resources are provided (availability is expressed in the per cent or as the probability),
- maintainability—probability of restoring the efficiency for object in the stated time:

  MTTR—Mean Time To Repair,
  MTBM—Mean Time Between Maintenance,
  MTTM—Mean Time To Maintenance,
  maintenance costs,
  operational costs,
  LCC—Life-cycle costs,

- Safety—freedom from a unacceptable risk of harm.

An EN 50129 standard is devoted to issues of analysis of threats and risk, as the combination of the probability and potential consequences of the determined dangerous event. This norm defines the safety as the lack of the unacceptable risk. The system is being regarded as safe, if the risk is associated with the functioning of the system is acceptable. For railway traffic control systems safety integrity is specified as one of four discrete levels SIL (Safety Integrity Level). SIL is specifying safety integrity requirements of the safety functions to be allocated to the safety related systems defined through the Tolerable Hazard Rate. The THR value is determined analytically. The least restrictive requirements concern the level SIL1, the most SIL4 (Table 1).

Table 1 Tolerable hazard rates and safety integrity level according to EN 50129 [14]

Tolerable hazard rates (THR)	Safety integrity level (SIL)
$10^{-9} \leq \text{THR} < 10^{-8}$	4
$10^{-8} \leq \text{THR} < 10^{-7}$	3
$10^{-7} \leq \text{THR} < 10^{-6}$	2
$10^{-6} \leq \text{THR} < 10^{-5}$	1

European standards are imposing an obligation to apply the safety analysis in the process of the decision making about implementation the system for the use. With reference to programmable systems (the modern railway traffic control systems are programmable) in the safety analysis methodology defined in the EN 50128 norm is often used. However in order to achieve the safe communication between elements of railway traffic control system one should consider the recommendations included in the EN 50159 norm.

3 Microprocessor-Based Semi-automatic Block Signalling System

Depending on the role of the human operators the activity block signalling system can be automatic (system works without participation of personnel) and semi-automatic (participation of personnel is required). The automatic block signalling increases the capacity of railway line through the division it into a series of blocks (sections), on which in one moment can be found one train. As a result on the whole railway line with block signalling system is allowed the movement of as many trains as the number of the railway line sections (blocks). In case of the semi-automatic block signalling system we usually deal only with one section linking neighbouring block station. Expediting the train for such a section is possible only in case when the previous train cleared the block and the stage is free. When the train arrives at the station (located at the end of the section) signalmen should ensure that the stage is free (no cars of the train have left there) and press special button to send arrival signal to the neighbouring station. Then the stage is considered to be free. Safety risk analysis will be performed for SABS (Semi-Automatic Block Signalling) which use the microprocessor-based technology. Working principle of this system are identical to a relay semi-automatic block signalling system. For one stage it contains two cooperating blocks: arrival and departure stations. Additionally every departure-block is followed by the permission block. If the stage is clear, then the chosen entrance-block can be unlocked and cooperating with it the exit-block locked. It will take place after turning on the block signalling and receiving the permission. Then on the departure semaphore from the station a free-way signal will be switched on.

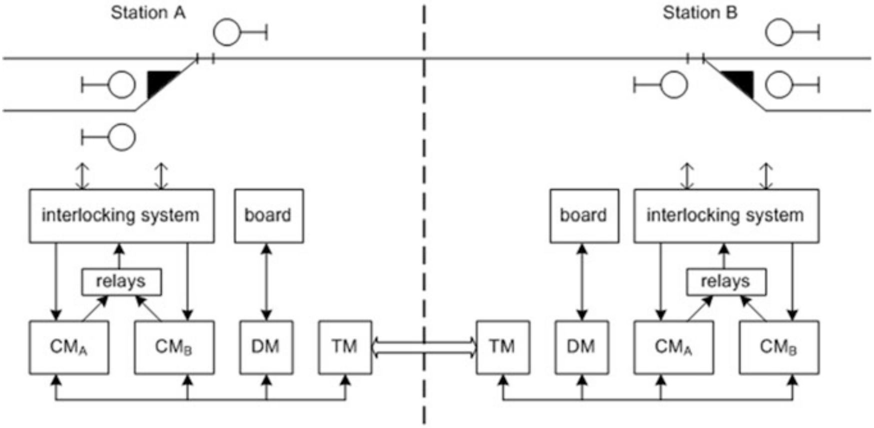

Fig. 1 Block scheme of microprocessor-based semi-automatic block signalling system

After leaving the station by the train and switching on stop signal on the departure semaphore, entry-block is locked and exit-block unlocked. Switching on a free-way signal for the second time is possible only after accepting the train by the neighbouring station and confirming it by blocking arrival block.

Discussed SABS contains following modules:

- CM—Control Module—responsible for data processing, cooperating with interlocking system and relays, as well as manages transmission between individual modules of the system. To the purpose of the safety integrity the data is processed by two independent channels (CM_A, CM_B),
- DM—Desktop Module—the task of this module is communication between the user (signalmen) and SABS system, as well as using buttons controls and showing information about the state of the block signalling,
- TM—Transmission module. The module communicates using modems between two cooperating parts of SABS systems, located on neighbouring stations.
- PSM—Power supply module.

The block scheme of SABS system was presented in Fig. 1.

4 Conception of Safety

The SABS system is an electronic system, whose safety was based on the safety of modules and safe wired transmission between modules. This system has to meet a criterion of the integrity of the safety—compliance with SIL4 and the CENELEC standards. In order to keep the adequate level of safety control, modules CM are configured as “2 out of 2”—two independent and redundant modules, that compare the results. The communication between devices is carried out using the digital transmission in the RS485 and RS232 standard.

The SABS system safety was examined using the Fault Tree Analysis (FTA) method. This method is used for a description and analysis of causes of the system failure which can cause the dangerous situation. Considering the extensiveness, this material is not presented in the article. In further part we will present only appointing fault intensity for individual components of the system and estimating the Tolerable Hazard Rate (THR), that is of acceptable risk level.

Based on the datasheets of the SABS system and on the Military Handbooks (MIL-HDBK), λ (fault intensity) was appointed for individual modules (Table 2).

These results were used for estimating the tolerated hazard rate of the SABS system which in the case of the system in "2 out of 2" configuration are calculated using the formula [18]:

$$THRs = \frac{FR_A}{SDR_A} \cdot \frac{FR_B}{SDR_B} \cdot (SDR_A + SDR_B) \quad (1)$$

where

FR_A failure Rate for the channel A,
FR_B failure Rate for the channel B,
SDR_A safe Rate Down for the channel A,
SDR_B safe Rate Down for the channel B.

For the system in which testing the availability takes place cyclically [18]:

$$\frac{1}{SDR} = \frac{T}{2} + NT = SDT \quad (2)$$

where

T time of cyclical testing system components,
NT negation Time, detection and negation time for a fault of the system element,
SDT safe time down, system response time for a fault.

On the assumption, that:

- time of cyclical inputs/outputs testing T = 250 ms,
- input negation time NT_{in} = 1.8 s,
- output negation time NT_{out} = 1.8 s.

Table 2 Fault intensity for SABS modules

No.	Module	λ	MTBF
1.	CM (CM_A, CM_B)	1.8075×10^{-5}	5.5326×10^{4}
2.	DM	7.2555×10^{-6}	1.3783×10^{5}
3.	TM	1.5309×10^{-6}	6.5319×10^{5}
4.	PWM	1.5497×10^{-6}	6.4530×10^{5}

we obtain:

$$\frac{1}{SDR_A} = \frac{1}{SDR_B} = \frac{250\,\text{ms}}{2} + 1.8\,\text{s} = 0.125\,\text{s} + 1.8\,\text{s} = 1.925\,\text{s} \approx 2\,\text{s}$$

and

$$FR_A = FR_B = 1.8075 \times 10^{-5} + 1.8075 \times 10^{-5} + 7.2555 \times 10^{-6} + 1.5309 \times 10^{-6} + 1.5497 \times 10^{-6} = 0.00004649$$

Hence benefitting from Eq. (1) we obtain:

$$THR_{A-B} = \frac{0.00004649}{\frac{1}{\left(\frac{2}{3600}\right)}} \cdot \frac{0.00004649}{\frac{1}{\left(\frac{2}{3600}\right)}} \cdot \left(\frac{1}{\left(\frac{2}{3600}\right)} + \frac{1}{\left(\frac{2}{3600}\right)}\right) = 2.40 \times 10^{-12}$$

The SABS system provides therefore the highest level for the safety integrity SIL4, since according to the norm EN 50129 for SIL4, a THR value is assumed between $10^{-9} \leq \text{THR} < 10^{-8}$.

5 Conclusions

The risk analysis is essential at the decision making about implementation every railway traffic control system. It is obliged legally requirement, but also results out of necessity of making rational decisions. Therefore, after developing the new system one should conduct the risk analysis which relies on the hazard identification and classification and determining for each of hazard, and then check if the risk is smaller than the acceptable level. The application of the principles the risk acceptance enables to identify safety methods, i.e. action which aim is a reduction frequencies of hazard or reduce their consequences.

It is possible to regard process of risk analysis as finished, when it is stated that it is achieved and will be maintained an acceptable risk level for all identified hazards. The next stage is the process of controlling the compatibility of the system with safety requirements, i.e. quality or quantitative factors which has an impact on the safety. In practice this process should include the actions associated with design, production, installation, verification as well as the validation and the acceptance of the system. hen in the process of verifying safety integrity the new hazards will be revealed the reanalysis of risk level is required.

A risk analysis and an assessment of the safety are complicated and extensive fields. In this paper a safety analysis for the microprocessor-based semi-automatic block signalling was described. Methodology accepted in this analysis can be used for the evaluation of safety factors for other electronic railway traffic control systems.

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The Choice of the Fire Ventilation System for a Short Road Tunnel

Aleksander Król and Małgorzata Król

Abstract The operation of the natural ventilation system and the operation of the mechanical ventilation system with axial fans during the fire development were compared in the study. The study was founded on the numerical fluid mechanics. Two models were built corresponding to the two systems being tested. The use of the CFD program (Computational Fluid Dynamics) allowed for the comparison of the values of important parameters at any points of both tunnels. The temperature, the velocity of the air and hot gases and the soot concentration were examined. The results have shown that the operation of mechanical ventilation with the axial fans cleans the access road to the source of the fire from one of the portals. In the case of the natural ventilation the same, however worse evacuation conditions are maintained throughout the whole tunnel. But it should be remembered, that this type of ventilation system is very sensitive to the effects of ambient air parameters such as the temperature and the wind direction and speed.

Keywords Short road tunnel · Fire ventilation · CFD computation

1 Introduction

Construction of road tunnels become nowadays a necessity. Tunnels allow to organize urban space more efficiently, reduce distance between the villages and limit traffic in cities. Since the construction of tunnels becomes increasingly popular form of organizing road traffic in cities one should pay attention to the details of the tunnels construction and ensuring the safety of their users.

A. Król (✉)
Faculty of Transport, Silesian University of Technology, Katowice, Poland
e-mail: aleksander.krol@polsl.pl

M. Król
Faculty of Energy and Environmental Engineering, Silesian University of Technology, Gliwice, Poland
e-mail: gosia.krol@polsl.pl

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The safe use of the communication tunnels needs meeting a series of technical requirements set out in the Ordinance of the Minister of Transport and Maritime Economy of 30th May 2000 on technical conditions to be met by traffic engineering objects and their location [1]. One of the basic conditions for the safe use of tunnels is the effective ventilation. It serves two basic functions during normal operation of the facility. It organizes the exchange and the air flow to meet strict compliance with the standards on the permissible concentration of carbon and nitrogen oxides. It also maintains acceptable levels of exhaust gas which results in adequate visibility in the tunnel. Such tasks require providing adequate amount of fresh air either for the drivers or the staff performing any works in the tunnel. In the case of fire outbreak new important challenges appear—the removal of the hot smoke and the other toxic products of combustion. The choice of method for delivering air into the tunnel and removal of hot fire gases depends mainly on its length and whether the tunnel is a two- or one-way.

The main aim of a tunnel ventilation system in a case of fire is providing a possibility of safe evacuation for people from tunnel. The fire ventilation system should also support the operation of the rescue teams and should be able to entirely removal of the smoke after the end of the rescue stage.

Road tunnels are so specific objects that the tunnel ventilation system and the fire ventilation cannot be considered separately. While designing the tunnel ventilation system one should be aware, that the system will have to cope also with the appearance of a fire hazard. The design of such system can be based on either German or US standards [2, 3]. The standards assume providing into the tunnel such amount of fresh air so as in every possible traffic conditions from free driving to congestion the hazard of the lack of fresh air for the people never could arise. Additionally it requires always the good visibility. The standards determine the allowable concentration of carbon monoxide and the level of visibility.

The first basic question is to determine the mode of operation: whether the overall air movement should be parallel or perpendicular to the tunnel axis. With the longitudinal (parallel) ventilation, air flows along the tunnel from the inlet portal to the outlet portal under the influence of natural or mechanical (caused by the fans action) pressure difference. The fan system efficiency should be adjusted to ensure suitable air flow velocity. As was mentioned earlier during normal use of the tunnel the longitudinal ventilation should be able to remove all pollution emitted by the vehicles, while in the case of fire it is expected to enable evacuation and then to support the rescue teams [4].

The natural ventilation systems are applied in one-way tunnels shorter than 400 m or two-way tunnels shorter than 240 m. Such system does not need any devices. The air exchange is caused by the difference of the air density between the portals, air flow induced by vehicles movement and the ambient wind and by the diffusion between polluted and fresh air layers.

If the longitudinal mechanical ventilation is applied (the axial fans are forcing the parallel air movement) the efficiency of such a system should be established to ensure a minimum air flow velocity. Also the maximum air flow velocity is strictly set: in case of normal operation of the tunnel the air velocity must be not greater than 8 m/s for two-way traffic and not greater than 10 m/s for one-way traffic [2, 3].

The jet fans force the longitudinal airflow in the tunnel. The air speed increases preventing excessive concentration of pollutants. In the case of fire the risk of smoke retraction toward the inlet portal also decreases. Most of fans are arranged in groups of two or four, at intervals of 50–200 m. The distance between groups is dependent on fan capacity and length of the tunnel. Such arrangement allows to pump the smoke in a required direction.

Such longitudinal mechanical ventilation can be applied in relative short tunnels with two-way traffic and for one-way traffic tunnels of any length. It should be noticed, that additional transverse smoke extraction system should be installed for longer tunnels to ensure proper operation in a case of fire. The important feature of described system is the possibility of reversible fans use. The change of the direction of the air flow should take place in dependence on current requirements according to location of the fire and the fire development. Some limitation while using fans of such type may be the fact that a change of rotation direction of the rotor blades affects the fan efficiency [5]. Fans at reverse flow mode are less efficient than at normal operation mode.

Transverse ventilation system is recommended for long tunnels. The air from the inlet ducts (intake) and towards outlet ducts (exhaust) flows in a direction transverse to the axis of the tunnel. The ducts are run along the tunnel. An important advantage of the transverse system is even distribution of air in the tunnel. The main drawback—the need for additional space for supply and exhaust ducts.

2 The Aim of the Study

A choice of a ventilation system for a road tunnel requires the wide knowledge and the experience. The usage of such available sources of technical knowledge as standards helps for proper system design. However only the contemporary engineering tools as programs implementing Computational Fluid Dynamics allow to test different variants of required solution in advance. It enables the evaluation of the considered system already at the design stage and allows for early corrections. The research of ventilation systems is particularly important for fire conditions because the phenomena are here very dynamic and difficult to predict at the design stage. The numerical analysis on conditions during the fire development require the choice of proper model and presumption of many parameters and it can be the weakness of such approach. On the other side it allows to check many variants combined with different ambient conditions and leads to better understanding of the system operation and the influence of the system parameters. Finally it results in a high quality project.

The main aim of the study was the choice of the ventilation system for short road tunnel with use of Computational Fluid Dynamics methods. The paper presents comparison of natural and mechanical ventilation systems in a short road tunnel. The numerical analysis were performed to check the phenomena occurring in the tunnel in a case of fire.

3 Methodology

For the purpose of proposed analysis two models of the road tunnel with a length of 150 m were built. Transverse dimensions of each of the tunnels were 4 m × 4 m. The ambient temperature was 20 °C and the pressure of 1013 hPa. The ventilation in one of tunnels operates only naturally, for the second the mechanical ventilation system was designed. It consists of two axial fans located under the ceiling at a distance of 50 m from one of the portals [6]. For both models the fire outbreak was assumed, the fire of power 30 MW according to the standard [2] was located at a distance 40 m from the same portal. The mechanical ventilation system (second model) was assumed to switch to fire mode after fire detection. In 60th second of fire development the fans start to work with the air speed of 12 m/s.

Due to the tidy task extent the dimensions of the elements of the numerical mesh were differentiated. In the fire area and near the axial fans (second model) the length of the cell edge is 20 cm. In the other regions the length of the cell edge is 40 cm. It gives the total number of cells equal to 62,000. The mesh is the same for both models, its overall sketch is shown at Fig. 1.

