Advances in Intelligent Systems and Computing 631

Grzegorz Sierpiński *Editor*

Advanced Solutions of Transport Systems for Growing Mobility

14th Scientific and Technical Conference "Transport Systems. Theory & Practice 2017" Selected Papers

Springer

Advances in Intelligent Systems and Computing

Volume 631

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Grzegorz Sierpiński
Editor

Advanced Solutions of Transport Systems for Growing Mobility

14th Scientific and Technical Conference "Transport Systems. Theory & Practice 2017" Selected Papers

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Editor
Grzegorz Sierpiński
Faculty of Transport
Silesian University of Technology
Katowice
Poland

ISSN 2194-5357 ISSN 2194-5365 (electronic)
Advances in Intelligent Systems and Computing
ISBN 978-3-319-62315-3 ISBN 978-3-319-62316-0 (eBook)
DOI 10.1007/978-3-319-62316-0

Library of Congress Control Number: 2017945737

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The growth of mobility observed in the areas of passenger and cargo transport has invalidated the former approach to planning and designing of transport system elements as being insufficient. New challenges require intense development of ICT solutions, but they also need to be addressed using a novel and technologically advanced approach to problems of modelling and optimization. The latter needs result from the emergence of new transport modes and organizational solutions implemented in smart cities. What proves particularly important for advanced transport systems is the environment-friendly solutions reducing the negative environmental impact of transport.

This publication contains selected papers submitted to and presented at the 14th "Transport Systems. Theory and Practice" Scientific and Technical Conference organized by the Department of Transport Systems and Traffic Engineering at the Faculty of Transport of the Silesian University of Technology (Katowice, Poland). The problems addressed in the publication entitled *Advanced Solutions of Transport Systems for Growing Mobility* have been divided into four parts:

- Part 1. Advanced Solutions of Modelling, Evaluation and Optimization,
- Part 2. Urban Passenger Transport—Solutions and Technologies,
- Part 3. Solutions to Improve the Efficiency of Freight Transport, and
- Part 4. Information as a Component of Intelligent Transport Systems.

The articles included in the publication are expressions of case study-based scientific and practical approach to the problems of contemporary transport systems. What one can also observe is the need for standardization which makes individual models or data sets become universal in the respective areas of application. Therefore, it is in fact an incentive to implement the proposed solutions in other parts of the world.

I would like to express my deepest gratitude to all authors, for reflecting the key problems of contemporary transport systems in a concise manner, as well as to reviewers, in recognition of their insightful remarks and suggestions without which this collection of papers would have never been published.

September 2017 Grzegorz Sierpiński

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14th Scientific and Technical Conference “Transport Systems. Theory and Practice” (TSTP2017) is organized by the Department of Transport Systems and Traffic Engineering, Faculty of Transport, Silesian University of Technology (Poland).

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Advanced Solutions of Modelling and Optimisation

Design and Evaluation of Transportation Systems

Jacek Żak(✉)

Poznań University of Technology, Poznań, Poland
jacek.zak@put.poznan.pl

Abstract. The paper presents the state-of-the-art in the fields of designing and evaluating complex transportation systems. Both components (design and evaluation) are presented as separate phases of a combined methodology and its major concepts and rules are described. Three alternative approaches to design/redesign of the transportation systems are presented, including: heuristic (intuitive - oriented) design supported by simulation, optimization (mathematical programming) - based design and hybrid approach based on the application of several combined procedures, including the 4-stage model. In the evaluation phase two major concepts are described, such as: Cost Benefit Analysis (CBA) and its variations and Multiple Criteria Analysis (MCA). The real life case study, focused on the heuristic redesign of the section of the transportation system, construction of alternative transportation solutions and their multiple criteria evaluation, is demonstrated.

Keywords: Transportation system · Methodology of design/redesign and evaluation

1 Introduction

Each transportation system is a set of components, such as: transportation infrastructure (roads, railways, passengers' terminals, stops, transfer points, airports, piers, hubs and depots, distribution centers, parking lots, garages) fleet of vehicles (cars and buses, trains and trams, boats and airplanes), human resources and governing rules (traffic regulations, service standards, management rules) that ensure a coordinated and efficient transfer/movement of people (passengers) and/or goods from their origins to destinations in a certain area [1].

Transportation systems are designed to provide a certain level of transportation service at rational (competitive) costs. This is achieved by/in each transportation system through proper coordination of the movement of people and/or goods with the corresponding movement of vehicles and appropriate utilization of the transportation infrastructure. Transportation systems are intended to offer reliable and timeless delivery of passengers and goods in a cost-effective manner through efficient utilization of transportation assets (vehicles and infrastructure).

Transportation systems can be single-mode or multi-modal transportation solutions [1]. In the first case they operate in one environment (air, rail, road, water) and use one type/mode of vehicles, while in the second case they operate in different environments

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_1

and utilize various types/modes of vehicles. In all transportation systems the transportation infrastructure is usually arranged in the form of a network with link (linear) components such as: roads, railways, airways, waterways and canals as well as node (point-oriented) components (terminals), such as: airports, railway stations, bus stations, warehouses, trucking terminals, refueling depots (docks, stations) and seaports. The vehicles used in transportation systems are [1]: automobiles (private, passenger-cars), bicycles, buses, trains, trams, trucks, boats, ships, barges, airplanes and helicopters. As far as the transported medium is concerned transportation systems can be principally divided into: passengers'-oriented facilities and freight transportation solutions. The former may be public (based on scheduled services) or private. Freight transportation systems are usually private and focused either on Full Truck Loads (FTL) or Less Than Truck Loads (LTL).

Planning and designing of a transportation system is a complex process of conceptualizing, developing and implementing the idea of moving people and/or goods in a certain area between their origins and destinations [1, 2]. It is focused on matching (satisfying) transportation demand by the provision of an appropriate transportation supply in the form of transportation infrastructure and fleet, properly managed by professional crews (people) and coordinated by certain operating rules. Design of a transportation system is a collaborative and team-oriented activity that requires the application of interdisciplinary knowledge and skills, common sense, scientific principles and information technology tools to provide for the safe, efficient, comfortable, and environmentally compatible movement of people and goods. Planning and designing of a transportation system is associated with defining transportation goals and policies for a certain area/region, analyzing and predicting transportation needs, development of various concepts of transportation solutions that satisfy these needs, elaboration of an investment plan and implementation of the proposed concepts/ideas.

Planning and designing of a transportation system has a strategic character [1–3]. Depending on the size and scope of the transportation system its design can be performed at a continental, national, regional and local levels. It is an activity of transportation policy makers, transportation and traffic planners and engineers, designers and developers of transportation infrastructure and/or transportation – logistics consultants. These groups of experts support governmental and private institutions, authorities at different levels (national, regional and local) and transportation systems operators to construct the most rational and desired set of components (described above) that constitute the transportation system. The design of a transportation system usually involves the following stages, described in Sect. 2 [1–3]:

- Analysis of transportation demand.
- Design of a transportation network.
- Traffic assignment.
- Definition of transportation modes (types of vehicles).
- Allocation of crews.

Planning and designing of a transportation system involves five basic categories of measures [1, 2, 4, 5] characterized in Sect. 2:

– Land use design.
– Infrastructure development.
– Implementation of management rules.
– Information provision.
– Design of pricing strategies.

All of them must be integrated and properly coordinated to create an efficient, safe, reliable, sustainable, accessible, affordable and user-friendly transportation system. In many cases the transportation system is not designed from scratch. Its certain components exist in a considered area but their further coordination, development and reshape is required. In such a case instead of designing the whole concept of a transportation system transportation planners focus their efforts on redesign, enhancement and improvement of certain segments or areas of the transportation system. The redesign of the transportation system consists in introducing substantial changes in several of its critical components [6]. It may involve: route changes (extensions, eliminations, reconstructions), relocation of stops/crossdocking points, construction of integrated multi-modal transfer terminals, fleet replacement and reassignment, better coordination of schedules, and many others. As a result different variants – transportation solutions of the transportation system can be constructed/developed. These variants of/alternative solutions for a transportation system are to enhance the standard of transportation service, improve overall efficiency of the transportation system and ensure the improvement of its major performance characteristics. In case of the transportation system redesign, the above mentioned measures (or their selected categories) and the above described stages of transportation system planning are applied to adjust the existing transportation system or its sections to new requirements, expectations and desires. The system is adapted to the new changing environment and both technological, organizational and social – oriented changes are introduced to improve its standard and performance. Both design and redesign of the transportation system requires substantial financial, environmental and social expenditures [1, 7, 8].

2 Design and Redesign of the Transportation System

As presented in Sect. 1 design and/or redesign of a transportation system involves 5 major stages. Their definition, content/scope and major characteristics are shortly presented below [1–3].

Analysis of transportation demand (either for passengers' movements and/or freight movements) in a certain area consists in recognizing current (existing) and future transportation needs [1, 2]. This analysis is based on survey research and personal interviews with prospect users of the transportation system. It results in a definition of the Origin – Destination (O-D) Matrix which is an overall representation of prospect (or existing) traffic flows in a considered area, between certain traffic zones and their central points, being the approximated representation of traffic origins and destinations.

Design of a transportation network is focused on [1–3]: definition of nodes, such as: road and railway crossroads, terminals, depots and hubs, warehouses/distribution centers, harbors, border crossings, transfer points and design of arcs corresponding to specific segments or legs of transportation connections/routes. In this phase single-mode and/or multiple modes transportation routes are designed. In this phase certain analytical tools and computer-based procedures (algorithms) usually support transportation planners in route/network design.

Traffic assignment consists in allocating traffic flows (passengers and freight) to the pre-defined transportation network. In this phase, based on the application of different network assignment algorithms [2] concrete traffic flows are allocated to specific segments/arcs of the transportation network. As a consequence the capacity utilization of specific segments of the network can be computed and visualized, and certain adjustments can be introduced. In the traffic assignment phase transportation planners search for a network equilibrium in an iterative procedure.

Definition of transportation modes (types of vehicles) refers to the analysis of different modal options of moving people and/or freight in a transportation system [1, 2]. Single mode or multi-modal solutions can be considered in this phase. Transportation planners recognize and assess different transportation modes/types of vehicles that are to serve the considered transportation network. After having been selected the transportation modes/types of vehicles are assigned to service the traffic flows and carry out concrete transportation jobs. In this phase different compositions of heterogeneous, multi-modal fleet can be considered, including: private passenger vehicles, commercial vehicles, trains, trams, vessels and/or planes. In public transportation systems this phase results in the definition of operating frequencies and headways on specific transportation routes and allows for generating the corresponding timetables. Different mode evaluation and fleet composition computational methods can be applied in this phase.

Allocation of crews (drivers, stewards, etc.) **to vehicles**; definition and scheduling of their tasks [1, 2]. This phase refers to commercial and public vehicles and is usually defined as rostering. It is not performed in case of individual, passengers' vehicles owned by private persons. In this phase various crew scheduling algorithms can be applied.

As presented by Garrett [1], Hansher and Button [2], Anderson et al. [4] and Hills et al. [5], five basic categories of measures must be used and coordinated to design an efficient, comfortable and convenient transportation system (see Sect. 1). These measures, often called necessary components of the transportation system development are characterized below. They must be integrated and properly coordinated to create an efficient, safe, reliable, sustainable, accessible, affordable and user-friendly transportation system.

First of them is **Land Use Design**, i.e.: an activity, process or professional branch encompassing various disciplines which seek to order and regulate land use in an efficient, sustainable and ethical way, thus preventing land-use conflicts. Based on the United Nations definition [9] Land Use Design means the scientific, aesthetic, and orderly disposition of land, resources, facilities and services with a view to securing the physical, economic and social efficiency, health and well-being of local (urban and rural) communities. The goal of Land Use Design is the welfare of people and their communities by creating convenient, equitable, healthful, efficient, and attractive environments for present and future generations. The land use design is required to properly integrate the transportation infrastructure with its surrounding environment and define its desired location. A good land use plan allows for provision of a transportation system with high accessibility, good connectivity and operating efficiency, environmental sustainability and high level of life comfort for local community. There is a growing interest in research focused on land use and transport planning integration. Many researchers prove [1, 2] that a strong interaction between land use and transport planning exist. They develop new, modern, advanced paradigms of combined land use and transport design [1, 2].

The next, critical measure of transportation system design is **Infrastructure Development** [1]. This phase is investment intensive and requires high level of expenditures and organizational effort. Transportation infrastructure is usually arranged in the form of a network with link (linear) components such as: roads, railways, airways, waterways and canals as well as node (point-oriented) components (terminals), such as: airports, railway stations, bus stations, warehouses, trucking terminals, refueling depots (docks, stations) and seaports. The transportation infrastructure development can be financed by both private and public institutions, which in some instances may establish a public-private partnership. The development of a transportation infrastructure is in many cases organized in the form of transportation projects, such as: extension of the metro line in the public transportation system; development of the segment of the national highway/motorway; construction of the regional distribution center; development of a roundabout or flyover in an urban transportation system; building a new sea terminal. Many computer based methods [1, 10] have been developed to support the transportation infrastructure development.

Another important component of transportation system design is **Implementation of Management Rules** [1, 3]. These rules control the flow of people (passengers) and goods in the transportation system. They are implemented in a hierarchical manner, from the top to the bottom and refer to strategic (e.g.: setting the location of the transportation depots, defining transportation modes), tactical (e.g.: elaborating a fleet replacement policy; designing fixed routes) and operational issues (daily dispatching of vehicles; rerouting crews and vehicles in case of unexpected events). In each transportation system, regardless the transportation mode, they cover such areas as: traffic regulation and control, marketing issues - customer service rules and standards (definition of service portfolio, establishing the quality standards), safety and security issues, information and communication principles (information flow associated with the traffic flow), technological standards, fixed assets management rules (including: fleet management policies and infrastructure management policies), human resource management rules (including selection of crew members, assignment and scheduling of employees to transportation tasks), environmental policies, financial policies (e.g. profitability; costs and incomes; payment policies; cash flows).

Information Provision is a stage focused on implementing proper communication standards and tools that provide information for customers in the transportation system [1, 3]. The current level of technological development allows for providing information in different ways, including: regular printed promotional materials (leaflets, brochures, posters), electronic boards with a variable informational content, web pages and portals, mobile applications and others. In general, information provision in transportation systems facilitates customers to use the transportation system, access the transportation service and find the most desired transportation solution corresponding to the customer's objectives. Information provision systems can be associated with the transportation infrastructure (fixed location), including information boards located at the terminals (airports, railway stations, bus terminals) and/or placed along the roads and highways. They can also have a mobile character as on-board tools the vehicles are equipped in. In the passengers' transportation systems the current standard of information provision are technologically advanced navigation systems and electronic passengers' trip planners [1, 3]. In the freight transportation systems the most common solutions are web portals [1]. The typical content of information provided in transportation systems includes: transportation connections (corridors) between pre-defined origins and destinations, operating dates and hours, including: departure and arrival times (frequencies), space/seats/capacity availability, transferring points/terminals, travel distance and time, prices/tariffs for transportation services, extra/additional services (e.g. insurance, cargo handling, transfer of additional equipment), travel conditions (e.g. weather, road works and/or accidents, traffic congestion), travel delays and/or diversions.

Design of pricing strategies is a final stage of transportation system development [1, 3]. It consists in defining prices for transportation and supplementary services offered by transportation systems and fees for using transportation infrastructure (terminals, roads, parking lots, etc.). In passenger public transportation prices are usually publicly announced and they usually depend on the distance to travel and the time advancement the travel is planned with. It also depends on the standard of traveling (1st, 2nd class) and the speed of movement (regular movements vs. express movements). In freight transportation the most commonly used tariffs are based on vehicle – kilometer prices or tone – kilometer prices. The first pricing strategy refers primarily to Full-Truck-Loads (FTL), while the second one is usually applied for Less-Than-Truckloads (LTL). In many transportation systems the following components of pricing strategies are implemented [1, 3]: congestion pricing (different fees for travelling in peak hours or peak seasons); parking/terminal charges; road tolls (depending on the standard); emissions fees; fuel taxation.

Design and redesign of a transportation system or its components can be performed in different manners [1, 3]. Based on the works of various authors [1–3, 11–15] three major approaches to design/redesign of the transportation system, can be distinguished. These include:

- heuristic (intuitive - oriented) design supported by simulation,
- optimization (mathematical programming) - based design,
- hybrid approach based on the application of several combined procedures, including the 4-stage model.

The first approach is based on the application of intuition, common sense and expert knowledge of designers (traffic engineers, experts – analysts, consultants, transportation managers, researchers) who use their experience and expertise to develop specific transportation solutions. This creative phase of transportation system (re-) design is combined with computational testing of the proposed concepts in the simulation software. The experts usually design several alternative options and compare them based on the results of simulation. The behavior of traffic flows is examined and the impact of concrete transportation solutions on the operations of the whole transportation system is investigated. In many cases this phase is not an individual work but requires a common, group effort. In this approach different methods of generating solutions can be applied, including: brainstorming, concurrent design of transportation solutions, step-wise design based on discussions and exchange of ideas between experts/designers. Usually, the analysis starts with a comprehensive diagnosis and evaluation of the existing transportation system and its corresponding transportation solutions. The status quo (current condition of the transportation system) is the benchmark for the design of new options. In many cases **SWOT ANALYSIS** of the current transportation system is developed and its strengths and weaknesses, opportunities and threats are defined.

The heuristic design/redesign of the transportation system may include such elements as: reconfiguration of the transportation network with elimination of certain routes/connections and extension of others, changes in the distribution of hubs/depots, terminals and stops, redefinition of the modal split and fleet composition (introduction of new transportation modes and reduction of others), infrastructural investments (road and tramway construction, introduction of parking lots – Park & Ride system, closing and opening new depots), changes based on legal regulations (e.g. speed limits), changes in pricing policies, changes in frequencies/headways of transportation means resulting in the redesign of the timetables. The overall objective of introducing the above mentioned changes is to enhance the overall efficiency and quality of the transportation systems.

As described above **in the testing/computational phase** the heuristically developed solutions **are simulated**. Simulation is a popular and effective operations research technique used to analyse a wide range of dynamically changing systems [16]. Researchers define the simulation as a controlled statistical sampling technique [17]. The essence of simulation is to carry out a series of computational experiments, using various input data introduced into a simulation model, that describes the operations of the real system and to generate a set of output data that characterizes and assess the considered system. Simulation allows us to check, monitor and evaluate the behaviour of the real system under different realistic conditions, in an artificial computer – based lab environment. There are many generic/universal simulation approaches, including [17]: Monte Carlo techniques, Markov Chains models or queuing theory - based methods. Several software packages, including: Arena, Extend Sim, Aris, Flexim and many others have been developed to carry out the above described analysis. The current state of the art simulation packages have graphical, object-oriented character and allow for simulating both continuous and discrete events.

As far as transportation systems are concerned a specialized simulation technique, called traffic simulation, can be applied. Based on the Highway Capacity Manual 2000 [18], traffic simulation is "a computer program that uses mathematical models to conduct experiments with traffic events on a transportation facility or system over extended periods of time". It can describe the entire transportation system (e.g. urban, regional or national) or its selected part or component, such as: several intersections, a motorway segment and/or a roundabout. The simulation model consists of two mutually interrelated components, i.e.: information on demand that characterizes the needs for movement (passengers, freight) and information on supply that describes transportation network, traffic zones (e.g. residential and business areas) and vehicles (public and private). Depending on their accuracy and scope the simulation models can be divided into [19]:

- Micro-simulation models that describe traffic at high level of detail and distinguish single, separate units in the traffic flow (different types of vehicles, pedestrians) and mutual interactions between them. They are usually applied for the detailed analysis of limited segments of transportations systems. The most popular micro-simulation tools are Vissim, Aimsun, Corsim.
- Meso-simulation models that describe traffic at an intermediate level of detail and distinguished particular units in the traffic flow but do not take into account interactions between them. They are less precise and usually applied for the components of transportation systems covering larger areas. The most popular meso-simulation tools are Netflo, Dynasmart, Transims.
- Macro-simulation models that describe traffic at a high level of aggregation, as a uniform traffic flow. They are based on deterministic relationships between the quantities characterizing the traffic flow such as: volume, speed and density. Macroscopic simulation has been developed to model an entire transportation network and/or system. The most popular programs that simulate the movement in the macro scale are Visum, Emme, Transcad.

The second design method, called **optimization (mathematical programming)-based design** consists in formulating the transportation system design problem in terms of mathematical programming. This approach is focused on constructing the original mathematical model of the decision situation and then solving the considered decision problem with the appropriate computer-based tools (commercial solvers, self-developed academic software) being the computer-implementation of certain quantitative, optimization methods, originating from the field of Operations Research (OR). In Operations Research - OR [17] **optimization** (alternatively: **mathematical optimization** or **mathematical programming**) is a quantitatively – oriented process focused on selecting the best (most desirable) solution/variant/action from a set of available/feasible solutions/variants/actions with regard to (a) certain measure(s) of merit (criterion/criteria). In general, optimization leads to solving an optimization (mathematical programming) problem that can be stated as follows [17]:

Given: a function $\boldsymbol{f}$: $\boldsymbol{A} \rightarrow \mathbf{R}$ from a set $\boldsymbol{A}$ to the real numbers
Sought: an element $\boldsymbol{x_0}$ in $\boldsymbol{A}$ such that $\boldsymbol{f(x_0)} \leq \boldsymbol{f(x)}$ for all $\boldsymbol{x}$ in $\boldsymbol{A}$ ("minimization") or such that $\boldsymbol{f(x_0)} \geq \boldsymbol{f(x)}$ for all $\boldsymbol{x}$ in $\boldsymbol{A}$ ("maximization").

Typically, $\boldsymbol{A}$ is a subset of the Euclidean space $\mathbf{R}^n$, usually defined by a set of constraints, i.e.: equalities or inequalities that the elements of $\boldsymbol{A}$ have to satisfy. The domain $\boldsymbol{A}$ of $\boldsymbol{f}$ is called the *search space* or the *choice set*, while the elements of $\boldsymbol{A}$ are called candidate solutions or *feasible solutions*. The function f is denominated by different terms, including: an **objective function**, a **utility function** or a **fitness function** [3]. The optimization process leads to the selection of an optimal solution, that is such a value of $\boldsymbol{x}$ in $\boldsymbol{A}$ that minimizes (or maximizes) the objective function $\boldsymbol{f}$. As described above the optimal solution is generated with the application of different computational procedures (algorithms) [17].

In this approach a transportation system design problem can be also formulated as a **multiple criteria (objective) optimization problem**. In such a case the designers also formulate the objective function $\boldsymbol{F}\ \boldsymbol{(x)} = \boldsymbol{f_j}(\mathbf{x})$, composed of $\boldsymbol{j = 1, 2,\ldots, J}$ criteria and a set of constraints that define the space of feasible solutions $\boldsymbol{x} - \boldsymbol{A}$. The designers are searching for such a solution $\boldsymbol{x}$ in the decision space $\boldsymbol{A}$ which image in the objective (criteria) space z^{x} generates the most desired values of the objective function $\boldsymbol{F(x)} = \boldsymbol{f_j}(\mathbf{x})$ [20, 21]. The image of a solution $\boldsymbol{x}$ in the objective space is a point $\mathbf{z}^{\mathbf{x}} = \left[z_1^{\mathbf{x}}, \ldots, z_J^{\mathbf{x}}\right] = \mathbf{f}(\mathbf{x})$, such that $z_j^{\mathbf{x}} = \boldsymbol{f_j}(\mathbf{x})$, for $j = 1, .., J$. Important notions in this context are: dominance relation and Pareto-optimal (efficient) solution that refer to optimality in a multiple objective sense. Point $\mathbf{z}^1$ *dominates* $\mathbf{z}^2$, $\mathbf{z}^1 \succ \mathbf{z}^2$, if $\forall j\, z_j^1 \geq z_j^2$ and $z_j^1 > z_j^2$ for at least one j. Solution $\mathbf{x}^1$ dominates $\mathbf{x}^2$ if the image of $\mathbf{x}^1$ dominates the image of $\mathbf{x}^2$ in the objective space. A solution $\mathbf{x} \in A$ is Pareto-optimal (efficient) if there is no $\mathbf{x}' \in A$ that dominates $\mathbf{x}$. Point being an image of a Pareto-optimal solution in the objective space is called non-dominated. The set *PO* of all Pareto-optimal solutions is called the Pareto-optimal set. The image *ND* of the Pareto-optimal set in the objective space is called the non-dominated set or Pareto front [20, 21].

In the optimization based design the designers must have advanced analytical skills and experience in mathematical modeling and OR-oriented approach to solving complex decision situations. They usually search for an optimal structure of the transportation network (nodes, links), the most efficient assignment of the traffic flows (vehicles, freight, passengers) to the network, the best vehicle routes (in terms of costs, travel times, safety), the most desired vehicles and crew schedules (timetables) and/or the optimal solution for a concrete transportation project (location, design structure- and/or material-wise).

The third design method, denominated by **hybrid approach** is a combination of the two previously described ideas. It encompasses both heuristic design, application of simulation techniques and optimization methods. This approach has an interactive and iterative character in which conceptual phases alternate with the computational phases. This approach is well rooted in the transportation research through the concept of a so called, **Four-Stage Model** [2]. The Four-Stage Model (FSM) is a primary tool for the transportation system analysis, assessment of its performance and prediction of its future behavior. It is assumed in the FSM that transportation system $\boldsymbol{T}$ and activity system $\boldsymbol{A}$ serve as exogenous inputs to performance procedures $\boldsymbol{P}$ and demand procedures $\boldsymbol{D}$, respectively. Transportation system T is defined as all elements of transportation infrastructure and services, while activity system $\boldsymbol{A}$ corresponds to spatial distribution of land uses and the demographic and economic activities associated with them. The overall objective of the FSM is the equilibration of the transportation system, i.e. the determination of the equilibrium flows in the considered transportation network. In some cases location procedures $\boldsymbol{L}$ and supply analysis methods $\boldsymbol{S}$ are required to support the efficient application of the FSM. Usually, they are combined with FSM but not formally integrated with the basic equilibration algorithm.

As its name indicates the FSM is composed of the following four phases [2]:

- Trip generation.
- Trip distribution.

- Modal split.
- Traffic assignment.

In each of these phases different analytical tools and computational procedures are applied to find a proper and most desired solution. The objective of the **first stage** is to define the magnitude of total daily movement (passengers and/or freight) in the model transportation system at the elementary unit (household, business) and zonal levels (Traffic Analysis Zones – TAZ-s) for various trip purposes. In this phase different, multiple factors regression models [2] are applied. Separate generation paradigms are applied for trip production and attraction. In the **second stage** the trip/movement ends (from trip generation) are recombined into trips either as production – attraction pairs or origin – destination pairs. In this phase various destination choice models and algorithms are applied. The most commonly used technique is the gravity model, equivalent to the Law of Gravitation. As a result a movement/trip matrix or O-D matrix is generated. The **third stage** consists in defining the **modal split**, i.e. the share of each transportation mode in all movements/trips. In this phase various assignment algorithms based on complex objective functions that include many human characteristics and behavioral factors are applied. These assignment or choice – based methods take into consideration choice probabilities of individual trip/movement – makers. The **last stage** concerns the **traffic assignment** and is strictly associated with the **route choice** by concrete trip/movement makers. In this phase modal O-D movement/trip matrices are loaded on the modal networks. As a result the paths chosen by trip/movement makers from their origins to the destinations are specified and the level of traffic flows (vehicles, passengers, freight) assigned to concrete sections of the transportation network (streets, public transportation routes) are determined. The Traffic Assignment is carried out with the application of advanced: Non-Deterministic Shortest Paths Search Algorithms, Multiple-Paths Assignment Procedures (Exponential Probability Function), Static and Dynamic Assignment Procedures [2].

3 Evaluation of Transportation Systems

Evaluation of transportation systems has been a widely discussed topic for many years [11, 12, 14, 22, 23]. Many authors have developed different methodologies of evaluating transportation systems, processes and projects, including: cost-benefit analysis (CBA) [24], cost-effectiveness analysis (CEA), regional economic impact study (REIS), environmental impact assessment (EIA) and Multiple Criteria Analysis (MCA) [11, 23].

The author of this chapter would risk a statement that two of the above mentioned methodologies are most popular for transportation applications and most frequently used for the evaluation of transportation systems. These are: Cost – Benefit Analysis and Multiple Criteria Analysis, often called Multiple Criteria Decision Making/Aiding.

3.1 The Methodology of Cost – Benefit Analysis

Cost – Benefit Analysis (CBA) [24] is a universal methodology of assessing socio – economic benefits of a certain solution, project and/or undertaking. It is commonly used in transportation systems to investigate whether a certain transportation concept generates overall benefits and balances the costs associated with its implementation. The major principle of CBA is the maximization of the global social welfare of the society. It is based on a core concept of a traditional economy, pointing out that a "rational consumer/customer" always behaves and acts to increase his/her overall welfare. It is assumed that he/she knows what are his/her individual needs and expectations and how concrete solutions/concepts and projects can contribute to their satisfaction, resulting in the increase of his/her individual welfare. It is further indicated that individual welfares can be added and in such a way aggregated to the overall welfare of the society.

The CBA measures if a concrete (transportation) project changes and enhances the above described welfare, i.e. increases the overall socio-economic benefits generated by a concrete (transportation) implementation. CBA recognizes and computes all positive (benefit-oriented) and negative (cost-oriented) effects of a considered concept/project/solution. It expresses all benefits and costs in financial terms and transforms all its outputs (positive and negative) into monetary units and compares them. Thus, in CBA the interests of different stakeholders, their preferences and benefits as well as shortcomings/weaknesses and costs of a certain project or investment are combined (aggregated) and expressed in monetary units. In the CBA three measures are usually computed to assess the overall profitability/utility of the considered project (investment). These include: Economic Net Present Value (ENPV), Economic Internal Rate of Return (EIRR) and Benefit-Cost Ratio (BCR) [24]. In all the above mentioned characteristics the discounted cash flows of benefits (positive flows) and costs (negative flows) are combined and compared. Through the discount mechanism the time value of money is taken into account.

The **Economic Net Present Value (ENPV)** [24] is a measurement expressed in monetary units of the profitability of a(an) project (undertaking) that is calculated by subtracting the present values (PVs) of discounted cash outflows (total costs, including initial investment cost) from the present values (PVs) of discounted cash inflows (benefits) over a period of time. A positive ENPV results in a profit, while a negative NPV results in a loss of a certain (transportation) solution/project. The ENPV measures the excess/surplus or shortfall/shortage of cash flows, in present value terms, above the cost of funds. In practical terms transportation investments/projects with the highest positive ENPVs are selected by the decision makers (DMs) for pursuing and real world implementation.

The Economic Internal Rate of Return (EIRR) [24], also called the discounted cash flow rate of return (DCFROR), on an investment or project is the "annualized effective compounded return rate" or simply rate of return that sets the Economic Net Present Value (ENPV) of all discounted cash flows (both positive and negative) from the investment/project equal to zero. Thus, it is the discount rate at which the total Economic Net Present Value of future positive cash flows (benefits) is equal to all negative cash flows (costs), including the initial investment. EIRR, expressed percentage-wise [%] is an indicator of the profitability, efficiency, quality, or yield of an investment. Based on the CBA principles DMs compare EIRRs of various financial activities/capital projects or investments, including the transportation ones, in terms of their rates of return and select those that generate the highest (maximum) values of EIRRs. The term *internal* refers to the fact that its calculation does not involve external factors, such as inflation or the cost of capital.

The Benefit-Cost Ratio (BCR) [24], sometimes called Profitability Index Rate (PIR) is an indicator that attempts to summarize the overall value for money of a (transportation) project or proposal. As its name indicates the BCR is the ratio of the discounted benefits (positive cash flows) of a project/undertaking, investment or proposal, expressed in monetary terms, relative to its discounted costs (negative cash flows), also expressed in monetary terms. Thus, the **benefit cost ratio (BCR)** is a dimensionless measure that takes into account the amount of monetary gain realized by performing a (transportation) project versus the amount it costs to execute it. General rule of thumb is that if the benefit is higher than the cost the project is a good investment. The higher the BCR the better. The BCRs are used extensively in transportation to carry out the cost-benefit appraisals of transportation projects over their service lives. In practical terms, when the DM copes with the budgetary constraints of a certain (transportation) project, the net BCR is computed as a ratio of ENPV (future net benefits) to total expenditure falling within the constraint, including initial investment and regular operating costs.

3.2 The Methodology of Multiple Criteria Analysis

Multiple Criteria Analysis (MCA), often called Multiple Criteria Decision Making/Aiding (MCDM/A) [20, 21, 25] is a field of study and a coherent methodology, originating from Operations Research (OR) [17] which aims at giving the Decision Maker (DM) some tools/methods in order to enable him/her to advance in solving complex decision problems in which several – often contradictory – points of view must be taken into account [21, 25]. MCA can help the Decision Makers (DMs) in analyzing and assessing transportation systems, solving complex transportation decision problems that arise in those systems, in evaluating innovative transportation projects, concepts and solutions intended to up-grade and enhance transportation systems, in analyzing trade-offs and balancing conflicting interests associated with the operations of certain transportation processes and systems, in searching for the most desired, compromise decisions for the users and stakeholders of transportation systems.

MCA/MCDM/A focuses its efforts on assisting the DM in solving multiple criteria decision problems, i.e. situations in which, having defined a set of actions/variants/solutions $\boldsymbol{A}$ and a consistent family of criteria $\boldsymbol{F}$ the DM tends to [21, 25]:

- determine the best subset of actions/variants/solutions in $\boldsymbol{A}$ according to $\boldsymbol{F}$;
- divide $\boldsymbol{A}$ into subsets representing specific classes of actions/variants/solutions, according to concrete classification rules;
- rank actions/variants/solutions in $\boldsymbol{A}$ from the best to the worst, according to $\boldsymbol{F}$.

As presented above there are two major components of each multiple criteria decision problem, i.e.: a set of actions/variants/solutions ***A*** and a consistent family of criteria ***F***. The set of ***A*** can be defined directly in the form of a complete list or indirectly in the form of certain rules and formulas that determine feasible actions/variants/solutions, e.g. in the form of constraints [20, 21, 25]. The consistent family of criteria ***F*** should be characterized by the following features [21, 25]:

- it should provide a comprehensive and complete evaluation of ***A***,
- each criterion in ***F*** should have a specific direction of preferences (minimized – min or maximized – max) to adequately indicate the global preferences and expectations of the DM,
- each criterion in ***F*** should not be redundant with other criteria in ***F***; the domain of each criterion in ***F*** should be disjoint with the domains of other criteria.

There is a variety of computerized, MCDM/A methods that help the DMs to solve the above described multiple criteria decision problems. These methods can be classified according to several criteria, including [21, 25]:

I. the overall objective of the decision method correlated with the category of the decision problem,
II. the moment of the definition of the DM's preferences,
III. the manner of the preference aggregation.

Based on the above mentioned classification criteria one can distinguish the following categories of MCDM/A methods, respectively [21, 25]:

- **I Criterion**
  - multiple criteria choice (optimization) methods (e.g. LBS, Steuer Procedure, Topsis),
  - multiple criteria sorting (classification) methods (e.g. Electre Tri, 4eMka),
  - multiple criteria ranking methods (e.g. Electre III/IV, AHP).
- **II Criterion**
  - methods with an a'priori defined preferences (e.g. Electre methods, Promethee I and II, UTA, Mappac, Oreste),
  - methods with an a'posteriori defined preferences (e.g. PSA method),
  - interactive methods (e.g. GDF, SWT, Steuer Procedure, STEM, VIG, LBS).
- **III Criterion**
  - the methods of American inspiration, based on the utility function [8] (e.g. AHP, UTA),
  - the methods of the European/French origin, based on the outranking relation [26] (e.g. Electre methods, Promethee I and II).

The MCA/MCDM/A methodology [21, 25] clearly identifies major participants of the decision making/aiding process, such as: the decision maker (DM), the analyst and the interveners (stakeholders) and describes their roles in this process. As opposed to classical OR techniques MCA/MCDM/A methods do not yield optimal solutions, because in reality the solutions that would simultaneously optimize several, contradictory criteria do not exist. Instead of that the methodology of MCA/MCDM/A searches for the compromise solution that satisfies the interests of the above mentioned parties, analyzes the trade-offs between the considered criteria and takes into account specific preferences and expectations of the DMs and stakeholders. In the MCA/MCDM/A methodology different criteria can be used to evaluate transportation systems or solutions, including: investment costs/profitability, safety and security, environmental friendliness, reliability (timeliness; schedule fulfillment), travel/delivery time, accessibility and others. As opposed to CBA in MCA these criteria do not have to be transformed to the monetary units and aggregated.

3.3 Basic Features of Selected MCDM/A Methods

In the presented analysis two most popular MCDM/A methods, i.e. ELECTRE III/IV and AHP, have been applied. The first one, based on the binary outranking relation [26] belongs to a European (French) school of MCDM/A, while the second one, based on the multi-attribute utility theory [27] is an important representative of an American school of MCDM/A. Both methods are classified as multiple criteria ranking methods; thus they rank the variants form the best to the worst.

ELECTRE III/IV method belongs to a family of ELECTRE methods, proposed by B. Roy [26]. In this method, the basic set of data is composed of the following elements: a finite set of variants, a family of criteria, and the preferential information submitted by the DM. The preferential information is defined in the form of criteria weights – w_j and the indifference – q_j, preference – p_j and veto – v_j thresholds [21, 25, 26].

The outranking relation in the Electre III/IV method [26] is built on the basis of the so called concordance and discordance tests. In the concordance test a concordance matrix, composed of the global concordance indicators $C(a, b)$, is constructed. The matrix presents the pairwise relationship between alternatives and indicator $C(a, b)$ expresses the extent to which the scores of a and b on all criteria are in concordance with the proposition a outranks b. The values of $C(a, b)$ depend on the values of concordance indexes for each criterion $C_j(a, b)$ and weights of criteria w_j. The concordance index $C_j(a, b)$ indicates to what extent the statement "a is at least as good as b" on criterion j is satisfied. The value of this index is between 0 and 1 and it is calculated on the basis of thresholds $q_j[f_j(a)]$ and $p_j[f_j(a)]$ for each criterion function $f_j(a)$. Afterwards, taking into account the relative importance (weights) w_j of each criterion index $C(a, b)$ is computed. In the next stage – called the discordance test, a discordance index $D_j(a, b)$ for each criterion j is calculated. The notion of discordance brings into play the veto threshold $v_j[f_j(a)]$ on specific criteria. The underlying idea of the veto threshold is as follows: even if the statement "a outranks b" is born out by all criteria except one, it is possible that the difference $f_j(b) - f_j(a)$ on the discordant criterion is so great that it becomes impossible not to take it into account.

When the global concordance indicator and the discordance indexes on specific criteria have been established, the Electre III/IV method constructs an outranking relation S for each pair of alternatives (a, b). The outranking relation indicates the extent to which "a outranks b" overall. This relation is expressed by the degree of credibility $d(a, b)$, which is equivalent to the global concordance indicator $C(a, b)$ weakened by the discordance indexes $D_j(a, b)$. The values of $d(a, b)$ are from the interval [0, 1]. Credibility $d(a, b) = 1$ if and only if the assertion aSb ("a outranks b") is well founded, ***d(a, b)*** = 0 if there is no argument in favor of ***a S b*** (not ***a S b*** – "***a*** does not outranks ***b***"). The definition of ***d(a, b)*** results in the construction of the credibility matrix based on which the method establishes two preliminary rankings (complete pre-orders) using a classification algorithm (distillation procedure). During this procedure one can obtain a descending and an ascending pre-order. In the descending distillation the ranking process starts from the selection of the best variant, which is placed at the top of the ranking. In the next steps, subsequent best variants are being selected from the set of the remaining variants and placed on the subsequent highest positions of the ranking, until all variants are ranked. In the ascending distillation the variants are ranked in the inverse order. The process starts from the selection of the worst variant and placing it at the bottom of the ranking. In the next steps, subsequent worst variants are being selected from the set of the remaining variants and placed on the subsequent lowest positions of the ranking, until all variants are ranked The final results can be presented either in the form of the ranking matrix or in the form of the outranking graph. They are the results of the intersection of the above mentioned complete pre-orders. The ranking matrix and the outranking graph define the pairwise relationships between variants. The following situations can be distinguished there: indifference (I), preference (P), lack of preference (P$\sim$) and incomparability (R).

The AHP (Analytic Hierarchy Process) method is a multiple objective ranking procedure, proposed by [28], focused on the hierarchical analysis of the decision problem. Through the definition of the overall objective, evaluation criteria, sub-criteria and variants the method constructs the hierarchy of the decision problem. On each level of the hierarchy, based on the pair-wise comparisons of criteria, sub-criteria and variants, the DM's preferential information is defined in the form of relative weights $\boldsymbol{w_r}$ [28]. Each weight represents relative strength of the compared element against another and it is expressed as a number from 1 to 9. All weights have a compensatory character, i.e.: the value characterizing the less important element (1/2, 1/5, 1/9) is the inverse of the value characterizing the more important element in the compared pair (2, 5, 9).

The algorithm of the AHP method focuses on finding a solution for a, so called, **eigenvalue problem** [28] on each level of the hierarchy. As a result a set of vectors containing normalized, absolute values of weights $\boldsymbol{w_a}$ for criteria, sub-criteria and variants is generated. The sum of the elements of the vector is 1 (100%). The absolute weights $\boldsymbol{w_a}$ are aggregated by an additive utility function. The utility of each variant $\boldsymbol{i}$ – $\boldsymbol{U_i}$ is calculated as a sum of products of absolute weights $\boldsymbol{w_a}$ on the path in the hierarchy tree (from the overall goal, through criteria and sub-criteria) the variant is associated with. The utility $\boldsymbol{U_i}$ represents the contribution of variant $\boldsymbol{i}$ in reaching an overall goal and constitutes its aggregated evaluation that defines its position in the final ranking.

The important element of the AHP algorithm is the investigation of the consistency level of matrices of relative weights $\boldsymbol{w_r}$ on each level of hierarchy. Through the calculation of a, so called, consistency index ***CI*** one can measure how consistent is the preferential information given by the DM. If the value of ***CI*** is close to 0 the preferential information given by the DM is considered to be almost perfect. The acceptable level of ***CI*** is below 0.1.

4 Real World Case Study. Design and Multiple Criteria Evaluation of a Section of a Transportation System

4.1 Major Features of the Considered Situation/Problem

The considered situation refers to the redesign of a major traffic artery in the medium-sized urban transportation system in Poznań, Poland. The considered street, called Grunwaldzka is 6.6 km long and connects the city center with the south-western boundaries of the Poznań metropolitan area. It runs from the Poznań major central roundabout Kaponiera in the south-western direction towards the suburbian residential area, called Kwiatowe (Flower) District. Grunwaldzka Street is the main access road to the Poznań City Football Stadium (Grunwald District) and the Local Municipal Cemetery (Junikowo). Both road and tramway traffic goes along this street.

The street redesign is carried out within the Poznań Transportation Infrastructure Development Plan associated with the Poznań city preparation for the European Football Championships – EURO 2012. Poznań as the EURO 2012 host city was expected to improve traffic connection between the football stadium and both suburbs and city center. The major objective of the considered redesign is the street capacity extension, resulting in the improvement of the comfort of travel for passengers and the reduction of the travel time. The major effort of the redesign is focused on the redevelopment of the road and tramway railroad at Grunwaldzka street on its specific segment between Smoluchowskiego and Malwowa streets (1.7 km long) and intensive reconstruction of the existing intersection Grunwaldzka – Smoluchowskiego, which is located in the area adjacent to the football stadium (see Fig. 1).

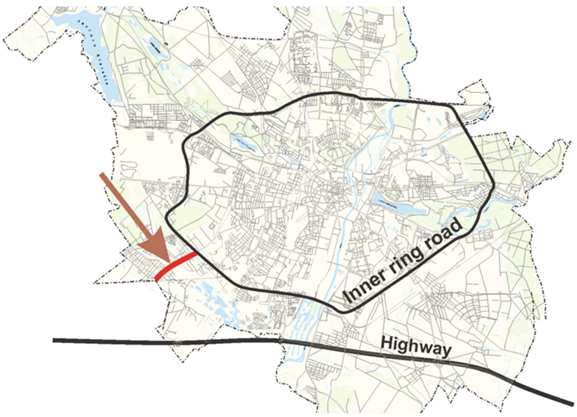

Fig. 1. The location of the considered redesign project (red color – segment of Grunwaldzka street) in the Poznań urban transportation system

As presented in Fig. 1 the considered segment of Grunwaldzka street connects the suburbs with the city inner ring road. The construction of this ring road is not complete. Its certain sections are already in operations, while others are still under development.

In the considered area the ring road goes along Smoluchowskiego street and crosses Grunwaldzka street at the critical intersection for the considered project, i.e. Grunwaldzka – Smoluchowskiego intersection. As presented in Fig. 1 the segment of Grunwaldzka street under consideration as located quite close to the National Highway A2 going in the East–West direction. Thus, the street redesign has also an impact on improving the highway accessibility for the local traffic.

The problem at stake consists in designing/developing and implementing the most desirable transportation solution for the considered segment of Grunwaldzka street. The project has been launched by municipal authorities acting together with the representatives of the UEFA (Union of European Football Associations). In the considered case the decision maker (DM) is the City Board that makes final decision concerning the selection and implementation of the concrete transportation solution at Grunwaldzka street. The DM wants to receive and assess several alternative concepts and evaluate them from different perspectives, including: economic, safety-oriented, technical, environmental and social. In the undertaken analysis the DM wants to take into consideration their own preferences as well as the interests of various stakeholders, including: local residents/travelling passengers, public transportation system operator, representatives of UEFA. The City Board (DM) wants to review several alternative transportation solutions and find the one that best fits theirs and stakeholders' expectations. To receive an independent, expert opinion they hire the analyst (author of the paper) to carry out the intended analysis. His task is to design and experimentally/computationally test the considered transportation solutions, evaluate them and finally select and recommend the most desired option.

4.2 Design and Testing of the Considered Variants

Five variants, denominated Variant 0 - V0, Variant 1 - V1, …, to Variant 4 - V4 have been considered as alternative transportation solutions for Grunwaldzka street redesign. They have been designed heuristically and tested with the application of the traffic simulation tool (Visum). Since Visum Software – the product of the German company PTV is a traffic simulator based on the 4-stage model framework one may conclude that the performed design phase has had a hybrid character.

Variant 0 - V0 corresponds to the existing transportation solution at Grunwaldzka street; thus it reflects the status quo and constitutes the benchmark for the considered analysis. Variants: V1, V2, V3, and V4 represent various, specific concepts of the redesign and are featured by different transportation solutions for the considered segment of Grunwaldzka street and its critical intersections. All transportation solutions have been designed heuristically and tested in the traffic simulation package Visum/Vissim. The variants are presented graphically in Fig. 2.

Variant 0 - V0 is a single level transportation solution along the whole street and at a critical intersection of Grunwaldzka and Smulochowskiego streets. The variant represents the current solution, which is a single road with one lane in each direction that extends to two roads with two lanes in each direction at the considered intersection. A separate tramway railroad runs parallel to the road along Grunwaldzka street on the considered length of the segment (1,7 km long). On the single road segment the

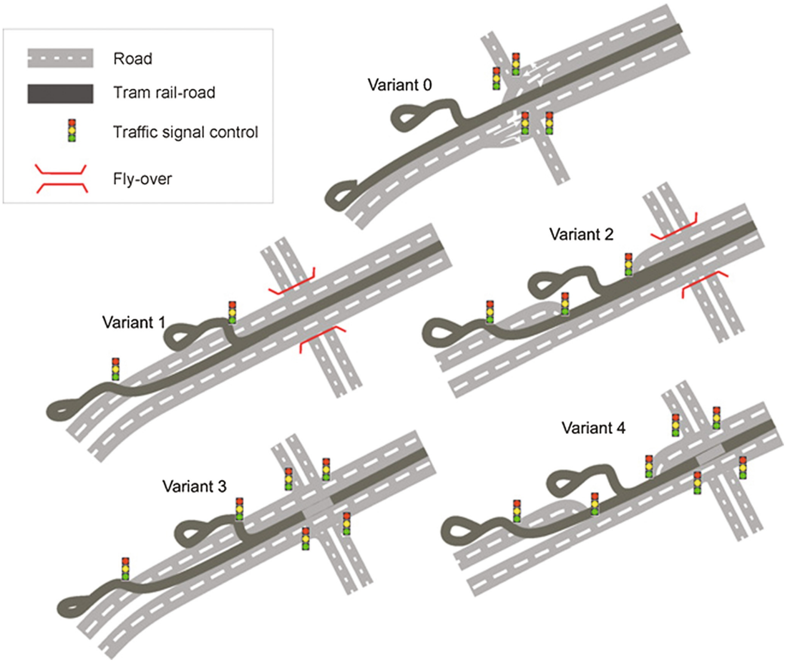

Fig. 2. Graphical representation of variants V0, V1, …, V4, i.e. transportation solutions/concepts developed for the redesign of the main artery in Poznań (Grunwaldzka street)

tramway corridor is located at the northern side of the street. At the intersection, where a single road extends to two roads it crosses the road traffic and goes in the middle of the artery, between roads moving traffic in the opposite directions (see Fig. 2). In this variant the prospect inner ring road that crosses Grunwaldzka street is in its present, underdeveloped form. It is a simple single collector/distributor road with one lane in each direction. It collects traffic from local roads and distributes it to arterials. This solution creates a serious bottleneck at the considered intersection. It is featured by the existence of two tram loops for various tram lines and four traffic signal controls at the intersection. **V0** is a zero - level investment solution, relatively safe but not very comfortable (travel time - wise).

Variant 1 - V1 is a two level transportation solution at a critical intersection of Grunwaldzka and Smulochowskiego streets with a fly-over above the proposed inner ring road (see Fig. 2). It is featured by two roads with two-lanes in each direction (arterial road) and a separate tramway railroad that runs along the whole segment of Grunwaldzka street. The tramway corridor is located in the middle of the artery, between roads. It crosses the northern road next to the integrated bus – tramway loop to provide access form trams there. In this variant the inner-ring road that crosses Grunwaldzka street is well developed, as a collector/distributor road with two separate roads, two lane each. This variant is featured by the existence of one tram loop for selected tram lines and another integrated bus – tramway loop for the majority of tram lines and all bus lines operating in this area. Two traffic lights are proposed in this variant to ensure smooth integration of the tramway traffic with the road traffic. **V1** is the most expensive and at the same time the most comfortable transportation solution.

Variant 2 - V2 is a two level transportation solution at an intersection of Grunwaldzka and Smulochowskiego streets with the flyover above the inner ring-road. This variant is a combination of two, two-lane roads (1.2 km) in the external sections of the considered street segment and a single two-lane road (0.5 km) in the central part of the segment (near the tramway loop). Thus, the two two-lane roads merge into single two-lane road in a certain segment of the street and then split again into two, two-lane roads (see Fig. 2). Similarly to variant V1, the tramway corridor in variant V2 is located between the roads and crosses the northern road to provide access to the tram loops. V2 is featured by the well developed the inner ring-road as in variant V1. The loop solutions are organized in the same way as in variant V1 (one tram loop and one integrated bus – tramway loop). Three traffic lights are required in this variant to properly integrate the tram and road traffics. Variant V2 can be considered as a median transportation solution in terms of investment costs and comfort of travel (travel time). Due to existence of three collision points of the road and tramway traffic in this variant it is featured by a relatively low safety.

Variant 3 - V3 is a single level transportation concept. It is featured by the same solutions as in variant V1 (see Fig. 2), except the fly-over that is replaced in variant V3 by a standard intersection. Again, it is featured by two roads with two-lanes in each direction and a tramway corridor located in the middle of the artery, between roads. The inner-ring road is well developed in this variant (as it is in variant V1). The loop solutions are identical to their equivalents in variant V1. There are six traffic lights in this variant, including four in the Grunwaldzka - Smoluchowskiego intersection and two to integrate tramway traffic with the road traffic. **V3** is a comfortable and expensive transportation solution.

Variant 4 - V4 is a single level transportation concept at an intersection of Grunwaldzka and Smulochowskiego streets. It is featured by the same solutions as in variant V2 (see Fig. 2), except the fly-over that is replaced in variant V4 by a standard intersection. Thus, it is a variant being a combination of two, two-lane roads (1.2 km) and a single two-lane road (0.5 km). Variant V4 is featured by a well-developed the inner ring-road as in variants V1 and V2. The loop solutions are identical to their equivalents in variant V2. There are seven traffic lights in this variant, including four in the Grunwaldzka - Smoluchowskiego intersection and three to integrate tramway traffic with the road traffic. **V4** is a uncomfortable (travel time - wise) and relatively inexpensive (investment cost – wise) transportation solution. Safety-wise it is not the recommended concept due to three collision points of the road and tramway traffic.

As mentioned above, all the variants: V0, V1, …., V4 have been simulated in the macro-simulation tool Visum. The macro approach has been selected due to the following arguments: 1. The considered area is relatively large and the traffic in this neighbourhood has a strong impact on the movements in the whole city. The area covers the connection between the city center and the suburbs. 2. For the considered event (European Football Championship – EURO 2012) it was essential to test the movements of passengers between the Football Stadium, city center, sightseeing attractions and Football Fun Zone. These locations are quite dispersed all over the city. 3. The DM’s wish was to test the influence of the proposed transportation solutions for the global movements/traffic in the whole metropolitan area, especially along major transportation corridors: Grunwaldzka, św. Marcin and Królowej Jadwigi streets; Głogowska and Pulaskiego streets; and around the Inner Ring.

For the traffic simulation experiments the traffic model of the Poznań Metropolitan area, developed by traffic engineers at the Poznań City Hall, has been applied. This model has been customized and properly adapted to the proposed changes – transportation solutions at Grunwaldzka street. These have involved: adaptation of the transportation network and slight adjustment of the traffic zones according to the variants assumptions, generation of a new modal split for the whole metropolitan area and re-calculation of the traffic assignment in the overall transportation network. To determine the new modal split the authors have applied the well-known nested logit model [1, 2] and have generated the realistic shares of travellers/passengers using public (M_{PuT}) and private (M_{PrT}) means of transport. The modal split has been computed for all considered variants. For the considered situation the proportion M_{PuT}/M_{PrT} has ranged as follows: 44%/56% for V3, through 45%/55% for V0 (current solution) to 46%/54% for V4. Using advanced traffic assignment algorithms the transportation network has been loaded by traffic and the volumes of passengers' and vehicles' flows on particular links of the network have been computed. Finally, certain parameters characterizing particular variants have been produced. These included in particular variants: ridership for all transportation modes, average travel and riding times, average waiting and transfer times at the stops, average passenger speed, aggregated traffic safety ratio, noise and pollution parameters. Based on these parameters the evaluation criteria have been defined and their values have been computed.

4.3 Multiple Criteria Evaluation of the Designed Transportation Solutions

The designed variants – transportation solutions have been assessed with the application of one of the most commonly used transport evaluation methodologies, i.e. the MCA (see Sect. 3). The parameters generated in the testing phase have served as the input for the construction – definition of the evaluation criteria of all designed variants. Based on the expectations of the DM and major stakeholders (mentioned in Sect. 3) different evaluation aspects have been considered in the formulation of specific characteristics.

The evaluation of the considered variants have been formulated as a multiple criteria ranking problem. Thus, the variants have been assessed by a family of criteria and ranked from the best to the worst. The following criteria have been defined:

Average Travel Time **(C1) [Minutes, Seconds] – Minimized (MIN).** This criterion represents an important component of the passengers' comfort of travel, thus it expresses the major interest of local residents - passenger (travellers). It is associated with both social and technical aspects of evaluation. The criterion is defined as an arithmetic average of individual travel/riding times required to cover a distance of the analysed road section by each passenger (in the considered traffic flow) travelling either by a private (individual) and/or a public mean of transport.

Traffic Safety **(C2) [-]** – is a criterion that evaluates road safety level of each considered variant (investment plan), measured by the predicted annual number of accidents on the considered section of the road. It represents, again, the socio-technical aspect of evaluation. The criterion is formulated as a function of the accident index corresponding to the risk associated with the accident occurrence on the above mentioned infrastructural solutions, and the vehicles traffic volume. This criterion is **minimized (MIN).** It is important for both local residents – passengers, public transportation system operator and UEFA.

Investment Costs **(C3) [mln PLN] – Minimized (MIN).** This criterion has an economic character and it is very important for local municipal authorities – the City Board (DM) - investor and UEFA (as a co-investor). Expressed in monetary units, it is defined as a total amount of money (overall costs) required to carry out a particular variant (transportation solution). In the criterion definition the following components are included: labor costs, material costs, costs of equipment and machinery.

Investment Profitability **(C4) [%] – Maximized (MAX).** This criterion is defined, again as a financial – economic parameter that evaluates financial performance (efficiency) of each variant. It is defined as an Internal Rate of Return (IRR) or in other words the interest rate at which the discounted investment costs and incomes generated by the considered section of the urban transportation system balance in a certain time horizon (25 years). This criterion is important for the City Board (DM), UEFA and public transportation system operator.

Environmental Friendliness **(C5) [pts] – Maximized (MAX).** This criterion characterizes the level of environmental friendliness of the considered variants. It is defined as a number of points (0–10), assigned by experts, that corresponds to the evaluation of the negative impact of particular investments on environment in the neighbourhood of the considered road section. The definition of this criterion is based on the assessment of noise and air pollution levels. The criterion has an environmental character and it is strictly correlated with the quality of life. Thus, it is important for local residents.

Based on the input data from the Visum Macro Simulation Software and additional external information the criteria values for all the considered variants have been computed. As a result the Evaluation Matrix have been constructed – see Table 1.

After having constructed the Evaluation Matrix computational experiments have been initiated. To increase the reliability of the generated results all computational experiments have been performed with the application of two most popular and representative multiple criteria ranking methods, i.e. ELECTRE III/IV and AHP (see description in Sect. 3). Computational experiments required the definition of preferences of the DM and major stakeholders.

All these groups (DM and stakeholders), composed of several individuals each, have been interviewed and surveyed. For each person an individual preference profile has been defined. It has included two elements: his/her perception on the importance of each criterion and his/her sensitivity on the changes of the criteria values. The individual preferences have been aggregated into a common group preference model for: City Board (DM), public transportation system operator, residents (passengers) and

Table 1. Evaluation matrix for the analysed variants.

Criteria		Unit	Direction of preference	V0	V1	V2	V3	V4
C1	Average travel time	[min, s]	Min	5 min 31 s	2 min 39 s	3 min 41 s	3 min 13 s	4 min 0 s
C2	Traffic safety	[accidents]	Min	1.36	1.74	3.12	2.29	4.10
C3	Investment costs	[PLN][a]	Min	0	55.72	44.12	47.77	36.17
C4	Investment rofitability-IRR	[%]	Max	2.58	3.28	2.62	2.86	2.21
C5	Environmental friendliness	[pts]	Max	2.00	8.32	7.01	8.04	7.97

[a]1 Euro = 4 PLN (roughly)

representatives of UEFA. Afterwards all four group models have been averaged and integrated into an overall, final model of preferences.

Different modeling techniques have been applied to construct the preference models characteristic for the Electre III/IV and AHP methods. As presented in Sect. 3 the Electre III/IV method preference model has been constructed with the application of weights $\boldsymbol{w_j}$, defined for each criterion (the aspect of criteria importance) and indifference $\boldsymbol{q_j}$, preference $\boldsymbol{p_j}$ and veto $\boldsymbol{v_j}$ thresholds, describing the interval-oriented sensitivity of the DM and stakeholders for each criterion. The AHP method preference model has been constructed based on the pair-wise comparisons of criteria and variants – transportation solutions. As presented in Sect. 3 this model of preferences is expressed in the form of relative weights $\boldsymbol{w_r}$ on the 1 to 9 point scale and has a compensatory character. The comparisons between criteria result in the definition of their importance, while the comparisons of variants for each criterion correspond to the definition of the DM and stakeholders sensitivity.

The following steps of the computational procedure have been performed:

- With the application of **ELECTRE III/IV method**:
  - Computing the concordance indicators $\boldsymbol{C(a, b)}$, presented as a concordance matrix.
  - Computing discordance indexes $\boldsymbol{D_j\ (a, b)}$.
  - Generating the values of the outranking relation $\boldsymbol{S}$ expressed by the degree of credibility $\boldsymbol{d(a, b)}$ and presented in the form of credibility matrix.
  - Performing descending and ascending distillations, resulting in producing complete pre-orders.
  - Obtaining the final outranking graph and the corresponding ranking metrix.
- With the application of **AHP method:**
  - Computing consistency indexes $\boldsymbol{CI}$ for each matrix of relative weights $\boldsymbol{w_r}$ at each level of the hierarchy (criteria and variants).
  - Generating a set of vectors containing normalized, absolute values of weights $\boldsymbol{w_a}$ for criteria and variants.
  - Computing utility of each variant i – $\boldsymbol{U_i}$.
  - Generating the final ranking of variants based on the values of their utilities $\boldsymbol{U_i}$.

Due to space limitation the above mentioned (space demanding) steps of the computational procedures of ELECTRE III/IV and AHP methods have been omitted and only final results have been demonstrated. For an interesting reader all these computational phases can be found in other publications of the author, e.g.: [14]. The final output (after all of the above mentioned steps of the computational procedures of both methods) is presented in Fig. 3.

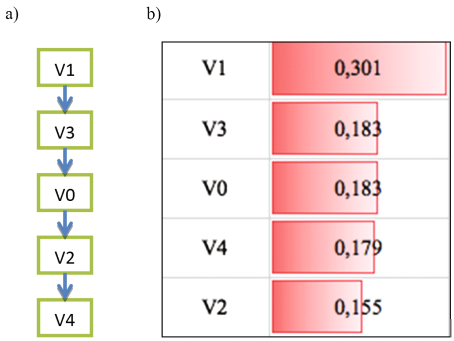

Fig. 3. Final results of computational experiments generated with the application of: (a) Electre III/IV method and (b) AHP method

As one can see the rankings generated by both methods, ELECTRE III/IV and AHP, have a similar but not identical form. The ranking produced by the application of ELECTRE III/IV method has a graphical character (outranking graph) and demonstrates the positions of all variants – transportation solutions in the ranking without showing the distance between them. The ranking generated by the application of the AHP methods gives both pieces of information, the positions of variants in the ranking and their distance between each other, measured by the difference of their utilities $\boldsymbol{U_i}$.

The leader of both rankings is variant V1 – two-level transportation solution with a fly-over above the inner ring road. As presented in Fig. 3(b) the utility of variant V1 is substantially higher than utilities of its counterpart variants V3 and V0, being placed at the next positions. In the ELECTRE III/IV method – based ranking variant V3 is preferred to variant V0, while in the AHP method – based ranking they are considered indifferent (equal value of utilities $\boldsymbol{U_i}$ = 0,183). As indicated by both rankings variants V2 and V4 are considered the weakest transportation solutions, although their positions are inversed in both rankings.

Based on the generated results variant V1 is the most desired transportation solution and it is recommended for implementation. Although it is the most expensive transportation solution (investment-wise) it guarantees excellent comfort of travel for passengers (travel time), very good traffic safety and outstanding environmental friendliness. It is also very promising profitability-wise. While comparing two leading variants V1 and V3 it is worth noticing that an 8 mln PLN (roughly 2 mln Euro) investment difference between these variants results in substantial travel time savings of 34 s. per passenger (18%), 24% improvement in terms of traffic safety, 15% higher investment profitability and 3% enhancement of environmental friendliness. The above mentioned unit travel time savings between variants V1 and V3 generate roughly (for the analyzed traffic) the overall annual travel time savings of 1200 h.

Variant V1 compared with the existing transportation solution – variant V0 generates enormous difference in terms of the following aspects: travel time – almost 3 minutes per passenger (roughly 50% improvement) and environmental friendliness (300% improvement). For the analyzed traffic the overall annual travel time savings (variants V3 vs. V0) amount to 6300 h. It is worth mentioning that the overall position of variant V0 is relatively high in the ranking due to 0 investment level and very good performance safety-wise. Variant V0 outperforms variant V3 in terms of traffic safety by 28%.

5 Conclusions

The chapter presents the basic and most popular concepts and methodologies of designing and evaluating complex transportation systems. The presented considerations have universal character and refer to different types of transportation systems, including both: single mode and multimodal systems as well as freight and passenger transportation systems. Universal rules concerning design and redesign as well as evaluation of transportation systems are presented. The paper contains both the theoretical background of the considered topics and the practical application of the presented concepts and methodologies.

As far as design/redesign of the transportation system is concerned, major stages of the design/redesign process are described. These include:

- Analysis of transportation demand.
- Design of a transportation network.
- Traffic assignment.
- Definition of transportation modes (types of vehicles).
- Allocation of crews.

The author demonstrates five basic categories of measures associated with planning and designing of a transportation system, such as:

- Land use design.
- Infrastructure development.
- Implementation of management rules.
- Information provision.
- Design of pricing strategies.

In addition, three major approaches to design/redesign of the transportation system are characterized:

- Heuristic (intuitive - oriented) design supported by simulation.
- Optimization (mathematical programming) - based design.
- Hybrid approach based on the application of several combined procedures, including the 4-stage model.

As far as the evaluation of a transportation system is concerned, two major methodological schools of assessing transportation systems are presented and confronted. These are: Cost Benefit Analysis (CBA) and Multiple Criteria Analysis (MCA), also denominated by Multiple Criteria Decision Making/Aiding (MCDM/A). Major terms, features and methodological principles associated with both fields are presented. Three basic measures used in CBA to assess the overall profitability/utility of the considered transportation solutions are characterized, including: Economic Net Present Value (ENPV), Economic Internal Rate of Return (EIRR) and Benefit-Cost Ratio (BCR). Basic terms of MCA or MCDM/A are also presented, including: the definition and classification of a multiple criteria decision problem, the description of a consistent family of criteria and the categorization of the MCDM/A methods. Basic features of two, most representative MCDM/A ranking methods, including: ELECTRE III/IV and AHP are demonstrated.

Practical applicability of the presented paradigms is presented in the case study (Sect. 4) that refers to the redesign of a critical section of a medium-sized urban transportation system. The redesign has a hybrid character. It is based on a heuristic construction of alternative transportation solutions supported by simulation and optimization (application of a Four Stage Model – FSM). The proposed solutions reshape the major artery that connects the city center with the suburbs of the metropolitan area. Four generated variants are compared with the existing transportation solution. In the assessment phase a multiple criteria evaluation of variants is performed. A series of computational experiments is carried out. The proposed solutions are ranked from the best to the worst.

From a theoretical/methodological point of view the presented research has generated the following original output:

– Presentation of the methodological principles of design and evaluation of transportation systems in a condensed, abridged form.
– Comparison of two alternative approaches of transportation systems' evaluation, i.e.: CBA and MCA.
– Testing two alternative MCDM/A methods and confirming their suitability for the evaluation and ranking of alternative transportation solutions.

From a practical point of view the critical findings of the presented research are as follows:

– Presentation of the real world redesign of a section of a transportation system. Development of several transportation solutions based on hybrid approach, including: heuristic construction of variants supported by simulation and optimization techniques.
– Multiple criteria evaluation of the proposed solutions – variants, including: definition of the consistent family of criteria, modeling DM's and stakeholders preferences, carrying out computational experiments resulting in the ranking of variants and final recommendation of a selected variant for implementation.
– Generating substantial improvements thanks to the real life application of the selected variant – V1 – two level transportation concept with a fly-over above the

inner ring road. The most radical changes refer to environmental friendliness (300% improvement) and comfort of travel (50% improvement).