Models were solved using the FDS program (Fire Dynamics Simulator), which implements Computational Fluid Dynamics [7]. This program was already used for testing the ventilation systems in tunnels [8, 9]. The application of such tool allows for examining the values of selected parameters as temperature, air and smoke flow velocity or soot concentration at chosen locations in considered area. The accuracy

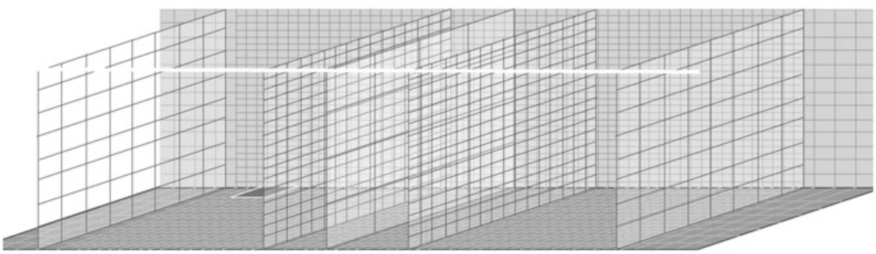

Fig. 1 The overall sketch of the numerical mesh

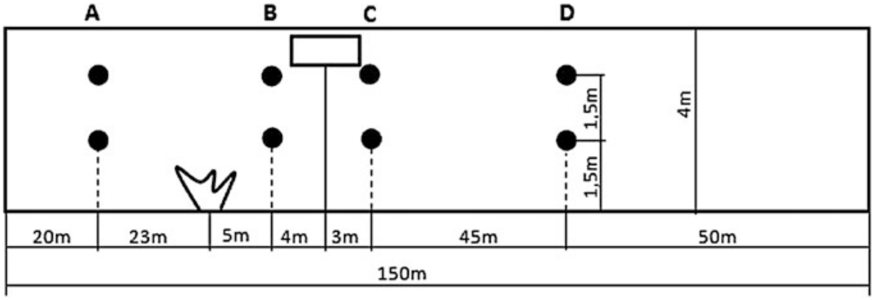

Fig. 2 The sketch of the tunnel model: the fire location, the fans placing (the model with the axial fans), layout of measurement points, the length of the tunnel is not in scale (*Source* [6])

of the reality representation of FDS program was frequently verified. The empirical researches and numerical calculations of the same subject were performed. The results of those comparative studies were very satisfactory [10, 11]. It allows to regard the obtained numeric outcomes as reliable. The application of Computational Fluid Dynamics methods to examine the spreading of smoke makes possible to get full information on any point of studied area at any time during the simulation.

Virtual result planes were built in both model. They allow for the visualization of distributions of the temperature, smoke density, air and smoke flow velocity during the simulation. The planes were placed at the tunnel axis. Also a set of additional measurement points was introduced to get exact values of the temperature and smoke density. The measurement points were placed at locations marked by consecutive letters A, B, C and D according to Fig. 2. At every location two points at heights of 1.5 and 3.0 m at tunnel axis were set [6]. Figure 2 presents the complete model of the short road tunnel equipped with the axial fans (the second model), the layout of measurement points and the fire location are the same for both models (the only difference for the first model is the lack of fans). The study covered 600 s of the fire development, it was assumed the simulation started at the moment of the fire outbreak. The analysis of the obtained results is presented below.

4 Results

The fire developing in a road tunnel produces the smoke that rises up, and after reaching the ceiling starts to spread towards the portals. In addition to the smoke occurrence the air temperature rises. The growth rate of the temperature depends on the power of the fire and the size of the tunnel.

Figure 3 presents the vertical distributions of the air temperature at the tunnel axis for a few moments of the simulation. The results derived from studies on both models (model no 1—short road tunnel with natural ventilation, model no 2—short road tunnel equipped with axial fans) are compared [6].

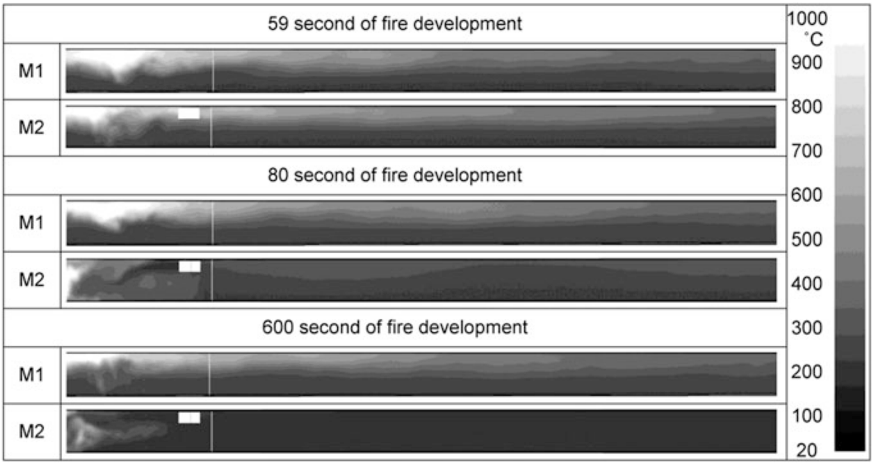

Fig. 3 The plains of the temperature distribution at the tunnel axis for three moments of the fire development, length of the tunnel is not in scale. The model no 1 is marked as M1 and the model no 2 as M2

The temperature distributions till the 59th second of the fire are the same for both tunnels. In the tunnel with the mechanical ventilation system (M2) the axial fans start work at 60th second. The effects of their operation can be seen already at 80th second: in a part of tunnel M2 the temperature starts to drop. However, even in this section of the tunnel, under the ceiling the temperature is still raised to about 150 °C. Meanwhile, in the tunnel M1, a layer of hot gas fills half of the height of the tunnel along whole its length. About the end of the simulation the situation at this case is near the same as at 80th second. It means, that in case of a short tunnel not equipped with the axial fans the conditions inside quickly becomes stable: the upper half part of the tunnel is filled with the hot fire gases. It should be here emphasized that conditions in such tunnel are strongly influenced by the parameters of the ambient air, mainly by wind speed and direction.

Thanks the measurement point placed in examined volume the exact values of temperature and visibility can be measured. The detailed analysis was performed for utmost locations A and D (defined at Fig. 2).

Figure 4 presents the time dependences of temperature for two heights at location A. The A location is placed 20 m from the outlet portal and about 30 m from the axial fan unit (in the case of the tunnel with mechanical ventilation). The significant difference between both tunnels can be observed at the height of 1.5 m. In the case of the natural ventilation the temperature remains near constant at the level of 90 °C for whole examined period of 10 min. Meanwhile for the tunnel equipped with the axial fans the temperature at this point has quickly and significantly risen reaching the value of 500 °C. It was caused by streaming the flow of

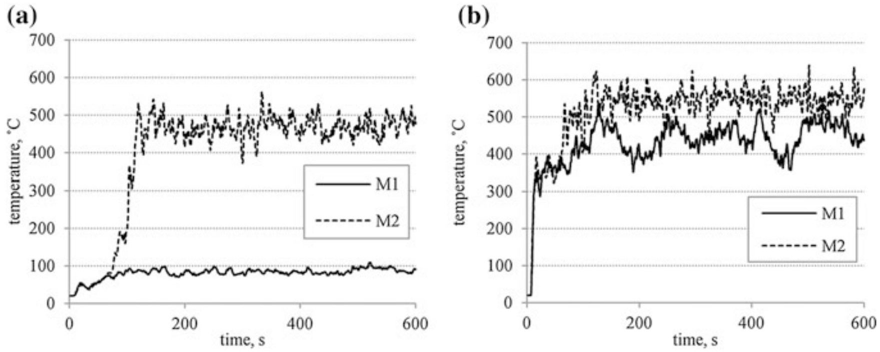

Fig. 4 The temperature measured for both models at A location at height: **a** 1.5 m; **b** 3.0 m

the hot gases by the axial fans, which blew the hot air towards the portal and mixed it. At the height of 3 m the temperatures were similar for both models, fluctuating between 400 and 500 °C.

The D location is placed at the distance of 50 m from the inlet portal and about 50 m from the axial fan unit (in the case of the tunnel with mechanical ventilation). The time dependences of the temperature at this location shown at Fig. 5 clearly demonstrate the effects of axial fans operation. Switching them on at 60th second of fire development has cleared of the hot fire gases the large part of the tunnel. This phenomena can be seen both at the height of 1.5 m and at the height of 3.0 m. Considering the tunnel with natural ventilation (model M1) one can notice the hot gases gathering under the ceiling and the lower part of the tunnel free of smoke. The temperature at the height of 1.5 m is about 70 °C and at the height of 3.0 m (near the ceiling) is about 200 °C.

The velocities of the air and hot gases flow was measured also for both models. The virtual result planes located at the tunnel axis were used here. The results are presented at Fig. 6.

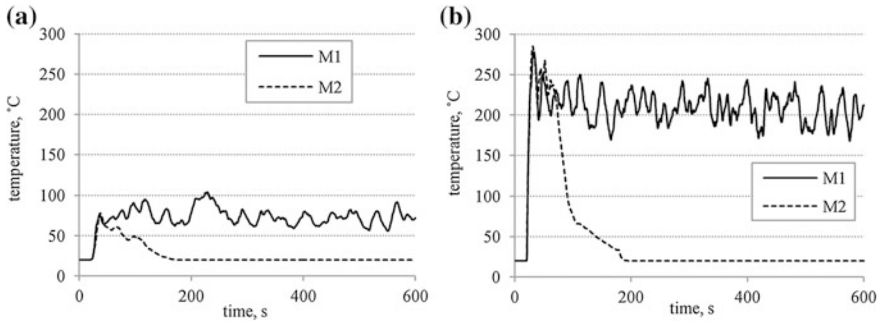

Fig. 5 The temperature measured for both models at D location at height: **a** 1.5 m; **b** 3.0 m

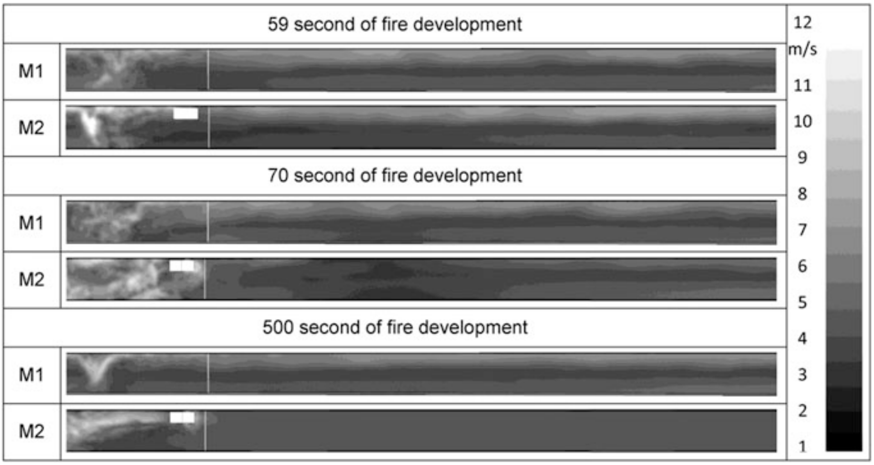

Fig. 6 The plains of the velocity distribution at the tunnel axis for three moments of the fire development, length of the tunnel is not in scale

The distributions of the air velocity until the 59th second of the fire development were similar for both models. The hot air was moving under the tunnel ceiling with the velocity of 4 m/s. For the model no 2 the axial fans were switched on at 60th second. As the result of their operation a stream of hot gases flowing from the fans unit towards the outlet portal was formed. The velocity of the stream was about 8 m/s. For the model no 1 (natural ventilation) the condition remained the same. It means the hot fire gases were still moving with constant velocity along the tunnel ceiling towards both portals.

The research tool here used allows to check the soot concentration inside the tunnel too. Figure 7 shows the soot mass fraction at A location for examined heights of 1.5 and 3.0 m.

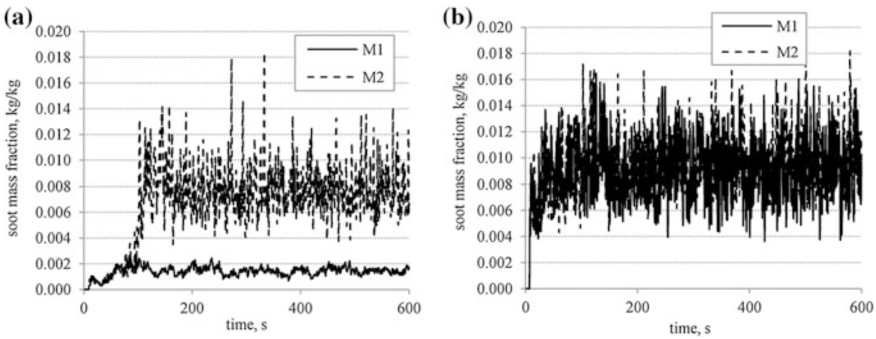

Fig. 7 Soot mass fraction for both models measured at location A at the height: **a** 1.5 m, **b** 3.0 m

The content of soot at the measurement location A, which lies between the portal and the axial fans unit is highly volatile. This is related to the intense air flow, which is the carrier of the carbon particles. The operation of the axial fans causes plunging the polluted air towards the outlet portal and at the same time bending of the air stream with soot downwards. At a height of 1.5 m significantly less amount of the soot is measured in the tunnel with natural ventilation. At a height of 3 m soot content is virtually the same regardless of the fire ventilation system. It is worth noting that the amount of soot measured by the virtual sensors is subject to very large fluctuations during the simulation.

In the case of the tunnel with the axial fans (model M2) the D location is placed in the part, where the hot air polluted by the fire gases is not blown (Fig. 8). It is just the part of the tunnel, where the evacuation of the people is possible. Then here the beneficial effects of the fans application are clearly visible. The fans started working at 60th second of the fire development and then were pumping the hot air and smoke towards the outlet portal. The operation of the fans had cleaned the large part of the tunnel as far as the inlet portal after about 180 s. The graph at Fig. 8b confirms that after 180 s this part of the tunnel with mechanical ventilation is completely free of smoke (both at height of 1.5 m and at height of 3.0 m).

In the case of a tunnel with the natural ventilation the soot content in the air varies within a large range but is kept at the same average level at a given height. Of course, the soot content is higher at a height of 3 m and is lower at a height of 1.5 m. The lack of fans operation causes that after the short time from the start of the simulation the average level of soot mass fraction was being stabilized and was maintained until the end. There is an important difference between the measurement at A and D locations to be observed: the values of soot mass fraction at D location are lower than values at A location. It is because the distance between location D

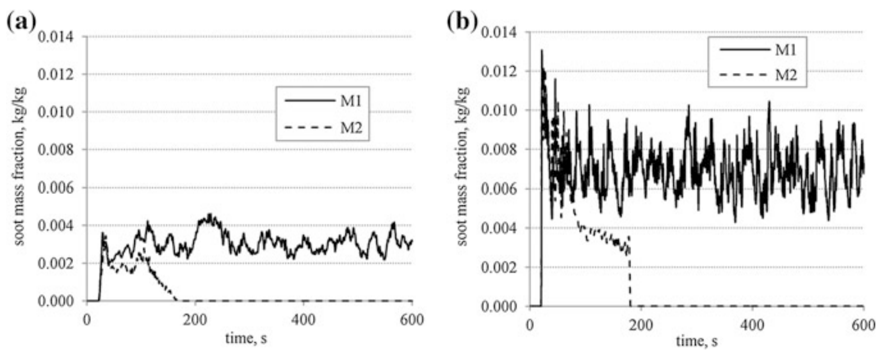

Fig. 8 Soot mass fraction for both models measured at location D at the height: **a** 1.5 m; **b** 3.0 m

and the fire position was about 60 m and the distance between A location and the fire position was only 20 m. The convection stream, which was rising above the fire and then was spreading symmetrically along the tunnel ceiling and had sucked the surrounding air. Thus the further from the source of the fire the larger amounts of air are gobbled and then the lower temperature and soot concentration were. But the volume of such mixture was growing with distance so the thickness of the hot contaminated layer is increased and could reach lower position.

5 Conclusions

The choice of the proper ventilation system for a road tunnel requires the great experience. While designing such ventilation system awareness is necessary that the system would have to operate also at hard fire conditions. It would then support the evacuation routes, so the safety of the people in the tunnel would depend on its efficiency.

The study has shown how the conditions in the tunnel in the case of fire are depended on the ventilation system selection. The tunnel with the natural ventilation and the tunnel with the mechanical ventilation implemented by the axial fans were examined.

The fire developing in the tunnel with the natural ventilation creates a convection stream spreading symmetrically under the ceiling. In this tunnel the conditions become stable quickly after the fire outbreak. This means that under the tunnel ceiling a smoke layer of the significant soot content and the high temperature was formed and such mixture was moving towards both portals. The lower part of tunnel volume was less contaminated, but the parameters determining the conditions of the safe evacuation were exceeded.

In the case of the tunnel with the mechanical ventilation the axial fans started to work at 60th seconds after the fire outbreak. After next 2 min the access route directly to the source of the fire from the inlet portal was completely cleaned, thus the safe evacuation route to the portal was established. However it should be here noticed, that the pass towards the second portal was practically impossible, because it was the direction where the axial fans pumped the hot gases and the fire smoke.

While designing the ventilation system for a short road tunnel besides the conditions of the normal operation the possibility of fire outbreak should be taken into account. Because of the empirical tests are in most cases impossible and the standards are too general only the numerical analysis give the opportunity for comprehensive study of the ventilation system being just designed.

The numerical analysis can show the dynamic development of the conditions inside the tunnel. They allow also to check the designed system operation under changing ambient conditions.

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Physically Disabled Pedestrians—Road Users in Terms of Road Accidents

Piotr Czech

Abstract Pedestrians are an integral part of the full-fledged road users. Like other users, they shape the traffic on the roads, as well as subject to all prevailing dependency on the road. Among a group of pedestrians can be distinguished group that will have a different specificity. This group includes people with disabilities. Such persons, because of their limitations, have different requirements for road infrastructure or means of communication. Way to move these people is also different. All these aspects must be taken into account by analysing the group in terms of past accidents on the road. The article presents issues that may be useful in the analysis of road accidents occurred involving pedestrian participants of roads, characterized by physical disabilities.

Keywords Physical disabilities · Pedestrian · Road traffic · Road accident

1 Introduction

One of many problems on the Polish roads are pedestrian safety, and more specifically the low level. By definition, the safety of people is their functioning without health damage.

Road safety is primarily to improve traffic management system, which aims to reduce vehicle traffic in areas where pedestrian traffic is increased. The same goes for speed limits, mostly in non-urban areas. Another very important factor is education. The direction of this type of action is to raise awareness of how one should behave on the road, as well as what kind of effects entails non-compliance of road safety rules.