In the author's opinion the following conclusions may be drawn from the presented research:

– The combination of heuristic design and different analytical tools generates a set of realistic transportation solutions. The intuitive construction of variants based on imaginative thinking, creativity and expert knowledge proves to be a reasonable approach. At the same time the author claims that a ridged, systematic verification of the generated concepts is required. Thus, their testing and improvement is strongly recommended through simulation and optimization techniques.
– When several variants have been generated their comparative analysis and evaluation is required. The MCDM/A methodology is a universal tool that allows for a comprehensive and complete evaluation of alternative transportation concepts/solutions. As presented in this chapter, in the multiple criteria oriented evaluation of transportation solutions different multiple criteria ranking methods can be applied. In the author's opinion, both AHP and Electre III/IV methods have generated satisfactory computational results and can used as generic tools of the transportation systems' evaluation.

In the author's opinion further research can be conducted in the following directions:

– Comparison of alternative design approaches, i.e. purely heuristic method with optimization – oriented design and hybrid approach. Analysis of generated transportation solutions for the considered case.
– Application of other MCDM/A methods (e.g.: Oreste, Promethee, ANP) in order to rank various redesign variants of a the considered section of a transportation system. Thorough analysis and comparison of the generated results.
– Application and comparison of MCA and CBA methodologies for the evaluation of the considered variants – transportation solutions.

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Modelling of Traffic Hazards at Urban Intersections Using Potential Collision Areas

Tomasz Szczuraszek(✉) and Radosław Klusek

University of Technology and Life Sciences in Bydgoszcz, Bydgoszcz, Poland
{zikwb, radoslaw.klusek}@utp.edu.pl

Abstract. Correct traffic safety management requires evaluation of infrastructure elements already at the stage of planning and designing in terms of the traffic hazards level. There are many methods in the world used for such evaluation of traffic safety for rural road sections, however, there are relatively few methods concerning urban intersections. The method presented in this article applies to the evaluation of traffic safety at urban intersections. It is based on the estimation of the number of road traffic incidents (RTIs) at the selected intersection areas, in which there is a possibility that two traffic streams, called potential collision areas, will converge at the same time. Preliminary research results show that the probability of an RTI in a potential collision area depends primarily on the probability of two traffic streams converging in the same area at the same time. To a large extent, the degree of traffic road incident occurrence hazard depends also on some factors connected to traffic conditions right before the given streams appear in a potential collision area.

Keywords: Road traffic safety · RTIs · Urban intersections

1 Introduction

Appropriate planning and designing of road infrastructure requires knowledge on the influence of the road features on the road traffic safety (rts). With regards to the evaluation of the existing road infrastructure, the level of rts can be evaluated based on the RTIs that had occurred earlier or by analyzing traffic conflicts and pre-conflicts. On the other hand, in order to accomplish such traffic evaluation at the stage of road infrastructure planning and designing, one needs to have a suitable method containing for example models of RTIs number forecast. Study concerning the modelling of the road traffic hazard phenomenon are conducted worldwide. The most popular methods of evaluating road safety have been developed in the United States [1] and Japan [2]. Unfortunately, in many countries, including Poland, there is no suitable method allowing to evaluate rts on an urban road network and it is of a great practical importance, especially at the stage of road infrastructure projects rts auditing, as well as in the process of the selection of project solution concepts.

The aim of this dissertation is to present a modelling method of the RTIs number at urban intersections, using potential collision areas. W.F. Babkow [3] was the first one to tackle this issue in 1975. Ever since then, this subject matter has constantly been developed in some countries. One of the most popular models of RTIs prediction is the

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_2

model developed in the United States of America (Surrogate Safety Assessment Model,) which is built on the basis of traffic flows observation [4]. In Europe such popular method of road safety evaluation is the Swedish method which is based on the modelling of traffic conflicts according to different types of distinguished conflicts [5]. Among the methods of traffic safety assessment, that are based on the analysis of single traffic flows, the method developed for the British Columbia should be also distinguish. This method is based on road accidents reported at the analyzed intersections within last 5 years [6].

2 The Basic Assumptions of the Method

The basic assumptions of the suggested method were based on the following theses, defined on the grounds of the authors' many-years' experiments and research:

1. RTIs at intersections are concentrated mostly in the areas (located on their surface and the surface of their influence) where it is possible for two streams (participants of the same kind, or different kinds), performing different manoeuvres, to converge. For the purpose of this dissertation, the authors call these areas potential collision areas.
2. From among the conflict manoeuvres which may take place in potential conflict areas at an intersections, the following need to be named:
   (a) crossing of traffic streams,
   (b) connecting of traffic streams,
   (c) disconnecting of traffic streams,
   (d) intertwining of traffic streams.
3. The probability for an RTI to occur in a potential collision area depends primarily on the probability of two traffic streams to converge simultaneously in the same area. Such probability depends to the highest extent on:
   (a) converging streams types,
   (b) kinds of manoeuvres performed by those streams,
   (c) traffic density of the converging streams,
   (d) travel speed of the traffic participants in those streams,
   (e) geometry and surface dimensions of the potential collision area,
   (f) time convergence of both streams' presence in the potential collision area,
   (g) lengths of vehicles partaking in the particular traffic streams,
   (h) potential speed alterations of the vehicles (accelerations, delays) in the potential collision areas.
4. To a large extent, the degree of traffic road incident occurrence hazard depends also on some factors connected to traffic conditions right before the given streams appear in a potential collision area. From among those factors, the authors deem the following ones the most important:

(a) speeds of vehicles,
(b) visibility conditions of a collision stream and a potential collision area (including the right-of-way signs, traffic lights display, etc.),
(c) waiting time of the particular streams' participants for the possibility of entering the potential collision area.

5. The average amount of RTIs that may take place in the given potential collision area of the "R" kind in the given city "M" within one year can be determined based on the following linear function:

$$LZ_{R,M} = \alpha_R \times \alpha_M \times \eta_W \times \eta_V \times \eta_{\Delta T} \times p(N_1, N_2)_R \quad (1)$$

for which $LZ_{R,M} = 0$ if $p(N_1, N_2)_R = 0$
where:

$p(N_1, N_2)_R$ - probability of two traffic streams to converge at the same time in a given potential collision area of the "R" kind;
α_R - factor taking into account the relations between the average number of RTIs in a given potential collision area of the "R" kind and the convergence probability of particular traffic streams in that area;
α_M - factor taking into account the influence of the city size on the change in the RTI hazard degree in a potential collision area;
η_W - factor taking into account an increase of a hazard caused by insufficient visibility of a collision stream and a potential collision area for a stream without right of way while arriving at a potential collision area;
η_V - factor taking into account an increase of a hazard caused by excessive speed of one or both streams arriving at a potential collision area;
$\eta_{\Delta T}$ - factor taking into account an increase of a hazard caused by excessive wait time for drivers to cross a potential collision area;

3 Specification of Potential Collision Area Types

A potential collision area is defined as a common ground at an intersection marked by the boarders of traffic corridors of vehicles from two traffic streams with different traffic directions or speeds. Taking into consideration varied manoeuvres performer by traffic streams, as well as the variety of traffic participants in the streams, different types of potential collision areas were specified. They were also classified according to the time convergence of the streams admission to the traffic. The division of potential collision area types is shown in Table 1.

Table 1. Types of potential collision areas

No.	Area type and a performed manoeuvre type		Traffic participants type	Convergence in time of the streams in a potential collision area
1	Disconnecting of traffic streams area	Direct disconnecting	Vehicle - vehicle	Constant (intersection without traffic lights)
		indirect disconnecting		In the same light signalling phase
2	Connecting of traffic streams area	Direct connecting	Vehicle - vehicle	Constant (intersection without traffic lights)
				In the same light signalling phase
		Indirect connecting		At a change of light signalling phases (during evacuation period)
3	Crossing of traffic streams area		Vehicle - vehicle	Constant (intersection without traffic lights)
				In the same light signalling phase
				At a change of light signalling phases (during evacuation period)
			Vehicle - pedestrian	Constant (intersection without traffic lights)
				At a change of light signalling phases (during evacuation period)
				During a red light display for pedestrians (a pedestrian entering through a red light during the whole cycle)
			Vehicle - cyclist	Constant (intersection without traffic lights)
				At a change of light signalling phases (during evacuation period)
				During a red light display for cyclists (a cycling entering through a red light during the whole cycle)
4	Intertwining of traffic streams area		Vehicle - vehicle	Constant (intersection without traffic lights)
				In the same light signalling phase

The surface of a potential collision area will be defined in various ways, depending on its type:

(a) In terms of disconnecting of traffic streams, the surfaces of a potential collision area are defined as an area in which drivers from one of the streams begin to reduce their speed in order to perform the disconnecting manoeuvre. The disconnecting manoeuvre is divided into two types: direct and indirect (using a disconnecting lane), shown in Fig. 1.

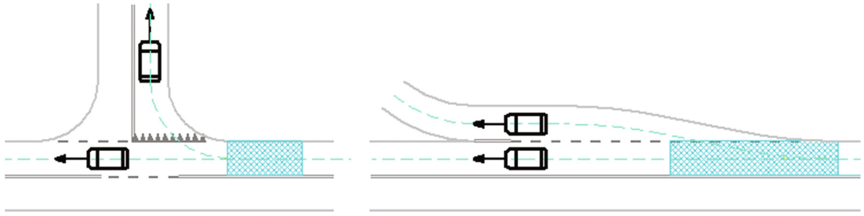

Fig. 1. Potential collision area at direct and indirect disconnecting of vehicles (Source: own research)

(b) In terms of connecting of traffic streams, the surfaces of a potential collision area constitute the area in which the stream with no right of way connects with the main stream, as well as the area in which vehicles with no right of way level their speed with the speed of vehicles in the main stream (when the initial speed of the stream with no right of way was lower than the speed of the right-of-way stream). The speed difference may cause a back collision. The connecting manoeuvre is also divided into two types: direct and indirect (using a connecting lane), shown in Fig. 2.

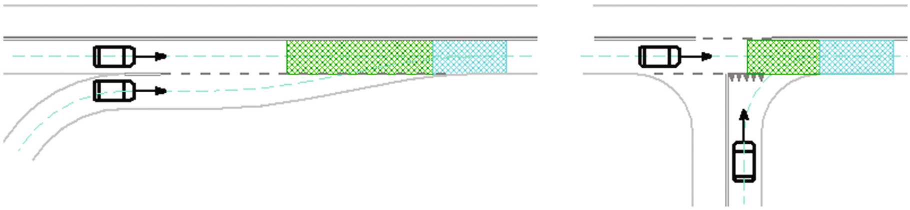

Fig. 2. Potential collision area at direct and indirect connecting of vehicles (Source: own research)

(c) In terms of crossing of traffic streams, the surfaces of a potential collision area are defined as the area designated by possible traffic corridor edges of streams that cross each other. The hazard in this collision area results from different traffic directions of the streams, which may lead to side collisions of vehicles, or running over pedestrians or cyclists. Because of the variety of streams with regards to of traffic participants, the following types of potential collision areas are defined: vehicle-vehicle, vehicle-pedestrian, vehicle-cyclist, shown in Fig. 3.

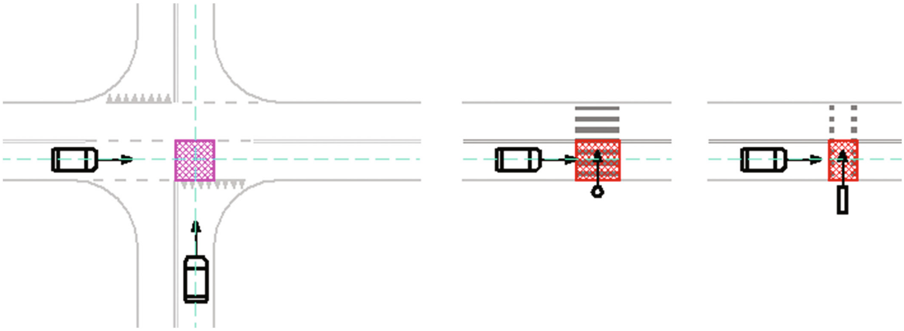

Fig. 3. Crossing of traffic streams (vehicle-vehicle, vehicle-pedestrian, vehicle-cyclist) (Source: own research)

(d) In terms of crossing of traffic streams, the surfaces of a potential collision area are defined as the area in which intertwining of vehicle streams occurs. This area, in the case of the simplest intertwining diagram (in two traffic lanes), can be divided into two potential collision areas for connecting of traffic streams and two potential collision areas for disconnecting of those streams. On the other hand, in terms of a multiple-lane intertwining section, the number of connecting and disconnecting zones will be respectively larger. A potential collision area for intertwining of two traffic lanes is shown in Fig. 4.

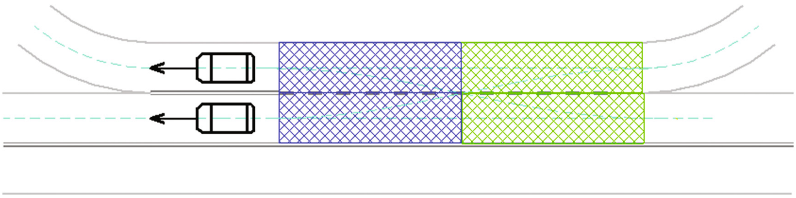

Fig. 4. Intertwining of vehicle streams (Source: own research)

Apart from designating potential collision areas based on the performed manoeuvre and the type of traffic participants in the collision streams, cases based on time convergence of multiple collision traffic streams in a given potential collision area are also included in models, where the following situations are distinguished:

(a) Constant, where the traffic streams are not divided in time by traffic signal control and a collision between them may occur at any time.
(b) During a common collision phase in a traffic signal control program at an intersection.
(c) At the evacuation time of one of the streams during a phases change in a traffic signal control program, which may occur at the moment of the entrance of an evacuating vehicle at a red light. This case also includes the possibility of a vehicle's entrance onto a pedestrian crossing at a red light or a pedestrian's entrance at a red light [7].

4 Probability of a Convergence of Two Traffic Streams Simultaneously at the Same Potential Collision Area

One of the main assumptions of the method is that the occurrence probability of a traffic road incident depends on the probability of a convergence of two traffic streams simultaneously at the same potential collision area and that this dependency is linear. A calculation method for the probability of a convergence of two traffic streams simultaneously at an example potential collision area for the manoeuvre of crossing of two traffic streams is presented below.

The probability of a convergence of two traffic streams simultaneously at a given potential collision area is a product of probabilities of each of the streams to exist in this area at the same time:

$$p(N_1, N_2)_R = p(N_1)_R \times p(N_2)_R, [-] \tag{2}$$

where:

$p(N_1, N_2)_R$ - probability of a convergence of two traffic streams simultaneously at a given potential collision area of the "R" [−];

$p(N_1)_R, p(N_2)_R$ - probability of existing of two individual traffic streams: '1' and '2' at a potential collision area [−];

The probability of existing of one stream in a potential collision area is the relations of the time, in which a given stream exists in this area within an hour to a whole hour:

$$p(N_{1,2})_R = \frac{T_{1,2}}{3600}, [-] \tag{3}$$

where:

T_1, T_2 - time of existing of a given traffic stream '1' or '2' in a potential collision area within an hour [s];

The time of existing of a given traffic stream in a potential collision area within an hour can be written down as a product of the stream's traffic volumes within an hour and the average time of existing of one vehicle from this stream in the potential collision area. The time of existing of a traffic stream in the collision area is then calculated from the formula:

$$T_{1,2} = N_{1,2} \times \frac{S_{1,2} + l_{1,2}}{V_{1,2}} \times 3,6, [s] \tag{4}$$

where:

V_1, V_2 - average speeds of vehicles in a stream, respectively ‘1’ and ‘2’ in a potential collision area [km/h];

N_1, N_2 - volumes of traffic streams, respectively ‘1’ and ‘2’ of a stream in a potential collision area [P/h];

S_1, S_2 - widths of a traffic lane respectively for streams ‘1’ and ‘2’ [m];

l_1, l_2 - average vehicle lengths in a stream ‘1’ and ‘2’ [m]

Replacing the time of existing of a traffic stream in a potential collision area in the formula for the probability of existing of one traffic stream in a potential collision area and assuming that:

$$P_K^{'} = (S_1 + l_1) \times (S_2 + l_2), [m^2] \tag{5}$$

where:

$P_K^{'}$ - actual surface of a potential collision area (enlarged by the surface occupied by vehicle bodies [m^2])

an equation for the probability of convergence of two traffic streams simultaneously at the same potential collision area is obtained:

$$p(N_1, N_2)_R = 10^{-6} \times \frac{N_1 \times N_2}{V_1 \times V_2} \tag{6}$$

5 Research Results

Based on the detailed data gathered on RTIs at intersections, as well as the data connected with the geometry of intersections and traffic volumes for a selected city [8], the analysis of potential collision areas was conducted. In the next stages of the analyses relations between the average number of RTIs per year in a potential collision area to the probability of convergence of two traffic streams in potential collision areas were compiled. Example results for potential collision areas connected with connecting and disconnecting of traffic streams at intersections with no traffic lights are presented in Figs. 5 and 6. It needs to be stressed that for every type of potential collision areas particularly large determination factors “R^2” (from 0,70 to 0,95) were obtained for the analyzed relations, which indicates a significant degree of explaining the relation of the number of RTIs that occurred at urban intersections to the probability function of an RTI occurring in a potential collision area, defined by the authors.

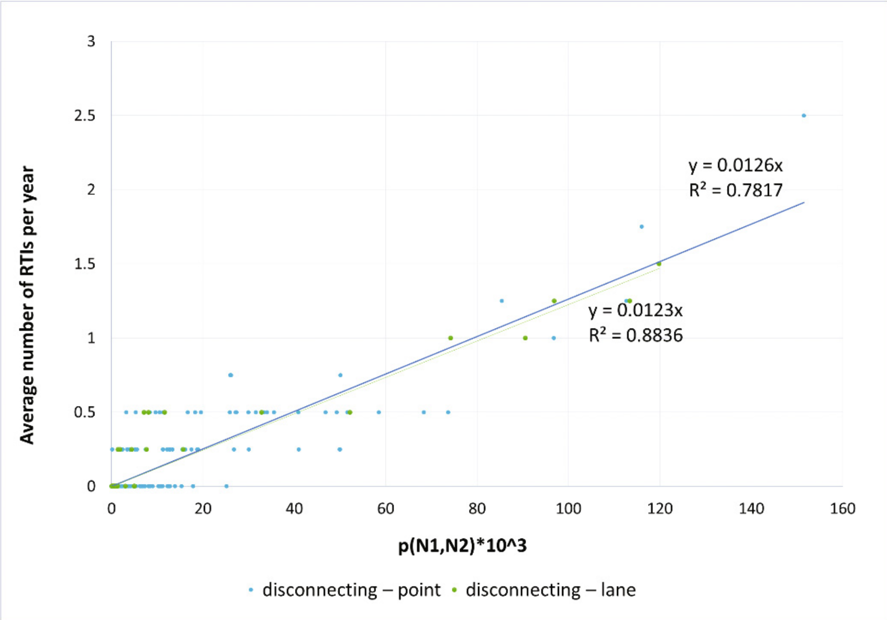

Fig. 5. A chart presenting the number of RTIs in relations to the probability function in a potential collision area for disconnecting traffic streams at intersections with no traffic lights (Source: own research)

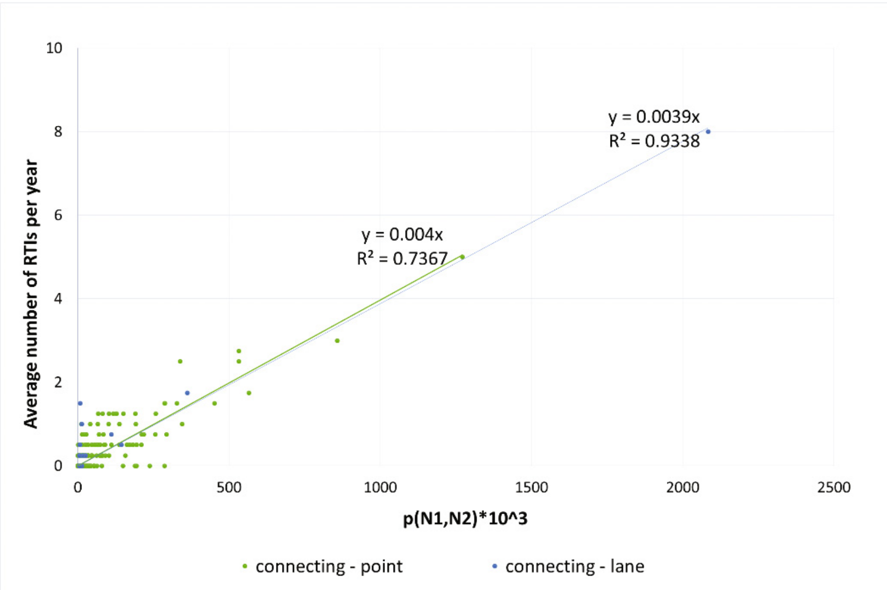

Fig. 6. A chart presenting the number of RTIs in relations to the probability function in a potential collision area for connecting traffic streams at intersections with no traffic lights (Source: own research)

6 Summary

Traffic hazard level at the stage of road infrastructure planning and designing can be estimated based on models forecasting the potential number of RTIs. An example of such models are models founded on the analysis of traffic hazards at an interaction of two single streams. The method used for modelling the number of RTIs at urban intersections presented in this article is grounded on determining the influence of the probability of simultaneous existing of two collision traffic streams in a potential collision area on the number of RTIs.

The method of modelling of traffic hazards at urban intersections is based on the influence of the probability of simultaneously being in the potential collision area of two traffic flows on the number of road accidents.

Based on the authors' previous analyses conducted on 61 intersections of a selected city (with a population of around 350 thousand) it is concluded that the proposed models have a high level of statistic trust. Owing to that, they provide great opportunities to compile a trustworthy method of estimation of traffic safety at intersections in the next stage.

The authors plan to include in their analyses an even larger number of intersections placed in different cities.

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The Roundabout Micro-simulator Based on the Cellular Automaton Model

Krzysztof Małecki(✉)

West Pomeranian University of Technology, Szczecin, Poland
kmalecki@wi.zut.edu.pl

Abstract. The paper presents the developed roundabout simulator. A model, which is the engine for the simulator, was developed based on cellular automata. The author discusses the technology were used and demonstrated examples of the research results. Noteworthy is the fact that the developed simulator is very flexible, allowing conducting research in diameter roundabout, pedestrians on the roundabout, traffic of passengers cars and commercial vehicles, and also research change the rules of the road. In addition, the simulator allows traffic research in terms of weather conditions, e.g. rain, snow, which causes that braking distance increases and more accidents reaches.

Keywords: Cellular Automata (CA) · CA roundabout model · Roundabout traffic simulation

1 Introduction

Roundabout is a form of crossroads surrounding the centrally located island. The entrance to the roundabout is dependent on vehicles circulating on the roundabout. Tests have shown that roundabouts reduce the number of points of conflict at the intersection [1]. Studies conducted in the United States showed a decline in the number of accidents by 29% and injuries by 81% following the introduction of roundabouts [2]. There are also publications, where authors identifying places where it is recommended to use roundabouts. In [3] determined on the basis of simulation, that roundabouts are particularly recommended in places where the traffic is evenly distributed between all the roads. The authors of [4] determined the causes affecting the capacity of roundabout. Further they said that the three-lane roundabout does not increase the bandwidth relative to the two-lane roundabout.

The purpose of this article is to present the possibilities of developed roundabout simulator and to conduct a few research experiments: the impact of pedestrians and commercial cars on the capacity of roundabout, the impact of vehicles and pedestrians on the capacity of roundabout and the impact of pedestrians and the diameter of roundabout on the capacity of roundabout. To achieve the goal, the CA model was developed. Based on the model the computer application was prepared and computer simulation was conducted to simulate traffic on roundabout. The capacity of the roundabout is measured by the number of iterations of cellular automaton; the higher the number of iterations the capacity of roundabout is smaller. It means, more time it takes to drive through the roundabout.

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_3

2 Related Work

Modeling of traffic, and in particular modeling of roundabout traffic, it is a difficult task and is currently under consideration by a number of research centers. The complexity of this problem is mainly due to its stochastic character. Study on road capacity can be carried out based on real solutions, but if it turns out that the solution made road does not improve the situation of the road the solution should have to be upgraded. It generates huge costs and traffic congestion. For this reason, we use a computer simulation systems supported by advanced mathematical models. The available literature describes mathematical models [5, 6], methods and algorithms [7], large simulation software systems: VISSIM, AIMSUN, SUMO, applications [8, 9], hardware simulators [10–12] and hardware-software simulators [13], as well as various analyses [14–16].

Cellular automata through its stochastic character perfectly suited to the traffic modeling. The Nagel–Schreckenberg (N-Sch) model is one of the basic models of cellular automata to simulate the cars' movement. It was developed in 1992 by Nagel and Schreckenberg [5]. This model describes the one-lane car's movement and is the basis for testing various traffic scenarios [17]. Another proven model is the model developed by Biham [18]. This is a simple cellular automaton model showing the traffic into two intersecting directions. Each array cell can be occupied with vehicle traveling in one of two directions (north or east). The vehicle moves by one cell to the chosen direction, when it is empty. In another case, it remains in its position. The most important model showing traffic within the intersection is the model by Chowdhury and Schadschneider [19]. The authors model the traffic on one-way single-lane roads. The development of this model to the version for two-lane and two-way roads is presented in [9]. The new model expands the original idea of the intersections with the mechanism of induction loops activating traffic light to eliminate congestion (keeping smooth movement at the intersection). An interesting modification of the N-Sch model is presented in [20]. The author has underlined that the study was intended for urban traffic flow simulation, involving vehicles of various sizes.

The traffic rules for roundabouts are addressed in [21], single-lane roundabout modeling in [22–24], and multi-lane roundabout modeling in [25–28].

In roundabout simulator described in this publication it is used author's model developed for modeling multi-lane roundabouts for measuring the capacity of roundabout in various aspects: the influence of the size of roundabout on the capacity, the impact of changes in traffic rules at roundabouts for the capacity, the impact of the participation of pedestrians on the capacity of roundabout and many others.

3 The Roundabout Micro-simulator Environment

The application was developed in JavaScript and it can be operated in web browsers as well as by means of a console. Running the application by means of a console is possible via NodeJS runtime environment based on V8 engine in the Chrome browser. Running the application this way is considerably faster, as the program may operate without the graphics layer. The application makes use of many free tools enabling the programming works. Figure 1 shows the structure of the application together with the tools applied.

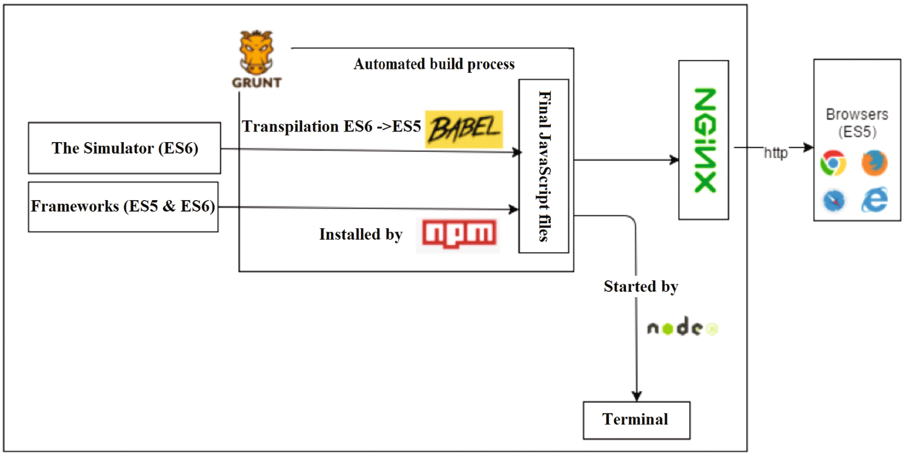

Fig. 1. The structure of the application. Source: own research.

Frequent problems with running the application are due to different runtime environments. The problems are solved by the combination of Vagrant and Ansible tools. Vagrant enables management of virtual machines, offering identical runtime conditions for applications. Ansible is used to ensure that the virtual machine is always equipped with any indispensable libraries. Upon starting, the program compares the current state of the machine with the expected one and carries out any necessary set-ups. Before that, it is necessary to prepare the configuration files that define the dependencies.

The application is written in JavaScript in accordance with the latest standards of ECMAScript 6. To enable correct operation of the application in web browsers, the Babel transpiler was used in order to change the code into the one compliant with ECMAScript 5. The process of transpilation and providing the application to the www server was automated by means of the Grunt program.

3.1 Programmes Supporting the Simulator

In addition to the simulate module of roundabout simulator, the application consists of scripts facilitate its launch and building. For proper start the application requires runtime NodeJS. It is available for all popular operating systems: MS Windows, MacOS and Linux. Along with the application configuration scripts are provided to programs Vagrant and Ansible that install all the necessary dependencies including NodeJS. Vagrant running on any platform, however, the application discussed here was examined on the operating system Linux Mint. The following instructions apply to just run the application on Linux. It is recommended to start using the program Vagrant, because it has a fully configured environment with the Web server. Vagrant download the installer disk image Linux Debian, and then create the instance, and it installs the necessary components. This allows the main operating system remains intact. After downloading and installing programs from the Vagrant https://www.vagrantup.com/ and VirtualBox from https://www.virtualbox.org/ you can go to the next stage, which is to prepare runtime environment for applications.

3.2 Preparation of the Environment

To create the environment you will need to use the console. Once it starts, you go to the root folder of the application code using the command `cd <path to folder>`. In this folder there is located the file called Vagrantfile, which contains information for the program Vagrant.

Fig. 2. Preparation of the environment. Source: own research.

In order to boot the system, enter the command `vagrant up`. After a few minutes you should receive a message indicating the success of the creation of the environment. To connect to the operating system on which the application is installed, enter the command `vagrant ssh`. As the name implies, this command uses the SSH protocol and enables issuing commands on the system with the application installed. After executing this command, you must navigate to the folder with the project by giving the command `cd/project`. This folder contains all the files of the project. These files are synchronized between the two machines. This means that modification of any file in the system root is also visible in the system with the application.

3.3 Build Application

The application discussed in this article is written in ECMAScript 6. To prepare files compatible with the ECMAScript 5 must build the entire application. To automate this process, the program Grunt was used. It should already be installed in the system accessible by the command `vagrant ssh`. In the folder with the project, use the command `grunt build` it will build all files. After this operation, under the given address should be available a graphical view of the simulation. The whole process shows a screenshot of the console shown in Fig. 2. The individual commands are numbered in red color on the left side of the Fig. 2.

Steps 1 to 4 are prepared according to the environment and installation. The last step is to build the application. As a result of this command 4 files are created:

- roundabouts.js,
- cli_measure_truck_ratio.js,
- cli_measure_island_diameter.js,
- cli_measure_rules.js.

The first file named roundabouts.js it is a built application ready to run in a web browser. After entering the page (e.g. http://192.168.100.100) should be running an roundabout simulator in a browser. Simulation parameters can be changed in the application code. For changes to be visible rebuild the application by command build and refresh the page.

Proper preparation of the environment, enable the start of the program, which screens are presented in the next section.

3.4 Presentation of Application

In Fig. 3 author shows the main window of the simulator. Users can start and stop the simulation, set the speed of the simulation and observe the numerical indexes for each vehicle. Figure 4 shows possible configuration settings:

- rules of the road,
- the maximum speed of different vehicles,
- the likelihood of the emergence of a pedestrian at a crosswalk,
- weather conditions.

In addition, a parameter that describes the required distance between vehicles is presented. This setting allows user to conduct research on the changing weather conditions and the impact of distance between vehicles on the number of road traffic collisions.

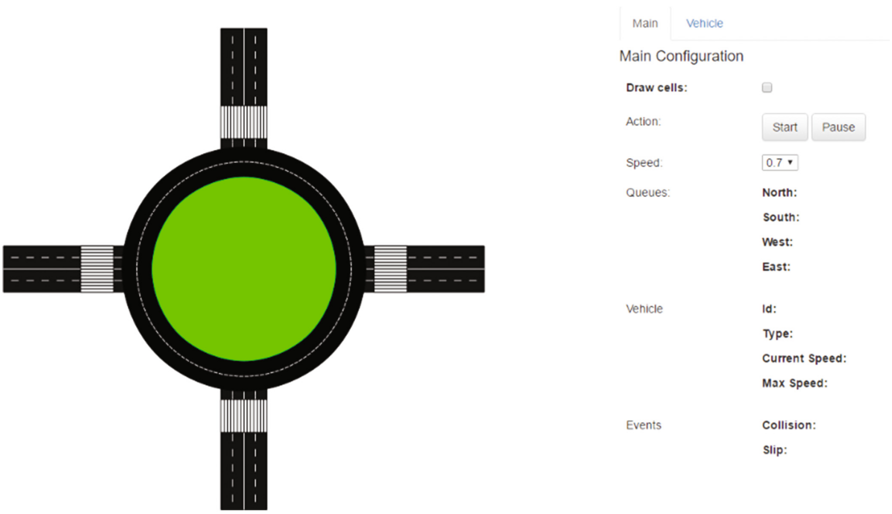

Fig. 3. The main window of the roundabout simulator. Source: own research.

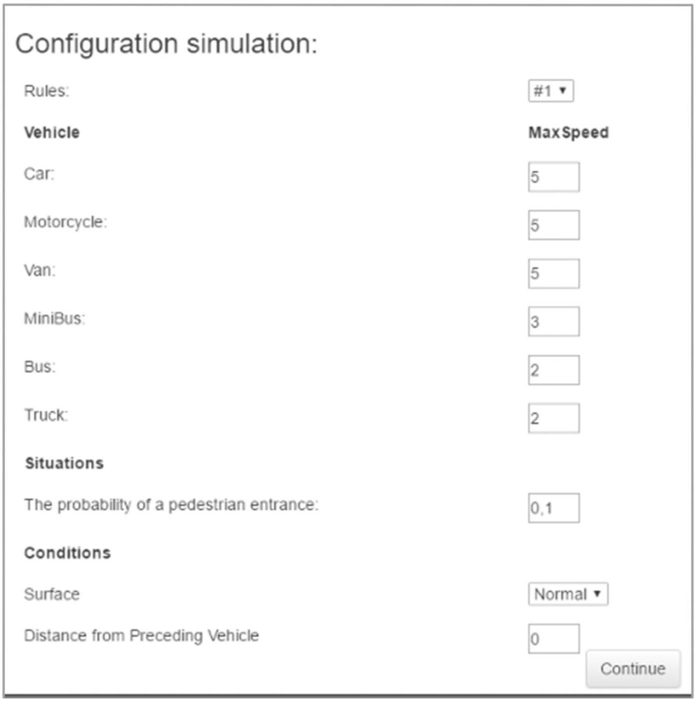

Fig. 4. The configuration window of the roundabout simulator. Source: own research.

4 Experimental Results

Traffic on the roundabout depends on many factors. Figure 5 shows the effect of the amount of trucks on the capacity of the roundabout. Additionally examined whether the character movement is changing under the influence of the amount of pedestrians passing through the roundabout. The different lines in Fig. 5 show the probability of vehicles generated during simulation process.

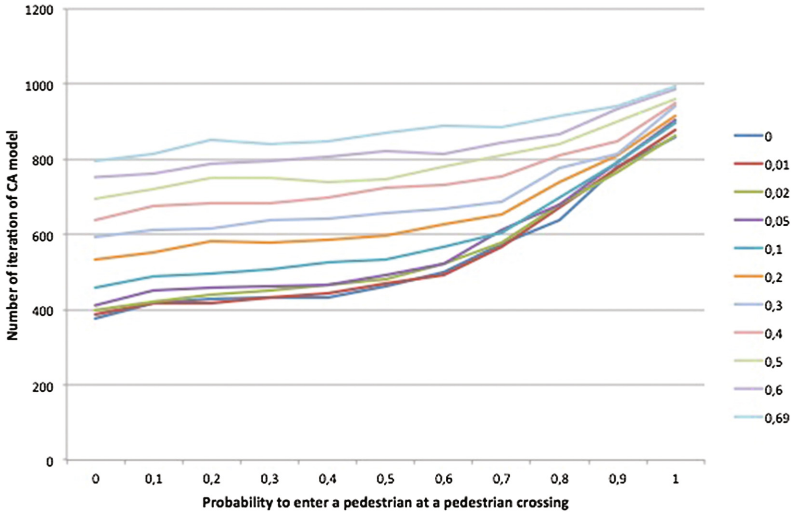

Fig. 5. The impact of the amount of pedestrians and commercial cars on the capacity of roundabout. Source: own research.

The results are unequivocal and show that the more pedestrian crossings, the more time it takes traversing through the roundabout. Additional slow traffic occurs when trucks are on the roundabout. The developed model takes into account the characteristics of such vehicles, which achieve a lower speed, slowly moving from the place and performs maneuvers slowly twisting and avoiding obstacles. This leads to the elimination of the heavy traffic of the cities in the great social activity during the day is necessary and will significantly improve the capacity of roundabouts.

The results of another experiment are shown in Fig. 6. The lines on the graph represent probability of the occurrence of pedestrians at pedestrian crossings. The X-axis shows the number of vehicles passing through the roundabout. The Y-axis is the number of iteration of cellular automaton, which in practice will mean throughput of the roundabout. Lines in Fig. 6 are distorted more than the test shown in Fig. 5. This is due to the characteristics of moving passenger vehicles. Drivers of such vehicles do not always wait for the release of the crossing by pedestrians. They passing pedestrians crossing already, when pedestrian is on the crossing but on the next lane of a multilane road that inlet to the roundabout.

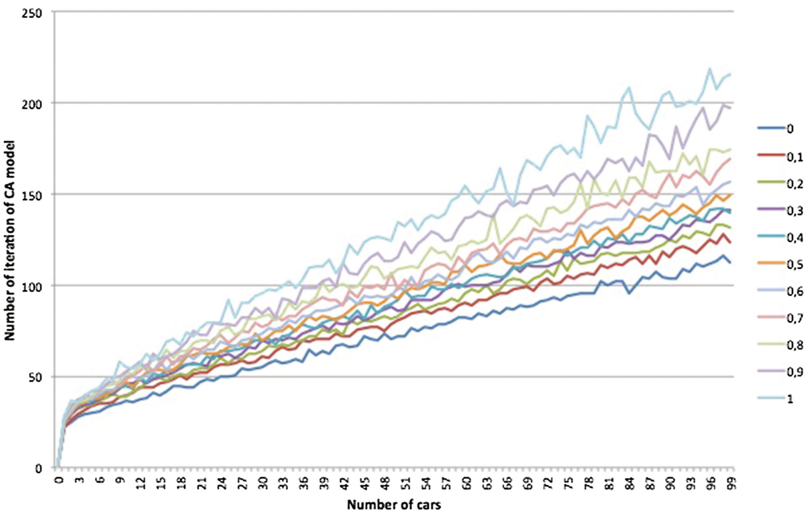

Fig. 6. The impact of vehicles and pedestrians on the capacity of roundabout. Source: own research.

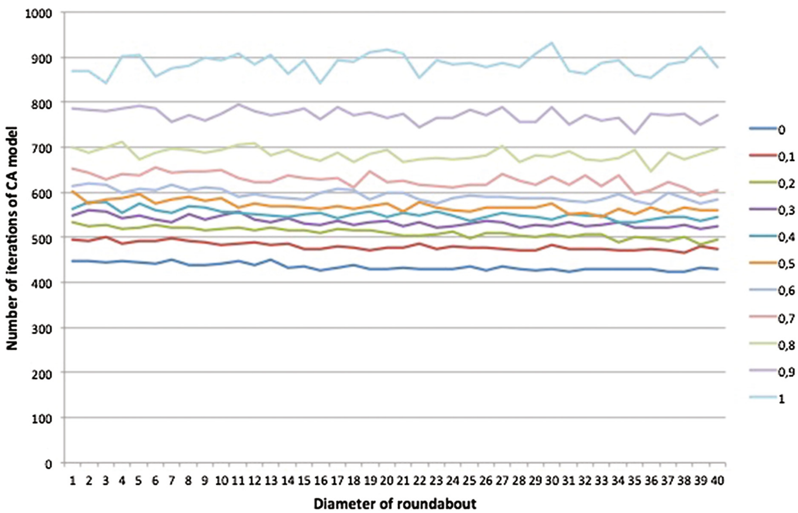

Fig. 7. The impact of pedestrians and the diameter of roundabout on the capacity of roundabout. Source: own research.

The last experiment concerned with the research about the size of the roundabout. The question is: does the size of roundabout have an impact on its capacity. An additional element of the study was a movement of pedestrians' crossings inlet and outlet roads, according to Fig. 3. The results of this research are shown in Fig. 7. Individual lines indicate the likelihood of the occurrence of pedestrians at pedestrian crossings, that is, the smaller the value is, the less pedestrian on the roundabout. The results show that the amount of pedestrian has an impact on the capacity of roundabout but changing the diameter of the roundabout does not affect of capacity of roundabout, at any number of pedestrians. The study was performed on randomly generated 500 cars, without commercial cars.

5 Conclusion

The article concerns an important issue, which is the modeling of roundabout traffic. Author shows a roundabout simulator based on the cellular automaton model. The areas of using developed simulator were applied. The way of preparing a software environment was discussed. A few results of the research were done and scientific discussion was conducted, from which the following conclusions are: increasing the diameter of the roundabout does not improve the capacity of this roundabout, a large impact on the capacity of roundabouts is the movement of vehicles (especially) commercial cars and pedestrians.

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Online Train Traffic Adjustments: Probabilistic Modeling and Estimating

Boris Davydov[1(✉)], Vladimir Chebotarev[2], and Kseniya Kablukova[2]

[1] Far Eastern State Transport University, Khabarovsk, Russia
dbi@rambler.ru
[2] Computing Center, Far Eastern Branch, Russian Academy of Sciences, Khabarovsk, Russia
chebotarev@as.khb.ru, kseniya0407@mail.ru

Abstract. Generic stochastic model takes into account an input lateness, delays at the stations and deviations of train run times. The updated model reflected the effect of adjustments that drivers perform permanently. Accounting the operational control allows you more reliably detect intertrain conflicts and assign rational adjustments. Modeling the process on open tracks shows that shape the time density is retained when passing the control points of route. The width of scattering the arrivals is subjected to change only. The results of real data analysis show that dispatching adjustments allows control the average of delay. Operational management unable eliminate the scattering of arrival times. The developed approach is effective in online traffic prediction and creating the optimal schedule adjustments.

Keywords: Train traffic · Online adjustments · Stochastic model · Optimal rescheduling · Train delays

1 Introduction

Train operation under real conditions is influenced by disruptions which cause deviations from the schedule. These random unscheduled impacts result in a scattering of arrival times. Online traffic control is aimed at reduction of the impact from disturbing factors and avoiding delays. Permanent adjustments are performed by drivers and traffic controllers. Their actions transform the distribution of arrival times. This process is under-studied, therefore, it does not allow for adequate traffic forecasting and create of measures intended to prevent train delays.

Dynamic modelling of train situations shows the process in its further development to determine the optimal regulation measures. A model of running a single vehicle (SV) is used as a basic element. Traffic prognosis significantly differs from the reality when using a deterministic model. The reason for this is the failure to take random disturbing factors into account. A vehicle movement is subjected to uncontrolled impacts such as the individual physical characteristics (tractive potential, haulage performance, resistance to motion, and others) and the specific conditions of its travel. In addition, traffic depends on the qualifications of a staff dealing with the local control (a locomotive driver) or on the specifics of the automatic train control system (ATC).

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_4

As a result, the actual speed of the train running along different elements of track and duration of stops are of probabilistic behavior. All the above substantiates the need for a real time stochastic model of an SV movement and of vehicle flow to develop adequate forecasting and adjusting measures.

Movement of SV is presented in the course of modeling as a complex of operations implemented on the railway sections of continuous run (at open tracks) and at the stopping points (at stations). Free motion operations and dwell operations are qualitatively different therefore the algorithms of operational management for corresponding processes are also significantly different. Analysis shows the dominant regulative roles are distributed as follows: priority belongs to the driver when SV moving at open tracks and to person (dispatcher) who coordinates dwell operations. The impact from adjustments is reflected in the change of the form and the parameters of probability distribution the operational times and therefore, arrival times.

The majority of the existing stochastic models are based on an assumption that the conditions of passage of a train along a section are invariable. Corresponding characteristics are considered fixed and independent of a train traffic situation, period of the day, etc. Certain works suggest that regulative measures are undertaken at stations. The primary types of adjustments are changes of stopping duration and the travel order. Existing models do not take the participation of locomotive drivers in traffic adjusting into consideration.

This paper is an attempt to fill a gap, i.e. to develop a stochastic model describing the process of scattering transforming the arrival time under operational management. After an analysis of the literature (Sect. 2) we describe a generalized model that reflects all the processes on the open tracks and at the stations (Sect. 3). Section 4 describes the transformation of time distribution caused by the adjustments performed by the drivers. Section 5 provides a convenient formalization of arrival time distribution and shows how these parameters change in the course of train run. In conclusion, we analyze the results of studying actual data on train traffic on the Russian Railways (Sect. 6). The analysis conducted distinctly confirms our assumptions concerning the impacts of adjustments which are implemented by drivers and dispatchers.

2 Literature Review

The majority of published papers are considered the rescheduling as a deterministic problem of train traffic on the congested network. The paper [1] provides an extensive overview of recovery models and algorithms for real-time rescheduling. Conflict detection and resolution (CDR) and train speed coordination (TSC) are the main types of problem which are solved in searching for optimal adjustments [2]. The best train order is the result of decision making. Problem of finding the optimal schedule is very time-consuming. Most frequently, the branch and bound algorithm is used as the optimization framework to rescheduling. Different heuristics apply to speed up the solution search [3]. The well-known works employ microscopic models to describe the process of moving in detail. But there is needed too much time to determine the optimal solution. Many authors have used more productively meso-model which deals with the running operations on relatively long sections and with the stops at stations. It allows you to develop a schedule for a large rail network in a shorter time.

Main disadvantage of deterministic models used for rational dispatching is insufficient consideration the risk of accidental disturbances. This drawback is largely compensated by using the stochastic models. In one of the first papers considering this problem [4] proposed analytical method for delay calculation by use the convolution of time distributions which describes input and current disturbances. The statistical model of train traffic on main line created in [5]. The approach is based on regression models, built using training sequences for the main indicators such as speed, duration of train processing etc. The model of formation the delays in the train packet [6] determines the total run time as a sum of the partial random intervals at the elements.

Recent papers to develop a probabilistic approach to the analysis of vehicle traffic with delays are [7–9]. There are used analytical methods to calculate a secondary delay as composition of distributions the individual operations. The optimization problem is aimed at finding the effective long-term train schedule for a large network.

The authors of majority the known papers suggest that adjustments of train movement to eliminate delays are carried at the stations only (see [10] for example). In most cases, used rigid rules that stipulate the procedure for change a train sequence. This action is applied when an inadmissible delay arises. There is a group of models that consider the random deviations of train run time. These models take into account the disturbances due to technical faults and due to the influence of other trains.

A comprehensive model describes the process of delay propagation takes random stops on open tracks and speed fluctuations into account [11]. However, there is no consideration of the control system that is a mechanism that reflects purposeful efforts of the driver (or of on-board ATC) for the perturbation compensation.

One of the most complete stochastic models of delay propagation thru the rail network is created in the paper [7]. This work examines the influence of the random scattering of run time on the passenger waiting process at the interlinking. The authors use a discrete representation of the probability distribution.

Stochastic model which comes really close to our approach is in [8]. The paper uses the train traffic model of mesoscopic level detailing and stochastic activity graph. The main purpose of research is to determine the right cumulative distribution function which is result of convolution the initial distributions.

Computer experiments show that the width of arrival time distribution has stabilized with extension the forecast horizon with using the effective management. This is a consequence of such the adjustment when optimized duration of stops the connecting trains. The output delay dispersion increases unboundedly if there is a weak control algorithm [10]. Similar behavior is actually observed and at an open tracks. Arrival times are scattered weakly by using strong management despite the fact that there are intense random influences. Obviously, this is due to an adjustment that carries out the driver (or the onboard automatic controller). There is no a model to adequate describe this process in the published papers.

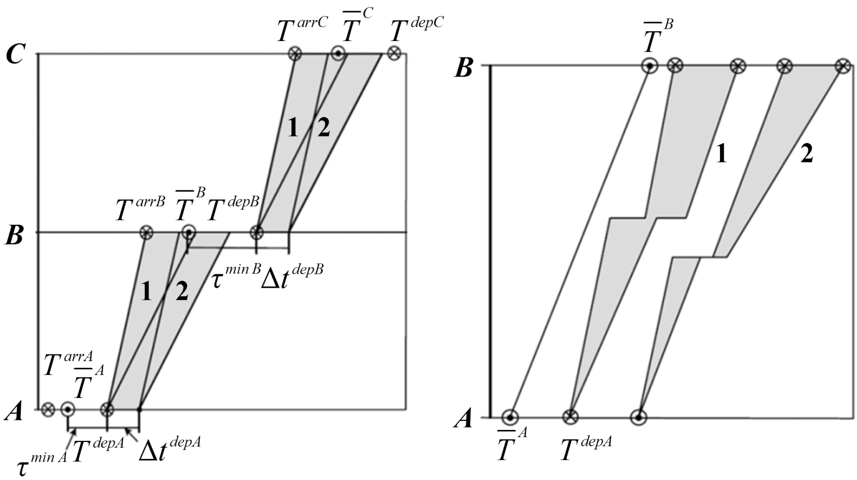
The analysis shows that there are insufficiently studied issues in the problem of stochastic modeling of train traffic. Effective implementation of adaptive traffic management requires development of an overall probabilistic model.

3 Generic Stochastic Model of Train Traffic

Generic model of train's movement integrates all kinds of violation the scheduled operating times as at the stations and on the open tracks. This model is used to determine the scattering function of the arrival at the control point. Such the approach is justified if the movement of trains considered at the meso-level of detail.

The train delay calculation and the conflict detection are made by the analysis of the arrival time distribution at the destination. The model takes into account both the own disturbing factors and the impacts which comes from the other trains.

Here we describe the mechanism of formation train delays and headways when there are random variations of operation times. Traveling time is formed by summing the values of duration the running and the dwelling operations. Disrupting factors shifts the actual initial and final times of operations relative to schedule. Train departure from the station (or from the control point) in this case is scattered within a certain interval Δt^{dep} (see Fig. 1*a*). Actual arrival and departure times are denoted as T^{arr}, T^{dep}. By $\overline{T}$ we denote scheduled times. Time interval τ^{min} satisfies requirements of safety and of passenger transfer. If there is a capital letter in the upper index of these quantities, then it means the station on which these quantities are considered.



a) single-train model *b*) two-train interacting model

⊙ – scheduled time; ⊗ – actual time

Fig. 1. Graphic interpretation of stochastic behavior the train traffic

The scheduled elementary time t_s appears in the absence of disturbances. In reality, the run time on the section (at *AB*, as the example) is exposed to random influences. These actions cause changes of speed or emergence the short stops that lead to the random variations of arrival time. Scattering of departure and run times display at the Fig. 1*a* as a set of path line "packets". Arrival time distribution is determined by the sum of random values that describe an input delay, run and dwell times. Random impact leads to scattering the arrival times concerning the scheduled moment $\overline{T}^B$ of the train entry to the station B. This deviation may result in departure delay from this station. Random behavior of departure time is caused by inaccurate actions of the train driver or by other disturbing factors.

In the known models, scattering of the run time on the open tracks are usually assumed to be fixed. In reality, the parameters are changed as each driver applies the braking action when there is dangerous approaching to the leader train. Accounting for this mechanism is the main innovation of the new stochastic model. The proposed method of displaying the operating time scattering is used to describe an interaction the pairs of trains. Figure 1*b* shows the graphical mapping of conflict on the line. Secondary delay is emerged due to unplanned stop of the leader train.

Note the scattering of arrival time the train 2 at the station B is formed on the basis of the random dwell time of the train 1 in addition to the travel time densities. The arrival time distribution is defined as the convolution of the densities for all the composing random variables. This is valid if summable random variables are independent.

The proposed formalization is clearly explained in the paper [9] which offers the following conclusion. Density of the train arrivals is determined by the multiple convolution of operating times distributions of all trains which are affected by conflict:

$$F_{out\,1}(t) = [(F_{run\,1}(t) * F_{dwell\,1}(t)) * (F_{run\,2}(t) * F_{dwell\,2}(t))] * (F_{run\,3}(t) * F_{dwell\,3}(t)), \quad (1)$$

where $F_{run\,i}(t)$ and $F_{dwell\,i}(t)$ are densities of run time and dwell time of *i*-th train.

4 Transformation of the Arrival Time Distribution as a Result of Adjustment

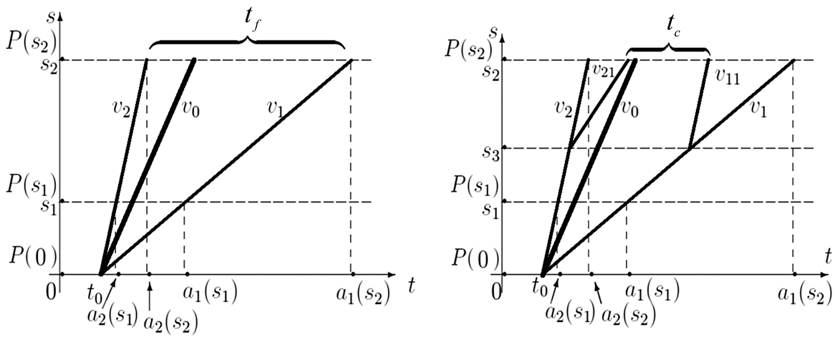
Let us consider a train moving on a section between points $P(0)$ and $P(s_2)$ (see Fig. 2). Assume scheduled times are $(t_0), (t_2)$ and assign the maximum and minimum run times. Values $a_1(s_j), a_2(s_j), a_0(s_j)$ denote arrival moments when minimum (v_1), maximum (v_2), scheduled (v_0) speed respectively. Lines v_1, v_2 delineate the sector that covers the possible trajectories of the train under the impact of random factors. The intervals marked with curly brackets correlates with the distribution $f(t;\ s_2)$ of arrival times. When there is an adjusting effect you can see the truncated output interval t_c (Fig. 2*b*). Random variable

$$Y(s) = \tau(s) - a_0(s) \quad (2)$$

is deviation of the arrival time $\tau(s)$ at the destination from the scheduled point $a_0(s)$.

We denote the probability density function of random variable $\tau(s)$ as $f(t;s)$ and the function of the random variable $Y(s)$ as $g(t;s)$, which suggests

$$g(t;s) = f(t + a_0(s);s). \quad (3)$$



a) in the absence of operative adjustments *b*) when there is the adjustments

Fig. 2. Train schedules considering the scattering of running time

The linear bounds of the fan-shaped scattering correspond to the limitations of the train speed. Considering this condition, it is defined that values $t' \in [a_2(s_2), a_1(s_2)]$ matches values $t \in [a_2(s_1), a_1(s_1)]$ according to $t' = A(s_2)t + B(s_2)$, where

$$A(s) = \frac{a_1(s) - a_2(s)}{a_1(s_1) - a_2(s_1)},\ B(s) = \frac{a_2(s)a_1(s_1) - a_2(s_1)a_1(s)}{a_1(s_1) - a_2(s_1)},\ s_1 \le s \le s_2. \tag{4}$$

In case of absence the real-time adjustments, the increase of the s value is accompanied by extension of the interval $[a_2(s), a_1(s)]$. The dispersion is big enough. The speed correction initiated by the driver prevents to constriction the distribution (see Fig. 2*b*), which in its turn results in decreasing the risk of deviation from the schedule.

Hypothesis. We make the following assumption: if the movement of the train from point s_1 to point s is not accompanied by the speed correction, then

$$\tau(s) \stackrel{d}{=} A(s)\tau(s_1) + B(s),\ s_1 < s \le s_2, \tag{5}$$

where $A(s)$ and $B(s)$ are the functions defined in (4), and $A(s) \neq 0$, then it leads to the following conclusion: $Y(s) \stackrel{d}{=} A(s)(Y(s_1) + a_0(s_1)) + B(s)$. We note that if $f(t)$ is the density function of the random variable X where A and B are constants, the $|A|^{-1} f((t - B)A^{-1})$ is the function of the random variable $AX + B$. On the basis of the previous assumptions and Eq. (3) we can conclude that for $s_1 \le s \le s_2$

$$f(t; s) = \frac{1}{|A(s)|} f\left(\frac{t - B(s)}{A(s)}; s_1\right), \tag{6}$$

$$g(t; s) = f(t + a_0(s); s) = \frac{1}{|A(s)|} g\left(\frac{t + a_0(s) - B(s)}{A(s)} - a_0(s_1); s_1\right). \tag{7}$$

This means, the increase of $A(s)$ is followed by an extension of support the density.

A driver uses real-time adjustments to lower the risk of deviation from the scheduled arrival time. Drivers' actions conform to the following logic. When a driver acknowledges the possibility of being late he increases the speed to the maximum acceptable value. The speed of the train is decreased if there is a risk of running ahead of the schedule. As the result of adjustments, impact of random factors decreases which leads to the contraction of scattering the arrival times (Fig. 2*b*). In Sect. 5 we show that in this case no deformation of the distribution occurs. The only affected value is the support that changes according to the distance between points s_3 and s_2.

5 Distribution Function of the Arrival Time

Experimental data show the arrival time density function is asymmetrical. This is true for all categories of the trains: passenger, commuter and freight. Preliminary analysis determined that scattering of the random value $Y(s_1)$ that describes the arrival times can be approximated by the gamma distribution, i.e.

$$g(t;s_1) \approx \psi_0(t;\alpha,\beta) = I(t>0)t^{\alpha-1}e^{-t/\beta}\frac{1}{\beta^{\alpha}\Gamma(\alpha)}, \tag{8}$$

where $\alpha > 0$, $\beta > 0$ are arguments, $\Gamma(\cdot)$ is the Euler gamma-function.

The choice of the gamma distribution is convenient since it describes the real scattering well and converges to the Gaussian at the same time. Furthermore, a great amount of statistical data received at the Russian Railways confirms, the arrivals really agree with the gamma law (for more information see [12]). The following analysis uses truncated modification of the gamma distribution to describe the traffic process.

Statistical data obtained on the railway with the heavy commuter traffic near Moscow confirm identity of the arrival density at different stations. Let us analyze the data for the section between stations situated on the 115th and 167th kilometers of the site. There are samples of train arrival times with size $n = 50$. The scheduled mean speed equals to 75 kmh with scattering boundaries such as $v_1 = 60$ kmh and $v_2 = 90$ kmh. The calculated arrival times to the points s_1 and s_2 are equal (in hours) to:

$$a_0(s_1) = 1.53,\ a_1(s_1) = 1.92,\ a_2(s_1) = 1.28,\ a_0(s_2) = 2.23,\ a_1(s_2) = 2.78,\ a_2(s_2) = 1.86.$$

This leads to the following conclusion: supports of the densities $g(t,s_1)$ and $g(t,s_2)$ belongs to the closed intervals [−0.26, 0.38] and [−0.37, 0.56] correspondingly.

We postulate the following hypothesis H_0: random value $Y(s_1)$ has the density

$$g(t,s_1) = I(t\in[l,r])J(l,r)\psi_0(t-b;\alpha,\beta), \tag{9}$$

where $J(l,r) = \left(\int_l^r \psi_0(t-b;\alpha,\beta)dt\right)^{-1}, b \in R$ and $l < r$ are arguments determined by the experimental data. The function that is the second part of the Eq. (9) is a "cut-off" function of the density function $\psi_0(t-b;\alpha,\beta)$ to the closed interval [*l*, *r*].

Moving further, we tried to verify the mentioned hypothesis with two significance levels 0.1 and 0.05 using the Kolmogorov-Smirnov test. We calculate sampling values: mean $\bar{x} = 1.4$ and variance $s_0^2 = 2.86$. We also received the arguments of (8):

$$\alpha = 1.69,\ \beta = 1.3. \tag{10}$$

We can put forward the statistical hypothesis based on the chart on the Fig. 3. The sample was fetched from the distribution with the density function (9) and arguments calculated above. The closed interval where the "cut-off" function of the gamma function was created is defined by the base of the bar chart and equals to [−1.44, 6.48].

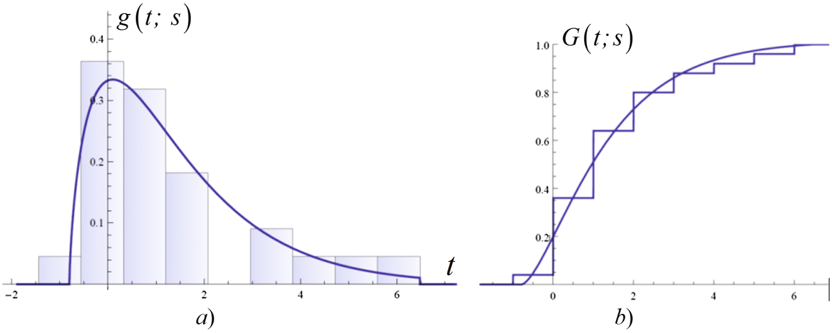


Fig. 3. Density $g(t;s_1)$ *(a)* and distribution $G(t;s_1)$ *(b)* functions

The calculations shows that $D_n = 0.1603$ is lower than critical values $\lambda_n(0.1) = 0.173$ and $\lambda_n(0.05) = 0.192$ which means that hypothesis H_0 accords with experimental data as determined by the Kolmogorov-Smirnov test.

The paper [12] was verified the hypothesis that the real-time adjustment does not change the arrival time distribution. The bar chart and the plot of the density $g(t;s_2)$ on the Fig. 4*a* is depicted based on the sample of the practical-used values $Y(s_2)$.

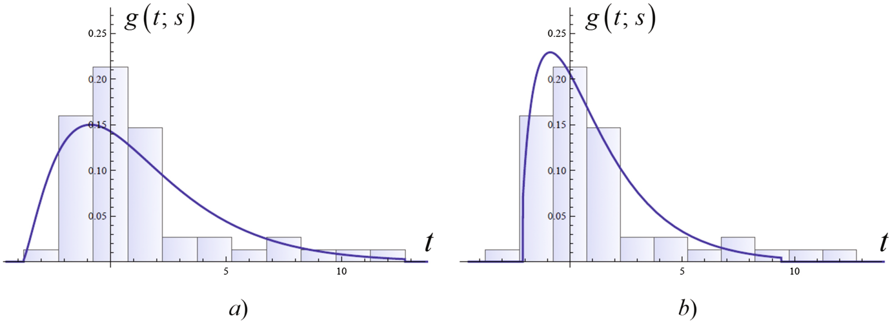


Fig. 4. Bar charts of scattering of arrival times to destination $P(s_2)$ *(a)* and density functions $g(t;s_2)$ *(a)*, $\tilde{g}(t;s_2)$ *(b)*

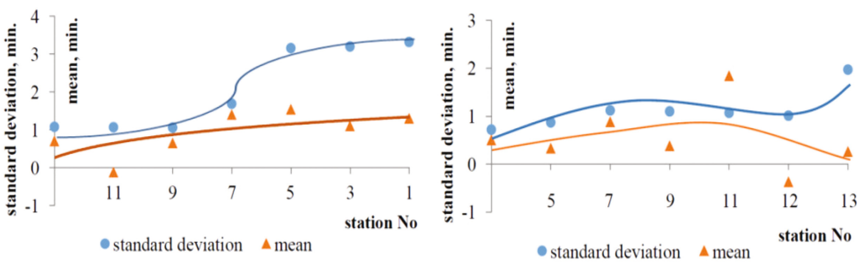
The closed interval that describes truncation of dispersion has the boundaries [−3.75, 12.75]. Comparison of plots from Figs. 3*a* and 4*a* leads to the conclusion: as train run along a site the support of the density expands if adjustment is absent.

As it is proved in mentioned paper, the distribution behavior remains the same in the destination point s_2 because of usage the linear transformation with the proportion (7). The random value $Y(s_2)$ which was modeled using this transformation has the truncated gamma function distribution. The plot of the corresponding density $\tilde{g}(t; s_2)$ is represented on the Fig. 4*b*. The values of the transformation ratios to form the variable $Y(s_2)$ are equal to $A(s_2) = 1.45$, $B(s_2) = 0$. The support of this distribution is the closed interval [−2.09, 9.41]. The corresponding interval for the distribution of the variable $Y(s_1)$ has boundaries equal to [−1.44, 6.48]. We note again that the value of the train's arrival dispersion is expanding as moving along the site.

6 Features of Scattering the Actual Operating Times

Research of dynamics the time distribution functions were carried out on various sites of Russian railways. Some of these sites are located in areas of intense commuter traffic while the other part belongs to the main railway lines with mixed freight and passenger traffic. Observations were made at different periods. In particular, traffic behavior analyzed in intraday peak and off-peak periods of passenger transit.

The study shows that means and standard deviation (SD) of arrival times depend on the path traversed on the route. Behavior of these parameters depends on the category of trains and on the flow features. Example of commuter train data shows the following. During morning peak hours the value of SD increases greatly (up to three times) when trains moving from the periphery to the center of megapolis (see Fig. 5a). This property comes from the fact that the train random delays determined by process of the passenger disembarkation. Random deviations of arrival times are much weaker when the train flow moves in the opposite direction. Average of delay is reduced when traveling along the route as shown in Fig. 5b. This indicates that effect of operative adjusting exceeds a destabilizing influence of random factors.



a) traveling to the center of megapolis b) traveling out from the center to periphery

Fig. 5. Behavior of mean and SD of commuter trains

The features of punctuality also analyzed for heavy haul freight traffic on the transcontinental rail mainline (East-West Transit Corridor). The study shows, deviation of average arrival times a little different on various stations of the line. During the day time this value does not exceed 0.2 h, at night it's no more than 0.6 h. The SD is much higher than the average arrival time. Its value reaches 1 h during daylight and 3 h at night time (see Fig. 6). There are two groups of intensive disturbing factors such as more intensive traffic and specificity of processes in a night period.

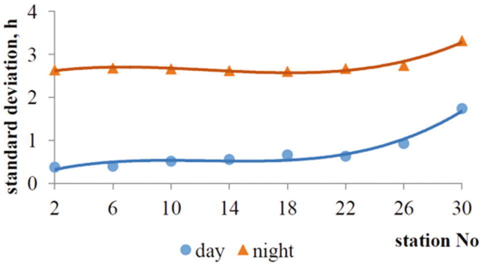
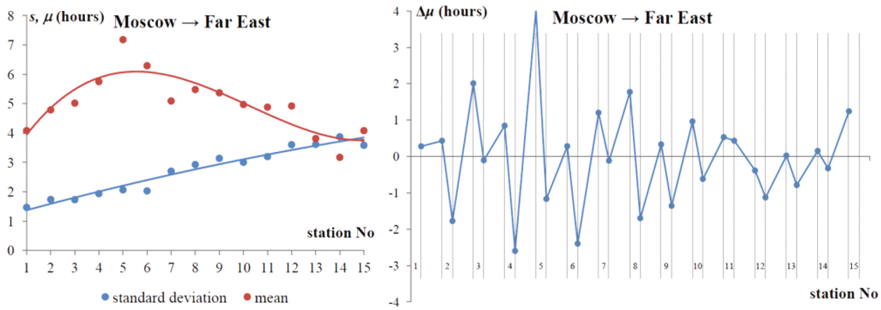


Fig. 6. Changes along the route of the arrival time SD (the heavy haul traffic)

Process of forming the delay scattering becomes evident clearly when analyzing the traffic of container trains along the longer (eight thousand kilometers) route. The average deviation from the schedule for the train arrivals at the main intermediate terminals is maintained about equal value along the entire route (see Fig. 7*a*). This clearly shows availability of a high-quality dispatching. Train managers pay more attention to the fact that the container train arrived on time as well as passenger services. But they are unable to overcome the influence of random factors.