Most problems regarding security of pedestrians occur in large and medium-sized cities, where car traffic is the biggest, and thus occur the biggest probability of accidents.

P. Czech (✉)
Faculty of Transport, Silesian University of Technology, Katowice, Poland
e-mail: piotr.czech@polsl.pl

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Technological progress means that engineers developing road infrastructure as well as means of transport reach for newer and newer technologies, which may affect the reduction in the number, or the consequences of road accidents. These actions are unfortunately not sufficient, because in the case of traffic accidents the most frequent cause is human error. It is the man mainly has the greatest influence on the development of events on the road.

At present in traffic accidents, many people were killed, as well as a large part has been disabled. According to the World Health Organization on the road on average every 30 s a man dies. This gives a yearly total of over one million people. In addition, as many as 50 million people suffer injuries [1].

2 Road Infrastructure and Solutions in Public Transport for Persons with Physical Disabilities

Considering the accidents, which were attended by physically disabled people, especially as pedestrians road users, it should be noted a different way of movement of such persons and resulting from this fact needs and problems.

Daily life requires constant human movement. Reaching the target, depending on the needs, can be done on foot, or by means of transport, including public [2]. For healthy people, these activities are not a problem in most cases. However, considering the case of persons with physical disabilities, these activities have become much more complicated. Even leaving home without of an elevator can be a problem. Then such persons may encounter on their way difficulties related to the width of the available pavement, the difference in height of the road surface, etc.

Also, the desire to take advantage of available public transport will not always result in effortless reaching the target. Fortunately, this matter are becoming more visible changes for the better.

In the case of tram and bus stops, are being used special engineering solutions designed to make it easier for people with physical disabilities, to make easier to reach public transport, to entrance or leave it. One of the solutions most commonly used at bus stops is the proper shaping of the driveway. As for the ground stops, where the road leads across a footbridge or underpass, it is necessary to use elevators, platforms or system of driveways. The choice of solution depends on the difference in height between the level of the stop and the ground, and the available space. Driveways are almost costless to use and easy to build. These solutions are used when there is little difference in height. In turn, solutions in the form of platforms or elevators are used where there is a large difference in height [3].

The use of driveways requires an adequate slope and width In addition, to avoid slips and falls, the surface may not be slippery—even when wet. If the length of the driveway exceeds 9 m the landing must be additionally applied. Its minimum length is 1.4 m. It is also important that the railing was mounted at the correct height.

As for public transport, they also are modified for the needs of persons with physical disabilities. Possible solutions to be used in this field are given in Regulations No 107 of the Economic Commission for Europe of the United Nations [4].

The main change in relation to the public transport not adapted for persons with physical disabilities is marking the vehicle. Proper marking of the vehicle makes that disabled people are able to determine whether they will be able to easily take advantage of the oncoming vehicle. The right information will allow them also to make the right choice of the door which they should use. Figure 1 shows the way of marking the public transport vehicle, which is adapted to persons with physical disabilities.

Further modifications of public transport are the implementation of the ramp, the lift or the kneeling system. They are to assist persons with disabilities in boarding and alighting from the vehicle.

In the case of ramp edges should be rounded with a radius not less than 2.5 mm, while the corners not less than 5 mm. The usable area of the ramp must have a width of 800 mm. The slope of the surface spread or extended on the ground may not exceed 36 %. In the case of the surface of the ramp unfolded or extended on the curb, whose height is 150 mm, the inclination may not exceed 12 %. The ramp, whose length in working order exceed 1200 mm must be equipped with a device to prevent rolling off the sides by the wheelchair. The outer edge of the surface of the ramp must be marked with tape width from 45 to 55 mm, which contrasts with the

Fig. 1 The way of marking the public transport vehicle, which is adapted to persons with physical disabilities

remainder of the ramp surface. Portable ramp, located in the ready-to-use position must be protected. It must be designated a suitable place where the portable ramp will be retractable. The ramp can be retracted and pulled out manually or mechanically. Mechanically operated ramp may be operated by the driver from his seat, if he sees it sufficiently to supervise its use and unfolding in a way that ensures safety. With the help of the sound signal and flashing yellow lights is signalled retracting and drawing of mechanically operated ramps. Safety devices must work while retraction and pulling of the ramp. In other cases, control devices should be located directly next to the lift. The driver from his seat can only turn them off or on. Manually operated ramps are designed to be operated it without considerable force.

Another device is a kneeling system. A control device that runs the raising or lowering of the whole or any part of the bodywork must be clearly marked and must be under control of the driver of the vehicle. With the help of control device within the reach of the driver seated in the cabin, as well as located near different control devices for handling the kneeling system, it can be inhibited and reverse the process of lowering. When the vehicle is in a lower position than the normal height while driving, there is no possibility that the vehicle was moving at a speed greater than 5 km/h.

All these solutions will have an impact on the decisions of a physically disabled person as to the manner of theirs movement in a particular case. In turn, this fact seems to be relevant in the case to an analysis of their participation traffic accidents.

3 The Speed of Movement of People with Physical Disabilities

One of the methods used in the process of assessment of road accidents—a method of time-space requires data on the speed of movement participants taking part in the incident. When it comes to the pedestrian traffic participants, literature provide a number of information in this respect. Unfortunately, there is no specific information especially needed to experts and a court expert. Especially poor is when it comes to people with physical disabilities. Therefore, studies were undertaken to determine the speed ranges in which such persons are moving.

The object of the study were physically disabled people, moving with a cane or crutches. The study was attended by 23 women and 23 men aged 15–75 years.

Parameter measured during the study was the time in which the participant of measurement, passed section with a length of 7 m, which corresponds to the minimum width of the roadway. The study was conducted by two methods. The first—from a standing start, the second—from a moving start. The first reflects the situation on the road, for example, when a pedestrian enters the road, standing before at a pedestrian crossing on a red light. The second simulates pedestrian intrusion into the street without first stopping in front of it. Test consisted of six measurements, each measurement was repeated three times to validate the result:

- measurement from a stop start:

– measurement 1—slow walking,
– measurement 2—normal walking,
– measurement 3—fast walking,

- measurement from a moving start:

– measurement 4—slow walking,
– measurement 5—normal walking,
– measurement 6—fast walking.

Before each test participant was instructed about the way of the test. A person alone determined whether to moves slowly, normally or fast.

The test results are summarized in Figs. 2, 3, 4, and 5. They represent the average value of the speed of movement of respondents according to their age and divided into men and women. In each figure, a trend line was added and the equation permitting designation moving speed of a pedestrian in a case other than measured. Each picture contains information for slow, normal and fast way of moving of the pedestrian.

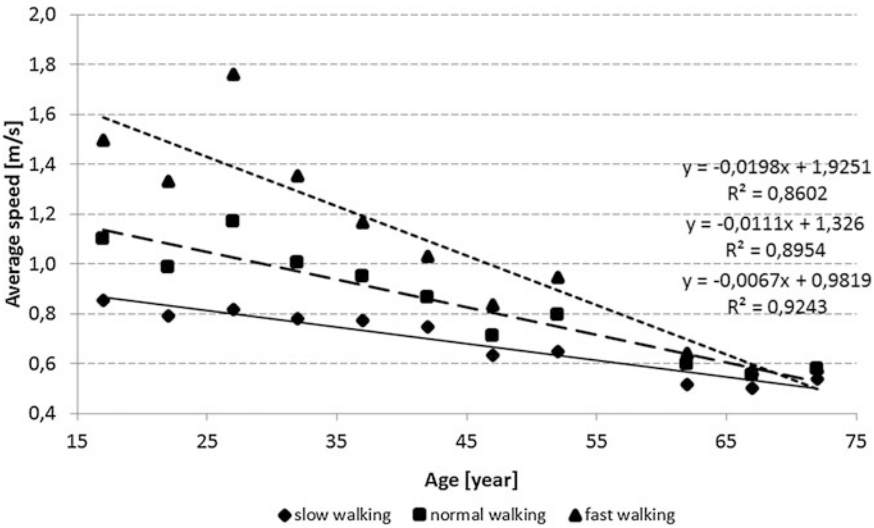

Fig. 2 Average values of movement pace for women—measurement from a stop start

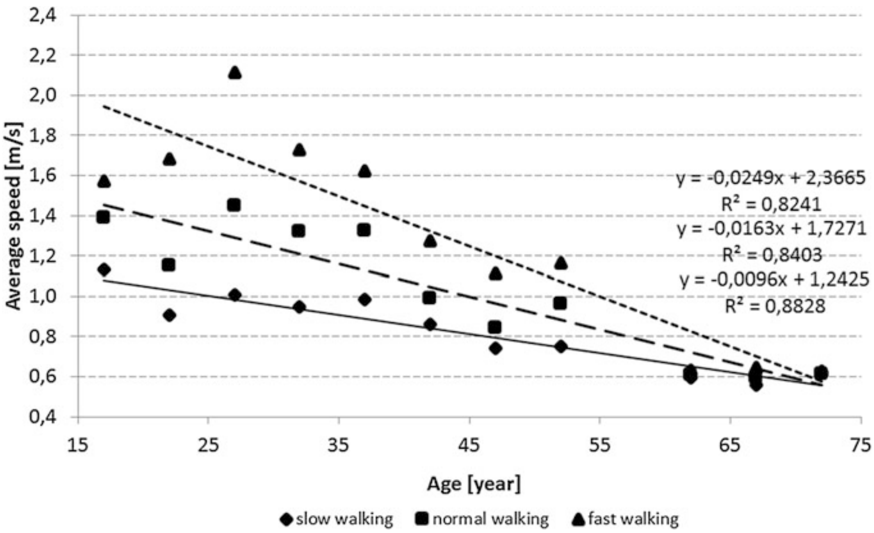

Fig. 3 Average values of movement pace for women—measurement from a moving start

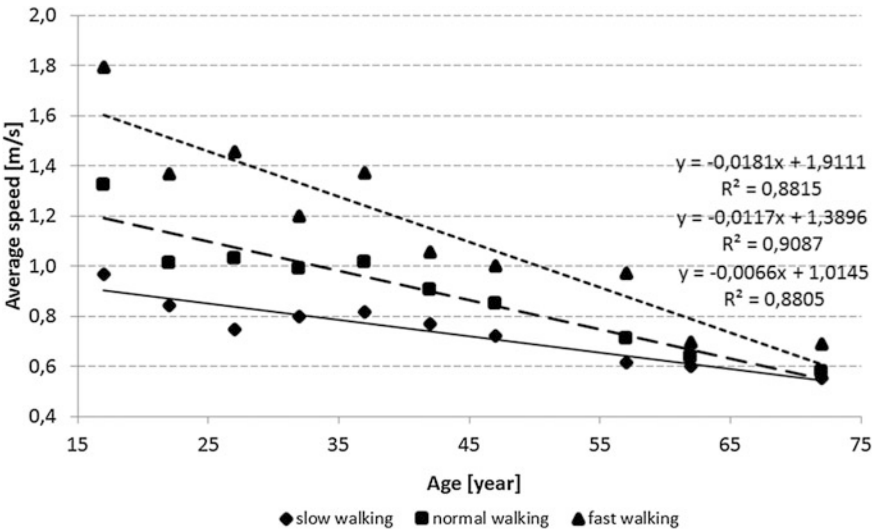

Fig. 4 Average values of movement pace for men—measurement from a stop start

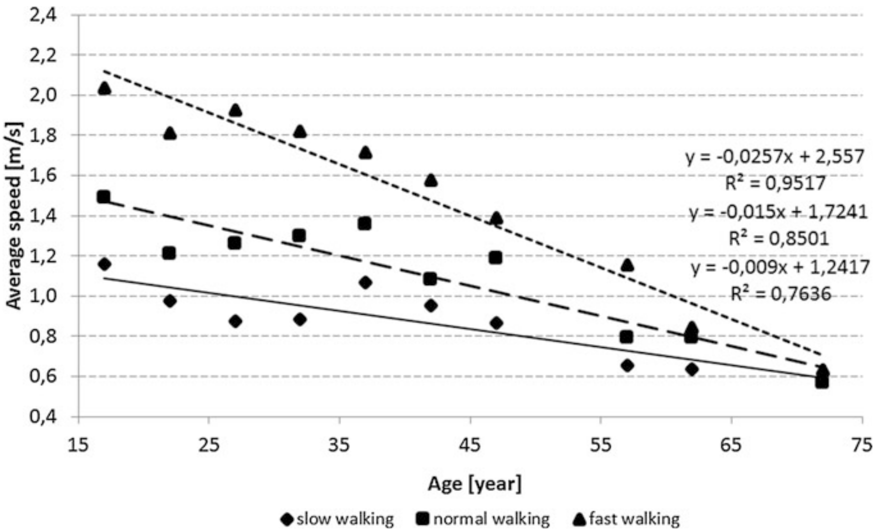

Fig. 5 Average values of movement pace for men—measurement from a moving start

4 Conclusions

Problems of traffic accident research occupies all over the world the number of institutions (sample test results can be found in [5–20]). They are guided in different ways and in different fields of science, including technology, medicine, social sciences, economics or psychology. In each of them are taken into account the various factors resulting from the different specificity of research and goals, as well as the selected object of research.

By analysing traffic accidents involving pedestrians road, should be considered a different group in the form of persons with physical disabilities. These individuals by virtue of their mobility limitations, will behave on the road in different way than healthy people. Their decisions about the way which they are moving, they make on the basis on the available infrastructure, which is often unsuited to their needs. It has also an impact the sample choice of means of public transport, where they intend to move in the further way and the need to get into it with minimal effort.

The study aimed to determine the limits of the speed with which physically disabled people are moving, using during the moving the sticks or crutches. The designated speed are in the following ranges:

- women:

– measurement from a stop start:
– slow walking: 0.50–0.87 m/s,
– normal walking: 0.55–1.22 m/s,
– fast walking: 0.57–1.90 m/s,

– measurement from a moving start:
– slow walking 0.56–1.18 m/s,
– normal walking: 0.59–1.65 m/s,
– fast walking: 0.63–2.34 m/s,

• man:

– measurement from a stop start:
– slow walking: 0.55–1.07 m/s,
– normal walking: 0.58–1.63 m/s,
– fast walking: 0.69–2.25 m/s,
– measurement from a moving start:
– slow walking: 0.60–1.33 m/s,
– normal walking: 0.57–1.80 m/s,
– fast walking: 0.63–2.39 m/s.

The results may be useful in the course of issuing opinions of road accidents involving the pedestrian with physical disabilities. The need to use this type of results occurs when using by experts from the method of time-space analysis of the accident.

By analysing traffic accidents should not be forgotten that irrespective of the fact who is involved in them (vehicle or pedestrian), contributing to their occurrence may be on the side of human, vehicle or road infrastructure. When it comes to vehicles and infrastructure, the current advances in technology and research conducted all over the world (for example [21–29]) affect the significant limitations of this type of evidence for the occurrence of traffic accidents. However, it remains a matter of man and his decisions, which nowadays contribute most to the occurrence of a road accident.

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Part IV
Advanced Systems of Traffic Engineering and Travel Models

Impact of Different Lengths of Urban Road Segments on Speed-Volume Relationship

Gundolf Jakob

Abstract Speed-flow equations have been developed for use in travel demand models to accurately predict the speed of traffic on urban roads. However, in urban environments the corresponding correlations are quite complex since they are influenced by relatively short road segments and signalized intersections resulting in interrupted traffic flow. Hence, networks, traffic and control strategies represent influencing factors with respect to the speed-volume relationship. In this context, the adequate length of a lane is a basic condition for a lane to realize its full capacity. Thus, this paper focuses on the investigation of the impact of different lengths of urban road segments on the speed-volume relationship by means of a simulative approach. The impact of both reductions and extensions of an urban road segment with respect to statistically significant changes in speed values under undersaturated and saturated traffic conditions will be presented.

Keywords Speed-volume relationship · Length of urban road segments · Microscopic simulation

1 Introduction

In recent years, some efforts have been made to accurately predict the speed of traffic on signalized or non-signalized urban arterial roads and networks. As a result, there are several curves based on different theories and models. Greenshields's model, the BPR curve and the Akcelik speed-flow curve are just some well-known representatives. In this context, it is worth mentioning that the accurate calculation of current traffic volumes or degrees of saturation out of speed based information represents a significant challenge since there is no simple analytical correlation between these two parameters in an urban environment. This is especially due to the

G. Jakob (✉)
Chair of Traffic Engineering and Control, Technische Universität München, Munich, Germany
e-mail: gundolf.jakob@tum.de

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fact that urban road networks, in contrast to motorways, are often characterized by relatively short road segments in between signalized intersections causing interrupted traffic flow.

Concerning speed-volume relationships in an urban context, there are various influencing factors, e.g. traffic, control strategies and network-related issues. A lot of effort has been put on the analysis of traffic composition and of interrupted flow conditions as a result of different traffic signal control strategies at intersections. However, as a basic and crucial condition, the capacity of a lane can only reach its full potential if the corresponding length of the lane is sufficient. Moreover, the adequate dimensioning of the lane is significant with respect to the functionality of the traffic signal control.

Thus, in this paper the impact of different lengths of urban road segments on the speed-volume relationship will be investigated. Hence, in the next section related work will be presented. In Sect. 3, the methodology by means of a simulative approach will be described. In Sect. 4, the corresponding results will be analyzed and illustrated. In the last section conclusions will be drawn.

2 Literature Review

There are both models referring to highways and concepts dealing with the speed-volume relationship within the frame of urban environments.

Concerning highways, a fundamental model was developed by Greenshields [1]. The corresponding correlations have been widely used to estimate speed from density due to its elegant and quite simple approach. However, this kind of concept is not appropriate with respect to urban roads. Thus, it is not recommended to convert it to speed-volume models and to deduce speed-flow relationships in urban networks.