(a) *(b)*

Fig. 7. Dynamics of the arrival moments and operational times along the route

You can see at the Fig. 7*a*, the distribution range increases along the train travel. Statistical data shows that efforts of operative management are not able to eliminate the random influences. But managers successfully are compensated the mean delay gain. Delay reducing is made by accelerate the processing of trains at the stations. This results in decrease of delays accumulated at the open tracks (see Fig. 7*b*).

7 Conclusions and Future Research

The study shows, it is effective use a historical data on infrastructure failures and on difficulties at the stations. This greatly improves the quality of the traffic prediction. In addition, the model takes actions of drivers and dispatchers into account to adjust the schedule. The paper proves the arrival time is well described by a gamma distribution which persists at the run along the section. This simplifies the calculation of statistical characteristics the arrivals at the destination. These conclusions supported by data on the real passenger and freight train traffic. In the future, the authors plan to create a methodology of the dispatching quality evaluation using stochastic modeling.

Acknowledgements. The research is partially funded by the JSC Russian Railways (Grant 2016 for development the scientific school).

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Simulation and Optimization of Passenger Flow Line in Lanzhou West Railway Station

Hualan Wang(✉), Lang Yu, and Shaochen Qin

School of Traffic and Transportation, Lanzhou Jiaotong University, Lanzhou, China
wanghualan126@126.com, 793354781@qq.com, qinshaochen2017@126.com

Abstract. Simulating and optimizing passenger flow lines in railway stations is the important method for meeting the travelers' needs and improving manage efficiency. This paper analyzed the kinds, the direction and the connection of passenger flow lines in Lanzhou West Railway Station. According to the characteristics of the passenger flow lines in Lanzhou West Railway Station, the dynamic simulation model was constructed. We simulated and optimized the station's passenger flow lines at present and in the future by using the simulation software – Anylogic. The simulation result shows that the security channels should be increased in the near future to shorter security processing time, and the proportion of four entrances' passenger flows should be adjusted to achieve better effects in the long run.

Keywords: Passengers flow line · Simulation · Optimization · Lanzhou West Railway Station

1 Introduction

Lanzhou West Railway Station is the principal station of Lanzhou Railway Bureau, located in Lanzhou Qilihe Xijin West Road. It is opened on 26 December 2014, mainly services passengers who take the high-speed trains. The passenger volume in peak hour is 13,000 persons. The actual survey shows that passenger flows jam and chaos happened in areas such as ticket lobby and security channel. Firstly, this paper analyzed the distribution of passenger flows in Lanzhou West Railway Station and then used the simulation software - Anylogic to stimulate and optimize the passenger flow lines. Finally, it provides the strategy of adjusting the number and the function of present facilities to improve passenger flow lines.

Domestic and foreign scholars have made a lot of research on the optimization problem of passenger flow line, and established various simulation models [1–6]. The author of the article [7] put forward the unique design ideas in the arrangement way of the transfer in railway and urban rail transit, and gave the concrete improvement strategy in the problems highlighted in the traffic coordination. The paper [8] revealed the scale of the facilities that the urban comprehensive transport hub should have by researching the relationship between the passenger flow lines and the facilities of the transport hub. The author of paper [9] systematically discussed the rational layout of urban transport hub by analyzing the distribution of urban passenger flow lines. The principle of

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_5

passenger flow lines design, which is combined with practical, local conditions, short and reasonable, noninteractive and clear is put forward in the article [10]. Authors of the article [11, 12] analyzed the passenger flow lines for entrance into the station and the key factors that affect the efficiency of passenger landing, proposed by adding the numbers of ticket entrance, simplifying the operating process of the entry and exit and other methods to shorten the stay time of passengers in the station. The author of the paper [13] established an evaluation model of passenger flow lines based on generalized cost, and then quantified the layout of the passenger flow lines of the station.

Based on the above research results, this paper simulated and optimized the passenger flow line of Lanzhou West Railway Station. The simulation result finds that the passing capacity of the four entrance security channels in north and south is the most direct factor leading to the queuing and congestion of the passenger. The setting of the ticket office inside the hall also has the problem of uneven distribution. Through the operation of the optimization program, it can find that the phenomenon of passenger gathering is alleviated by adjusting the facility number and changing the organization methods. You will find here guidelines for the preparation of proceedings papers to be published in TSTP Proceedings.

2 Analysis on Current Situation of Passenger Flow Lines

The passenger flow lines of Lanzhou West Railway Station can be divided into three parts: the elevated floor flow lines, the platform floor flow lines and the underground floor flow lines.

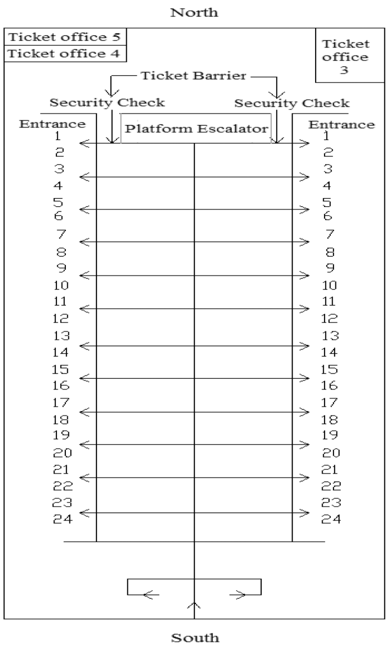

Fig. 1. The passenger flow lines in the elevated floor

The elevated floor flow lines are for entrance into station. Passengers can reach the elevated door by taking the car through the viaduct or arrive at the elevated floor by using the escalators or fixed stairs in the ground squares. And then they get to the waiting room through the security checkpoint. There is also set a considerable scale of the business district in the waiting room. Passengers can enjoy various services in the business district according to their own needs. According to these conditions, the passenger lines which are shown in Fig. 1 will be generated in the elevated floor.

Passengers can take the escalators and fixed stairs in the elevated floor down to the ground floor, which is usually known as the platform floor. The platform floor is the place for passenger's boarding and alighting. There are escalators and stairs to connect this floor and other floors. Passengers can get to the waiting room of the elevated floor or the underground floor through the stairs and escalators. They also can walk to the station square through the exits on the ground floor and transfer different modes of urban transportation. Due to the isolation between the platforms, passengers cannot arbitrarily go to another platform from one platform. The structure of the platform floor is shown in Fig. 2.

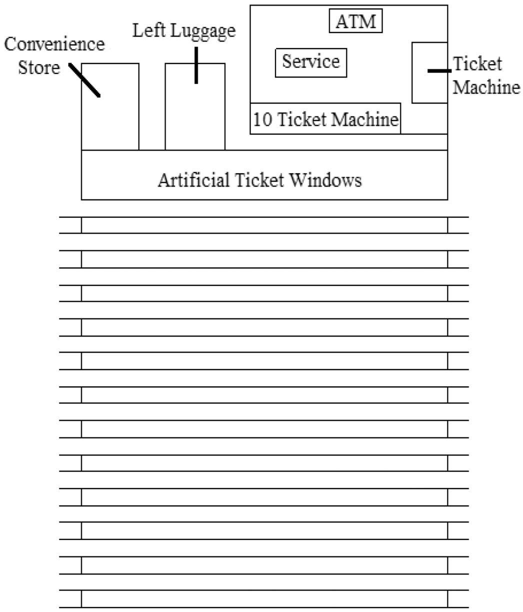

Fig. 2. The structure of the platform floor

There are two main kinds of passenger flow lines in the underground floor: walking out flow lines and transfer flow lines inside the station. For walking out flow lines, passengers arrive at the platform, and take the escalators or stairs pass the ticket entrance then arrive at the outbound hall, and reach the station square by the escalators or the stairs, or it can go to the underground parking lot through the underpass. Passengers can choose a bus, taxi or other social vehicle to leave the station quickly.

For transfer flow lines inside the station, if passengers transfer the subway, they can pass through the high-speed rail ticket entrance, reach the metro ticket lobby by the stairs and escalators, and buy a ticket, then go through the metro ticket gates, and take the elevator to the platform and leave by subway. If passengers want to transfer another train, they can enter the waiting hall again by the elevator which in the transfer channel. Figure 3 shows the passenger flow lines in underground floor.

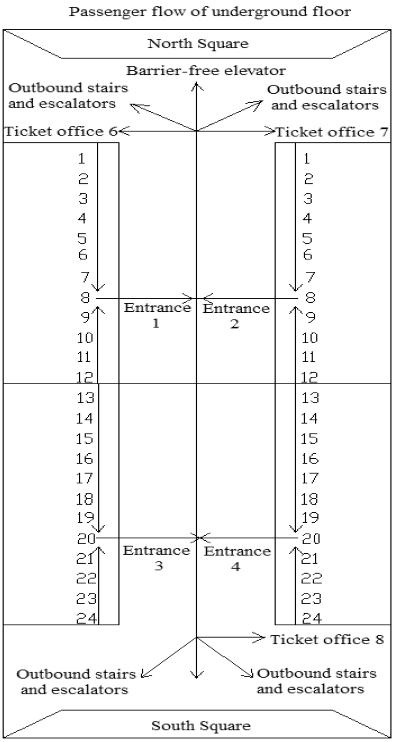

Fig. 3. The passenger flow lines in the underground floor

Based on the above description of the current situation in different floor passenger flow lines, it has some serious crossovers between the passenger flow lines of the north and south entrances in the elevated floor. In addition, it will cross with the passenger flow lines in the elevated floor when arriving passengers transfer to other trains. At the same time, different passenger flow lines from ground and underground floor will also produce crossovers in the front area of the escalators and fixed stairs in the elevated floor. For the outbound passenger flow lines, there are dedicated channels for passengers to leave the station or transfer subway, so the outbound passenger flow lines are almost no cross. The crossovers mainly exist in the starting direction of passenger flow. So the optimization focus on the passengers flow lines for entrance into the station.

3 Dynamic Simulation Analysis of Passenger Flow Line

In consideration of the application fields, popularity, technology maturity, software access of various micro-simulation software, etc. Anylogic's pedestrian module is the most accurate in the process of imitating pedestrian flow. In this paper, we use the social force model of Anylogic professional 7.0.2 version to simulate the passenger flow and research the various situations of passenger flow lines.

3.1 Simulation Environment

The Anylogic pedestrian model consists of two main parts: environment and behavior.

1. Anylogic modeling of environmental facilities:

   Step 1: Use straight lines, polyline, rectangle, etc. depicting tools of the presentation library to simulate various kinds of actual environment.
   Step 2: Setting the module parameters. Such as: service time, passenger arrival rate, pedestrian walking rate, pedestrian waiting time, the probability of passenger choice path.

   At the same time, the modeling of environmental facilities need to specify the proportion of the simulation map to the actual environment and the simulation time step by Ped Configuration module.

2. Pedestrian behavior modeling:
   The behavioral modeling of pedestrians is defined by flow chart, which is shown in Table 1.

Table 1. Module and the corresponding meaning.

Name	Meaning
Ped Source	Passenger source
Ped Sink	Passengers disappear from the source
Ped Go To	Passengers choose path and target
Ped Services	Passenger service source
Ped Wait	Passengers wait and stay
Ped Select Out Put	Probability of selection

3.2 Micro Dynamic Simulation

Passengers enter the elevated floor waiting hall and get through the platform to take train. The main process is that passengers get into station from the four entrances in north and south direction, accept the security check, wait and take train on the platform. A small number of passengers will go to the ticket office after the security check. The simulation process is: entrance - security check - waiting - entering the station.

3.3 Build Simulation Environment

1. Input Lanzhou West Railway Station elevated floor structure diagram which is used as base map to the Anylogic interface.
2. Use Anylogic to build simulation environment
   Drawing the wall, entrance, service window, area and other major entities in the corresponding position on the base map. It is shown in Fig. 4.
3. Build modules and flow line paths

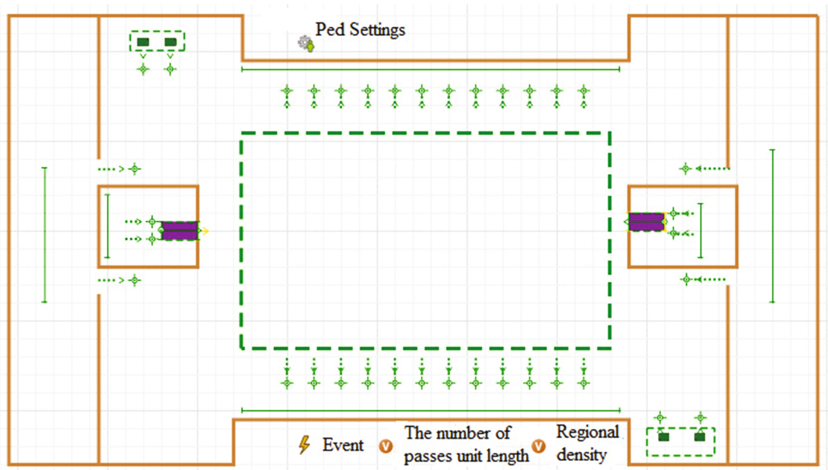

Fig. 4. The elevated floor model of Lanzhou West Railway Station

Build device modules of security checkpoint, ticket, waiting area, ticket entrance and functional modules of selection, passes, disappear and others. According to the process which is to enter from entrance, go through security, choose to purchase tickets, access the waiting area and check ticket, we connect the modules together and add selection modules. Now, the flow path of the elevated floor lines is formed, which is shown in Fig. 5.

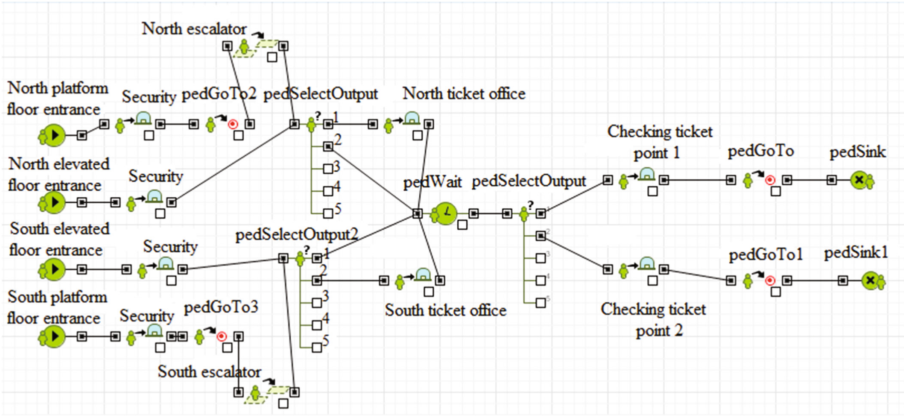

Fig. 5. The elevated floor module of Lanzhou West Railway Station

3.4 Parameter Determination

1. Entrance flow volume
   Assuming that passenger entering from the north elevated floor occupies 25% of the total passengers, 20% of the passengers entering from the south elevated floor, 30% of the passengers entering from the north platform floor, 25% of the passengers entering from the south platform floor. According to the statistics and analysis, the passenger volume is 24 million persons per year at this stage, it will reach 45 million persons per year in the long period. The arriving passengers in peak hour are 5,000 persons per hour and will reach 10,000 persons per hour in the long period.
2. Means of buying tickets
   Because of rich ticket service centers at all floors and the development of online ticketing, only 10% of passengers choose to buy tickets in the waiting room.
3. Service time
   (a) Ticket check time outside the station in the platform floor is 1 second/person;
   (b) Security check time in the elevated floor is 2 seconds/person;
   (c) Ticket time at the windows is 30–45 seconds/person;
   (d) Ticket check time in the station is 5 seconds/person.
4. Pedestrian walking speed
   The pedestrian walking speed is set to 1 m/s in this model.

3.5 Model Operation and Analysis

After running the model, we found: there was a significant congestion in the entrances of the north elevated floor and the north platform floor. The queuing in the south entrances was not obvious at first, but as time goes on, there would be queuing. Part of the reason for this situation is the actual passenger volume entering the station from north entrances is greater than the south, but the main reason is that the entrance security channels are insufficient, security time is too long and the process is cumbersome. Figures 6 and 7 show the congestion situation of north entrances in the platform floor and the elevated floor, respectively.

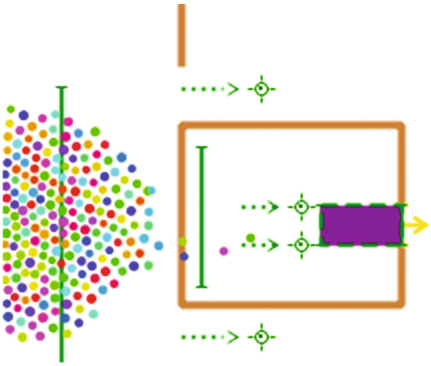

Fig. 6. The congestion situation of north entrance in the platform floor

Fig. 7. The congestion situation of north entrance in the elevated floor

A reasonable security process is necessary, which is the premise to ensure the safety and comfort of passengers. So it cannot shorten the security processing time to improve the passengers' passing rate. The feasible method is to increase the security channels.

The simulation shows there is no a large flow of people and confusion at the ticket area. The reason is the rich ticketing windows and well-developed online ticketing. But two ticket points are set on the north and south sides of the waiting hall, it increased the crossover of the passenger flow lines from both north and south entrances and caused the passenger flow organization pressure. It is recommended that the ticket offices should be also set up on both sides of the east and west. To avoid the waste of ability, it is appropriate to reduce the ticket windows at each ticket office. The situation of the north and south ticket office is shown in Fig. 8.

Fig. 8. The situation of the north and south ticket office

The waiting hall can accommodate more than 10,000 passengers. It can not only provide passengers with the needs of waiting, but also to meet the requirements of a variety of business travelers. Its capacity is plenty at present stage and even in the future. It will cause some pressure on the organization of passenger flow with the rise of the attraction of Lanzhou West Railway Station and the increase of passenger volume. However, this problem can be improved by the methods which can reduce the passenger's residence time in the station, such as adding trains, adjusting the train diagram, and shortening the train interval.

4 Optimization of Passenger Flow Lines

4.1 Optimization Based on the Current Situation

The simulation results show that there are obvious queuing phenomena in the four entrances of the elevated floor. This phenomenon can be improved by increasing the security channels and shortening the security time. The new module diagram shown in Fig. 9 is established to optimize the passenger flow lines. We can get the optimize program, which is to increase two security channels in each entrance of the elevated floor and one security channels in each entrance of the platform floor. We can also change the security time to optimize the entrance flow lines. According to the program, the above phenomenon significantly disappears in the new simulation process after changing the parameters. The optimized effect of the entrances is shown in Fig. 10.

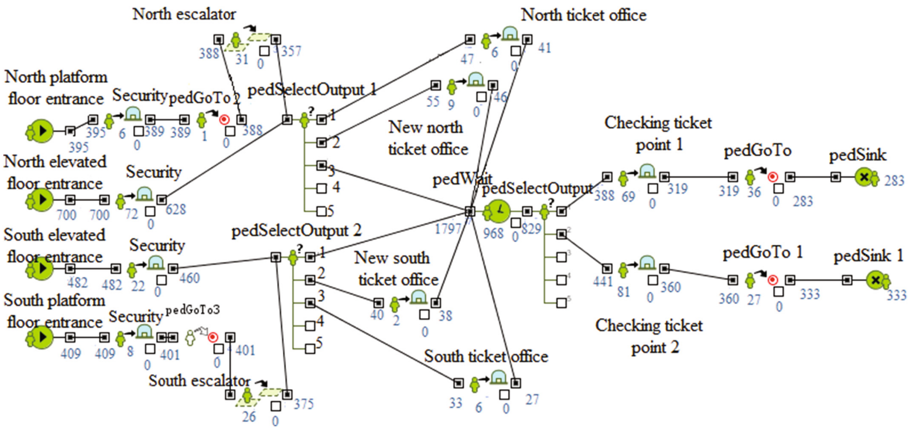

Fig. 9. The optimized module

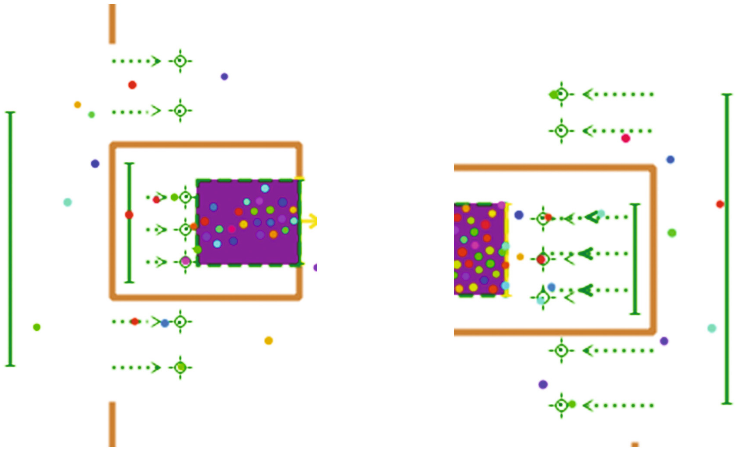

Fig. 10. The optimized effect of the entrance

For the problem of crossover between the ticketing flow lines and the entrance flow lines, we increase the ticket offices to reduce the conflict of multiple passenger flow lines at a particular node. Considering the number of passengers to buy the ticket at station ticket windows is small, it can properly reduce the ticket windows of each ticket office. The optimization program is to change the ticket office distribution. The changed layout of ticket offices is shown in Fig. 11.

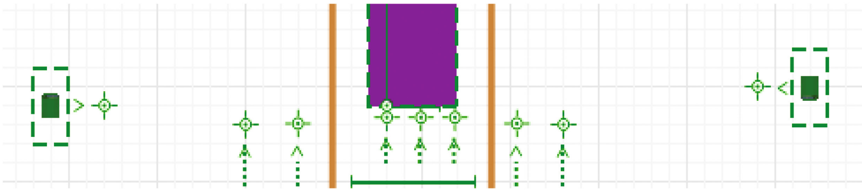

Fig. 11. The changed layout of ticket offices

4.2 Optimization Based on Long Term Prediction

When the passenger flow peak is 5,000 people/hour, it can completely satisfy passenger's business for entrance into station to increase two security channels in each entrance of the elevated floor and one security channel in each entrance of the platform floor. Setting the ticket points scatteredly can reduce the crossover of the passenger flow lines for entrance into station and avoid confusion.

As time goes on, the completion of the construction of Lanzhou Railway Station and the improvement of infrastructure will attract a large number of passengers. The optimization results mentioned in the previous section no longer satisfy the future passenger's requirements. Because of the narrow place in the entrances of the platform floor and the limited capacity of the escalators and fixed stairs, it can be appropriate to adjust the passenger proportion of four entrances to make the process of entering the station unimpeded. Assuming that the passenger volume in peak hour will reach 7500 persons in future, the passenger proportion of four entrances is adjusted as follows: the passenger volume of each entrance on the platform floor is 1500 people/hour, the persons of the north entrance and the south entrance on the elevated floor are 2500 people/hour and 2000 people/hour respectively. To avoid forming a long queue and the interaction of various flow lines, the ticket windows at four ticket offices should be increased. After these optimization methods, it can be found that there is no crowded phenomenon at the entrances. Figure 12 shows the passenger situation of entrances after optimization.

When the passenger volume rises to 10,000 people/hour, we adjust the passenger proportion of entrances as follows: the passenger volume of the entrances on the platform floor is 2000 people/hour, of the north entrance and the south entrance on the elevated floor is 3500 people/hour and 2500 people/hour respectively. The simulation found: it cannot realize that the passenger flow smoothly enter the station only by adjusting the passenger's proportion of the entrances. The other optimization measures must be adopted. We choose to add the security channels of the entrances on the elevated floor and increase the ticket windows at the ticket offices. The program simulation result is satisfied. Because of the station waiting hall can accommodate 13,000 people to wait and shop, so we do not consider the ability of the waiting area.

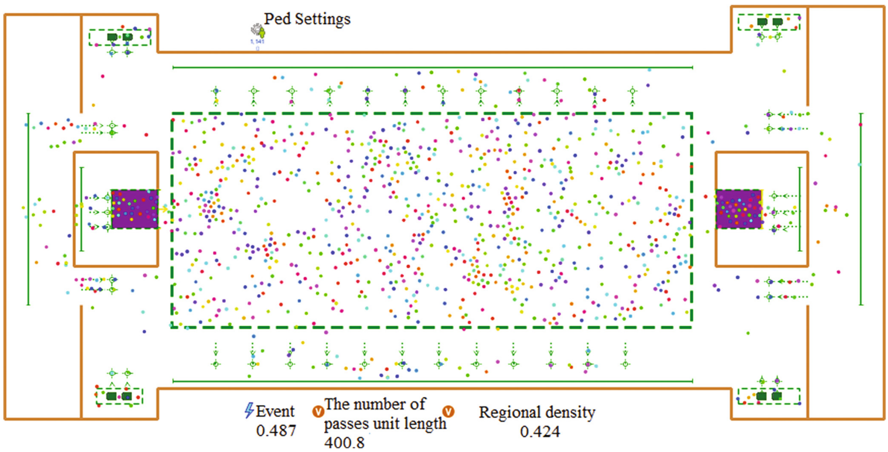

Fig. 12. The passenger situation of entrances after optimization in the future peak hour

5 Conclusion

The simulation model is used to analyze the passenger flow lines of Lanzhou West Railway station. We find out insufficient capacity of security channels of entrances is the restrictive node which affects the whole capacity of Lanzhou West High Railway Station in the near future. It can be improved by adding the number of security channels or cutting time of security check. At the same time, the long-term impact of station carrying capacity is increasing passengers. By adjusting the passenger proportion of entrances, we can found that there doesn't appear crowded phenomenon at the entrances when the passenger volume is less than 7500 people/hour. On this basis, adding the number of security channels of the entrances and the ticket windows of the ticket offices, the requirement of further growing passengers can be meet.

The model established in this paper is simple in structure and easy in parameter design. The station choke points found by the model are consistent with the actual data analysis in the experiment. In future work, we will focus on the pedestrian traffic behavior research. The subjective factors such as passenger preferences, etc. will be considered to build a more realistic model.

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GTPlat: Geosimulation for Assessing the Application of Incentives to Transport Planning

Ander Pijoan[1,2(✉)], Oihane Kamara-Esteban[1,2], Iraia Oribe-Garcia[1,2], Ainhoa Alonso-Vicario[1,2], and Cruz E. Borges[1,2]

[1] DeustoTech - Fundación Deusto, Avda. Universidades, 24, 48007 Bilbao, Spain
{ander.pijoan, oihane.esteban, iraia.oribe, ainhoa.alonso, cruz.borges}@deusto.es
[2] Facultad Ingeniería, Universidad de Deusto, Avda. Universidades, 24, 48007 Bilbao, Spain

Abstract. Motor vehicle abuse entails emitting large amounts of greenhouse gases to the atmosphere. In order to reduce climate change and life expectancy loss, authorities want to launch a set of sustainable travel policies which should be evaluated before their deployment. Although multi-agent systems for traffic analyses are very popular, they mainly focus on faithfully reproducing vehicle displacement and interaction between vehicles. It is therefore necessary to go one step further and integrate the transport choice factors that take place before starting everyday journeys. We present the baseline Geosimulation that integrates all the steps of citizens home-to-work commutes for assessing the impact green travelling policies would have.

Keywords: Green travelling policies · Transport modeling · Transport choice modelling · Traffic management

1 Introduction

The transportation sector is responsible of around a quarter of the greenhouse gas (GHG) emissions produced within the European Union (EU) making it the second largest GHG emitter after the energy sector. In particular, road transportation stands for one-fifth of the total CO_2 emissions of the EU [1]. Far from diminishing, these emissions are still growing due to our rising need for mobility. Local authorities have so far put a range of policies in place aiming at lowering emissions in the transportation sector involving strategies to foster public transport and encourage the use of electric vehicles. However, implementing these policies without a prior analysis can caught the authorities off guard and backfire the efforts to reduce environmental and social impact. As occurred with the Norwegian incentives model [2], allowing electric vehicles to use public infrastructure has resulted in saturating bus lanes where time lost by thousands of bus passengers became far greater than that gained by a few electric car drivers.

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_6

Therefore, the precise quantification of the impact resultant from sustainable transport policies is essential in order to take the right decisions and not creating a future problem. One of the most common approaches used for this purpose is traffic modeling, which consists in emulating an entire road network with vehicles travelling through in order to be used in decision support tools. These tools are typically employed by infrastructure managers and public administrations to evaluate different parameterizable scenarios (e.g. with electric vehicles usage quotes, electric vehicles features, incentive policies, etc.) according to several costs, as well as social and environmental impacts.

In this article we present a methodology to predict both the positive and negative impacts that green travelling policies will have if applied.

2 Methodology

Traditional approaches that calculate the impact of the travelling sector consist on creating a specific, whether fixed or approximated, amount of vehicles that represent a vehicle fleet, schedule their itineraries throughout the city, estimate the global impact derived from the configuration of a single scenario, and compare the results with those obtained from the simulation of other scenarios.

Multi-agent systems have been an active area of research in the last three decades. What started as isolated systems for simple problem-solving have turned into full-scale simulation platforms that are able to integrate several state-of-the art technologies. Specially, for transportation modeling, agent-based simulation models have proven to be very useful. In these models, every vehicle is represented as a software object, a so-called intelligent agent, has its own set of parameters and attributes that define how the agent will behave, interact, take decisions, and communicate with other agents in the system. This approach allows to build a thoroughly detailed description of the model-population.

The literature shows a great amount of research concerning traffic simulation through agent-based systems. The most important projects in this area are detailed as follows.

- **SUMO** [3]: (Simulation of Urban MObility) is an open-source, microscopic and multi-modal traffic simulation package designed to handle large road networks and establish a common test-bed for algorithms and models from traffic research. It facilitates interoperability with external applications during run time, using TraCI (Traffic Control Interface). SUMO comes with a mechanism to import cartographic material and automatically generate an input for traffic simulation taking data directly from OpenStreetMap. The main drawback of SUMO is having to explicitly define by hand multi-modal route steps for each citizen instead of the simulation being able to calculate them according to the existing available public transport vehicles.
- **MATSim** [4]: is an open-source, agent-based transportation simulation that is able to simulate large-scale scenarios. Currently, MATSim offers a framework for demand-modeling, agent-based mobility-simulation (traffic flow simulation), re-planning, a controller to iteratively run simulations as well as methods to analyze the output

generated by the modules. Originally MatSim only considers simulations for private car traffic, trimming its capabilities to answer sophisticated questions posed to advanced models that include several types of vehicles. However, in later versions the functionality was extended to all kinds of public transports, including pedestrians and cyclists.

- **Vissim** [5]: is a microscopic, time step and behaviour based simulation model developed to analyze the full range of functionally classified roadways and public transportation operations. It models cars with a high-fidelity model based on the Wiedemann-Model. and allows to very accurately create traffic simulations defining the amount of vehicles and types that travel through its network. It is very recommended for highly realistic studies but not suitable for large scale simulation studies.
- **PRIMES-TREMOVE** [6]: is an economic model for transportation simulation that combines modeling of microeconomic behavior concerning distribution of mobility and vehicle choices. It contains a transport demand module based on decision trees emulating the decision process of different profiles choosing their best transport method according to their income constraints.

These methodologies are relatively easy to follow and have many proven success stories but have a fundamental problem: they focus primarily on the calculation and estimation of routes and congestion avoidance, but fail to consider the social behaviour which influences the decision of using one transport method or the other. Simulations need to consider this previous step to include how the social behaviour affects the output of the evaluation of a scenario. This implies modeling social preferences when travelling such as time cost, comfort, monetary cost or environment friendly awareness.

Actual platforms for road simulation do not cover these needs, either due to the impossibility to parametrize the initial system configuration according to social variables, or due to the distribution of such modules as additional commercial packages. In order to overcome these issues, the current paper proposes a methodology based on the use of geosimulations by working on the GeoSmartSim [7] general purpose platform. GeoSmartSim is a urban simulation platform revolving around two very important axis, a Geographic Information System (GIS) and a Multi-Agent System (MAS). This approach brings together the benefits and advantages of both areas: Artificial Intelligence provides precise parametrization of each individual together with the capacity to interpret interactions with others while spatial models allow the representation of physical aspects and constraints of the real world.

Everyday commutes follow the conventional four-step structure consisting on trip generation, destination choice, transport mode choice and route choice. In order to achieve a simulation that faithfully represents this reality, the following section describes the structure of the Geosimulations.

2.1 Multi Agent System

GTPlat simulations are carried out using a MAS. It is a big computer system composed of small pieces of code called agents capable of interacting with each other. Each intelligent agent comprises an independent program that emulates a certain behavior that can perceive its environment, process perceptions and respond or act in a rational way as would the entity that represents. Agents are executed in parallel either by competing with each other or by cooperating to achieve a common goal. In this way, it is possible to create agent networks working together to respond to complex problems that may be beyond the individual capabilities and knowledge of each entity separately.

Within MAS, the Agent Environment concept (where all these agents live and interact) has been recognized as an independent and living element essential to correctly model dynamic real world problems [8]. In GeoSmartSim, the Agent Environment consists on two main pieces: on the one hand, a Physical, Social, Time and Network environments which come together to form the universe where both passive entities and agents are situated. On the other hand, a Simulation Engine which is in charge of modeling the behaviour of the agents living within, and define the skills of communication and means of interaction among them.

2.2 Agent Skills

In the real world, skills are the degree of competence that differentiates and empowers people to perform tasks. The same concept can be applied to agents. The skills serve both to characterize entities in the MAS and are the way to perceive or propagate actions into the agent environment and other entities. Agents will have a set of skills that will help them in their decision making process. However, every skill needs to be contained within a context and behave under some restrictions. We believe that it is the task of the Agent Environment to hold the responsibility of ensuring that these constraints are met and limit the capabilities of each entity.