There are several factors, interacting with each other, that influence the speed-volume relationship in an urban context. Accordingly, there are different approaches and models for analyzing the speed-volume relationship, e.g. in case of an interrupted oversaturated flow with heterogeneous traffic [2]. The corresponding functions can be used to estimate speed, delay, average queue and maximum queue based on traffic volume.

A more detailed study on the effect of traffic composition on the speed-volume relationship can be found in [3]. Results indicate the existence of eight different regions of speed-volume behavior that can be allocated to three basic patterns of the speed-volume relationship. The first pattern reflects free-flow conditions with travel speed exhibiting a weak oscillating behavior around a mean value whereas volume shows a stronger variability. Concerning the second pattern, volume oscillates less around mean values whereas speed varies greatly. The third pattern reflects the state when speed takes on low values probably illustrating congested situations. It was determined that the contribution of traffic composition varies in each region and pattern. Hence, with the exception of high speed values where trucks significantly affect the speed-volume relationship, motorcycles and taxis play a critical role in most regions of the speed-volume relationship.

Moreover, speed data of all vehicles combined at a section of an urban road may not follow the normal distribution due to the heterogeneous nature of traffic whereas in case of an individual vehicle it generally follows a normal distribution [4]. The term by the name of Speed Spread Ratio (SSR) is considered a good predictor of normality in the speed data. It is the ratio that is calculated by dividing the difference in 85th and 50th percentile speed to the difference in 50th and 15th percentile speed. If this ratio is in the range of 0.86–1.11, then speed data would follow a normal distribution. With the presence of slow moving vehicles the speed spread ratio will deviate from the range and the speed data will not follow the normal distribution.

Another focus within the scope of urban speed-volume relationship can be put on the impedance effect of exit intersections [5]. Traffic conditions on one road can have a strong impact on other roads, especially under oversaturated traffic flow. This is due to the fact that urban roads are rather short and therefore a traffic queue on one road can extend to its upstream roads causing a spillover of congestion. Hence, this approach considers the impedance effect of exit intersections that is strongly related to the traffic conditions on downstream roads. Corresponding estimation errors of this approach are constantly lower as compared to Greenshields' model [1] that refers to traffic situations on highways.

Moreover, on urban arterials traffic signals are strongly influencing travel times [6]. Hence, these travel times can be used to deduce information about the performance of traffic signals. The volume-capacity ratio computed based on demand and signal timings is correlated with corresponding travel times collected in the field by means of a point-to-point travel time measurement technology. The resulting volume-delay function can be used to estimate volume-capacity ratios and other signal performance metrics.

In this literature review, relevant work within the frame of urban speed-volume relationship has been presented focusing on traffic-related factors, e.g. traffic composition and traffic conditions, and control-related aspects, e.g. traffic signal control. Furthermore, there is another component influencing urban speed-volume relationships representing network-related issues, e.g. the length of urban roads. Hence, this paper is focusing on the impact of different lengths of urban road segments with respect to speed-volume relationship since length is a critical factor for realizing the full capacity of a road segment.

3 Simulation Model

3.1 Overview

In order to evaluate the effect of different lengths of road segments on urban speed-volume relationship a simulative approach is used. There are several microscopic simulations tools [7–9]. In this paper, the microscopic, time step and behavior-based simulation model VISSIM is applied to analyze the operations on urban street networks [10]. VISSIM simulates the traffic flow by moving "driver-vehicle-units" through a road network. Every driver with his specific behavior characteristics is assigned to a specific vehicle. Consequently, the driving behavior corresponds to the technical capabilities of his vehicle. Attributes that characterize each driver-vehicle-unit can be subdivided into three categories: technical specification of the vehicle, behavior of driver-vehicle units and interdependence of driver-vehicle units.

3.2 Modeling of Driving Behavior

Longitudinal Movement—the quality of the modeling of vehicles is crucial for the accuracy of a traffic simulation model. Concerning the longitudinal vehicle movement, VISSIM applies a psycho-physical car-following model developed by Wiedemann [11]. The name of the model is due to the fact that there is a combination of psychological aspects and physiological restrictions of a driver's perception. The basic idea of the Wiedemann model is the assumption that a driver can be in one of four driving states, i.e. free driving, approaching, following or braking. Hence, the driver of a faster moving vehicle starts to decelerate as soon as he reaches his individual perception threshold to a slower moving vehicle. Since he is not able to precisely determine the speed of this vehicle, his speed will fall below that vehicle's speed until he starts to slightly accelerate again after reaching another perception threshold. The result is an iterative process of acceleration and deceleration (Fig. 1).

The minimum safety distance in the Wiedemann model is calculated as shown in (1). Furthermore, approaching a traffic signal results in a higher alertness for drivers at a distance of 100 m in front of the stop line.

$$ABX = AX + (BX_{add} + BX_{mult} \cdot z) \cdot \sqrt{v} \quad (1)$$

Here, AX represents the average standstill distance defining the average desired distance between two vehicles. The calibration parameters BXadd and BXmult are the additive and multiplicative part of the following distance, respectively. The variable z is a driver dependent parameter normally distributed around 0.5 with a standard deviation of 0.15. The speed of a slower moving vehicle is represented by the variable v.

Lateral Movement—in addition to the psycho-physical car-following model for longitudinal vehicle movement there is also a rule-based algorithm for lateral movements [12]. A driver may have the desire to change lane if he has to drive slower than his desired speed due to a slow leading vehicle. Hence, the driver has to decide whether the driving situation in the neighboring lane is suitable for a lane change and whether he can improve his present situation by changing lanes.

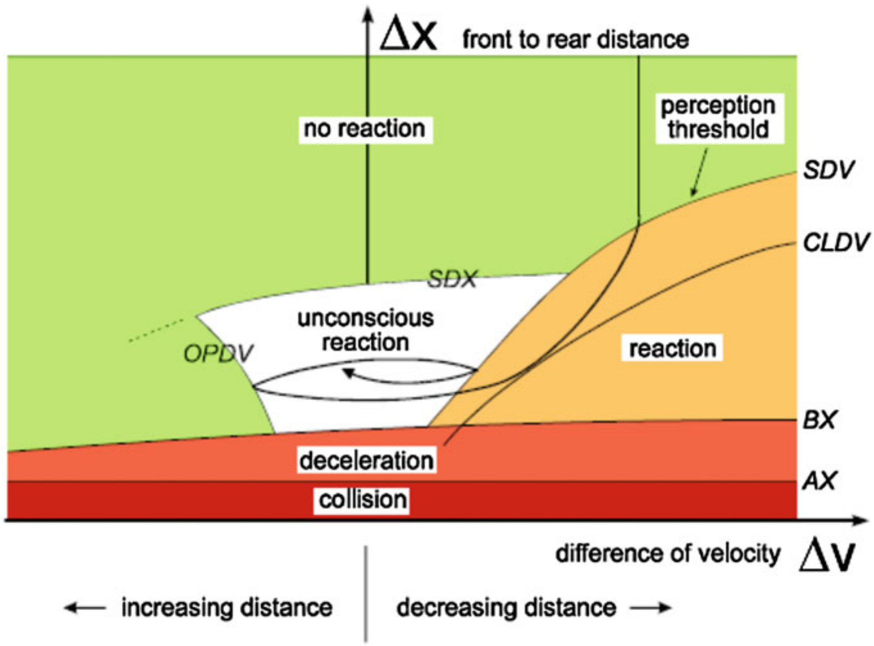

Fig. 1 Car-following logic according to the Wiedemann model (*Source* [11])

Moreover, the driver has to determine whether the manoeuvring to the neighboring lane is possible without creating a dangerous situation.

3.3 Implementation of the Simulation Network

For a completed VISSIM simulation network there are four building blocks required: network, traffic, control and output. The output block is essential for defining evaluation types, selecting measurements of effectiveness and obtaining numerical and graphical results from the simulation runs. In this section, the implementation of the simulation network will be described with respect to network, traffic and signal control related aspects. Furthermore, calibration and validation issues will be addressed.

Network—the network building block is required to represent the physical infrastructure of roadways. In order to identify a suitable site to investigate the impact of different lengths of urban road segments on the speed-volume relationship, several frame conditions have to be taken into account. Hence, infrastructural characteristics of the road section, traffic-related legal aspects and traffic volumes as well as traffic compositions have to be considered. Furthermore, safety issues and space requirements play an important role within the scope of taking own measurements on the corresponding road section to calibrate and validate the simulation model.

As a result, an arterial road section in the medium-sized German City of Ingolstadt has been identified as being representative and suitable for the objective of this study. This road has a connecting function between a highway and the site of a car manufacturer headquartered in the City of Ingolstadt. Hence, high traffic volumes as well as congested situations can be found on this road section because of the vast amount of employees working shifts and suppliers delivering goods at certain periods of the day.

The road segment to be investigated consists of two lanes with a speed limit of 50 km/h and is situated in between two intersections controlled by traffic signals (Fig. 2). It has a length of 363 m that will be varied during the different simulation runs to deduce the impact of different lengths of urban road segments on the speed-volume relationship in form of a sensitivity analysis.

Traffic—the traffic building block is used to illustrate the vehicular movements in the network. Traffic demand is specified by volume, traffic composition and travel routes. In this simulation study, different traffic volumes are considered by means of corresponding levels of saturation degrees both under undersaturated and oversaturated traffic flow conditions. The saturation degrees are derived according to the rules and regulations outlined in the German Highway Capacity Manual HBS [13].

Concerning traffic composition, the heavy vehicle traffic share with respect to the whole traffic volume is an important parameter. In this study, a corresponding share of 2 % has been implemented. Furthermore, traffic is spilt only into cars and heavy

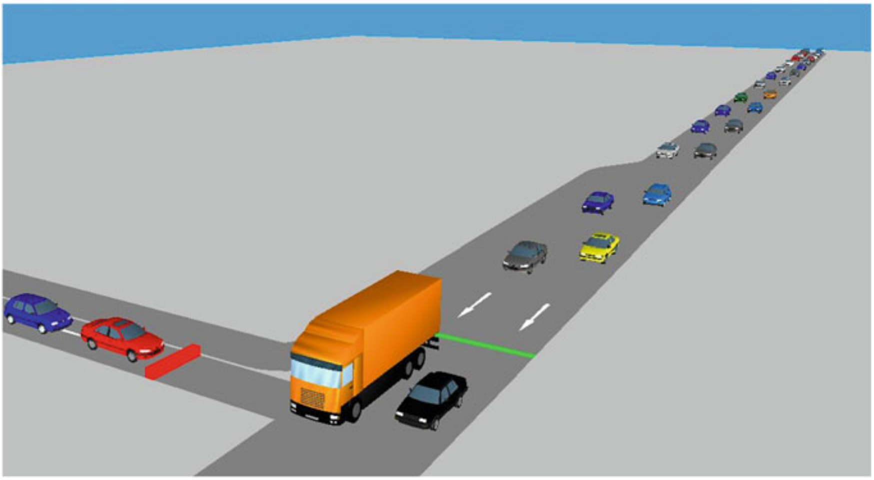

Fig. 2 3-d view of the network

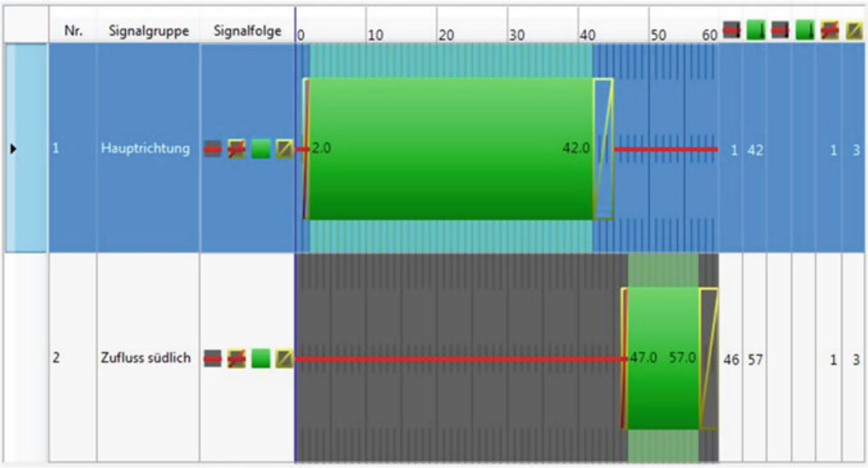

Fig. 3 Scheme of a signal program in case of a fixed-time traffic signal controlled intersection

vehicle traffic whereas motorcycles, cyclists and pedestrians are not considered. Travel routes can be used for a better representation of the actual traffic pattern in the road network. They can be applied to specify the amount of right turning vehicles at an intersection.

Control—control strategies are required for defining the traffic behavior in case of conflicting movements. Signal heads belonging to a fixed-time traffic signal control are implemented as a control element in the area of the intersection. The corresponding signal program consists of two signal groups in order to facilitate the movement of traffic (Fig. 3). Traffic in the main direction has been assigned signal group no. 1 whereas signal group no. 2 has been applied in case of traffic arriving from the minor direction at the intersection. In this study, a fixed cycle time of sixty seconds comprising a green time period of forty seconds for the main direction and an intergreen time of five seconds are specified.

Calibration and Validation—are crucial steps in a simulation process to be able to get meaningful and reliable results. Calibration describes a process aiming at the adjustment of different simulation parameters whereas validation is the proof that by using the calibrated model an empirical data set can be reproduced with a sufficient accuracy. It has been shown that the simulation model VISSIM is suitable to reflect different traffic situations, both in case of German and US scenarios [14].

In this context, field data are an important basis, e.g. in order to develop improved field-calibrated speed-flow equations to predict the mean speed of traffic on signalized urban arterial streets [15]. Hence, travel time measurements and field observations on the road segment in the City of Ingolstadt have been implemented to calibrate and validate the simulation model. Thus, reliable results concerning the impact of different lengths of urban road segments on the speed-volume relationship can be deduced.

3.4 Data Collection

The objective of this study is to determine the impact of different lengths of urban road segments on the speed-volume relationship in form of a sensitivity analysis. Hence, the length of the segment on the arterial road in the City of Ingolstadt will be varied during the simulation as follows: 213, 263, 313, 363, 413, 463 and 513 m.

Furthermore, for every of the seven cases illustrated above eight different traffic volumes ranging from 333 vehicles per lane per hour to 1778 vehicles per lane per hour representing corresponding saturation degrees of 0.25 to 1.33 have been considered.

In order to get reliable and significant results, at least in case of undersaturated and saturated conditions, for every combination of segment length and traffic volume several simulation runs applying different random seed numbers have to be performed. Using a different random seed number changes the profile of the traffic arriving and therefore results may also change. Hence, the stochastic variation of input flow arrival times can be simulated. For significant results it is recommended to determine the arithmetic mean based on the results of multiple simulation runs with different random seed settings. The amount of required simulation runs has been calculated by using the following Eq. (2) resulting in five simulation runs for every combination of segment length and traffic volume.

$$n \geq \frac{t(\alpha, n-1)^2 * s^2}{e_a^2} \tag{2}$$

Here, n represents the minimum number of required simulation runs, $t(\alpha, n-1)^2$ is a value of the Student t-distribution, s^2 is the variance and e_a^2 is the maximum error of the estimate.

Each simulation run comprises 21,600 simulation seconds including a warm-up period of 1800 s. Warm-up times need to be included in the total simulation period allowing the simulation to reach a steady-state condition with normal traffic patterns, but they should be excluded from the final calculation of the simulation statistics.

4 Simulation Results

As already mentioned above, for every combination of segment length and traffic volume five simulation runs have been performed to obtain meaningful results. In a first step, it can be generally deduced that speed values vary according to different road segment lengths, especially in case of undersaturated and saturated traffic flow conditions (Fig. 4).

Secondly, for further investigations a t-test was implemented to verify statistically significant differences in speed values depending on the road segment length.

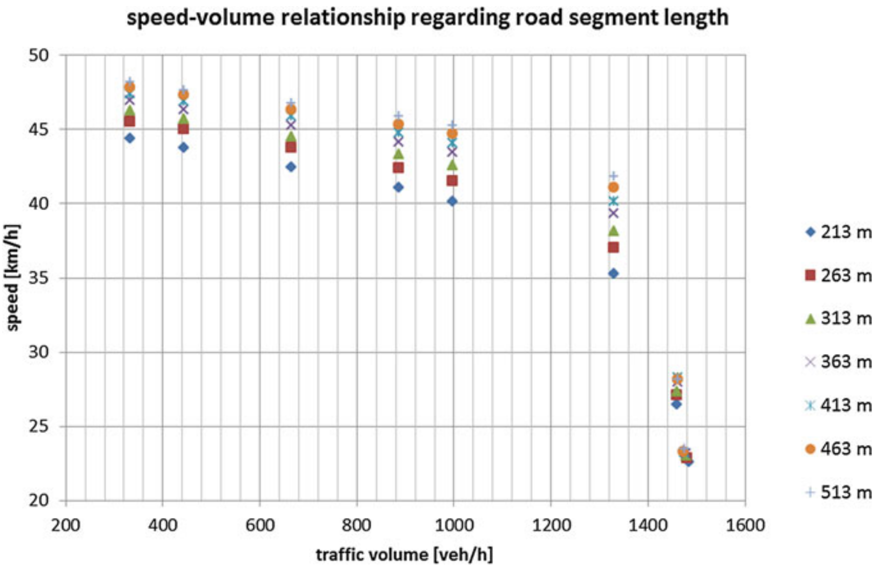

Fig. 4 Speed-volume relationship with respect to different road segment lengths

Consequently, based on the actual and reference segment length of 363 m, both the reduction and extension of this length by 50, 100 or 150 m lead to significant changes in speed values (Table 1). In general, the higher the traffic volume, the higher is the percentage change in corresponding speed values. These findings apply to traffic volumes of 333 vehicles per hour per lane up to 1333 vehicles per hour per lane corresponding to saturation degrees of 0.25 to 1.00 representing undersaturated and saturated conditions.

Thirdly, referring to the reference segment length of 363 m, it can be deduced that a reduction of this segment length has a stronger effect on speed values as compared to a corresponding extension. As an example, regarding a traffic volume of 667 vehicles per hour per lane the speed reduction comprises 6.25 % when reducing the segment length by 150 m whereas the increase in speed is only 3.36 % in case of extending the segment length by 150 m.

Concerning oversaturated traffic conditions, hence, e.g. in case of a saturation degree of 1.1, the findings presented above only partially apply in case of certain segment lengths as can be seen from the corresponding statistically significant combinations marked with an asterisk in Table 1.

Moreover, concerning a certain level of traffic volume, not only do increased segment lengths imply continuously higher speed values, but they also lead to reduced variances of these speed values under undersaturated traffic conditions. This is due to a reduced traffic density enabling drivers to travel at their own individual desired speeds and to interact less with other vehicles. Thus, e.g. in case of a traffic volume of 667 vehicles per hour per lane the corresponding variance of

Table 1 Analysis of impact of different road segment lengths on speed-volume relationship

Speed (km/h)	333 veh/h (g = 0.25)	444 veh/h (g = 0.33)	667 veh/h (g = 0.50)	889 veh/h (g = 0.67)	1000 veh/h (g = 0.75)	1333 veh/h (g = 1.00)	1467 veh/h (g = 1.10)	1778 veh/h (g = 1.33)
213 m	44.39*	43.80*	42.45*	41.09*	40.15*	35.30*	26.45*	22.60
263 m	45.55*	45.00*	43.76*	42.39*	41.55*	37.01*	27.09*	22.84*
313 m	46.30*	45.73*	44.53*	43.32*	42.59*	38.14*	27.36*	23.02*
363 m	46.95	46.34	45.28	44.16	43.46	39.35	27.97	23.17
413 m	47.38*	46.91*	45.93*	44.81*	44.09*	40.13*	28.29	23.21
463 m	47.85*	47.34*	46.37*	45.32*	44.74*	41.12*	28.18	23.27
513 m	48.23*	47.63*	46.80*	45.88*	45.29*	41.87*	28.16	23.49*

* significant values at a confidence level of 95 %

the speed value is reduced from a level of 1.32 down to 0.52. Furthermore, in the area of saturated traffic conditions, e.g. at saturation levels of 1.00 or 1.10, a sharp increase in the variances of the corresponding speed values can be seen.

5 Conclusions

The objective of this paper was to investigate the impact of different lengths of urban road segments on the speed-volume relationship. The investigated road segment had an actual length of 363 m that was varied during different simulation runs with respect to the objective mentioned above.

It has been deduced that based on this reference length of 363 m both reductions and extensions lead to statistically significant changes in speed values under undersaturated and saturated traffic conditions with effects being stronger at higher traffic volumes. Furthermore, reductions of this segment length had greater impacts on speed values as compared to corresponding extensions. Moreover, increased segment lengths also led to reduced variances of these speed values. This phenomenon could be attributed to a reduced traffic density allowing drivers to travel at their desired speeds and to interact less with other vehicles.

Concerning further research, different heavy vehicle traffic shares and other traffic signal control strategies, e.g. traffic actuated signal control, should be investigated within this context. Moreover, it may be interesting to conduct a similar study according to the driving behavior in other countries.

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Moulding of Travelling Behaviour Patterns Entailing the Condition of Road Infrastructure

Marcin Staniek

Abstract The paper provides a discussion on a trip planner used as a tool for moulding of travelling behaviour patterns of persons moving in a dense transport network. The solution proposed entails the road infrastructure condition while planning transfer routes. Having defined the travel origin and destination points, a trip planner user receives information on the proposed travelling routes corresponding to roads of better technical condition. Thus the user is offered a choice of the route for the travel to be made with higher travelling comfort. Studies enabling the road infrastructure condition to be described were conducted under the Green Travelling project using mobile devices recording linear accelerations while travelling within the transport network area of the central part of Silesian Voivodeship.

Keywords Multimodal trip planner · Travel behaviour patterns · Road pavement conditions · Travelling comfort

1 Introduction

It is through human behaviour that people adapt to the environment in which they function, including all of its advantages as well as flaws and constraints. Such behaviour is moulded by environmental stimuli or a man's reactions towards this environment, i.e. its complex structure of interrelations and functional features. In other words, human behaviour is in fact a specific conduct (frequently complex) oriented at achieving the intended goals in a pre-defined environment, in strictly defined time limits [1–3].

Travelling behaviour patterns observed among travelling persons are manifestations of people's approach towards travelling by different means of transport in the sphere of time and space. Many a time, they are conditioned by diverse

M. Staniek (✉)
Faculty of Transport, Silesian University of Technology, Katowice, Poland
e-mail: marcin.staniek@polsl.pl

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motivations and dependences between the decisions being made and certain socio-demographic factors. The very stage of making a choice for the sake of the transfer goal relies on current capabilities and limitations of organisational, infrastructural, economic or social nature. It is also frequent that the factor determining the manner in which one travels is a habit [3–5].

Fundamental knowledge on travelling behaviour patterns of people travelling in the given area represents the actual condition of the transport system and its functional capacities. It highlights both its strengths and its constraints which should be eliminated or considerably limited in the future. It also provides vital information for similar areas from the perspective of appropriate development of the transport policy of towns, agglomerations or regions.

At present, travels made with passenger cars account for a decided majority of all transfers. The continuous increase of the number of vehicles using roads is becoming the cause of traffic obstacles, particularly in urban areas where one is faced with the phenomenon of congestion. It consequently increases the time loss as well as costs incurred by those travelling. It additionally contributes to the rise of both noise and atmospheric emission of hazardous substances. Counteracting these negative effects in towns or agglomerations is possible through changing the modal split of traffic to the benefit of eco-friendly travelling solutions [6–8]. Switching from a passenger car to such means of transport as a bus, a trolleybus or a tram decreases the number of vehicles in roads, thus reducing congestion.

Unfortunately, moulding of travelling behaviour patterns among travelling persons is not an easy task, and it requires long-term and complex publicity campaigns. Educating and informing travellers is an objective of a campaign which must address a wide range of recipients in the transport system environment. An additional advantage of such a solution is the economic efficiency against the costs of implementation of the Intelligent Transport Systems (ITS) technology or investments in infrastructure and means of transport. This fact is becoming even more important for towns or agglomerations bearing the contemporary financial conditions in mind.

This paper provides a proposal of a method to mould travelling behaviour patterns entailing the condition of road infrastructure. It has been assumed that road infrastructure, along with its condition, constraints and capacity, exert a major impact on the behaviour patterns displayed by transport system users. A hypothesis has been proposed that condition of the road infrastructure will be a determinant of travel planning for the existing transport system in a part of the Silesian agglomeration. The method proposed for moulding of travelling behaviour patterns involves a trip planner to be used for setting the route planned, entailing the road infrastructure condition. The trip planner tool as well as the survey being a source of the road pavement condition description were both developed under an international project entitled “A platform to analyse and foster the use of Green Travelling options (GREEN TRAVELLING)” implemented as a part of the ERA-NET Transport III Future Travelling programme.

2 GT Planner as Tool for Moulding of Travelling Behaviour Patterns

Popular and commonly available web-based trip planners make it possible to seek connections between two points within a specific area for a pre-set transport network. They are often offered to users by collective transport operators as a means to support travel planning. However, such solutions are encumbered with a significant flaw, namely the exclusivity of planning with reference to the given transport operator, which translates into inability to compare all potential travelling options. Newly developed, expanded trip planners meet the criterion of comprehensive approach to travel planning, at least to a limited degree. In this respect, planning a travel within the territory of a pre-defined transport network can be brought down to walking, using a passenger cars and collective transport. The connection search criteria implemented in algorithms used to find an optimum solution (i.e. travel) are those of distance and time. Based on the distance criterion, the algorithm searches for the shortest route between the points of origin and destination. What is identified as optimum with regard to the time criterion is the travel with the shortest time [9].

The trip planner developed under the Green Traveling project (GT Planner), besides the basic functions shared with other popular planners, makes it possible to define routes in various modes:

- individual, where one of the following set of transfer options: walk, bike, electric car, car, motorcycle, is taken into account while the travelling route is planned,
- multimodal, where different means of collective transport as well as travelling on foot are taken into account in the planning, namely the following options are available: “walk and public transport”, “walk and urban bike”, “walk and urban car”, “walk and urban transport”,
- individual + Multimodal, where solutions based on multiple means of collective transport and individual transport, such as: “walk and Park and Ride”, “walk and Bike and Ride”, are taken into consideration in trip planning.

There is also an additional “All” mode available, searching through all the possible solutions for the travel completion based on each of the aforementioned modes. Irrespective of the above route searching modes, what has been implemented in GT Planner is a criterion for seeking both the route and the means for travelling on minimisation of environmental emission of harmful substances, this being referred to as the “greener” criterion. In the GT Planner version used and discussed, searching for “greener” routes is based on the CO_2 emission minimisation. The fact that the said tool has been implemented makes it possible to modify the database of emission-related coefficients or adding new chemical compounds of crucial importance from the perspective of the environmental impact of transport. Next to the “greener” criterion, GT Planner features a criterion for searching the cheapest solution. As input data are entered for the sake of the route planning, the planner user defines travelling costs for the chosen individual means of transport, i.e. the price for a unit of energy and the energy consumption per 100 km. As regards urban bicycle or car rental services, including electric cars, rental costs are defined in a dedicated file by the GT Planner administrator. If individual parameters are unknown or have not been set by the planner user, calculations entail default values entered in the course of the tool implementation. Trip planning based on collective transport relies on a static timetable acquired from transport operators servicing the given transport system area in the GTFS (General Transit Feed Specification) standard. A detailed presentation of the planner features has been provided in publication [9].

The GT Planner capabilities addressed determine the options for moulding of travelling behaviour patterns. The user is informed about the possible ways to travel between the pre-set points of origin and destination in a graphical and tabular form. Furthermore, the information thus provided, on account of the implemented routing modes and optimisation criteria, highlights the transfers promoting eco-friendly solutions. The “greener” criterion, developed and implemented in the planner, makes travellers realise the environmental impact of the travelling mode they have chosen. In this respect, it should be noted that a person about to set off is often lacking sufficient knowledge about an alternative travelling mode available within the given area, one which is characterised by reduced emission. Every travel route planned as a result of GT Planner’s operation comprises such data as the travelling path, means of transport, travel time and length as well as cost and emission.

An additional function of GT Planner is the possibility of taking data about the road infrastructure condition into account while planning the route. The solution proposed entails real data concerning the condition of road pavement used in trip planning. By that means, the GT Planner user is guided to a route of better technical condition which directly affects the former’s travelling comfort.

3 Road Infrastructure Condition Assessment

Infrastructure and means of transport are the two key elements of passenger and cargo transport. Without appropriately developed and maintained road infrastructure, indicators of road transport quality and traffic safety will never attain a satisfactory level, and users of this system will dispense with the given specific transport offer. Therefore, assessment of the road pavement condition is a priority component of the system of road infrastructure maintenance and road traffic safety assurance [10, 11]. The assessment methods applied [12, 13] make it possible to identify the road sections which constitute a real hazard to the safety of vehicle traffic and which require that overhaul or repair works be undertaken immediately.

For the sake of the road pavement assessment, one must first define such technical and operating parameters as its load bearing capacity, pavement condition entailing the identification of bumps, patches, fractures as well as transverse and longitudinal evenness or anti-skid properties. Duration, precision and degree of comprehensiveness of measurements are the priorities of the road pavement diagnostics system. Such an approach determines application of state-of-the-art solutions in terms of measurement of technical road parameters. The latest diagnostic solutions are non-invasive in nature, meaning that they do not interfere with the road structure while measurements are conducted, and at the same time, the measurements do not cause hindrance to traffic participants [12]. The assessment and analysis of results thus obtained makes it possible to draw conclusions concerning the road infrastructure condition as well as to establish time limits and the scope of necessary repair procedures or overhaul works. And when integrated with a strategic approach, it enables planning and distribution of funds required to maintain the road infrastructure operational.

3.1 Acquisition of Data Concerning the Road Infrastructure Condition

The survey of the road infrastructure condition was conducted along with studies of travelling behaviour patterns among travellers in October and November 2014 under the Green Travelling project, based on a sample of 100 persons being inhabitants of Silesian Voivodeship. For purposes of the survey, mobile devices were used featuring a dedicated application, AP1, enabling data of both the position and linear accelerations to be stored, simultaneously keeping records of the travel origin and destination as well as of the means of transport used in individual transfers. The recorded data were automatically saved in three CSV files, respectively containing the MEMS accelerations, the GPS-defined position and the travelling history in pre-set time intervals. On account of the purpose of the measurements, namely developing the road infrastructure condition description, the sampling frequency of the MEMS accelerometer was set to a hundredth of a second, depending on the device parameters [14, 15].

The transport network area subject to the survey as well as individual routes in which the survey participants travelled have been provided in Fig. 1.

Road sections where the linear accelerations were recorded have been designated as coloured broken lines. On account of the nature of the travelling behaviour patterns displayed by those who travelled within the area shown in the above map, routes covered by such means of transport as tram or train have also been marked.

Further on in the paper, the transport infrastructure, limited to the road network, has been parameterised [16]. The travel parameters recorded by an AP1 application user were defined as a set of elements:

$$C = \left\{ f_x, f_y, f_z, GPS(t), v(t), ds(t), TM \right\} \quad (1)$$

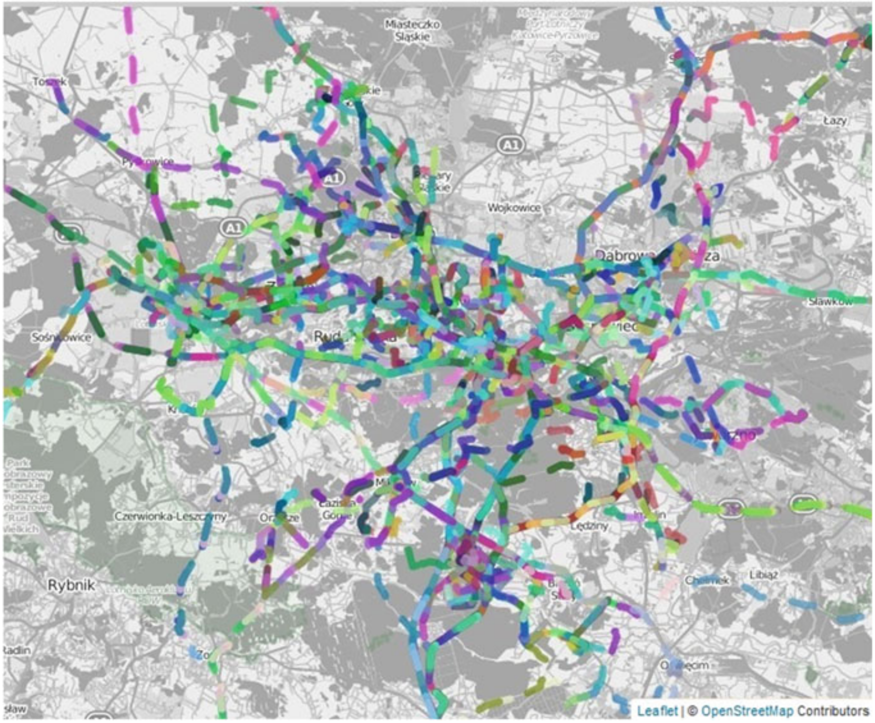

Fig. 1 Scope of the survey within the area of Silesian Voivodeship

where:

$f_x(t)$	momentary acceleration in the direction of the X axis,
$f_y(t)$	momentary acceleration in the direction of the Y axis,
$f_z(t)$	momentary acceleration in the direction of the Z axis,
$GPS(t)$	set defining latitude and longitude as well as altitude,
$v(t)$	momentary velocity [km/h],
$ds(t)$	momentary path accretion [km],
TM	set of means of transport used while travelling.

Sample results of the linear accelerations recorded in the course of travel in individual road sections have been provided in the figure below. Individual cases correspond to different levels of the road infrastructure condition, as per the Pavement Management System [PMS] guidelines: Class A—section with pavement assessed to be in good condition, Class B—section with pavement assessed to be in satisfactory condition, where individual defects occur, Class C—section with pavement assessed to be in unsatisfactory condition, in need of planned repair procedures, and Class D—section with pavement assessed to be in bad condition, in need of repair procedures or overhaul works.

4 Considering the Road Infrastructure Condition in the Travel Route Planning

In order to enable GT Planner to plan the travel route taking the road infrastructure condition into account, a solution was proposed that the road network model be created with an additional attribute, i.e. a technical parameter describing its condition. For that purpose, it was necessary to process the data from the road infrastructure condition measurements and save them in a format supported by GT Planner.

On account of the set of measurement results obtained and the projected area of travel planning, namely a dense transport network, what was assumed as an elementary section for purposes of the model was a link between any chosen junctions in the graph, i.e. points corresponding to branching or intersection of roads, or to locations of bus stops, tram crossings or pedestrian crossings. The road-related data are acquired from Open Street Map (OSM) databases. Road section extracted from the OSM maps are then broken down into elementary sections. Figure 2 shows an extracted fragment of Katowicka street in Tychy, being a road section intended for breaking down, along with intersections marked within this section.