2.3 Agents

Agents represent the entities that come to play together in the simulation. Agents are able to perceive, think, react and interact with other entities living in the Intelligent Environment. They can be categorized into two different groups whether they have their own behavior (active agents), or just react to stimuli (passive agents). Active agents are scheduled to follow a certain particular behavior and interact with other entities or the Environment through the use of skills. Passive entities, on the contrary, have their own logical behaviour as a response to the interaction initiated by other entity. Actions and perceptions are programmed using a pub-sub event handling where any number of objects can connect to in a loosely coupled way. A class which publishes a signal neither knows nor cares which agents receive the message and arguments of any type can be sent. Each simulation comprises the identification, definition, connection and parameterization of large amount of agents in order to create an scenario as similar as possible to the real world.

In this simulation we have the following passive entities:

- **Administrative area:** Geographical localization of municipalities, neighbourhoods, or administrative boundaries on which departure and arrival points for daily commutes are defined.

- **Building:** Buildings within the administrative areas for citizens to be distributed are proportionately in accordance to the area and building levels.
- **Transport Lines:** Network that enables the movement of agents through the environment. A set of transport lines of the same type make up a specific transport graph. GeoSmartSim creates several transport graphs according to the different type of vehicles available in the simulation scenario. Therefore, a graph is created for roads, another for railways and, finally, another graph for pedestrians. Agents are only able to travel through one of these graphs, depending on their type. Additionally, each TransportLine has a maximum speed, length, allowed agent types, crossing price if any, and the skill to host one or more vehicles inside according to its length and lanes (Figs. 1, 2 and 3).

Fig. 1. Roads (Source: OpenStreetMap)

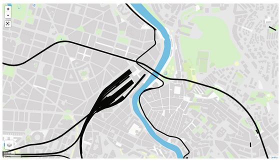

Fig. 2. Railways (Source: OpenStreetMap)

Fig. 3. Walk paths (Source: OpenStreetMap)

- **Public Transport Stops:** Represent special connection nodes shared by two graphs, making it possible for people to change between means of transport. If the stop is a Bus Stop, it will be connected to the Roads and Walk graphs whereas if it is a Rail, Tram, Subway or Funicular stop, it will be connected to the Railway and Walk graphs. It is important to note that people walking to public transport stops cannot continue their journey by walking on the rail or roads. Stops have the skill to contain waiting people and emit signals whenever a public transport vehicle arrives or departs. These notifications contain information about the vehicle arriving, its driver, and a list of remaining stops. Therefore, all users that want to use a specific public transport, can enter the Public Transport Stop, subscribe to its notifications, and wait for the train, bus, or tram, to arrive. When the users receive a notification of vehicle arrival, they look for their destination in the list of remaining stops, and decide whether to get on the public transport vehicle or not.
- **Traffic Signals:** These are connected to their nearest road graph node. They alternately close and open all entering Roads and Walk Paths every 15 s, so as to manage the crossing permissions of vehicles and pedestrians.

Conversely in this simulation the active agents would be:

- **Private Transport Vehicles:** Private vehicles (cars, electric cars, motorcycles, and bicycles) that people can use to travel through the scenario. Vehicles have two important skills: a move skill that allows them to change position along a road, and a produce pollution skill that generates contaminant emissions and consumes fuel according to the emissions model described in Sect. 2.8.

- **Public Transport Vehicles:** An extension of normal vehicles, the public transport vehicles emit signals to notify their occupants of the arrival to a public transport stop. In this way, the passengers inside the vehicle will connect to know whether they have arrived at their destination.
- **Public Transport Drivers:** People that drive the public transport vehicles along the transport lines. For public transport itineraries definition, drivers are created from files supplied by the transport operators in General Transit Feed Specification (GTFS) [9] format. These drivers will follow the theoretical timetable scheduled in the GTFS file, stopping at each public transport stop to pick up or drop passengers.
- **Citizens:** Agents that emulate persons in the daily travelling between their houses and their work or study places. Section 2.4 covers the main description for them.

2.4 Citizen Modeling

Both the passive and active agents previously mentioned represent the minimum necessary baseline from which to emulate the real world. The main characters of the simulation, however, are the citizens. Each person in the simulation will have a different profile based on their personal preferences which will directly influence the transport mean selected for travelling. For the experimentation, census data has been used in order to build these profiles.

A profile is composed of an origin point, a destination point, a departure time, and a set of all the transport means available to the citizen. Prior to each simulation, the platform preprocesses the input data to geolocate each Citizen agent on the environment by performing a weighted distribution. This process assigns the origin of each Citizen agent to buildings in the municipality and the destination to available amenities, commercial or industrial buildings, based on the building size and levels, i.e. the bigger and taller the building, the bigger the probability of assigning a citizen to it. Once located, Citizen agents are scheduled to wake up at an specific time and initiate their daily commutes by selecting the appropriate transports that meet their needs.

All Citizen agents are run together in the simulation to emerge everyday traffic congestions, traffic light stopping times and how these affect time travels and emissions. The simulation will also make possible to compare the estimated travel times with the real ones resultant from bringing together all the commutes.

2.5 Journey Features

Another of the main modules of GTPlat is the Transport Selection Model. Big research has been made [10] about transport mode choice and the variables that influence these decisions using diverse approaches. Although logit and probit models are most widespread models in transport selection, these tend to characterize all individuals following the same pattern, which may work at a macroscopic level but does not fit the reality. Fuzzy logic has been proven to achieve also high success in emulation of individual preferences for transport mode choosing [11] and enables wider level of parameterization for each citizen's profile.

In spite of using different techniques, all authors agree in emphasizing the variables that determine the modal split of a territory, which can be grouped into four categories as described in Table 1: time, price, distance and pollution.

Table 1. Journey features grouped in categories (Source: features identified in [10])

Categories	Itinerary features
Time	Walking time to transport stop from origin
	Walking time from transport stop to destination
	Travelling time inside the vehicle
	Transfer waiting time between two transports
	Poor waiting time
Price	Public transport fares
	Private vehicle purchase cost
	Private vehicle fuel cost
	Private vehicle parking cost
	Tolls and congestion charges
	Economic incentives
Distance	Walking distance
	Biking distance
Pollution	Environmental sustainability of the transport mode

2.6 Multi-modal Router and Incentives

Getting to make the right decision involves having precise data of all available transport options each citizen has. GTPlat agents have a set of available vehicles they are willing to use, for which their itineraries will be calculated. Available transport options are WALK, BICYCLE, CAR, ELECTRIC CAR, PUBLIC TRANSPORT, PARK & RIDE, BIKE & RIDE, URBAN CAR and URBAN BIKE. Itineraries are calculated using, GTPlanner, a multi-modal algorithm [12] that is capable of providing routes which combine transfers between vehicles and transport modes. Itineraries are divided into legs according to the type of vehicles being combined. For each leg, the agent will have a starting and an ending point, a transport mean, journey duration, journey length, journey price, and estimated pollutant emissions. A simplified public transport itinerary response would contain the information in Fig. 4.

While Citizen agents calculate their itinerary legs, the objective of the simulation is to quantify how the application of different incentives or restrictions over these legs affect their final choice. It is important to take into consideration that the current research focuses on the evaluation of non-physical incentives, such as changes in the price of the journey, whether it is a discount for using public transport or an additional tax for using private vehicles, reductions in the duration of the journey, or the application of congestion charges. Even as the framework we are building allow to assess physical changes like modifying public transport lines or modifying infrastructures, these are out of the scope for the moment.

```
"itinerary":
        {
         "duration" : 4211, "startTime" : 1490257800000, "endTime" :
1490260211000, "walkTime" : 1092, "transitTime" : 1311, "waitingTime" :
8, "walkDistance" : 1273.6906992374816, "transfers" : 1, "pollution_CC"
: 0.003567395424801314,
         "legs":[
           {
            "mode" : "WALK", "start" : 1490257800000, "end" :
1490258546000, "distance" : 911.814, "from" : { "lon" : -
3.0082774176765663, "lat" : 43.30321750209903 }, "to" : { "lon" : -
3.0137010338329, "lat" : 43.2989136508072 }
           },
           {
            "mode" : "BUS", "start" : 1490258547000, "end" :
1490258827000, "distance" : 4823.12, "from" : { "lon" : -
3.0137010338329, "lat" : 43.2989136508072 }, "to" : { "lon" : -
2.98918424176295, "lat" : 43.2932903929508 }
           },
           {
            "mode" : "WALK", "start" : 1490258828000, "end" :
1490258968000, "distance" : 294.23, "from" : { "lon" : -
2.98918424176295, "lat" : 43.2932903929508 }, "to" : { "lon" : -2.98936,
"lat" : 43.2956 }
           },
           {
            "mode" : "SUBWAY", "start" : 1490258973000, "end" :
1490260004000, "distance" : 2173.905, "from" : { "lon" : -2.98936,
"lat":43.2956 }, "to" : { "lon" : -2.92071, "lat" : 43.2597 }
           },
           {
            "mode" : "WALK", "start" : 1490260005000, "end" :
1490260211000, "distance" : 305.04, "from" : { "lon" : -2.92071, "lat" :
43.2597 }, "to" : { "lat" : 43.25731364536219, "arrival" : 1490260211000
},
           }
         ]
}
```


Fig. 4. GTPlanner, multi-modal routing algorithm response (Source: Transportation Research Procedia 14 pp. 1743–1752)

Table 2. The effect of incentives in itinerary features

Incentive/Restriction	Feature altered
Reduce public transport price by half	put_price := put_price * 0.5
Make all public transport free	put_price := 0
Reduce transfer waiting time by half	transfer_time := transfer_time * 0.5
Free parking for electric vehicles	electric_parking := 0
A 5€ congestion charge to vehicles entering the city	car_price := car_price + 5

Table 2 describes some of the objectives [13] different City Town Halls in Biscay plan to apply in order to foster the use of greener means of transport and avoid congestions inside the city. Incentives are loaded into GeoSmartSim using a set of keywords that modify the features of the itinerary legs calculated by the multi-modal algorithm. For example, reducing public transport price would alter only the legs concerning public transport or having to pay a 5€ congestion charge to enter the city, would increase private car leg costs. Once all the incentives have been applied to each itinerary leg, it is time for the transport selection model to chose the transportation for each citizen according to their preferences.

2.7 Transport Choice Model

Each citizen's transport selection model is based on a Fuzzy Logic engine [14] that processes the fuzzy rules provided by the profile of each Citizen agent. Rather than attempting to model a system mathematically, fuzzy logic solves a control problem through a simple natural language rule-based approach. Classical logic only allows conclusions to be True or False. By contrast, fuzzy logic defines a set of rules that map numeric data into linguistic terms and create fuzzy sets indicating the extent to which each term is part of.

For each Citizen agent, the transport selection model evaluates all the itineraries and extracts the duration, length, price and pollution from each. In order to map these features into linguistic variables, the fuzzy logic engine has a set of triangular membership functions to group the values in four categories, as shown in Fig. 5.

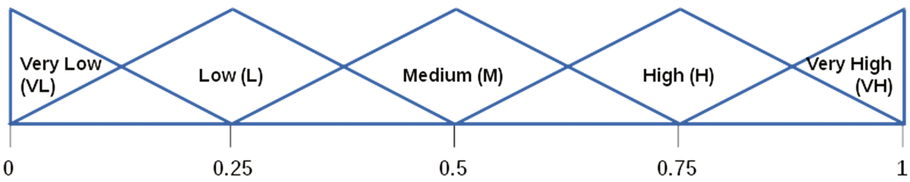

Fig. 5. Fuzzy Logic membership functions for itinerary features (Source: own development)

If some additional border case terms are needed, the fuzzy logic engine provides fuzzy value modifiers or hedges that serve this purpose by adding natural language keywords such as any, not, extremely, seldom, somewhat or very. Having characterized each itinerary's features, the profile's fuzzy rules are used to compare the differences between all itineraries and extract the one that suits the citizens preferences. According to literature [15] and internal transport surveys carried out in the Green Travelling project [16], a set of fuzzy rules collected in Fig. 6 have been written to reproduce this behaviour, where p is the price, t is the time, d is the distance and e are the emissions of the journey.

$$
\begin{aligned}
T_p = VL \vee (C_p = L \wedge\ C_p = M \wedge\ C_p = H \wedge C_p = VH) &\Longrightarrow T \\
T_p = L \vee (C_p = M \wedge\ C_p = H \wedge C_p = VH) &\Longrightarrow T \\
T_p = M \vee (C_p = H \wedge C_p = VH) &\Longrightarrow T \\
T_p = H \vee C_p = VH &\Longrightarrow T \\
T_t = VL \vee (C_t = VL \wedge\ C_t = L \wedge\ C_t = M \wedge\ C_t = H \wedge C_t = VH) &\Longrightarrow T \\
T_t = L \vee (C_t = VL \wedge\ C_t = L \wedge\ C_t = M \wedge\ C_t = H \wedge C_t = VH) &\Longrightarrow T \\
T_t = M \vee (C_t = M \wedge\ C_t = H \wedge C_t = VH) &\Longrightarrow T \\
T_t = H \vee C_t = VH &\Longrightarrow T \\
M_d = VL \vee (C_p = H \wedge C_p = VH) &\Longrightarrow M \\
M_p = M \vee (C_p = H \wedge C_p = VH) &\Longrightarrow M \\
W_d = VL \wedge\ W_d = L &\Longrightarrow W \\
W_t = VL &\Longrightarrow W \\
B_d = VL &\Longrightarrow B \\
B_t = VL &\Longrightarrow B
\end{aligned}
$$

$$
\begin{aligned}
C_p = VL &\Longrightarrow C \\
C_t = VL \vee (T_t = H \wedge T_t = VH) &\Longrightarrow C \\
C_t = L \vee\ T_t = VH &\Longrightarrow C \\
C_t = M \vee\ T_t = VH &\Longrightarrow C \\
C_t = H \vee\ T_t = VH &\Longrightarrow C \\
C_t = L \vee (M_t = M \wedge M_t = H \wedge M_t = VH) &\Longrightarrow C \\
C_p = VL \vee (T_p = VL \wedge\ T_p = L \wedge\ T_p = M \wedge\ T_p = H \wedge T_p = VH) &\Longrightarrow C \\
C_p = L \vee (T_p = VL \wedge\ T_p = L \wedge\ T_p = M \wedge\ T_p = H \wedge T_p = VH) &\Longrightarrow C \\
C_p = M \vee (T_p = M \wedge\ T_p = H \wedge T_p = VH) &\Longrightarrow C \\
C_p = H \vee (T_p = H \wedge T_p = VH) &\Longrightarrow C \\
C_p = VH \vee (T_p = H \wedge T_p = VH) &\Longrightarrow C \\
C_d = H \vee\ B_d = VH &\Longrightarrow C \\
C_d = M \vee (B_d = H \wedge B_d = VH) &\Longrightarrow C \\
T_d \neq VL \vee\ T_d \neq L \vee\ T_d \neq M \vee\ T_d \neq H \vee\ T_d \neq VH &\Longrightarrow C
\end{aligned}
$$

Fig. 6. Fuzzy logic rules (Source: own development)

Membership functions and rules are put together into the Fuzzy Logic engine and this decides which is the most appropriate itinerary for the citizen to follow. It will then start its journey using the transport method and route selected.

2.8 Emission Model

For every travelling vehicle, its emissions and fuel consumption is monitored and quantified during all the simulation with an emission model [17] based on the measures provided by the Handbook of Emission Factors for Road Transport (HBEFA) and Genikomsakis and Mitrensis. The model calculates the aggregation of direct and indirect emissions for each road segment travelled by every vehicle and translates it into Climate Change contribution and Life Expectancy loss.

3 Experimentation

The experimentation takes place in the province of Biscay, in the Basque Country which covers a total area of 2217 km^2. This province is divided into 88 municipalities, all of them connected together by train, bus, highway or a set of secondary roads. In addition, a subway infrastructure links together the capital city, Bilbao, with its metropolitan area (a total of 25 municipalities), a region known as Gran Bilbao.

In 2011, the annual census carried out by the Spanish National Statistics Institute (INE) [18] included questions with the purpose of measuring the origin, destination and means of transport used by citizens when going from home to work. The participants could choose one or several options from a fixed list that included car (with a distinction between traveling as driver or as passenger), bus, subway, motorcycle, foot, train, bicycle, or other. Particularly, regarding the transportation questions, trips are completely anonymised for those municipalities with less than 20000 inhabitants, i.e., the name or postal code are not disclosed, but replaced by an internal code that classifies them according to their population. Therefore, detailed information is given for those participants, referred to as travellers from now on, whose points of origin or destination belong to the most populated municipalities of the selected region. In case of Biscay, these municipalities are Bilbao, Barakaldo, Basauri, Durango, Erandio, Galdakao, Getxo, Leioa, Portugalete, Santurtzi and Sestao.

Simulations have been carried out using the municipal term of Bilbao defining the displacements in three groups, access to municipality, exit from municipality and inter-municipality journeys. The original census was then filtered, resulting in a dataset formed by 17810 travellers with a known living or working municipality, from which it is extracted that Biscay's modal use is split as depicted in Fig. 8.

Additional information for modeling the environment regarding geographic location and characteristics of buildings, transport network and amenities were gathered from the volunteer geographical information platform OpenStreetMap [19]. Besides, Biscay's public transport lines and frequencies were added into the environment using open data transport feeds from the Basque Government. Finally, land elevation is obtained from the CGIAR Consortium from Spatial Information (CGIAR-CSI) [20] which supplies Shuttle Radar Topography Mission (SRTM) datasets that provide high quality elevation models for large portions of the developing world.

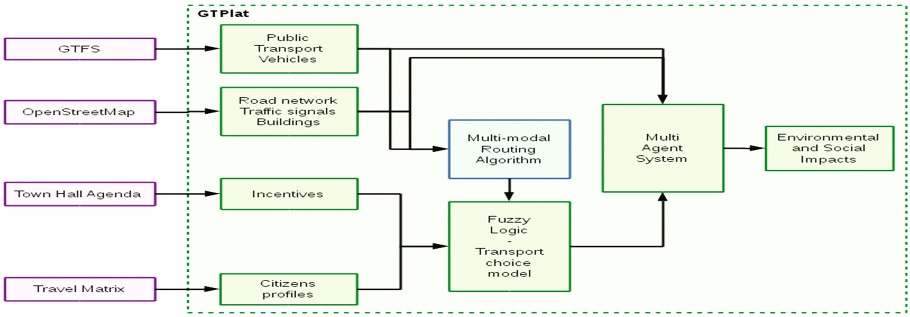

Fig. 7. GTPlat components architecture. (Source: own development)

Figure 7 describes how all the components fit together to form GTPlat for the evaluation of the environmental and social impacts of applying incentives for green travelling fostering. As seen, the input data is comprised of transport feeds (GTFS), geographical data (OpenStreetMap), data about incentives that local authorities wish to apply (Town Hall Agenda) and everyday commutes taken from the local census (Travel Matrix). These datasets are loaded into GTPlat to build the multi-modal routing algorithm together with the transport choice model, and to create the scenario in the Multi-Agent system where the agents will interact. The multi-modal algorithm along with the transport choice model and incentives are used by Citizens to select the way they will travel. All these commutes are executed together in the Multi-Agent system to provide information about the environmental and social impacts of the overall modal split.

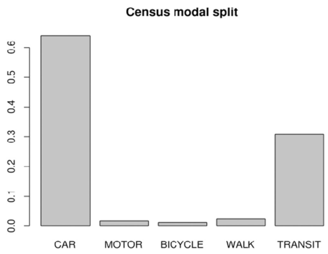

Fig. 8. Census modal split (Source: Census data from INE [17])

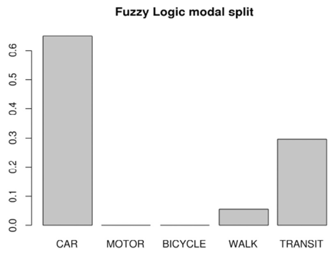

Fig. 9. Obtained modal split (Source: own development)

4 Results

Reproducing the original census dataset without applying any incentive yields the following results in terms of modal split (Fig. 9) and travel times (Figs. 10 and 11).

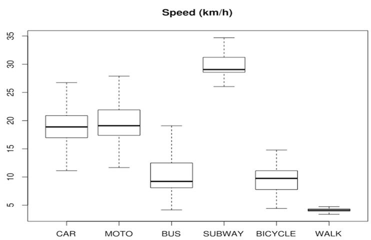

Fig. 10. Obtained speed per vehicle type (Source: own development)

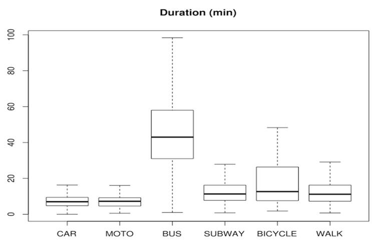

Fig. 11. Obtained duration per vehicle type (Source: own development)

4.1 Modal Split

Comparing the two modal splits, the amount of agents that choose CAR is somewhat higher than that of the real census. In the same way the amount that choose WALK is higher, contrasting heavily with the amount of agents that choose MOTORCYCLE or BICYCLE. We believe that the characteristics of the Fuzzy Logic rules are pushing private vehicle users to CAR instead of MOTORCYCLE due to the fact that the values for distance and time are similar. The same concept with distances and prices can be applied to people being pushed from BICYCLE to WALK.

4.2 Travel Time

Regarding travel time and durations, launching the geosimulation achieves a scenario where all agents run in parallel generating traffic jams with more reliable results. Figures 10 and 11 outline that private vehicle is the fastest option for home-to-work commutes. However, these do not maintain the best average speed, since that position belongs to SUBWAY which does not lose time in traffic jams, crossings and signals. Thanks to traffic jams, MOTORCYCLE achieves a slightly higher average speed as they can overtake stopped cars.

Figure 12 highlights the hegemony of private vehicle both for inter and extra municipal displacements. All private vehicle commutes (CAR and MOTORCYCLE) can be made in less than 40 min, a result consistent with the distance to the municipalities evaluated. It can be seen that quite a few people also choose the private car as a means of transportation for inter-municipal trips.

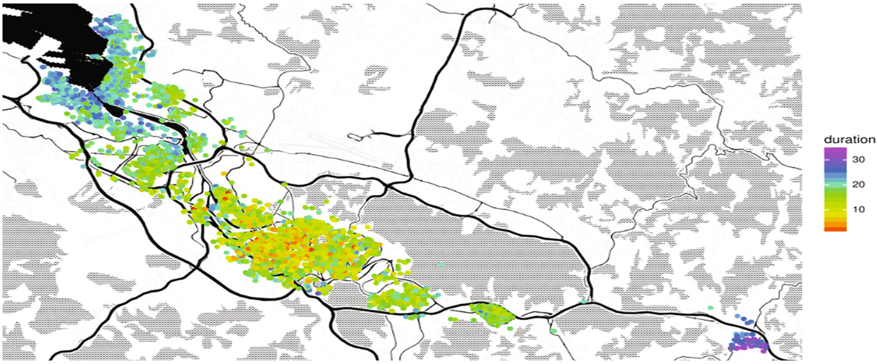

Fig. 12. Obtained private vehicle commutes geolocated (Source: own development)

Figure 13 shows that there is a large part of the population of the census that chooses public transport for inter-municipal and extra-municipal commutes. Unlike with private vehicle, journey times take much longer according to the distance to public transport stops and frequency of the service. This last one is the factor why individuals

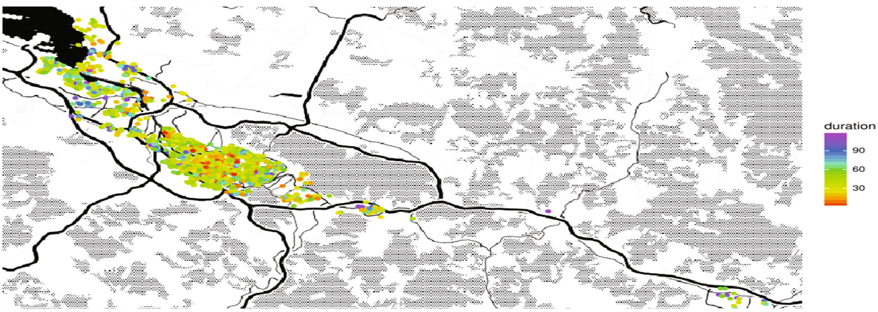

Fig. 13. Obtained public transport commutes geolocated (Source: own development)

who depart from similar locations take a very different time in completing the commutes as they have to wait for their specific BUS or SUBWAY to arrive.

Finally, Fig. 14 shows that walking option has only been chosen for mainly inter-municipal commutes that is for short commutes. However some walking times exceed one-and-a-half hours which suggests having to improve the Fuzzy Logic transport choice model.

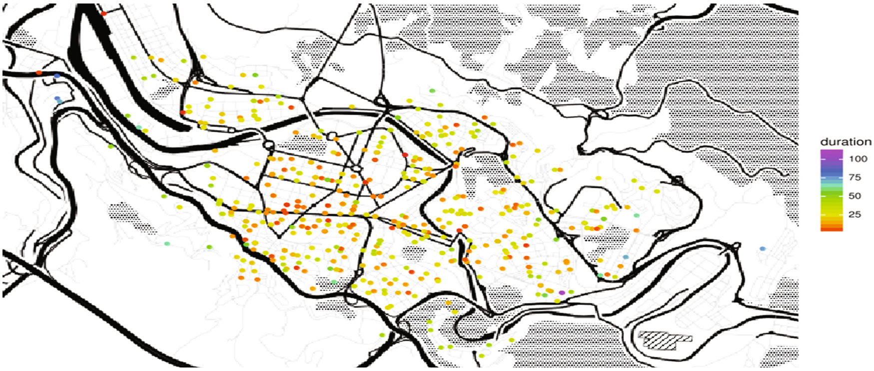

Fig. 14. Obtained walking commutes geolocated (Source: own development)

5 Discussion and Conclusions

Preliminary results, though at a very early stage, suggest that the methodology here proposed is promising for evaluating the impact of applying green travelling policies. The main advantage of using fuzzy logic to model the baseline scenario is that it does not need lots of data to train, as well as the ease in the interpretability and simplicity of the resulting model. However, the accuracy of the results can be improved by adding more geographical and sociological information to the models in order to better represent the baseline scenario.

The transport choice model, has emerged as the most important and critic module of the project due to its subsequent heavy and direct influence on the results. Working with census data entails lack of personal information and, therefore, the impossibility to know personal preferences that made each individual choose the transport mode. This model would be enriched by adding sociological variables that represent how the personal choices affect the degree of success of the green travelling policies.

The addition of detailed spatial data would also improve the accuracy of the simulations. Information such as the speed of the vehicles, occupation and capacity of public transport, number and type of road lanes, duration of traffic lights, etc. would help create a baseline model close to reality that would enhance, in turn, the reliability of the results.

Future work arising on this research will pivot around two main objectives:

1. **Improve the Fuzzy Logic Model:** The accuracy of the baseline model is intended to be improved by applying a coevolutionary algorithm that will, on one part, estimate the best parameters to build model membership functions, and on the other part, build the fuzzy logic rules that describe the process of transport choice. Currently, the algorithm is already implemented and is now in the tuning phase. The coevolutionary is composed of two genetic algorithms one for the evaluation of the best Fuzzy Logic rule sets and another for the evaluation of the best input membership functions. The union of these two allows to create the best configuration of rules and input membership functions that fits the census modal split. However each iteration of the algorithm is computationally expensive, therefore the overall execution and tuning is a high time consuming process.
2. **Evaluate the application of green travelling policies:** The model will be tested by simulating the application of green travelling incentives and restrictions on the baseline scenario and analyze how the application and modification of the sociological parameters affect the results.

Acknowledgements. This work was partially supported by: (a) GREEN TRAVELLING (Era NET Transport 6/12/IN/2014/195 label) partially funded by Diputación Foral de Bizkaia through the Plan de Promoción de la Innovación (6/12/-IN/2014/195) and by the Basque Government through the GAITEK program (IG-2014/0000133). (b) Industrial Ph.D. grant given by the University of Deusto (2015–2018), and (c) Ph.D. grant PRE_2015_2_003 given by the Basque Government.

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Urban Passenger Transport – Solutions and Technologies

Inducing Modal Shift in Passenger Transport Through ICT Solutions

Przemyslaw Borkowski(✉)

University of Gdansk, Gdańsk, Poland
przemyslaw.borkowski@univ.gda.pl

Abstract. One of the main goals of modern transport policy is a drive to induce modal change through ICT solutions. It is believed that the user given the benefits of modern ICTs in making travel experience more seamless and reasonably cheap will be willing to resign from private car in favour of public transport. The research presented in this paper refers to the field studies on the acceptance of different ICTs by transport users. It shows results from rural and urban travel. Based on this the feasibility of the possible enforcement of change and resulting modal shift is questioned. Although ICT solutions are widely accepted for majority of transport users they are not sufficient to change transport behaviours and ensure switch from private car to public transport.

Keywords: ICT in transport · User acceptance of ICT · Modal shift

1 Introduction

The possibility for use of ICT solutions which are offered by recent technical advances in passenger transport is wide and addresses solutions applicable to [4]:

- Transportation management systems change in order to improve efficient planning and running of the transport system.
- Traveller information systems designed in order to provide traveller with basic information (travel time, routes, traffic conditions, etc.).
- Electronic ticketing and tolling applications providing users with easy access to tickets and options for payment.
- Vehicle-to-infrastructure (V2I) applications facilitating communication between vehicles and transport infrastructure.
- Vehicle-to-vehicle (V2V) applications facilitating communication between different vehicles using the same or connected infrastructure.
- Demand-responsive transport services (DRTS) providing on demand public transport services in designated areas within the prices usually associated with fixed bus services

The popular belief as expressed by transport authorities is that by introducing those tools into public transport multimodality and co-modality will be supported [5, 6] and the use of private car in transport will be reduced. The ultimate result should be a massive change in transport behaviours with substantial portion of current private car users switching to highly comfortable, timely and convenient public transport. This is

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_7

based on the assumptions that due to ICT transport subsystems could be better coordinated, that information on all travel options will be obtained effortlessly and that this process will not increase price of public transport too much.

There exist several factors limiting ability of local or central governments and private transport operators to produce ICT intensive transport system [2]. Economic factor is one due to the fact that ICTs are usually capital intensive tools and as such are more likely to be considered by transport planners and organizers active in wealthy regions. Lack of capital, general poor financial ability of transport users have been often perceived as serious barriers to the introduction of ICTs. Geographic location could also be a limiting factor more peripheral areas increases need for ICT solutions improving long trip, core areas tend to be heavily congested thus needing ICT solutions allowing better handling of large numbers of passengers using transport in short periods of time. Another determinant could be culture and landscape both heavily influencing tourism and touristic destinations require more ICTs and more advanced ICTs to handle increased traffic and diverse needs of international travellers.

While the degree to which those factors could be considered in practice in development of local transport system is discussable [3] this is not the point of this research. It is assumed that introduction of ICTs into transport system will not face any serious organizational, financial (in terms of investments) and technical barriers (while in reality those barriers might be preventive of any ICT use). The field research conducted and reported here deals with potential transport system fully utilizing certain ICT solutions. Thus the research question presented to the users addresses their reaction to an ideal transport system with ICTs providing all the benefits they theoretically could offer. Therefore in this ideal testing environment the only critical factors determining ICTs ability to induce modal shift are user acceptability, individual user willingness to pay and finally comparison of advantages of ideal ICT rich public transport vs. private car.

2 Field Research Framework

The user response to the potentiality that ICTs offers has been researched within two different setups. One is an interurban travel and the other short distance urban transport environment. The first study was developed in one of the rural regions of Poland – in warminsko-mazurskie voivodship and addressed users of interurban travel options. The other captured users from the Tri-city area in Pomerania in northern Poland (Tri-city is a reference to the Gdansk metropolitan area encompassing cities of Gdansk, Sopot and Gdynia). The first study has been selected during research within COMPASS project in order to check the impact of ICTs on rural and poorly developed region [2]. The second was performed by author as a separate field research in 2016 and was oriented at relatively rich and well developed area.

While assessing users response to ICTs in transport system several barriers have to be taken into consideration. Firstly users may simply lack knowledge necessary to take advantage of more advanced ICTs. Secondly they might lack access to mobile/computer based applications. Those barriers are mostly associated with pre-introduction phase. As soon as ICT solution is in operation users quickly learn how to use it. The barrier of lack of technical platform has mostly been eliminated by widespread use of mobile devices (phones, tablets). This however could still be a barrier for older users not accustomed to use of those devices in daily activities. This is more likely to happen in the rural settings than urban because of demographics (higher share of younger users in urban than rural environments, better average education and skills in use of modern technology are also more typical for urban citizens). In both setups similar although not identical applications were evaluated. ICT solutions are specific in regard to both modes included and geographic locations. Yet they show similarity of the purpose. For rural transport scenario ICTs researched encompassed:

- Electronic travel planners.
- Electronic information about delays in real time displayed at electronic boards at stations/stops.
- Electronic information about expected arrival at destination taking into consideration current travel conditions displayed on electronic boards inside vehicle.
- Electronic ticketing (without specifying print and no-print options).
- DRTS in the form of public bus serving on demand.

For urban scenario applications considered were the following:

- Electronic information about timetables available through dedicated app in smartphone.
- Electronic information about timetables available at specific www site.
- Electronic real time information showing actual location of public transport vehicle available through dedicated app in smartphone.
- Electronic real time information showing available at specific www site.
- Electronic information about delays in real time displayed at electronic boards at stations/stops.
- Electronic information about expected arrival at destination taking into consideration current travel conditions displayed on electronic board inside vehicle.
- Possibility to buy public transport tickets online (printing of the ticket was necessary).
- Possibility to by public transport tickets online (printing not necessary – electronic app).
- DRTS in the form of public bus serving on demand.

In warminsko-mazurskie voivodship field research among users and non- users has been conducted in the area which is primarily serviced by coach transport. The responses were collected from the statistically valid group of 300 users and non-users. The group was a sample across all age groups thus in some groups some barriers to the use of ICTs were more likely to be encountered (non-familiarity with technology and reluctance to use smartphones among older users). The transport mode on which study of potentiality for ICTs was performed was coach services. The potential competitors to this mode in the area were rail and individual passenger cars. However frequency of rail services was low and destinations were very limited therefore only real competition was from the privately owned cars. Thus the research objective of testing willingness to shift from private to public transport in response to ICTs was ensured. In this setup ICT solutions could have contributed to making public transport more efficient and more user friendly and above all were able to provide competitive edge to the coach operators.

In Tri-city study questionnaire was prepared in which respondents were to evaluate usefulness of different ICTs in urban transport. This study was based on a sample of 101 users. The users were to evaluate their acceptance of particular ICTs and then to answer the questions about maximum additional payment they were ready to make in exchange for ICTs. The last stage of the study was the research of willingness to resign from private car in favour of enhanced by ICTs public transport. Contrary to the previous study this one was oriented at young transport users (20–25 years old). This group could be characterized by better knowledge of modern technology, easy access to necessary ITC enabling tools (smartphones, tablets) and lowered reluctance towards innovations.

3 Users Acceptance of Possible ICTs

The tests of some of the ICT solutions potential conducted in the rural regions of Poland prove that highest acceptance levels for ICTs could be found among younger people who operate in competitive environment from childhood and who are familiar with modern technology. For older users reluctance might result from deeply rooted behaviours but could also be result of fear of new technology and unwillingness to learn how to use it. Overall picture of user responses to proposed ICT solutions is summarized in Fig. 1.

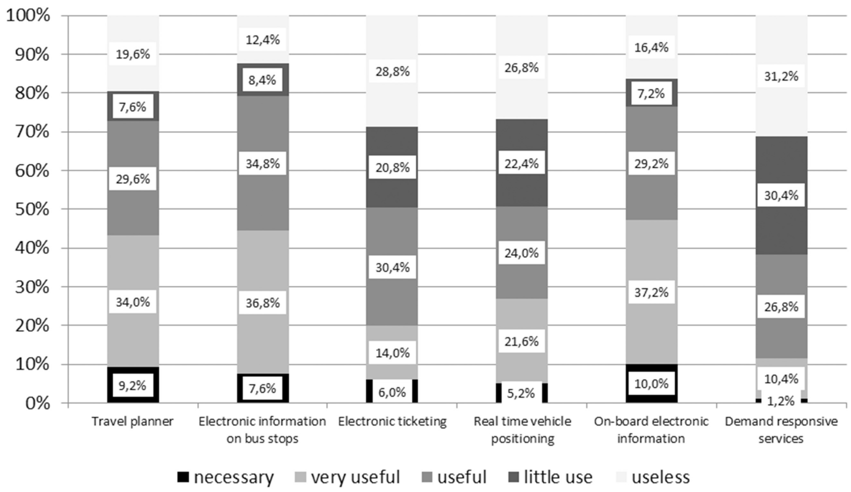

Fig. 1. User acceptance of selected ICT solutions – rural scenario (Source: own elaboration based on [1])

The acceptance levels are attributed to the necessary, very useful and useful answers. For multimodal travel planners acceptance among users reaches therefore 72.8%, for electronic information presented at bus stops it is even higher – 79.2%. It is slightly lower but still above 50% for electronic ticketing and real time vehicle positioning available on-board reaching 50.4% for the former and 50.8% for the later. Those lowered levels result from the sample composition. Respondents were selected in order to represent all age groups with significant share of older users reluctant to adapt innovations which required from them obtaining new skills. The lowest score is associated with demand responsive services (only 38% of users accepted them outright). Focus groups research which accompanied questionnaire study revealed that it was mainly due to poor understanding how DRTS works and lack of belief that it could actually work in timely manner. Another important observation from focus groups was that although some solutions were scoring significantly as being of "little use" it did not imply outright rejection of the solution. It was rather adoption of "wait and see" posture.

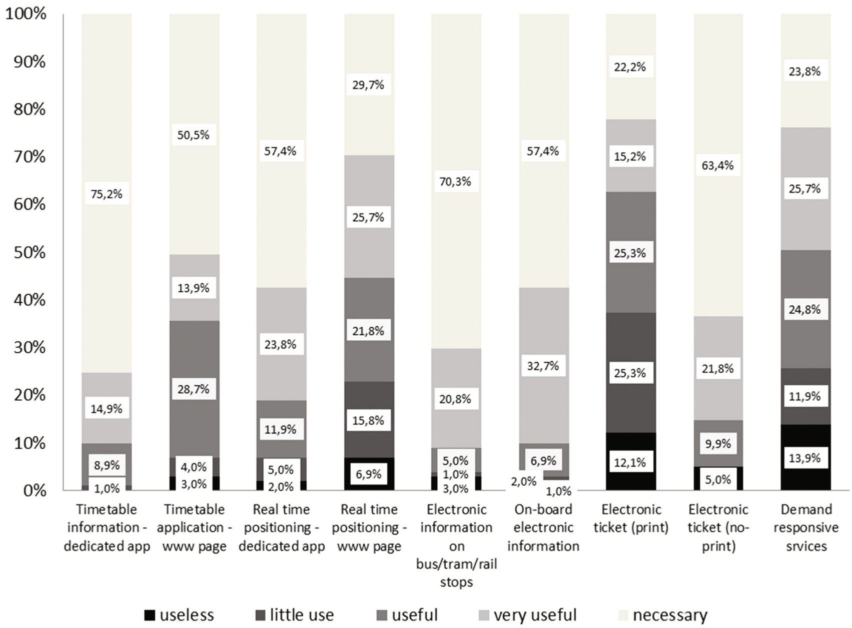

Fig. 2. User acceptance of selected ICT solutions – urban scenario (Source: own elaboration)

The handicap of having a group of older users in the sample is not present in the Tri-city study conducted among young users thus eliminating the skill and ability to use smartphone barrier. Those users will - because of demographic trends - constitute majority of transport users in the timeframe in which complete set of ICTs can actually be introduced into transport system. The results from that study are show in Fig. 2.

Not surprisingly acceptance levels are even higher than in rural scenario. Timetable information through dedicated app scores in overall positive notes at 99%! The same solution offered through webpage has acceptance levels of 93%. Similar acceptance can be noted for dedicated application showing real time position of the vehicle on the move while the same solution available through webpage access scores at 77%. Electronic information on bus/tram/city rail real time arrival available on the display boards at the stops achieved acceptance levels of 96%. The same information displayed on the electronic boards inside moving vehicle is highly valued by more than 97% of users. Interesting comparison can be made by looking into electronic ticket which could be purchased online but still requires printing it vs. no-print version saved in the smartphone/tablet. The first solution was positively evaluated by 62% of users while the second by as many as 95% of all users. This clearly shows that young urban users are not only familiar with modern technology but use smartphone/tablet as natural tool of daily activities support. They prefer not to revert to traditional solutions as much as possible. Similarly like in the rural scenario demand responsive services are less favoured then other ITC options, but the difference is lowered in comparison to previous scenario with positive score of 74%. The urban traveller is more familiar with this type of service having experienced similar solutions in the form of occasional services offered by individual drivers (e.g. Uber cars).

4 User Willingness to Pay for ICTs

While the acceptance for ICTs in transport system is generally high across rural and urban scenarios at the same time willingness to pay for those additional services remains low. This has to be considered a serious limiting factor given the rather expensive nature of the ICTs both in terms of initial expenditure necessary to have system in place and later maintenance costs. The users are generally unwilling to pay for those additional services and expect that cost will be fully born by service provider. This pattern is observed in both rural (see Fig. 3) and urban (see Fig. 4) scenarios.

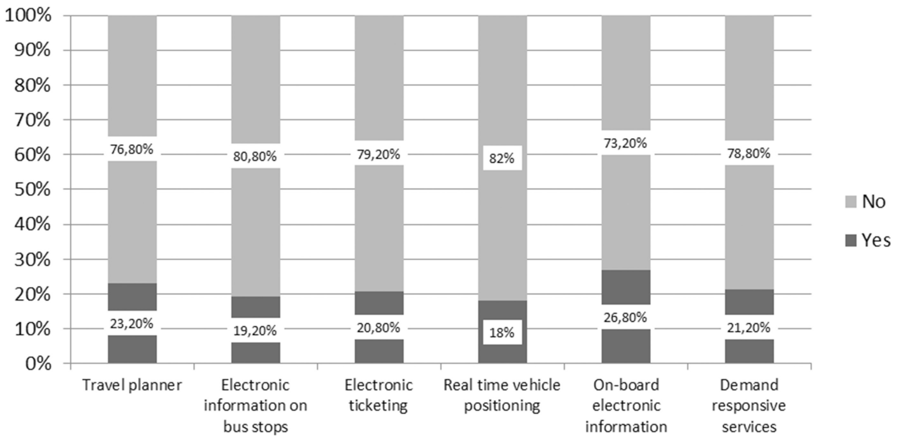

Fig. 3. User willingness to pay for ICT – rural scenario (Source: own elaboration based on [1])

On average only one out of 5 rural users is willing to pay. The more detailed analysis reveals that within this number only half are willing to pay more than 1 PLN [1]. For urban scenario willingness to pay is considerably higher with dedicated apps reaching even as much as 50% of users ready to pay. This is still not sufficient to justify expenditure on the transport service provider part. Especially that the average willingness to pay oscillates around 1.2 PLN per ICT (range is from 0.71 PLN for real time positioning via webpage to 1.8 PLN for electronic ticket without necessity to print it).

Another note that transport providers should make is that users are considerably more likely to pay for dedicated app then the same solution offered in less user-friendly way. The difference in monetary value expressed by maximum price for dedicated app vs. web page is around 100% in favour of the former.

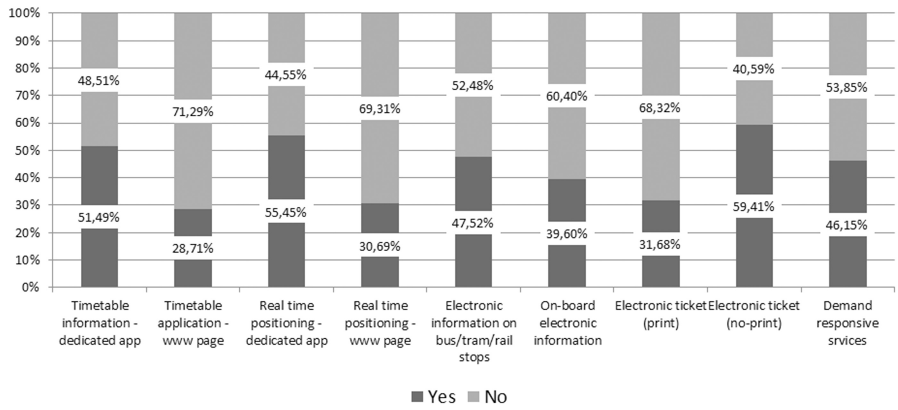

Fig. 4. User willingness to pay for ICT – urban scenario (Source: own elaboration)

5 Possibility for Modal Shift

While the acceptance and willingness to pay provide some view on the possibility of inducing modal shift through ICTs it is a direct question which gives us best answer. The previous two issues have to be considered as enablers. If ICTs are rejected obviously there is no attractiveness in them which in turn will not help to convince car user to abandon it in favour of public transport. Similarly if price is high than perceived cost ratio of public versus private option worsens. One must remember that this ratio is in favour of public transport without ICTs present and yet it fails to be a factor attracting car users to change into public transport en masse. Any worsening of the ratio (e.g. increase in public transport price due to ICTs introduction) might as well create additional barrier.

In this research both rural and urban scenarios assumed that additional charges resulting from ICTs given potential users unwillingness to pay are set at zero. This is theoretical environment in which the possibility to change from private car to public transport has been tested under the assumption of maximum gain from ICTs. Results for rural setup are presented in Fig. 5 while for urban one in Fig. 6.

About 50% of users will not change from their private car to public option even if the latter is upgraded by ICT. Those who are certain to switch are few – slightly more than 1% in response to travel planners introduction, 2.3% in regard to electronic information on bus stops, 5.7% for electronic ticketing, 1.7% in response to real time

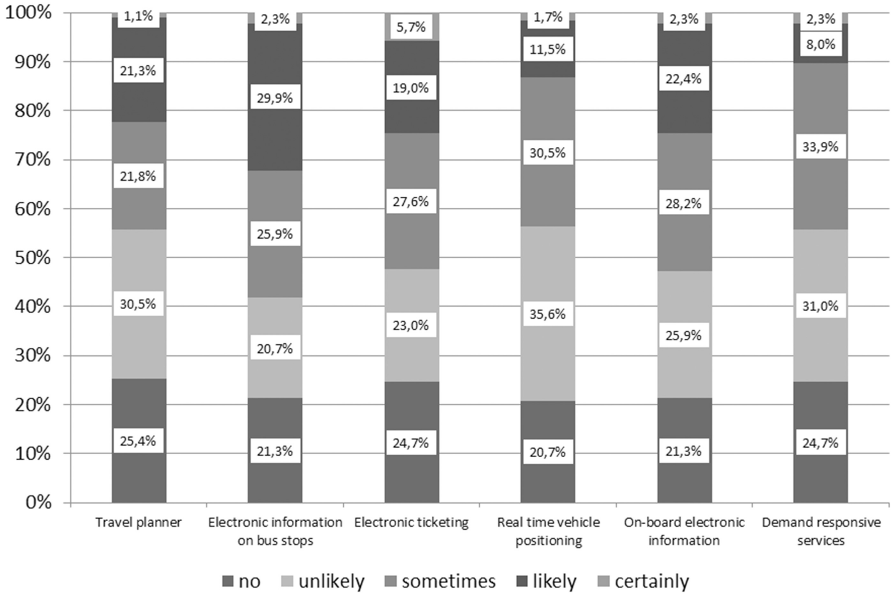

Fig. 5. Possibility for modal shift due to ICT – rural scenario (Source: own elaboration based on [1])

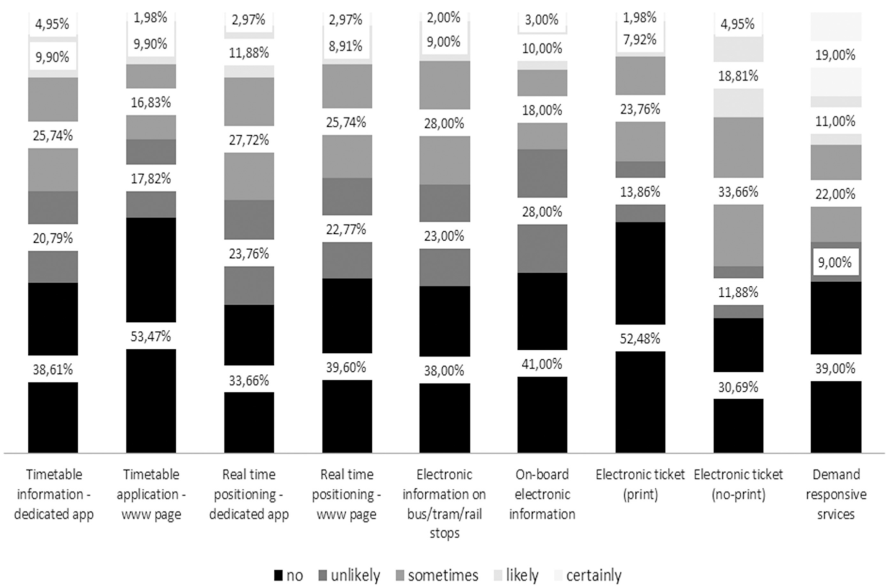

Fig. 6. Possibility for modal shift due to ICT – urban scenario (Source: own elaboration)

vehicle positioning and 2.3% for both on-board electronic information and demand responsive services. There is however significant group declaring that they are likely to switch to public option ranging from 21.8% of all users in response to travel planners to 33.0% of them in reaction to introduction of demand responsive services. This group likely adopts the waiting posture. If ICTs would work as promised they would most likely abandon private cars in favour of public transport, if it does not fulfil promises they stick to private cars. This has an important ramification for transport planners, ICT has to work perfectly from the beginning otherwise users will turn away from it.

The study among urban users reveals many similarities to rural case. About 40% of users are not willing to switch to public transport under any circumstances. The figures representing certain change oscillate around 3% with notable exception of demand responsive services.

Urban users seem to understand how it works better then rural ones probably from the experience of using similar option in the form of privately owned cars offering occasional taxi services. The “likely change” answer shows close to 10% support for both dedicated app on timetables and for the same thing but accessible via webpage and strong 12% for real time positioning app as compared to about 9% for the same service available through webpage. For electronic information on stops it is 9% and on board of the vehicles respectively 10% result. Electronic ticket (print option) scores at close to 8% while without necessity to print at almost 19%. In general the more innovative (app oriented) solutions score better than their webpage based counterparts. The overall average acceptance levels for urban scenario do not differ considerably from rural scenario with the exception of direct responsive services.

6 Conclusions

There is a mix of barriers preventing significant modal shift to be induced by ICT solutions. Those barriers are similar in both rural and urban settings even if slightly different ICTs have to be employed in both environments. User acceptance is high and it should not create any significant barriers. It is noticeably lower for older users in rural scenario, but those users constitute less and less of overall number of users. Moreover in time all ICTs are introduced into transport system current young users would be older and it is unlikely that in the process they were to somehow lose the ability to take advantage of ICTs. Acceptance is therefore high and will certainly work in favour of inducing modal shift. Low willingness to pay could however become serious barrier. Firstly it means that additional financial burden should be covered exclusively by service provider without possibility to increase ticket price to compensate. This of course could be perceived as serious handicap in development of ICT’s and their practical introduction. On the other hand in-depth analysis as described earlier shows that willingness to pay is significantly higher among younger users thus ICT solutions are much more feasible in the future. But another danger exist. Even young users do not associate payment with service but rather with application they use on their smartphone/tablet. This means that any payments associated with application use can be captured by application developer and not necessarily by transport sector. If price is to increase then the cost of public transport as compared to private car use will increase as well thus preventing any modal shift towards public transport with possibility of reverse action. Finally as both field studies show there is a considerable group (50% in rural and 40% in urban settings) that is unlikely to change transport behaviours regardless of how good is public transport. Even ICT reach public transport cannot compete with private option in some areas (comfort, directness). Those users are irrelevant to the ICTs. Therefore another question arises is it worthy to expedite high amounts of money on solutions which are not being used by about half of the society? On the other hand the remaining half is sensitive to the quality of public transport and ICTs can certainly induce some – although limited - shift towards public transport. ICTs have limited ability to enforce modal shift by themselves but as a positive tool cannot be overlooked. Yet they are not as powerful as negative tools (like car excluding zones for instance). It is therefore in the end a question of political decision which path of transport system development to pursue. If policy makers prefer to use soft measures advocating slow and voluntary shift then ICTs should be pursued. In case swift and radical change is sought they will certainly not offer sufficient result.

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Bike-Sharing as an Element of Integrated Urban Transport System

Piotr Czech(✉), Katarzyna Turoń, and Roman Urbańczyk

Faculty of Transport, Silesian University of Technology, Katowice, Poland
{piotr.czech, katarzyna.turon, roman.urbanczyk}@polsl.pl

Abstract. The following paper is meant to illustrate the use of the idea of bike-sharing system in urban logistics. In their work, the authors referred to cycling in Poland and to the Poles' attitude towards the use of the bike as an alternative means of transport in the city. The idea of self-service public bike rental system has been widely presented in the article. Further, the components of the architecture system have been discussed. The authors presented the principle of functioning of the self-service public bike rental system, called bike-sharing, as well as its transport accessibility in cities in Poland. Moreover, the authors illustrated the principle of functioning of the system by the case of public bike rental in the city of Katowice, called 'City by Bike', and in the city of Cracow, called 'Wavelo'. The main aim of the work was to present the idea of self-service public bike rental (bike sharing), its functionality and chosen examples.

Keywords: Bike-sharing system · Urban logistics · Urban mobility solutions · Sustainable development

1 Introduction

Continually increasing traffic volume connected with the dynamic development of transport, congestions of transport, tightening of ecologic restrictions or the requirements of balanced transport are only a few of those problems which currently cities must face every day [1].

Fulfilling all those requirements in the context of urban logistics is not an easy task [2]. It is because the process of creating balanced urban logistics is connected with the necessity of maintaining the balance between three main domains of balanced development: the economic, ecological and social realm [3–5].

As far as the economic and ecologic aspects are concerned, with the support of good management, the government of the city can easily create innovative and pro-ecologic transport investments. The human factor, though, seems to be the hardest one to influence on. In practice, it means encouraging the society to change their attitude towards the way they move around the cities. In other words, the change of their attitude to urban mobility and the use of alternative means of transport, and create sustainable mobility [6].

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_8

One of the possibilities of moving by the use of alternative means of transport is cycling. It is also an element of integrated transport system. Although cycling is not a new idea, in the times of smart cities, (those cities which use information and communication technologies in order to boost the interactivity and efficiency of urban infrastructure as well as to raise the awareness of inhabitants), it is possible to improve the attractiveness of mobility in the cities [7, 8].

Such action is possible by the means of the bike rental system – the idea of bike-sharing.

This article is meant to present the idea of self-service public bike rental (bike-sharing), its functionality and chosen examples, as a way to improve the attractiveness of mobility of urban logistics.

2 Cycling in Poland

If we perceive the bike as an alternative means of transport, we can point out many advantages of its use and prove its superiority to traditional means of transport, used in urban logistics. First of all, bike is one of the most economic vehicles, favourable to the urban transport. In terms of mobility, cycling is not only an effective way of travelling but also beneficial to health [8]. Due to shorter time of covering the distance in crowded cities and due to improving conditions of linear and point infrastructure (building of bike lines, appropriate signage, etc.), cycling is becoming more and more popular among European capital cities but in Poland as well [7].

According to the report "Rowerowa Polska" [Cycling Poland] compiled from 1 May till 30 September 2016 by Allegro All For Planet Foundation, on the sample of 25000 respondents, for several years the increase in number of people using bike as a means of transport in Poland, especially in Spring-Summer season, can be observed [9]. Moreover, the examination shows that:

- 785 of respondents ride the bike every day or few times a week,
- 2/3 of respondents who are active cyclists, are drivers as well,
- Cyclists in Poland cover 60,4 km per week, on average,
- Among the cities with the biggest percentage of cyclists are: Opole, Wrocław i Łódź [9].

The research defined also the profiles of Polish cyclists. For the purposes of this article the attention was given to the profile of a cyclist using the bike in terms of the urban transport. Also the 'urban cyclists' are constitute the largest group among the respondents. Reaching an advantage over groups such as recreational, occasional and sports cyclist. A detailed list of profiles of Polish cyclists are presented in Fig. 1.

The research shows that a typical urban cyclist is a person who uses the bike at least a few times a week. That cyclist uses their bike as the basic means of transport. Nonetheless, they use the bike mainly to cover the distance of commute to school, university or work. On average, it is a person up to the age of 51 [9].

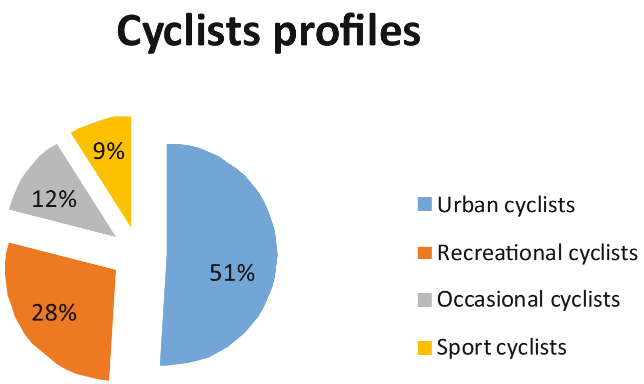

Fig. 1. The detailed list of profiles of Polish cyclists (Source: author's own collaboration based at [9])

Nowadays, the use of the bike on the area of many of Polish cities does not require having that means of transport on our own. Such solution is achievable due to the implementation of the concept of bike-sharing (self-service bike rental) in Polish cities.

3 The Idea of Bike-Sharing System

The rental of public bikes (bike-sharing, "Public-Use Bicycles", smart bikes or "Bicycle Transit"), functioning in the system of bike-sharing, is very popular in European cities. They constitute a means of urban transport which relies on temporary and chargeable rental of a bike, tandem bicycle, rickshaw or a scooter and next on returning the vehicle in any place in the city [8]. Bike-sharing is being promoted mainly in big urban agglomerations, on the grounds that it eliminates the necessity of bearing the costs of owning the vehicle [10–13].

However, bike-sharing system is not a new idea. It is claimed that it has been functioning since 1965, when the first generation of free of charge bike rental companies started to work in Amsterdam [13]. During the following years, the system evolved from free of charge offers to chargeable systems which included numerous additional services.

Apart from the possibility of renting the bike, new components of the system were gradually becoming available, which in practice meant the possibility of rental of different kinds of bikes, including electric bikes, rickshaws and scooters. The next stage was the increased number or docking stations for the bikes [11–14]. Besides those technical components, the amount of additional services offered by the rental companies increased as well, the most important of which are [15]:

- Distinct bicycles,
- GPS tracking,
- Real time availability,
- Locked bikes,
- Smart card access and others.

The proper functioning of the bike-sharing system relies on the link between such components of the system as [10]:

- The owners of the vehicles to rent,
- The users,
- The law,
- Rental,
- Organization and management of the system,
- Infrastructure of the system,
- The support of the system.

The components of the bike-sharing system are presented in the Fig. 2.

When analyzing the next components of the system, the essential one is constituted the owners of the vehicles. Among them might be some national public institutions such as local authorities or private companies which provide services to the cities [8]. The main operator of public bikes in Poland is a German chain of self-service rental companies NextBike.

Next group is represented by the users of public bikes [8]. This group includes those who according to the report "Rowerowa Polska" match the profile of the urban cyclist.

The following component of the system is the law, conditioning the rules of traveling by bike [8]. In Poland those rules are defined by the Act of 20 June 1997 – Law on Road Traffic (Prawo o Ruchu Drogowym).

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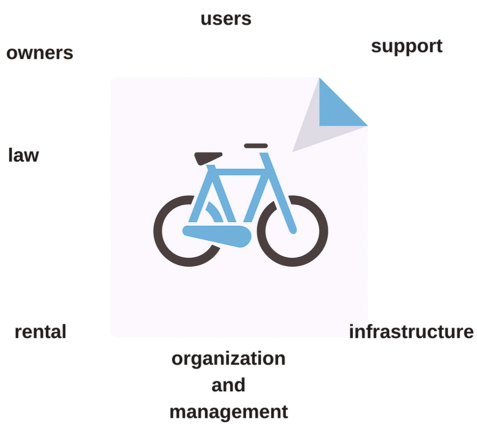

Fig. 2. The bike-sharing system elements (Source: author's own collaboration based at [8])

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The rental companies are the next component of bike-sharing system. We can distinguish private rental companies, public rental companies and rental companies which function in traditional or virtual system. The latter ones have the option of booking/buying the bike for limited period of time, via the online website or specially designed mobile application [8]. An example of possibility of booking a bike by the use of mobile application of system Wavelo used in Cracow is presented in Fig. 3.

A further group of components of the system constitutes of appropriate organization and management. Those elements are responsible for the proper functioning of the activity, from the very moment of the invention of the idea of the system to its creation and implementation [8].

The last two components of the system are the infrastructure of the system, which is meant to facilitate the traffic and to ensure the proper level of road safety, and the element which is defined as the support, meaning all kind of projects, e.g.: projects fund by European Union, offering grants for the development of innovative transport solutions [8].

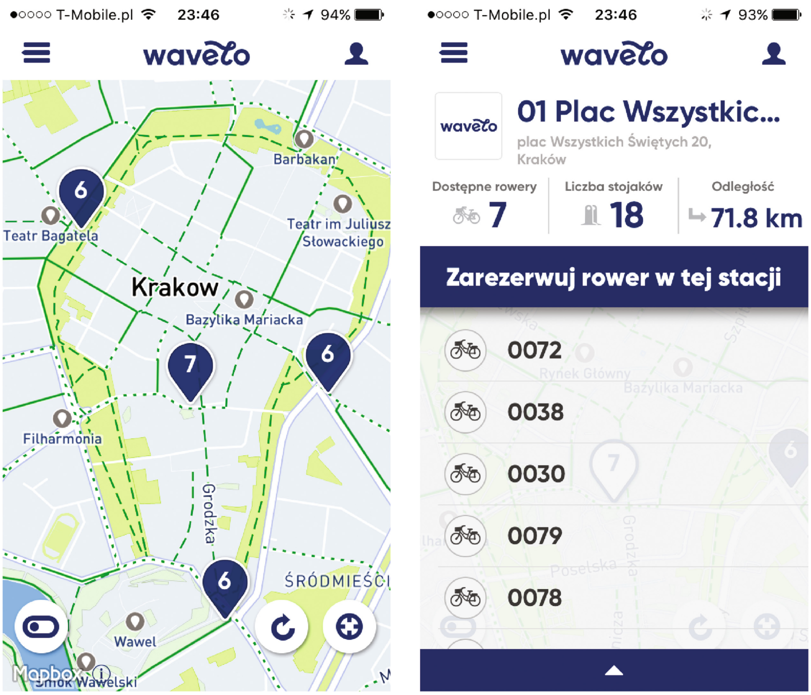

Fig. 3. Illustration of booking a bike on mobile application Wavelo

4 The Functioning of Bike-Sharing System - City by Bike Katowice from Katowice Case Study

The first step to use any bike-sharing system is the registration on the online website of the operator or by mobile application. In case of the system which functions in the city of Katowice, it is possible to use the City by Bike offer. The process of registration is connected with so called initial fee which activates the account in the system. The next step is to check the availability of the bikes on the map offered by the system. An example of the localization of the bikes on the map of Katowice obtained by the system 'City by Bike' is presented in Fig. 4.

The following step is the actual renting of the bike. It can be done by approaching the terminal and entering the phone number as well as an individual PIN code. From this moment the bike is ready to use. After the use, the bike should be left at one of the City by Bike bicycle racks and fasten by the electric lock. In case of no free racks, the bike must be fasten by a combination lock to any rack or to any other bike. The user must choose the option "return" on the terminal of the bike. Right after finishing the travel it is possible to rent another bike or the same one after the period of 3 min [16]. The use of the system is fairly intuitive and consists of four basic steps, presented in Fig. 5, and it should not cause any trouble to the users.

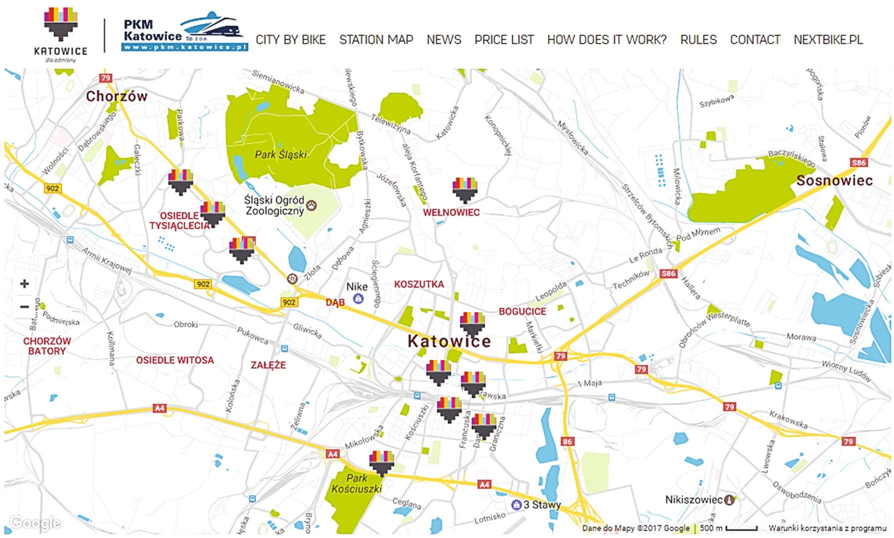

Fig. 4. Localization of public bikes on the map of the city of Katowice – system City by Bike. The places where renting the bike is possible are tagged by the sign of heart. (Source: [16])

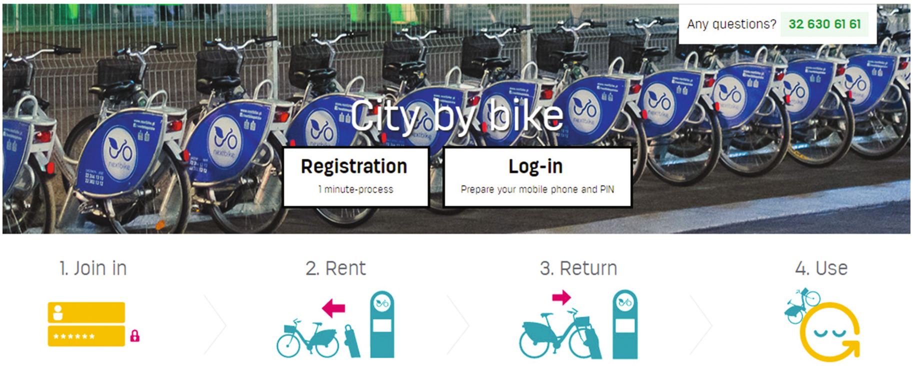

Fig. 5. Operating principle of City by Bike Katowice (Source: [16])

The City by Bike system is available for users from 2015. The popularity of the system provides the amount of:

- loans,
- new registrations in the system,
- available bikes,
- available dock-stations,
- loans by the most active system user,
- daily maximum loans,
- monthly maximum loans.

These data from the beginning of the system implementation in May 2015 to October 2016 are presented in Table 1.

Table 1. Development of the popularity City by Bike Katowice system in 2015 and 2016 (Source: [16])

Season	2015	2016
Amount of loans	7571	38217
Amount of new registered users	2632	6549
Amount of bikes	40	88
Amount of dock-stations	3	11
Amount of loans by the most active system user	51	170
Daily loan record	139	524
Monthly loan record	1787	8490

The operator of the bikes provides 15-minute free of charge ride. However, it should be noted that the one-off initial fee will be charged. It is also worth remembering that in case of exceeding the 12-hour time of the use of the bike, a 200zł fee will be counted, and in case of a theft, losing or destroying the bike, the user will be charged a 2000zł fee [16].