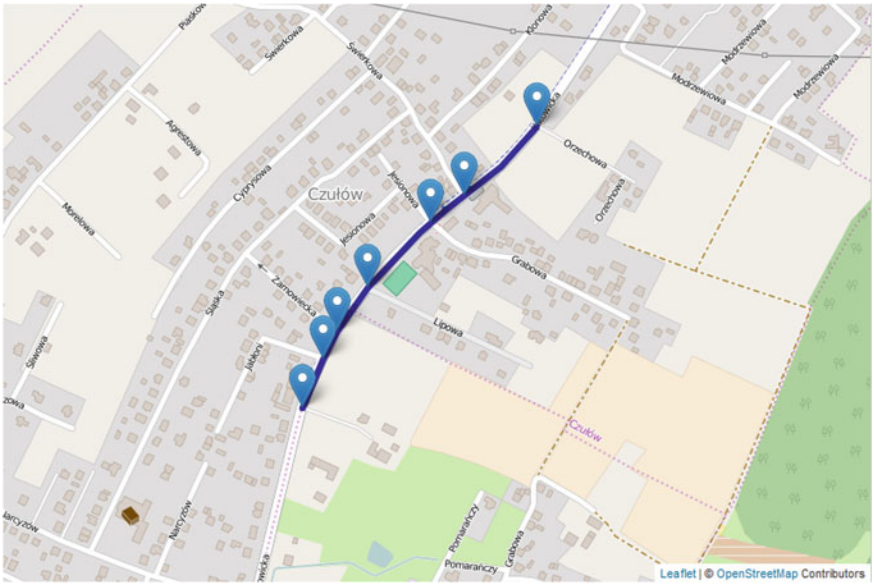

Fig. 2 Road section according to OSM, prior to breakdown into elementary sections

Fig. 3 Elementary road sections with linear accelerations assigned

The elementary sections obtained in the process of the road breakdown with the assigned linear accelerations, as recorded by the travelling persons, constitute input data for GT Planner. An example of the foregoing has been provided in the Fig. 3.

Based on how linear acceleration characteristics have been assigned to individual elementary sections, one can affect the route setting algorithm, either time or distance-based, by taking the pavement condition into account while planning the travel route using GT Planner.

4.1 Examples Showing the Influence of the Road Infrastructure Condition on the Travel Route Planning

As an example of the route planning process, a travel between the intersection of Beskidzka and Katowicka streets and Kwiatowa street in Tychy has been analysed. The output data from the travel planning have been provided in Table 1. The acronym CRI in the table stands for Conditions of Road Infrastructure.

Figure 4 shows the routes established for the travel planned according to the optimisation criteria. A description of differences between individual routes has been provided in Table 1. When the distance criterion was applied while seeking solutions and the road pavement condition was taken into account, the suggested travel route was switched to a road with pavement of better technical condition.

Table 1 Travel parameters for the optimisation criterion assumed

Optimisation criterion	Travel time change coefficient	Distance to travel [km]	Travel route
Quicker without CRI	1.0	7.0	Figure 4a
Quicker with CRI	1.0	7.0	Figure 4a
Shorter without CRI	1.2	4.7	Figure 4b
Shorter with CRI	1.4	5.9	Figure 4c

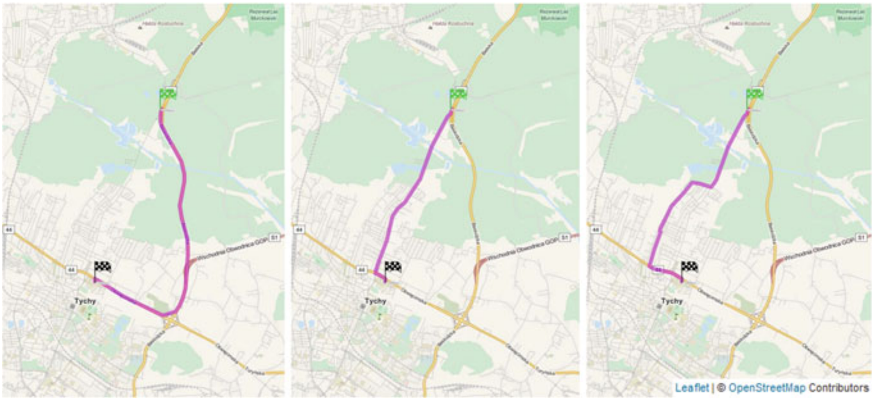

Fig. 4 Routes established for the pre-set travel optimisation criteria

5 Conclusions

The solution comprising the use of information about the road infrastructure condition, as proposed by the author of this article, has been implemented and verified with a positive effect. The sample results obtained clearly imply that, in the course of the computational procedure, the algorithm seeking the optimum solution eliminates road sections with pavement of inferior technical condition, switching to adjacent roads. This allows for swapping the basic route established by the user according to the time or the distance criterion (without considering the road infrastructure condition) for an alternative route with pavement of better condition. Such a solution makes it possible to foster specific travelling behaviour patterns with the travelling comfort increase in mind. Even a small change in the travel distance and time may exert a crucial impact on its quality.

GT Planner, the application developed under the Green Traveling project, is a means to affect travelling behaviour patterns. Using an intuitive interface, the user can define input data required to plan the travel, and then acquire such results as the travel route, means of transport, travel time and distance as well as cost and emission.

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Development of the Transport Model for the Masovian Voivodeship

Tomasz Kulpa and Andrzej Szarata

Abstract The paper presents regional travel model development procedure, including supply and demand models. In the supply model, a division into traffic analysis zones and network development was presented. According to a four-step model, all stages were described, highlighting important issues related with regional travel models. In particular, commune-type dependent trip generation rates were developed. Moreover, freight trip generations were applied to single generators. Additionally, approach to modelling park and ride trips was proposed. In summary key issues on model verification were presented and a regional model development procedure was discussed.

Keywords Regional travel models · Trip modelling 4-stage model

1 Introduction

Describing transport systems is very difficult because of their high degree of complexity and interdependence between their various components. Hence, it is necessary to develop mathematical models, which would sufficiently map the analyzed transport system. Transport models are a set of mathematical formulas that describe two components of a transport system (supply and demand), taking into account the interdependence between them in time. Travel models are characterized by a relatively high level of aggregation and significantly simplify the real transport habits. This is the result of the approach to the problem, namely considering a trip, as a basic unit [1]. The process of making travel-related decisions is mainly due to the nature of spatial planning and the parameters of the transport network.

T. Kulpa · A. Szarata (✉)
Department of Transportation Systems, Cracow University of Technology, Cracow, Poland
e-mail: aszarata@pk.edu.pl

T. Kulpa
e-mail: tkulpa@pk.edu.pl

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However, despite their imperfections and numerous simplifications, four-stage models are still the primary means of trip modelling in the Polish cities. This is caused mainly due to the input data and a well-established way of obtaining the required information, for instance Comprehensive Travel Study (CTS) [2]. Traffic and travel modelling process is an essential element that supports the creation of Transport Master Plans (TMP) or the determination of a functional effectiveness of selected investment projects in public transport, as well as the organization of this system in the whole city, agglomeration, region or a country.

The development of the model should be preceded by a marketing analysis, performed using survey results as well as cordon and screen measurements designed in such a way that it was possible to calibrate the parameters of the functions used in the simulation. Regional traffic model is significantly different than the models used in urban areas, because of a significantly different nature of the users of the transport system in the city and in the region. In the first case, the system is built to handle peak periods, associated with travelling to and from work and school, whereas in the regional system, the trips are much more flattened in the 24-h period, have mixed purposes, which only in certain areas is associated with commuting to schools and work. The majority of the journeys relate to other trip purposes (e.g. business, tourism, domestic, social, etc.).

2 Supply Model

Travel model for the Masovian Voivodeship is a regional-range model [3]. Its spatial coverage requires assumptions that determine the methodology of its implementation. In the first phase of the works, it is important to divide the modelled area into traffic analysis zones (TAZ) corresponding to the communes, as basic territorial units, with the possible division of selected bigger communes and cities into smaller areas. The adoption of such a division into regions stems from the essence of the regional model, whose main objective is to replicate the trips between the communes and poviats (counties). In addition, the supply model is based on household surveys [4], where a commune is assumed as the smallest division unit. At the same time the location of measurement points to be used in the calibration of the model, makes it impossible to verify traffic volumes inside of the commune (points are located mostly on the cordons corresponding to the administrative boundaries of the communes). The model structure was based on the zones that are communes (432 units), and selected poviats (42 units). When dividing a part of the areas into smaller units, the transport model of the Masovian Voivodeship was divided into 640 zones (including 555 internal zones).

The model was fed with an extensive set of input data obtained from the System of Spatial Information of the Mazovian Voivodeship. This collection included, among others, a full road network (including 23,046 links), complete the railway network (including 1158 links), all railway stations (396 stations) and bus stops (489 bus stops). The assumed limit was one stop per one TAZ.

When developing a transport model, the existing transport model for the city of Warsaw was used. It was assumed that the internal traffic of Warsaw influences the external traffic (origin and destination). Therefore, in order to map the congestion affecting the path choice in the model of traffic distribution, the results of the model in Warsaw in terms of traffic during peak hours were included: morning and afternoon peaks as well as speed levels (and the resulting travel times) in each section in Warsaw and the Warsaw Agglomeration. In order to map the real travel times through other urban areas (Ciechanow, Ostroleka, Plock, Radom, Siedlce), the speed during the morning and afternoon peak hours was used. The speeds were obtained from the websites that provide information on the recorded speeds during peak hours: Targeo Maps [5] and Google Maps [6]. Therefore, instead of the classic mapping of the impact of congestion on the travel time by the volume to capacity ratio, real-time speed obtained in the model was used (for Warsaw) and the observed speed on the Internet map services (for other cities). As a result, it was possible to achieve a mapping of real road conditions in the cities, while the process of searching the route (in the procedure of the assignment of traffic on the network) takes into account traffic congestion in all the cities within the model.

Two sets of sources of information about bus connections in the voivodeship were used: a list of authorizations obtained from the Marshall's Office and the collection of data about urban and suburban transport lines. Bus line routes were mapped in the whole voivodeship. When creating the model, also updated timetables were used (as of March 2015). As a result, 1090 bus lines were obtained. In the case of suburban bus connections; publicly available information posted on the websites of the official carriers was used (current routes that service suburban connections and timetables). The model takes into account 1259 bus lines. In the case of Warsaw simplified PT network, consisting of 2 subway lines and 12 tram lines were considered. Information about routes and timetables of relevant lines was obtained from the official website of the Department of Urban Transport in Warsaw. This is how the most important and the most frequent tram lines were selected that service the extreme districts of Warsaw.

3 Demand Model

In trip modelling, usually two main approaches are used: a trip-based and an activity-based model [7]. The four-stage model, which is a trip-based approach was used in this study [3], consisting of:

- trip generation, which is the number of trips commenced and finished in different parts of the zones in a unit of time (day, hour),
- trip distribution, that depicts the flow of passengers (or goods) between the traffic zones,
- modal split, that determines the share of private means of transport in all trips,
- trip assignment on the transport network.

The basis for the analytical work carried out on the construction of a demand model were the results of interviews performed in households, conducted in the Masovian voivodeship in 2014 [4].

3.1 Trip Purposes

In the surveys conducted in the framework of the study [4], 11 trip purposes of the beginning and the end of the trip were distinguished. As part of the developed model, the most important groups of trip purposes were aggregated as follows: home—work (HW), work—home (WH), home—school (HS), school—home (SH), home—other (HO), other—home (OH) and non-home based (NZD). For each trip purpose trip generation, trip distribution and modal split models were developed.

Explanatory variables were referred to the traffic zones, and their selection was based on the criterion of data availability, reliability, as well as forecasting capabilities. In particular number of inhabitants (INH), number of work places (EMP) and number of pupils in schools (PUP) in each TAZ was used. The explanatory variables were obtained from Local Data Bank of Central Statistical Office of Poland and General Geographic Database and distributed to each TAZ.

3.2 Trip Generation

Formulas for communes were determined in the trip-generation model. It resulted from the available household interview database, where commune was the smallest unit considered. Next developed formulas were used to calculate trip generation for all zones, even when dividing the commune into several smaller TAZ. Division into types was assumed, which is compliant with the territorial division of the Central Statistical Office of Poland, which distinguishes: urban communes (1), rural communes (2), urban and rural communes (3) and additionally urban and rural communes are divided into cities and town in an urban-rural commune (4) and rural areas in urban-rural communes (5). Daily trip generation rates were obtained for groups of communes as shown in Tables 1, 2 and 3, while there was no statistically significant difference between rates in particular groups. A different methodology for calculating the trip generation was used for cities with the status of poviats: Ostroleka, Plock, Radom, Siedlce, Ciechanow and Warsaw.

For urban communes and cities in the urban-rural communes (areas 1 and 4), high coefficients of determination were obtained. For rural communes and rural areas in urban-rural communes (areas 2 and 5), the results are somewhat weaker, but still at an acceptable level. In the process of trip generation model development, numerous explanatory variables were analyzed, as well as other parameters that may affect the size of the trip demand. The above formulas gave the best results. At the same time, no influence of the railway availability on the trip generation was

Table 1 Trip generation rates for urban communes and towns in urban-rural communes

Trip purpose	Production rate	Explanatory variable	R^2	Attraction rate	Explanatory variable	R^2
HW	0.361	INH	0.85	1.701	EMP	0.87
WH	1.419	EMP	0.82	0.275	INH	0.84
HS	0.115	INH	0.72	0.845	PUP	0.73
SH	0.836	PUP	0.76	0.105	INH	0.72
HO	0.182	INH	0.78	0.922	EMP	0.77
OH	1.003	EMP	0.79	0.203	INH	0.81
NHB	0.466	EMP	0.69	0.620	EMP	0.69

Table 2 Trip generation rates for rural communes and rural areas in urban-rural communes

Trip purpose	Production rate	Explanatory variable	R^2	Attraction rate	Explanatory variable	R^2
HW	0.303	INH	0.69	1.061	EMP	0.56
WH	1.009	EMP	0.65	0.269	INH	0.64
HS	0.195	INH	0.65	1.239	PUP	0.58
SH	1.279	PUP	0.57	0.191	INH	0.63
HO	0.229	INH	0.61	1.296	EMP	0.37
OH	1.435	EMP	0.44	0.261	INH	0.62
NHB	0.634	EMP	0.31	0.650	EMP	0.31

Table 3 Trip generation rates for urban-rural communes

Trip purpose	Production rate	Explanatory variable	R^2	Attraction rate	Explanatory variable	R^2
HW	0.319	INH	0.69	1.514	EMP	0.66
WH	1.469	EMP	0.65	0.282	INH	0.64
HS	0.159	INH	0.65	1.059	PUP	0.58
SH	1.026	PUP	0.61	0.134	INH	0.63
HO	0.200	INH	0.61	1.120	EMP	0.57
OH	1.149	EMP	0.54	0.224	INH	0.62
NHB	0.662	EMP	0.61	0.608	EMP	0.61

observed, or this influence was irrelevant (insignificant reduction of trip generation with increasing distance to the nearest railway station). In the simulation model, trips between the communes will be distributed on the network. It is therefore necessary to determine the trip demand between the communes. The formulas given above determine the total trip generation of the communes. In order to calculate the inter-commune trip generation, it is important to use the coefficients given in Table 4 as a multiplier.

The model of trip generation was supplemented by an external trip generation of Warsaw based on the facilitated simulation model. The production was

Table 4 Inter-commune trips coefficients

Trip purpose	Ciechanow, Ostroleka, Plock, Radom and Siedlce		Other communes	
	Production	Attraction	Production	Attraction
HW	0.13	0.24	0.73	0.61
WH	0.24	0.13	0.61	0.73
HS	0.02	0.42	0.65	0.53
SH	0.42	0.02	0.53	0.65
HO	0.08	0.28	0.59	0.48
OH	0.28	0.08	0.48	0.59
NHB	0.07	0.07	0.44	0.44

Table 5 Truck trip generation rates (daily trips/1000 m^2 of developed area)

Generator type	Light trucks (VAN)	Heavy trucks (HGV)
Production	0.7	1.3
Logistic	2.6	3.1
Commercial	2.0	1.8
Airports	1.3	2.1

calculated as the sum of the external OD matrices. Moreover, additional traffic generators were contemplated, for which separate formulas to determine the trip generation rates were determined. There are four types of generators: production, logistics, commercial and airports. With regard to the first two types of generators, based on a certain number of jobs, a trip demand values was calculated in HWH trip purposes based on the formulas for the commune, where such a generator is located. Other trip purposes were not considered. In the case of commercial and airports, HWH trips were complemented by HOH trips. In case of airports trip generation was determined based on the number of passengers handled by the airport and the surface of commercial areas. Additionally for single generators truck trip generation rates shown in Table 5 were assumed based on [8].

3.3 Trip Distribution

The trip distribution for inter-commune trips was conducted using gravity model. Gravity model elements were calculated using a complex distance-decay function according to following equation:

$$f\left(l_{ij}\right) = a \cdot l_{ij}^{b} \cdot \mathrm{e}^{c \cdot l_{ij}} \tag{1}$$

where:

Table 6 Gravity model parameters

Trip purpose	a	b	c	R^2
HWH	0.010	1.723	−0.122	0.94
HSH	0.025	1.371	−0.119	0.96
HOH	0.008	2.050	−0.156	0.97
NHB	0.002	2.602	−0.180	0.91

l_{ij} distances between traffic zones measured on the network,
a, b, c parameters of the resistance function.

When estimating the parameters of the friction function, different functions were contemplated for the trips performed to Warsaw, to five former voivodeship cities and among other communes. These features differed among themselves, so high determination coefficients were obtained for them. However, aiming at increasing the readability of the model structure (the use of one trip matrix for each motivation), it was decided to use one gravity model for the entire area, broken down into groups of trip purposes. Despite the use of one function, it maps the parameters of each function taking into account both the shorter travel times to smaller towns as well as longer to Warsaw. Resistance function parameters were presented in the Table 6.

With respect to the external trips, a different approach was used. In order to determine the matrix of inbound, outbound and through trips, the National Transport Model (KMR) was applied. By excluding the Mazovian Voivodeship from the KMR for 2015, external travel matrices were obtained. These matrices have been calibrated to the traffic volumes on cordon of the Masovian Voivodeship, and then added to the internal trips matrices.

3.4 Modal Split

Due to the structure of the transportation model, where in many cases the zone overlaps with the commune, the distances inside the commune will equal zero. Thus, when assigning distances from the network model to private trips, in the estimation of the parameters of the share of pedestrian trips, erroneous results would be obtained, because all the trips inside the commune would have a length equal to zero. At the same time, when travelling outside the commune, the distances change gradually in steps, making it impossible to contemplate pedestrian trips occurring on the boundaries of communes. The distances between the communes are of several or a dozen of kilometers and not all the trips are made by foot. This could be the case that in the model, all trips inside the commune are pedestrian trips, and all external ones, are motorized. In this case, the sum of the matrix of trips taken from the study and the model would differ one from another. Hence, a decision was made to use the average share of motorized trips in the trips between the communes. The shares were listed in the Table 7.

Table 7 Share of motorized trips in communes

Trip purpose	Ciechanow, Ostroleka, Plock, Radom and Siedlce	Other communes
HW	0.93	0.81
WH	0.93	0.75
HS	0.63	0.60
SH	0.73	0.55
HO	0.76	0.43
OH	0.83	0.42
NHB	0.87	0.71

Then, a modal split was determined, classifying the trips performed by public transport (PuT) and private transport (PrT) that was based on travel times. The modal split uses a logit function in form of:

$$P_{PuT} = \frac{e^{\mu \cdot U_{PuT}}}{e^{\mu \cdot U_{PuT}} + e^{\mu \cdot U_{PrT}}} \quad (2)$$

where:

P_{PuT} probability of selection of the means of public transport,
U_{PuT} utility function of public transport,
U_{PrT} utility function of private transport.

The utility function of the various means of transport is defined as the product of the weight and a parameter characterizing the given means. The model assumes that the utility function will be based on the travel time between zones, respectively by public and private transport. The weights were calibrated for each trip purpose separately in order to map users' behaviors when selecting a given means of transport. Efforts were made to obtain a modal split that would be similar to that one, obtained as a consequence of household travel surveys. Thus the μ parameter was calibrated. Depending on the trip purpose, the μ parameter ranges from −0.03 to −0.005.

In order to analyze Park & Ride trips, the results of households travel surveys and interviews with passengers of trains were used. In general, Park & Ride trips were assigned to trips undertaken by public transport. On the other hand, it was necessary to take into account the additional load of the road network when commuting to railway stations. First, based on the results of surveys in households, a model of trip generation for Park & Ride trips was developed. The following formula, with $R^2 = 0.87$, was obtained:

$$P_{P+R} = 0.014 \cdot INH \cdot e^{-0.1 \cdot D_{RAIL}} \quad (3)$$

where:
P_{P+R} trip demand of zones in P+R trips,
INH number of residents in a zone,
D_{RAIL} distance of the zone to the nearest railway station.

Then, according to the formula (3), trip demand in Park & Ride was calculated for zones, where the distance to the nearest railway station does not exceed 20 km. The adoption of 20 km as the limit value for Park & Ride trips is due to the analyses of surveys conducted in trains. By comparing the point of commencing the trip and the initial station, distances of car rides necessary to drive to railway stations were obtained. It turned out that more than 80 % of commuting by car to the train station is shorter than 20 km. At the same time, interesting results of the location of the origin of a trip and the starting station were obtained. Depending on the means of transport used when commuting to a railway station, the share of commuting to the station in the same zone in relation to commuting to the station in a different zone. It was observed that approximately 20 % of those who drive to the railway station by car, as a driver or passengers, select a station in another zone. This is mainly due to the density of the stops (in each zone there is at least one stop), and minimizing the time and distance of access to a train station by the drivers.

In the next step, a matrix of trips in Park & Ride system using gravity model was calculated. Parameters of the friction function were estimated based on the results of surveys conducted in trains. The following results of the function, with $R^2 = 0.83$, were obtained:

$$F_{P+R}\left(l_{ij}\right) = 0.9 \cdot \mathrm{e}^{-0.1 \cdot l_{ij}} \tag{4}$$

where:

F_{P+R} distance delay function in Park&Ride trips,
l_{ij} distance between the zones measured along the network.

Another assumption was that the regions in which the railway stations are located, while in the gravity model a limitation that the total production has to remain unchanged. As a result, trips in the model will be carried to the nearest station, which is in line with the reality. The above procedure concerned the appointment of matrices of commuting by car to railway stations, from which the subsequent trips are carried by train. The "return" matrices, i.e. the return from the railway station to the source of travel were obtained by a transposition of "access" matrices. Matrices calculated in the above-mentioned way were added to the matrices of trips performed by passenger cars.

4 Model Validation and Calibration

The comparison of the obtained results with results of the conducted survey and measurements constitutes an essential part of travel model development. In particular, the obtained trip generation rates and trip length distributions are verified based on household survey. Moreover, modeled traffic volumes are compared with volumes obtained from trip assignment.

Mobility rate obtained from household surveys is 1.71 daily trips. It is a value that also takes into account the trips of the Mazovian region inhabitants outside the zones they live. However, in the case of exclusion from the sample trips, which origin and destination are outside of the analyzed zones the survey mobility was at the level of 1.44 daily trips, while in the model value of 1.42 daily trips was obtained.

The number of internal trips (excluding Warsaw, Ciechanow, Ostroleka, Plock, Radom and Siedlce) calculated using the gravity model is 4 159 987 trips per day. Comparing to the number of trips calculated in the model, which is 4 106 208 trips per day, the difference is only 1.3 %.

An average trip length was calculated based on a simulation model, assuming that one traffic zone corresponds to each commune. Because in household survey trip origin and the destination were related to communes, such an approach is justified. The average trip length based on the surveys was 38 km, while the average trip length obtained in model is 40 km.

At the stage of the modal split, a high compliance with the model was also achieved. The share of public transport in the external trips (inter-commune trips), determined from the household survey is 26 %, while for private transport, it is 74 %. In the model obtained share of public transport is at the level of 24 % and private—76 %.

The last part of the model verification is to compare obtained traffic volume with measurement results. For this purpose, the results of cordon measurements in private and public transport were used. From available measurements, a set of relevant and reliable measurement points was selected. Points with small public transport passenger volumes were not considered (less than 50 passengers per hour), as well as those where there were measurement errors (e.g. lack of information about saturation in many trips). For private transport, it was possible to obtain a reliable set of measurements on all cordons. For public transport, it was only possible for the cordon of Warsaw and the voivodeship. For private trips, more than 200 calibration points were used, and for public transport—more than 100. For both peak hours (morning and afternoon), high levels of model accuracy were achieved. The R-squared was at least 0.95 for all sets of data (public transport, passenger cars, light and heavy trucks during the morning and afternoon peak hours. Moreover, for the majority of measurement points, high statistical compliance GEH (less than 5) was achieved. Moreover, for all measured cordons, a high compliance of a total flow crossing the cordon was obtained. Of note, the GEH conditions are very strict and exclude points that typically would be considered as well calibrated ones (i.e. for the measured volume of 1000 cars per hour, the model volume of more than 1170 cars per hour would exceed a critical value of 5). Additionally, the compatibility condition of the total flow in the cordon (GEH < 4) is rigorous. For instance, cordons with small traffic flows, like Ostroleka where the sum obtained from the measurement was 800 cars per hours allows an error of 40 vehicles. Therefore, one should approach calibration with caution and evaluate the quality of the model at all stages.

5 Conclusions

The network model contains mapping of all the national and regional (voivodeship) roads and the major poviat (county) and commune roads. In the case of large cities, the road network has been mapped in a simplified way due to the spatial scale and the purpose of the model. Nevertheless, it is sufficient considering development of regional travel model, which main purpose is to model trips between the communes and between poviats. The trip demand model was based on a single linear regression. In this case, the following explanatory variables were applied: number of residents, number of students, and number of work places. A spatial distribution of internal trips was adopted, according to a gravity model broken down into trip purposes. The form of the distance-decay function was adopted for the whole area (depending on trip purposes). This is due to efforts made in order to minimize the matrices of trips generated in the simulation model. Due to the difficulties related to the analyzed area size, there were no surveys on the outer cordon, only traffic volume measurements. Thus the matrices for external traffic were determined from National Travel Model. A primary modal split was assumed in relation to the separation of non-motorized trips. This is due to the spatial extent of the model, in particular considering only inter-commune trips. Bicycle trips are also treated as non-motorized trips. Modal split between private and public transport was assumed as a secondary one. Due to a small share of Park & Ride travels, they were included in public transport trips. However, a Park & Ride travel methodology was proposed in the model.

This paper presented complete procedure of regional model development. Nevertheless, there are still issues related to regional models development that need to be discussed and standardized.

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The Comparison of Models for Critical Headways Estimation at Roundabouts

Elżbieta Macioszek

Abstract The basic parameters that determine traffic capacity on the roundabouts entries include in particular values of main traffic intensity in the collision area on the circular roadway at an entry and two parameters that characterize the process of vehicles entering the roundabout from the entries, such as critical headway and follow-up headway. The paper presents a comparative analysis in terms of studies connected with determination of critical headways for drivers of vehicles at the entries of single-lane roundabouts, two-lane roundabouts and turbo roundabouts.

Keyword Critical headway · Roundabouts · Gap acceptance theory · Traffic engineering

1 Introduction

It is adopted that the critical headway for drivers of vehicles moving from the roundabout entry (tg) is the value of headway between the vehicles in the main stream such that each headway with the value equal or greater will be used for performing a manoeuvre of entering the roundabout lane by the respective driver from the subordinated entry (average in statistic terms) whereas each distance with value lower (that prevents performing the intended manoeuver) cannot be used. Critical headway is not a constant value. It adopts different values for different drivers and for each driver at different times. Critical headway is a random variable, with its value depending on the characteristics of human and vehicle and geometrical and movement conditions of the intersection, which can be characterized by probability distribution.

In the models used for determination of traffic capacity of the entries to intersections with right of way and roundabouts based fully or partially on gap acceptance theory, the critical headway and follow-up headway (t_f) are the basis

E. Macioszek (✉)
Faculty of Transport, Silesian University of Technology, Katowice, Poland
e-mail: elzbieta.macioszek@polsl.pl

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parameters of the decision-making process in organization of vehicle traffic. These parameters usually represent the average behaviours in a population of drivers. In more extended models used in the literature, based on complex probability distributions, the number of model parameters increases. For example, in models based on the Cowan's M3 distribution, apart from parameters t_g and t_f, determination of two other parameters is also needed. These are values of minimal headways between vehicles in the main stream and the share of vehicles moving freely. This group of models includes the models presented in a study [1].

There are a number of studies concerning various problems connected with traffic on roundabouts [2–16]. The paper presents an analysis in terms of studies connected with determination of critical headways for drivers of vehicles at the entries of roundabouts. Due to the very rich set of studies published so far, the focus was on the most important and most popular models and the most recent studies in this field.

2 Methods of Determination of Numerical Values of Critical Headways

Values of critical headway are not measured directly. They can be determined directly based on the headways rejected and headway accepted by individual drivers from the entries. Therefore, apart from typical errors connected with performing measurements, evaluation of this parameter also involves the error that results from indirect method of determination. This fact caused the development of many different methodologies and techniques to determine the consistent and unbiased estimator of the critical headway. There were over thirty various techniques and methods used for evaluation of critical headway at the intersections without traffic lights. Individual methods of estimation often yield very different values of critical headway. The most popular and the most frequently used techniques and methodologies for determination of critical headways are [17–20]:

- Method by M. Raff and Hart based on cumulative curves. It is one of the first methods of estimation, where cumulative curves of rejected and accepted headways are construed. The value t_g is read at the location of intersection of the curves. Therefore, t_g is the value of the headway for which the number of headways accepted shorter than this value is equal to the number of headways rejected longer than this value. According to this method, critical headway corresponds to median (the second quartile, medium value).
- Graphical techniques that use the gap acceptance curve (e.g. Harders method, Blunden method, Ashworth method with correction that depends on the variance of distribution of individual critical headways). It is adopted that t_g corresponds to the value of 50 % of the acceptance curve. The acceptance curve is construed through determination of quotients of the headways accepted and the total of headways rejected and accepted for each class range of headways.

- The method of estimation for parameters of critical headway at the assumed type of probability distribution that uses the tools of mathematical statistics. These include: probit method, logit method and the method of highest credibility [22]. As explained in studies [18, 23], the method of highest credibility has a very high practical importance since it allows for obtaining estimators which are consistent, unbiased, best asymptotically efficient and linear with respect to random variables. The random distribution of the critical headway for the population of drivers is logarithmic-normal distribution which is characterized by the fact that it is rightward skewed and does not adopt negative values although it accepts occurrence of a short headway t_g.

There is a probability in the estimation procedure that t_g should occur between values of logarithms: the highest headway rejected by the driver and the headway accepted. This method assumes that the sample obtained from measurements represents the event with the highest probability possible, which is identical with the condition that credibility reaches maximum. The probability that t_g will be between the values of logarithms of the highest headway rejected by a driver and the headway accepted is evaluated from the equation [18, 22]:

$$L = \prod_{i=1}^{n} [F(a_i) - F(r_i)] \tag{1}$$

where:

$F(a_i)$ cumulative distribution function for headways accepted,
a_i logarithm of the i headway accepted,
$F(r_i)$ cumulative distribution function for headways rejected,
r_i logarithm of the i headway rejected.

The condition of the highest credibility is used for determination of the estimators of parameters of critical headway distribution, i.e. mean value $E(t_g)$ and variance $D^2(t_g)$. These estimators are a function of the parameters of logarithmic-normal distribution m and σ^2 and are evaluated using the following relationships:

$$E(t_g) = \bar{t_g} = e^{m + \frac{\sigma^2}{2}} \tag{2}$$

$$D^2(t_g) = E(t_g)^2 \cdot \left(e^{\sigma^2} - 1\right) \tag{3}$$

- The algebraic method that uses the relationship proposed by Drew [21] (this method is similar to the method by M. Raff and Hart):

$$t_g = t + \frac{(t_3 - t_1)\Delta t}{(t_2 + t_3) - (t_1 + t_4)} \quad [s] \tag{4}$$

where:

t_1 t_2, t_3, t_4, are values of headways which are searched in the sample so that they meet the condition that the number of headways accepted (t_1, t_2), lower than the specific value t is similar (or equal in ideal case) to the number of headways rejected (t_3, t_4) greater than the specific value t [s],

T time that corresponds to the beginning of the range where the values t_1, t_2, t_3, t_4 [s] were located,

Δt span of the time range [s].

- The method based on headway histograms. It is assumed that critical headway corresponds to the modal value in the test.
- Method by Weiss and Maradudin [24] that takes into consideration time loss incurred by drivers at the entries and drivers impatience. According to the assumptions of this method, the value t_g decreases with the increase in time loss incurred by drivers at entries. With the increase in time loss, drivers are willing to accept shorter headways, i.e. probability of acceptance of a headway is increasing and the following inequalities are true:

$$\eta_1(t_g) \le \eta_2(t_g) \le \ldots \le \eta_n(t_g) \quad (5)$$

where:

$\eta_i(t_g)$ probability that the headway t_g will be accepted by the driver i at the entry.

- Method by Hagring [25] where t_g is obtained as an optimal value between the values of critical headway that ensures entering to the main roadway of the intersection with maximal safety and the critical headway accepted by the driver in the case of high values of time loss incurred at the entry (in this case, t_g is connected with risky and dangerous entering the circular roadway).
- Method by Siegloch for conditions of saturation with traffic [18] where the value t_g is evaluated from the function of using headways in the main streams.

In many cases, values of critical headways evaluated based on the above methods differ from each other.

3 Comparison of Models for Estimate Critical Headways at Roundabouts

Roundabouts are one of the more interesting road traffic arrangements, so they are frequently elements of multifaceted analysis (f. eg. [26–33]). Due to the importance of gap-acceptance and its impact on roundabouts capacity, a large number of critical headway researches and studies have been conducted. The selected studies characterizing the critical headway for drivers at one-lane roundabouts entries are presented in Table 1. Hagring [34] state that gap acceptance models can be classified as macro and micro approach. Macro approach applies to interactions between traffic streams and geometric considerations and micro approach applies to the driver level. The approach adopted in this article is based on micro analysis using detailed data of drivers behavior and vehicles trajectories. The main challenge of critical headway estimating is that the parameters of the distribution of the critical headways, can be estimated as a function of various explanatory variables like speeds of vehicles, traffic conditions, roundabout location, waiting time for a appear gap, type of vehicle and much more other factors. Depending on the structure of model, for estimation of parameters of the models a number of methods have been employed. For many modeling approaches the maximum likelihood method provides a lot of advantages and gave superior results. Taking into account estimating the critical headway at roundabouts, a number of studies have been conducted but focused mainly on one-lane roundabouts.

Table 1 Comparison of critical headway models for one-lane roundabouts

Country	Author	The model/value of the parameter t_g [s]	The applied calculation method
Australia	Troutbeck [35]	1.4–4.9 (average 3.1)	Regression method
Germany	Baier et al. [36]	For $13m \leq D_z \leq 24m$: 4.7	N.a.
	Brilon and Wu [37]	For $26m \leq D_z \leq 40m$: $t_g = 3.86 + \frac{8.27}{D_z}$ 4.07–4.18 (average 4.12)	Regression method
USA	HCM [38]	4.1–4.6 (average 4.35)	N.a.
	NCHRP 572 [39]	4.2–5.9 (average 5.10)	Maximum likelihood method. The probabilistic distribution for the critical headways is assumed to be log-normal
	HCM [40]	5.19	N.a.
	Xu and Tian [41]	For $19m \leq D_z \leq 37m$: $t_g = 5.21 - 0.00128 \cdot Q_{nwl}$ $[s]$ 4.5–5.3 (average 4.85)	Maximum likelihood method
	Hainen et al. [42]	75th percentile: 2.8; median: 2.2	N.a.
Denmark	Greibe [43]	For urban area: 5.1, for rural area: 4.7	Regression method
Slovenia	Tollazzi [44]	Average 4.8	N.a.

(continued)

Table 1 (continued)

Country	Author	The model/value of the parameter t_g [s]	The applied calculation method
Poland	Guidelines from 2004 [45]	For $24m \leq D_z \leq 36m$: 4.5–5.0 (average 4.75)	Regression method
	Chodur [23]	For $28m \leq D_z \leq 44m$: $t_g = 1.92 \cdot t_f + 0.316 \cdot b_{wl} - 0.427 \cdot l_{pa} - 0.126 \cdot D_z - 0.00198 \cdot Q_{nwl}\ [s]$ 4.25–5.80 (average 5.03)	Regression method
	Macioszek [19]	For $22\ m \leq D_z \leq 45\ m$ and $4\ m \leq l_{jr} \leq 8\ m$: $t_g = 8.83 - 0.11 \cdot D_z - 0.09 \cdot l_{jr}\ [s]$ 3.16–6.05 (average 4.60)	Regression method
Italy	Gazzarri et al. [46]	For $28m \leq D_z \leq 55m$: 3.83	Maximum likelihood method
Spain	Romana [47]	3.3–3.5 (average 3.4)	N.a.
Portugal	Vasconcelos et al. [48]	3.2–3.7 (average 3.45)	Maximum likelihood method, Raff method, other methods
Israel	Polus et al. [49]	For $22m \leq D_z \leq 38m$: $t_g = \frac{(10.34 - 0.037 \cdot t_w)}{2.5}\ [s]$ 3.25–4.13 (for t_w = 60 s and t_w = 0 s), (average 3.69)	Logit method

where t_g—critical headway [s], Q_{nwl}—circulating flow [PCU/h], D_z—roundabout external diameter [m], l_{jr}—the width of main road of roundabout [m], l_{pa}—the width of the roundabout entry lane [m], t_f—follow-up headway [s], t_w—driver waiting time at the roundabout entry [s], b_{wl}—the distance between the collision points for: entering and exiting drivers from main road of roundabout [m], N.a.—non available

It can be concluded from Fig. 1 that mean value of the parameter t_g for all models is 4.40 s. The values t_g below the mean can be observed in such countries as Israel, Portugal, Spain, Italy, Australia and the USA (data from HCM 2000 [38]) and Germany (studies by Brilon and Wu [37]). Furthermore, the values of the parameter t_g which are higher than the average were found for such countries as Slovenia, Denmark, Poland and Germany (studies by Baier et all. [36]) and the USA (with is shown in the most recent studies cited in NCHRP 572 [39] and HCM 2010 [40].

Moreover, the potential impact one of psychotechnical parameter t_g on one-lane roundabout entry capacity estimate is examined by varying the parameter t_g from minimum to maximum limits under different circulating flows (Q_{nwl}). Critical gap value change between 2.2 and 5.2 s. This t_g values were adopted on the basis of various authors research presented in Table 1 (see Fig. 2). Follow-up parameter is assumed to be constants. As can be seen from Fig. 2 one-lane roundabout entry capacity is higher if smaller critical gap values are accepted by drivers. Therefore, more accurate determination of the critical headway value is very important because improves the accuracy of roundabout entry capacity estimation.

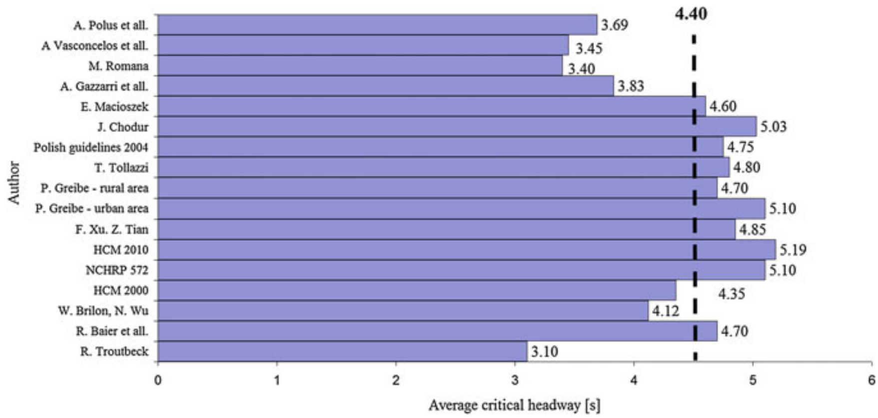
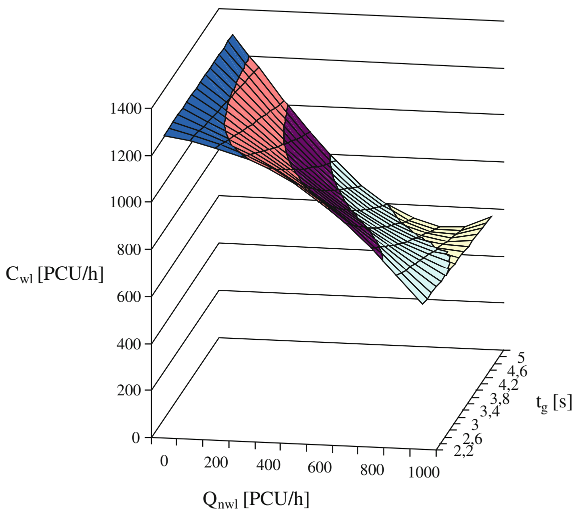


Fig. 1 Critical headways for one-lane roundabouts by different authors (*Source* Own)

Fig. 2 The change in one-lane roundabout entry capacity estimated with different values of parameter t_g (*Source* Own)



Fewer models and results of evaluation of the parameter tg compared to single-lane roundabout can be found in the literature for entries at two-lane roundabouts. Selected models of the parameter t_g for two-lane roundabouts were presented in Table 2. Table 2 shows that part of models were defined with accuracy of a single traffic lane at the entry and part of them concern only the general value of the parameter t_g for the whole entry.

It should be noted that for two-lane roundabouts the average values of critical headways are different by each entry lane and they are distinguished for the inner and outer circulating lanes. Figure 3 shows that mean value of the parameter tg for drivers from the right and left traffic lane at the entry of the two-lane roundabout amounts to 3.83 and 4.05 s. This means that the drivers from the right lane accept

Table 2 Comparison of critical headway models for two-lane roundabouts entry

Country	Author	The model/value of the parameter t_g [s]	The applied calculation method
Australia	Troutbeck [35]	– Dominant lane: 1.60–4.1 s (average 2.85), – Subdominant lane: n.a.	Regression method
Germany	Brilon and Geppert [50]	4.0	Maximum likelihood method
	Geppert [51]	4.0	Maximum likelihood method
USA	NCHRP 572 [39]	– Right lane: 3.4–4.9 s (weighted average 4.3 s, average 4.20), – Left lane: 4.2–5.5 s (weighted average 4.8 s, average 4.50)	Maximum likelihood method. The probabilistic distribution for the critical headways is assumed to be log-normal
	HCM [40]	– Right lane: 4.11 s, – Left lane: 4.29	N.a.
	Xu and Tian [41]	For $46m \leq D_z \leq 61m$: $t_g = 5.21 - 0.00128 \cdot Q_{nwl}\ [s]$. – Right lane: 4.0–4.8 s (average 4.42 s), – Left lane: 4.4–5.1 s (average 4.75 s)	Maximum likelihood method
	Li. et al. [52]	$t_g = 0,0345 \cdot V_{50th} + 4,4428\ [s]$ – Right lane: 3.6 s, left lane: 4.3 s	Regression method
Denmark	Greibe [43]	For rural area: 4.0	Regression method
Sweden	Swedish highway capacity manual [53]	For right and left traffic lane on entry: $t_g = 4.904 + \frac{0.090}{Q_{nwl}} - 0.52 \cdot l_d + 0.56 \cdot (z - 1) + 1.1 \cdot (u_c - 0.061)\quad [s]$ where: z = 1 for outer traffic lane on main road of roundabout, z = 2 for inner traffic lane on main road of roundabout – Right lane: 4.38 s, – left lane: 4.04–4.86 s (average 4.45)	Maximum likelihood method
	Hagring [25, 34]	– Right lane: 3.68–4.27 s (average 3.97),	Maximum likelihood method

(continued)

Table 2 (continued)

Country	Author	The model/value of the parameter t_g [s]	The applied calculation method
		– Left lane: 4.40–4.68 s (average 4.54)	
Poland	Guidelines [45]	For $D_z \geq 45m$: 3.9–4.1 (average 4.0)	Regression method
	E. Macioszek [1]	For $41.0\ m \leq D_z \leq 75.0\ m$ and $8.0\ m \leq l_{jr} \leq 11.5\ m$: – Right lane: 4.13–4.50 s (average 4.31), – Left lane: 3.99–4.36 s (average 4.17)	Regression method
Italy	Gazzarriet al. [46]	For $34m \leq D_z \leq 49m$: – Right lane: 3.64 s, – Left lane: 3.85 s	Maximum likelihood method
Spain	Romana [47]	3.3–3.5 (average 3.4)	N.a.
Portugal	Vasconcelos et al. [48]	3.2–3.7 (average 3.45)	Maximum likelihood method, Raff method, other methods
Turkey	Ersoy et al. [55]	2.84–3.21 (average 3.02)	Values obtained from Troutbeck's method [54] calibrated for Turkish conditions for $Q_{nwl} \leq 1200$ PCU/h: $t_g = t_f \cdot \begin{pmatrix} 3.6135 - 3.137 \cdot 10^{-4} \cdot Q_{nwl} \\ -0.339 \cdot w_L - 0.2775 \cdot n_c \end{pmatrix}$ for $Q_{nwl} > 1200$ PCU/h: $t_g = (3.2371 - 0.339 \cdot w_L - 0.2775 \cdot n_c) \cdot t_f$

where: u_C—the share of heavy vehicles in traffic stream [–], l_d—the length of weaving area [m], V_{50th}—50th percentile speed [m/h], w_L—the average entry lane width [m], n_c—the number of circulating flow lanes [–]

lower headways between the vehicles on the circular roadway than the drivers of vehicles from the left lane at the entry. The values t_g which are over the mean value can be observed in such countries as Sweden, the USA and Poland (study by Macioszek [1]).

Such type of roundabouts like turbo roundabouts are fairly recent development and projects connected with critical headways have only been implemented in a few works (Table 3; Fig. 4). Parameter t_g depending on the scheme of conflict area with one or two circulating streams. So, the t_g values are calculated separately for left and right lane on turbo roundabouts entry. The entering vehicles are faced by one or two circulating streams depending on scheme of conflict area.

The study [20] presented the empirical examinations aimed at determination of the value of the parameter t_g on single-lane roundabouts. For the collected samples, the critical headway t_g was determined graphically based on cumulative curves of the accepted and rejected headways and acceptance gaps as well as by means of the D. Drew's method. Mean values and medians were also evaluated for individual samples of the accepted headways. Values of critical headways estimated using various calculation methods were presented in Table 4 and in Fig. 5.

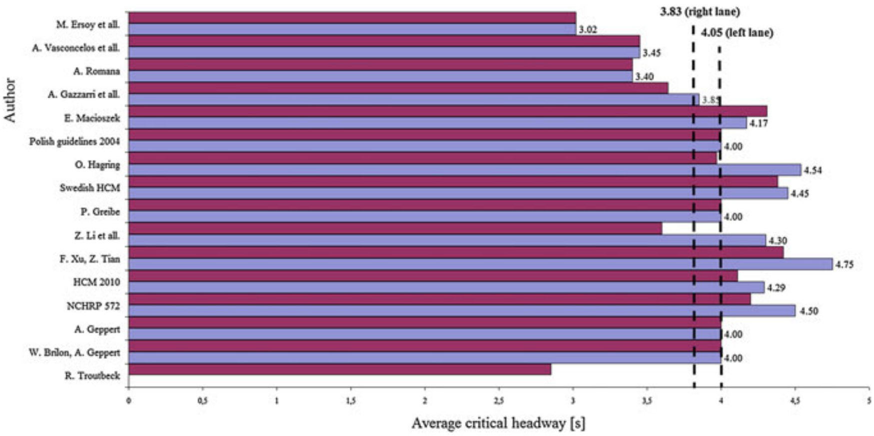


Fig. 3 Estimates of critical headway for two-lane roundabouts by different authors (*Source* Own)

Table 3 Comparison of critical headway models for turbo roundabouts entry

Country	Author	The model/value of the parameter t_g [s]	The applied calculation method
Netherland	Fortuijn [56]	– Right lane: 3.37–4.93 (average 4.15), – Left lane: 2.79–3.72 (average 3.25) depending on traffic control on entry	N.a.
Germany	Geppert [51]	4.0–4.5 (average 4.25) depending on traffic control on entry	N.a.
Poland	Macioszek [1]	– Right lane: 2.88–4.35 (average 3.61), – Left lane: 3.21–4.66 (average 3.93) depending on traffic control on entry	Regression method

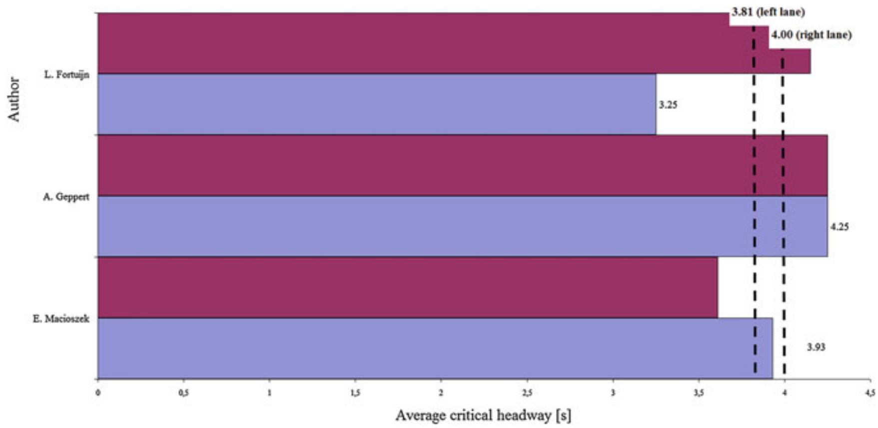


Fig. 4 Estimates of critical headway for turbo roundabouts by different authors (*Source* Own)

Table 4 One-lane roundabouts results comparison for different estimation method

The applied calculation method	One-lane roundabout number											
	1	2	3	4	5	6	7	8	9	10	11	12
Average values for each roundabout [s]	4.45	4.20	5.10	6.55	6.10	5.40	5.00	4.56	4.50	5.10	4.52	5.30
Median [s]	4.45	4.10	5.10	6.52	6.05	5.40	5.00	4.50	4.45	5.10	4.51	5.20
Drew equation [s]	4.44	3.60	4.51	6.10	5.58	4.48	4.50	4.16	4.20	4.38	3.82	4.40
The cumulative curves [s]	4.44	3.60	4.51	6.10	5.58	4.48	4.50	4.16	4.20	4.38	3.82	4.40
The acceptance curve [s]	4.44	3.60	4.51	6.10	5.58	4.48	4.50	4.16	4.20	4.38	3.82	4.40
Average for all roundabouts [s]	4.73											

Values of critical headways evaluated based on the above methods differ from each other. Critical headways estimated from cumulative curves for headways accepted and headways rejected, acceptance curves and using the D. Drew's method adopt the same values. However, these values are slightly lower than the values estimated as mean value and median of headways accepted (maximal difference of ±1.0 s).

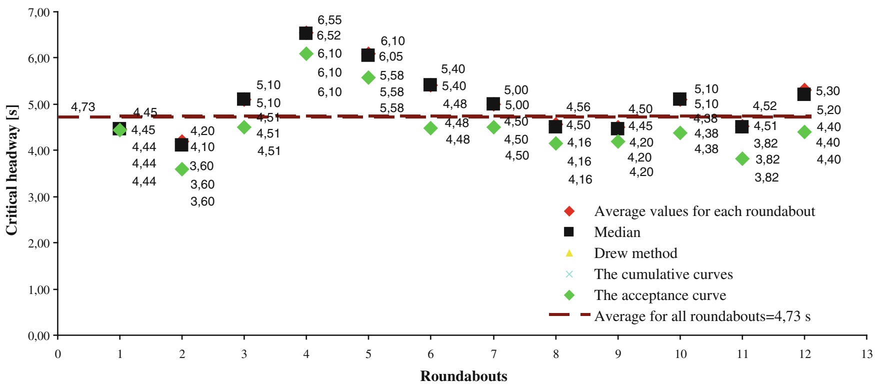


Fig. 5 One-lane roundabouts results comparison for each estimation method (*Source* Own)

4 Conclusions

The comparative analysis presented in the paper in terms of studies connected with determination of critical headways for drivers of vehicles at the entries to single-lane roundabouts, two-lane roundabouts and turbo roundabouts reveals that the values of the parameter tg obtained by individual authors differ from each other. These differences are in particular caused by the fact that values of this parameter cannot be measured in an indirect manner, which causes that, apart from the error connected with measurement, there are also errors that result from direct determination of the parameter tg. The values of the parameter tg presented in Tables 1, 2 and 3 were obtained by different methods such as regression, maximum likelihood method, logit method, Raff method, Troutbeck's and other methods.

Differences in the values of the parameter tg for individual countries are also caused by cultural diversity, differences in behaviours of drivers, their habits and customs. The consequence of this fact is difference in traffic capacity of roundabouts in individual countries. Therefore, the attempt to adapt the model used for determination of traffic capacity at entries of roundabouts built in a country to the conditions of another country requires previous calibration of the model, which should in particular concern psychotechnical parameters of drivers' vehicles at the entries of roundabouts i.e. critical headway and the follow-up headway.

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