5 Summary

In summary, according to research the idea of cycling is among Poles increasingly popular. The article, and especially the example of system operating in Katowice, shown the development of bike-sharing system in Poland over the years. The City by Bike case study presented an increase of amount of bike loans to 30 646 during one year of functioning. It could be stated that the bike-sharing is a possibility of a better dissemination of traveling with the use of bicycles as a primary mode of transport in urban logistics. The examples of the functioning of the bike sharing, show that the principle of the system is simple and intuitive for users. Moreover, the system has many additional functionalities like: GPS tracking, real time availability, Locked bikes or distinct bicycles. All these features, along with the financial benefits such as a free 15-minute bike ride are likely to increase public interest in cycling, and ultimately contribute to increase the attractiveness of traveling by bike in city traffic.

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Interchanges as a Key Element of Competitive Sustainable Public Transport in Urban Areas

Zofia Bryniarska(✉)

Cracow University of Technology, Kraków, Poland
z_bryn@pk.edu.pl

Abstract. Transportation needs of city residents in urban areas are met more and more increasingly by walking, cycling and using public transport. One of the essential elements of the urban transport system are interchanges providing passengers with the places where they can change the means of transport in an efficient and convenient way and continue moving in a way which is more effective for them, for the city and for the surroundings. Moreover, interchanges may also become centers of social life and business activities.

The general characteristics and role of interchanges in public transport systems, results of multi-criteria assessment of the largest interchange in Krakow and analysis of satisfaction and preferences of passengers using this interchange have been presented in the article.

Keywords: Interchange · Urban public transport · Competition · Urban area

1 Introduction

In recent decades, more and more people have lived in cities or urban areas around these cities year to year. It is estimated that by 2050 their share will have amounted to up to 75% [1]. Cities and urban areas get extended, but people have to travel in order to fulfill their various needs (household, business, educational, cultural, health, recreation and others). They have to move inside the city, but also between cities and villages in the immediate area, in the country and in the world. On the one hand, transportation needs are on the increase, but on the other hand, travelers and other transport stakeholders are becoming more demanding. Passengers value their time highly and expect that travel duration will be as short as possible, or that when traveling they will be able to spend their time working or enjoying any pleasures. Moreover, they have growing environmental awareness. Stakeholders appreciate the importance of transport, but they are also aware of the external costs generated by transport. Problems of threats to transport development and transportation needs of urban residents have been identified in the documents of the EU [2–4]. Recommendations for the development of sustainable transport, which will provide efficient, safe, effective transportation options and, at the same time, ensure economic development of urban areas and access to them, improvement of life quality and environmental protection, are formulated in these documents. The solutions have been seen in a more accessible, intelligent, safe and reliable urban transport, where the share of walking, cycling and urban public transport will increase. The vision of a competitive and sustainable transport system and the need

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_9

to support integrated mobility while achieving the target of reducing emissions by 60% has been highlighted in the next White Paper 2011 [5].

This complex system of transport stakeholders and passengers contributes to the search for solutions aimed at creating an efficient passenger transport system, but it requires consistent participation of various modes of transport and the preparation, planning and development of this system. The idea of integrated development of passenger transport is reflected in the documents formulated at different levels of transportation management: by international, national, regional and local authorities in the form of Integrated Transportation Strategies [6] and the research undertaken within the framework of European projects [7, 8]. The idea of integration is about the pursuit of synergy and removal of barriers [9], creation of tools for assuring continuity of journey from door to door [10]. Integration is a process carried out within a local (urban) transport system in conjunction with the systems of extended range, including combination of movements by various modes of transport [11] and combined impact on different levels: spatial, constructional, organizational, economic, financial as well as informational. Interchanges belong to the places where the signs of public transport integration can be observed in the most apparent and the most significant way.

The ways of shaping interchanges that connect various modes of public transport in cities and urban areas have been presented in the article. The conditions that are to be met by interchanges, the ways of quantitative assessment of interchanges and creation of interchange space according to the passengers' preferences are demonstrated. It is worth emphasizing that interchanges fulfill an important role in the efficient movement of passengers and their proper formation may contribute to increasing the share of public transport, the development of land adjacent to the interchange and the gaining of business advantage and economic benefits from this neighborhood.

2 Literature Review

The problem of the growing transportation needs of urban area residents and ineffectiveness of measures involving only transport infrastructure size and capacity increase has been known for years [12]. Additionally, the growing external costs of transport [13] and threats to the environment caused by transport [14] are disquieting.

"Transportation is often referred to as the "lifeblood of cities", because it provides the essential link among activities and, in the long run, it helps shape the city" to a large extent [15, 16]. In order to promote sustainable and livable urban environments, private, public and non-motorized transport must functionally complement each other by forming balanced intermodal systems [17, 18]. However, it is mobility that is important for sustainable urban development and for improved quality of life of its inhabitants. That mobility should not be guided by the paradigm of speed and capacity but equal access to mobility options. Such objectives have been defined as possible to be reached by the establishment of an effective multi-modal travel network between the cities, the development of ecological urban transport and commuting, the promotion of transportation behaviors that are compatible with sustainable development, the implementation of technical and technological innovations, the construction of modern infrastructure and the creation of a single European transport area [5, 19].

It was emphasized that the main features of high-quality services are attractive timetables, comfort, easy access, reliability and integration with other means of transport. This problem has been developed in the Communication of the EU [20], where an additional mechanism - Sustainable Urban Mobility Plan (SUMP) - has been created to encourage local authorities to more complex activities for urban mobility [21]. The concept of sustainable mobility encompasses four basic thematic areas, which are the starting point for activities related to urban mobility. It is worth pointing at the postulate to optimize the use of existing, available and proven technologies. Thanks to process innovations such as implementation and facilitation of inter-modality in urban public transport, or product innovations such as integrated tariff-ticket systems, new conditions/opportunities for the development of a sustainable modal split in urban areas are created [22]. To sum up, the promotion of environmentally friendly and human-oriented transportation seems to be the main objective of transit integration allowing cities to develop, to provide efficient collective public transport and to decrease the role of private cars.

Interchanges are important elements of an integrated transport system, especially in urban areas. The problem has been elaborated on in many projects funded by the EU (e.g. MIMIC, PIRATE, GUIDE, LINK, NICHES+, CITY-HUB, Sintropher projects).

3 Description of Research Object

3.1 Interchange Definition, Role and Classification

Interchanges are usually defined as places where passengers can change their mode of transport during their journey easily and conveniently [23]. This way, the crucial role of interchanges can be stressed. Interchanges consist of public transport stops and possibly also railway and/or bus stations as well other facilities (e.g. Park & Ride car park, bicycle stands, kiosks, toilets, etc.). Interchanges help passengers to transfer between, for example, train, metro, buses, trams and non-collective means of transport such as cars and bicycles [24].

It should be noted that interchanges fulfill their roles on three planes: as a node in a public transport network, as a point servicing users/passengers and as a place where public transport vehicles stop. The retail/commercial advantage for the environment the interchange is located within is emphasized more and more frequently.

Each of these functions provides specific requirements for proper design [25]. Interchanges are situated at transport networks nodes, where transport connections of one mode of transport intersect with connections of other modes of transport. They enable and facilitate the change between means of urban transport (trams, buses, metro, light trains), but also between public transport and regional transport (rail, buses), national and international transport (heavy rail trains, planes).

The basic principle in the designing of interchanges should be its accessibility for everyone by means of integrating mobility and enhancing collective transport modes. Its consequence is the elimination of technical barriers hindering the use of the platforms that are typical of different modes of transport within the interchange, the creation of comfortable and functional passageways between these platforms, and pleasant and effective connections from means of transport to passengers' destinations (shops, services, homes, work places). These places serve to link local, regional, national and international passenger services and act as a junction between the transport system and society.

Interchange is also a place where public transport vehicles stop. It has to provide a platform of suitable length, sufficient space to perform the necessary maneuvers, visibility and secure driveways leading to bays.

Commercial and residential development around interchanges (serving stations on the high-speed and other rail network, bus terminals, airports and urban transport nodes) is common throughout Europe and has attracted interest from academics and policy makers [26].

To sum up, interchanges should be designed and built purposely [27]. The planning process has to foresee the future development in relation to the transport infrastructure and the surrounding area.

The specificity of interchange operation depends on many factors. Qualitative survey undertaken in the CITY-HUB project gave classification in two "dimensions" and groups of factors that affect the determination of the needs which the node should meet, and continue on its size and characteristics [28]. The first dimension relates to their functions and logistics aspects in terms of demand, modes of transport, services and facilities, and determines the need for interchange space. The size (demand) of the interchange is defined as the number of passengers per day (less than 30,000, between 30,000 and 120,000, and over 120,000). In the field of transport modes, three types of interchanges are distinguished: interchanges with buses or interchanges with rail as a predominant means of transport, and interchanges with two or more means of public transport of different lines of the same mode jointly. The services and facilities are defined at three different levels as follows: offering a few kiosks and vending machines, or a few retail shops, cafes or food facilities or a location of a shopping mall integrated with the interchange.

The second "dimension" encompassing local constrains defines the strength of interactions with the surrounding area. Location in the city is classified as: suburban area, at the entrance to the city and in the city. The features of the surrounding area have an impact on the use of the interchange in the sense to foster the use (commercial center, sport fields) or limit the use (green areas, heavy industry). The interchange position and its chances for redevelopment and modernization are deeply connected with the local development plan. The results of considerations as regards the second dimension allow the author to specify the strength of interchange integration (cold/hot, partially or fully integrated).

3.2 Characteristics of Interchanges Area

Three basic zones can be defined within an interchange: access/egress zone, facilities and retail zone, and transport/transfer zone. Every zone requires the consideration of different characteristics and amenities for passengers. Characteristics of interchange users depend on their personal features (age, professional activities, travel behaviors, physical constrains), sort of travel (motives, mode, peak-time or not), travel frequency (every day, occasional) and the use of the service facilities at the interchange.

The access/egress zone should allow different groups of passengers (pedestrians, cyclists, car users) to access and depart from every stop within the interchange. To allow efficient and convenient movement in and out as well as inside and outside of the interchange for passengers, short, convenient, clear routes should be marked and no points of congestion, proper signposting and way-finding should be provided outside and inside interchanges. Particular attention should be paid to ensure safe roadway crossing (pedestrian crossing with/without signaling), passageways between public transport stops, information about the local area including taxi and dial and ride information. Facilities for cyclists and drivers (park & ride, bike & ride, city bike rentals) and sheltered waiting areas for passengers waiting for public transport should also be in the access/egress zone.

A facilities and retail zone is a part of the interchange where facilities such as ticket machines or desks, shops, food outlets, newspaper kiosks, information desks are available. They are important for passengers waiting longer for their next means of transport. But they also give opportunities for business (shops, cafés) in the surrounding area to gain more customers and to earn money.

The transport and transfer zone is a place where passengers will be waiting for transport within the interchange. It is usually situated at the platform for passengers boarding on and alighting from modes of transport but it is sometimes arranged as a waiting room equipped with CCTV, seats, help points for users but with easy access to platforms.

3.3 Quantitative Assessment of Public Transport Interchanges

Public transport interchanges in the urbanized area operate under specific conditions. They are mostly used by city dwellers for everyday commuting. The primary need of transport users is to minimize travel time and effort associated with the changing of transport means. Proper and attractive interchanges should meet the basic criteria of functionality [28] such as compactness, safety, availability, reliability, clarity, information and convenience.

A comprehensive method for quantitative evaluation of the interchange was proposed in the NICHES+ project [29]. It includes eight indicators (W1–W8). W1 indicator concerns the spatial compactness of the interchange evaluated on the basis of the weighted average distance to walk between public transport stops located within the interchange or arithmetic average distance to walk. W2 indicator refers to the legibility of the interchange and relies on determining the average number of visible public transport stops. W3 indicator determines the quality of basic infrastructure, and expresses the ratio of stops that comply with guidelines for the design of public transport (width and length of the platform and the pavement, the length of tram and bus stops, the quality of the surface, no evidence of obstacles within the stop). The value of W4 indicator depends on the assessment of how the bus/tram stop platform and walk links are accessible for the disabled, the elderly, the visually impaired and hard hearing people (warning tiles with insets in a contrasting color (yellow) along the edge of platforms, in front of stairs and roadways crossing, lowered curbs, audible signals at crossings with traffic lights, ramps or elevators in places with difference in level). W5 indicator includes an assessment of passenger information (timetables, tariff information, network diagrams, maps of the node and its surroundings, dynamic passenger information with buttons for the visually impaired and directional marking on crossings between stops and branches, stairs). W6 indicator is used to assess the level of personal security in accordance with the level of relevant stop lighting and monitoring at each interchange element (at tram/bus stop platforms, roadway crossings and stairs). W7 indicator provides an assessment of the conventional level of security at a roadway crossing (isolated from traffic, zebra crossing with or without traffic lights, no markings). W8 indicator includes an assessment of the additional equipment and facilities (sheltered platforms and pedestrian passages between platforms, waste bins and additional benches, ticket machines, shops, toilets, bicycle racks, city bike rentals). In the case of W3–W6 and W8 indicators, for individual public transport stops it is checked if all of the accepted criteria for this index (score 0 - fails to meet even one criterion, score 1 - meets all criteria) are fulfilled. For the interchange, its evaluation is determined as a percentage of the platforms and passages that meet the criteria within the interchange.

3.4 Integration of Public Transport Modes Within Interchanges

Integration should be realized on different planes: spatial (location of public transport stops towards one another within the interchange and transport junction), building (passageways connecting public transport stops, overpasses, under-passes, shared stops for public transport modes), organizational (coordination of timetables), economic-financial (integrated tariffs and tickets), informational (overall/complex information about public transport operators, lines, bus/tram stops, timetable, possibility of changes, actual departures of public transport vehicles, substitute transport, travel planes, interchange layout). The benefits of integration do not only apply to public transport as a whole, but they are clearly visible within the interchange. They allow for boosting the competitiveness of public transport in relation to private transport [30], the better use of different modes of transport, the decrease in traffic congestion in city streets, cost of transport, and environmental pollution, reduced travel duration, improvement in the influence of spatial accessibility on society and the surrounding area.

3.5 Passengers' Preferences and Requirements

Currently, each organization should be customer-oriented [31]. It is a customer (passenger) who knows best what he needs or what is missing for him from the offer. Passengers should have a decisive voice also with regard to public transport services and interchanges (despite their diverse characteristics). Marketing surveys show that passengers prefer to wait longer for direct connections than to change means of public transport [32]. They also evaluate negatively the access time to public transport stops and the waiting time. The tiresomeness of waiting time for the arrival of public transport is taken with a weight of 1.5 in relation to its duration, as well as the perception of access time [33]. In summary, the travel time (from the start of the trip at the beginning point, through travel time by public transport to the final time at the destination) is the time passengers are very sensitive to. In addition, it is worth recalling that the changing of means of transport involves also physical burdensomeness resulting from boarding and alighting activities on/from the next vehicle and walking between public transport stops as well as a sense of uncertainty concerning whether the process of changing vehicles will take place without interruption and mistakes, and often the necessity to purchase another ticket for the rest of the journey.

Hence, it is really important to learn about the needs of passengers, their preferences and satisfaction with proposed solutions and to eliminate the identified quality gap.

4 Case of Interchange in Krakow

4.1 Interchange Characteristics

The Rondo Mogilskie public transport stop is the largest interchange in the public transport network in Krakow [34], located in the city center area. Numerous facilities of universities, business centers, university hospital clinical, residential estates and communication hub (national rail and bus connections) are located round the interchange. The interchange infrastructure is a part of the local development plan. Over 31,000 passengers get on and off public transport vehicles every working day at the interchange, and because of that the Rondo Mogilskie interchange can be classified as a medium interchange according to the demand value.

The interchange was rebuilt and modernized in 2006. It is now a two-level intersection. Tram stops, night bus stops, bike and pedestrian paths are located on the lower level of the roundabout. Road traffic takes place on the upper level and all bus stops are also situated on this level. The reconstruction of the intersection contributed to the improvement of traffic organization, increased safety of vehicles, bicycles and pedestrians, and nicer appearance of the place (refreshed greenery and uncovered historic ruins of the Lubicz stronghold). But the solutions related to the organization of public transport stops are not positively evaluated by all passengers and experts.

There are five tram stops and four bus stops within this interchange. Trains of 3–4 tram lines stop at each tram stop and buses of 2–9 lines stop at each bus stop within the interchange. All bus stops are located at exits from the intersection. Such a solution definitely helps passengers find orientation about a direction the bus is moving in. Tram stops are situated on four sections of tracks within the intersection. Thus, three stops are located at the exits of three different directions, and the trams going in the same “fourth” direction stop at two tram stops “at the entries.” However, a huge and undeniable advantage is the location of all tram stops away from road traffic, which minimizes the distance to walk between tram stops and creates a friendly atmosphere in the public space with neatly finished retaining walls with mosaics and carefully designed green areas. Yet all bus stops are located at a considerable distance from tram stops, but there are footpaths, ramps, escalators and lifts with which the stops can be accessed in a comfortable way, even by people in wheelchairs. Walk links to each public transport stop within the interchange do not require the crossing of the street [34].

4.2 Quantitative Assessment of the Interchange

The share of changes of transportation means within the Rondo Mogilskie interchange both in the morning and afternoon traffic peak hours exceeds 63% and 62%. The majority of transfers take place at tram stops. In the morning peak hours, they represent about 80% of transfers, and in the afternoon rush hour even 92.5% of transfers. Transfers between different tram lines stopping at the same tram stop constitute 22.2% in the morning hours and in afternoon hours about 32.0% of transfers within the interchange. As the arithmetic average distance between stops, the indicator of compactness W1 amounts to 312 m, but as the average distance weighted by the number of passengers using the various transfers amounts to 78 m only, as the majority of transfers take place between trams. W2 legibility indicator equals 31% as not all bus stops are visible. Basic infrastructure (W3 indicator) at all bus/tram stops, passageways and stairs meets the criteria of quality and provides the convenience for passengers arriving and waiting for the public transport vehicles. The assessment of tram/bus stops and passages from the point of view of people with disabilities (W4 indicator) is negative. All the stairs from the lower to the upper level have ramps, escalators or elevators, but along the tram/bus stop platforms, there are no tactile markings, warning tiles with insets in a contrasting color. Information for travelers (W5 indicator) is limited at bus/tram stops to timetables and tariff information (also in English) as well as public transport network maps. There is dynamic passenger information with buttons that allow people with low vision to launch a voice announcement at all tram stops. However, the diagrams with tram/bus stops location within the interchange are placed only at some of tram/bus stops. Moreover, there is no directional information (signs) or stair signs in points where pavements fork. Also, elevators are unmarked. A good solution is to place a large LCD display showing the actual departure times of trams, signs of tram stops and a map of tram stop location in the center of the bottom level of the interchange. The tram stops on the map are labelled with letters (A–E), but tram shelters are not marked in the same way.

Personal security (W6 indicator) at stops is ensured by adequate lighting and information on video surveillance. However, crossings and stairs within the Rondo Mogilskie interchange are not monitored. Traffic safety (W7 indicator) is 100% guaranteed at roadway crossings within the Rondo Mogilskie interchange. All walk links are isolated from road traffic. It is worth stressing the arrangement of bike paths and their constant interweaving with pedestrian passages. Cycling is very quiet and fast from the point of view of pedestrians. The collision of pedestrian and cycling paths is not included in traffic safety indicators within the interchange.

Additional facilities (W8 indicator) include extra benches and waste bins in all stops, city bike rental stations and bike racks, ticket machines but even though there is a lot of space, there are no retail outlets or food points on the bottom level, or any other ways to create a small local center of public life there. Platforms and passages within these two interchanges are not sheltered.

4.3 Assessment of Passengers' Satisfaction and Preferences

Marketing survey was conducted among 875 passengers at tram/bus stops within the Rondo Mogilskie interchange. People changing means of transport were asked with which line they came and which line they were waiting for at the bus/tram stop and how they evaluated the transition convenience between tram/bus stops. There were also questions about the quality of passenger information and, a kind of troubles while transferring. Passengers starting their journey were asked about problems encountered when reaching the stop. The overall assessment of the quality of transfers within the interchange and the quality of passenger information were recorded on a scale from 1 to 6 (where 6 means ideal conditions, 5-very comfortable, 4-comfortable, 3-acceptable, 2-uncomfortable, 1-very uncomfortable conditions of transferring). Surveys have identified the number of transferring passengers between every stop within the interchange.

Average assessment of the convenience of transfers in the survey shows that passengers appreciate the convenience of transfers within the Rondo Mogilskie interchange in a scale of 1–5 at the level of 3.8. Noteworthy is the fact that the negative grade was chosen only by 1.3% of respondents, and 3.7% rated transfer conditions to be perfect. About 71% of respondents rated the quality of information for passengers as good and very good. The length of walking distance (time to reach) to the stop from the starting point of travel, too long time of waiting for the green signal on the crosswalk, the need to overcome the wide thoroughfare were mentioned among the troubles with accessing bus/tram stops. The lack of synchronization of schedules, the illegibility of the node, the crossing of the pedestrian walkway by the cycling paths were pointed as troubles encountered when transferring at tram/bus stops within the interchange.

5 Presentation of Analysis and Discussion

Solutions proposed within interchanges depend on many factors: the means of transport, the size of the demand, their functions, location in urban areas, equipment, and economic and social links to the surrounding area. The specificity of an interchange has a significant impact on the solutions adopted during the planning, but also the management, operation and monitoring processes. The type of proposed technical and technological solutions should depend on a number of stakeholders: those who have the power and experience, who are positively or negatively affected, who have an influence on the implementation of decisions, or who have their stake in the issue [35]. But in the end, it is the passenger who knows what is best for him, what he misses and he takes a decision whether to use public transport or not.

An extensive set of different competition tools is also available in case of interchanges [30]. It is constantly evolving with the arrival of new innovative technical and technological infrastructure and vehicles, new ways of communicating and sharing information and it provides many opportunities to facilitate the planning of journeys and travelling, reducing the uncertainty associated with the journey, shortening the travel duration, providing a convenient and comfortable environment also for passengers at an older age, with movement dysfunctions and visually impaired.

Interchanges are, on the one hand, a places negatively perceived by passengers due to interruptions in their journey, physical effort, uncertainty related to the change of means of transport, but on the other hand there are many advantages for passengers and the surroundings of the interchange. It gives passengers the opportunity to reach new destinations, not available for direct journeys, to take advantage of the cultural, commercial and economic offer at the place where they interchange. For interchange-related stakeholders the interchange gives a chance for additional development. Hence the postulate of treating interchanges in a broad sense as economic and transport mini-centers [24].

A stage associated with the access and egress to and from public transport stop is also essential for passengers. Access pathways are often excessively long, and if not, the quality of these roads, aesthetics and safety do not encourage passengers to use public transport. "P & R" car parks have to be linked with systems of fast and high frequency modes of public transport. Great importance should be paid to the development of integrated tariff schemes. Facilities and competitive tools on price, quality, communication and information should be used together on many different levels of passenger service and many stages of the journey in order to strengthen the impact and achieve the synergy of action.

6 Conclusions

There are different types of mobility available in the urban area, from walking and cycling, to travelling by motorized transport (modes of public transport and private cars). Some of them are recommended in cities as they offer, on the one hand, massive transport service and, on the another hand, reduction of energy resources and transport cost as well as transport externalities (pollution, noise) and additionally well-being and good physical conditions for pedestrians and cyclists.

Interchanges are not only the nodes at the transportation network, but they give travelers the possibility to transfer between modes of mobility and this way to make the sustainable system effective. Interchanges are much more complex than tram/bus stops or stations. Properly designed and operated interchanges can increase added value for passengers, support the goal of transport sustainability and play an economic role for the surrounding area and a social role for city mobility needs. They can make public transport more competitive and attractive. The easier the transference from one mode to another, the more effective the overall system is.

The functionalities of the interchanges expected by passengers and operators should be learnt and addressed to transport organizers as a list of recommendations and requirements.

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Charging Electrically Driven Buses Considering Load Balancing in the Power Grid

Hubert Büchter[1(✉)] and Sebastian Naumann[2]

[1] Fraunhofer Institute for Material Flow und Logistics - IML, Dortmund, Germany
hubert.buechter@iml.fraunhofer.de
[2] IFAK - Institut für Automation und Kommunikation e.V. Magdeburg, Magdeburg, Germany
sebastian.naumann@ifak.eu

Abstract. Electrically powered buses in public transportation are increasingly being put into operation. The energy supply needs a careful planning just to keep all busses continuously in operation and to avoid power peaks in the grid. This problem is solved by a two-step planning procedure which is based on a linear model. The first step is an analytical optimization under simplified constraints. In a second step a simulator works on an extended model. The planning objectives are to minimize the investment and to minimize the power peaks. Additionally a simple decision algorithm computes the charging power at run time. The models are developed in detail and a small numerical example illustrates the work.

Keywords: Optimizing · Electromobility · Charging infrastructure · Smart grid · Public transportation

1 Introduction

Introducing electrically driven buses in a large scale needs a lot of planning afford. At least the following questions must be answered: How big must the batteries be? Where should be charged? What is the best time to charge? What is the optimal charging power? Which transformer station should supply the power?

The charging problem of electrically driven buses has two aspects, a static and a dynamic aspect. The first one is the planning process which assigns charging devices to selected bus stops. This is a static problem which is to solve *offline*. The aim is to minimize the total cost of invest.

The second aspect is an *online* algorithm for the charging controller. Whenever a bus arrives at a charging station, the optimal charging power must be computed. This depends on the current state of charge (SOC) and of the load within the grid. The goal is to minimize the investments and the peaks in the grid. These power peaks make it difficult for the supplier of the energy to keep the grid in balance and finally the customer has to pay penalty for overdrawing the assured amount of energy.

The idea for the planning algorithm is based on a simplified linear model which is improved from step to step by addition of more restrictions. All these models work on

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_10

accumulated power consumption over time. The result is a condensed view without any details about sequences of ways. With this assumption we get only necessary conditions which are not always sufficient. A second planning step keeps track of the dynamic aspects during the planning process. This step is based on best case conditions where all buses arrive at their stops in time. All other dynamic influences including delays are left to be evaluated at run time.

Figure 1 shows the integration of the infrastructure planning in a complete planning for a bus system.

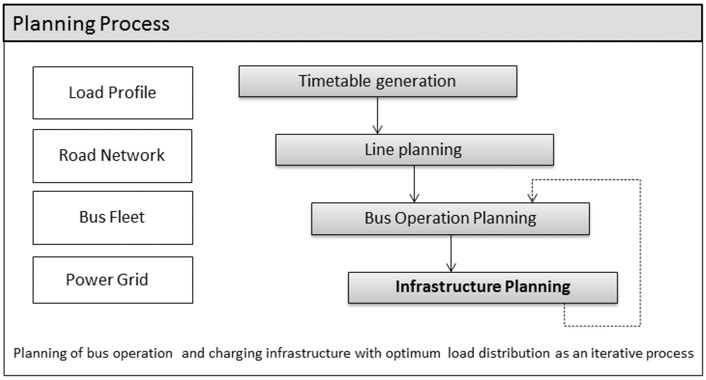

Fig. 1. Planning of bus operation and charging infrastructure with optimal load distribution as an iterative process

A Motivation for introducing electrically driven buses with respect to renewable energy is given in [8]. Most of the publications about the charging problem deal with individual traffic and not with public transportation (see [3–5, 7]). Albert et al. [6] analyzed the complexity of the planning problem. Büchter and Naumann ([1, 2]) described a planning algorithm for different charging methods but the power grid is out of scope. A theoretical background for the applied linear models is given in [9].

This paper starts with an introduction of the charging problem from the sight of the buses and from the power grid. A static and a dynamic solution are developed in the following sections. Finally the complexity of the algorithm is discussed and results for memory consumption and CPU time are presented.

2 The Charging Problem for Scheduled Traffic Systems

All public transportation systems work more or less cyclic with a specific cycle time.

This cycle time T_{cycle} is typically in a range from some hours up to a whole day. Within a cycle a bus runs several times over different ways. Each way requires a specific amount of energy for different types of buses. For the following equations we define the sets for buses, ways, bus stops and transformer stations:

$$\begin{array}{lll} \text{Buses} & \mathrm{i} \in \boldsymbol{B}, & \boldsymbol{B} = \{1, \ldots, t\} \\ \text{Ways} & j \in \boldsymbol{W}, & \boldsymbol{W} = \{1, \ldots, m\} \\ \text{Bus Stops} & k \in \boldsymbol{S}, & \boldsymbol{S} = \{1, \ldots, n\} \\ \text{Transformer Stations} & p \in \boldsymbol{T}, & \boldsymbol{T} = \{1, \ldots, w\} \end{array} \tag{1}$$

The *frequency* of bus drives over ways is expressed by a schedule matrix $\boldsymbol{SW} \in \mathrm{N}_0^{|\mathrm{B}| \times |\mathrm{W}|}$

$$\boldsymbol{SW} = \begin{pmatrix} sw_{11} & \cdots & sw_{1m} \\ \vdots & \ddots & \vdots \\ sw_{l1} & \cdots & sw_{lm} \end{pmatrix} \quad sw_{ij} : \begin{cases} \text{Frequency of driving} \\ \text{bus i over way j} \end{cases} \tag{2}$$

The *energy demand* of bus drives over ways is expressed by the matrix $\boldsymbol{Q} \in R^{+|\mathrm{B}| \times |\mathrm{W}|}$

$$\boldsymbol{Q} = \begin{pmatrix} q_{11} & \cdots & q_{1m} \\ \vdots & \ddots & \vdots \\ q_{l1} & \cdots & q_{lm} \end{pmatrix} \quad q_{ij} : \begin{cases} \text{Energy demand for driving} \\ \text{bus i over way j} \end{cases} \tag{3}$$

Additional a base load $\boldsymbol{p_{base}}$ for lighting, air condition and other on board devices is required. Finally the energy consumption $\boldsymbol{e}^-$ for the buses can be calculated by multiplying $\boldsymbol{SW}$ by $\boldsymbol{Q}$, selecting the diagonal elements and adding the base load.

$$\boldsymbol{e}^- = diag(\boldsymbol{SW} \cdot \boldsymbol{Q}) + \boldsymbol{p_{base}} \tag{4}$$

The battery energy varies in a range $[\boldsymbol{e_{min}}, \boldsymbol{e_{max}}]$. At begin of the operation the batteries are full of charge $\boldsymbol{e_{max}}$ and they can be ran down to $\boldsymbol{e_{min}}$ during the operation cycle. The charging problem is to offer an amount of energy $\boldsymbol{e}^+$ that at least meets the energy demand.

$$\boldsymbol{e}^+ + \boldsymbol{e_{max}} - \boldsymbol{e_{min}} \geq \boldsymbol{e}^- \tag{5}$$

It is up to charging controller to charge the batteries with an appropriate value of power.

Batteries can be charged at special equipped bus stops, or the buses can take their energy during the drive by a kind of pantograph and charge the batteries simultaneously, or the batteries can be swapped. We choose the first method and call it point charging. The other methods a similar to model and are out of the scope of this paper.

3 Avoiding Power Peaks in the Grid

A power grid must always be driven in balanced state. The sum of all amounts of consumed power should be equal to the produced power which is fed into the grid. For this reason we take the power grid into the planning process to make sure that the power supply is distributed over several transformer stations. Typical peaks arise, when several buses charge with high power in short interval of time. A typical power flow is shown in Fig. 5 with a power peak over approximately 60s at about 1200s.

Each transformer station is limited in power $\boldsymbol{pt_{max}}$ which can be delivered to several charging points. Each connection needs specific investment for building a line from transformer t to a charging point s. The static optimization goal is to minimize the overall costs for all connections and to do not overload the transformer stations while satisfying all energy demands. This is the static view which must be fulfilled by the optimization and a succeeding simulation. Figure 2 shows the basic structure of collaboration between the optimizer and the simulator for a static planning process.

The dynamic algorithm at runtime keeps the overall power consumption over the whole system below a certain level p_{limit}.

$$\forall t \leq t_{cycle} : \sum_{i \in B} pcb_i \leq p_{limit} \quad \text{where} \quad pcb_i \text{ is the power consumption of bus } i \tag{6}$$

The energy consumption of bus i is the integral over the power consumption for the cycle time:

$$e_i^- = \int_{t_{cycle}} pcb_i \cdot dt \tag{7}$$

The restriction (6) must be fulfilled during the planning and it is a static condition. At run time it is possible, that more than the secured amount of power is requested. These peaks should be kept away from the grid. The simulator can check the system for such peaks. In practical operation an algorithm decides which bus should charge and how much charging power is allowed to avoid peaks. This needs real time communication between all charging controllers and an adjustment between the SOC values of all buses. A more sophisticated solution works with traffic forecasts to estimate the travel times to the next charging stations.

4 Static View

The first step is an offline planning of the charging infrastructure. Input data are the bus operation plan and the localization of the transformer stations. There is a mutual influence between the bus stops selected to become charging stations and the bus operation plan. This is solved by looping over these planning steps (see Fig. 1).

We assume a cyclic operation where all buses after the end of their trips start the next cycle at the same start point as in the cycle before. On each cycle there is a consumption of energy which must be recharged by an offer of energy. The planning algorithm minimizes the total invest for all charging devices and for all power lines between the transformer stations and the charging stations. In conclusion it is an optimizing problem.

Planning point charging needs to know the minimal time, which is usable for charging. This time must be available at any cycle. From the timetable the frequency of stopping a bus at a specific bus stop can be read from the timetable as well. These values are stored in the matrices $\boldsymbol{TS}$ and $\boldsymbol{SS}$:

$$\boldsymbol{TS} = \begin{pmatrix} ts_{11} & \cdots & ts_{1\mathrm{n}} \\ \vdots & \ddots & \vdots \\ ts_{\mathrm{l}1} & \cdots & ts_{\mathrm{ln}} \end{pmatrix} \; ts_{ik} : \begin{cases} \text{Stop time for bus i} \\ \text{at bus stop k} \end{cases} \tag{8}$$

$$\boldsymbol{SS} = \begin{pmatrix} ss_{11} & \cdots & ss_{1\mathrm{n}} \\ \vdots & \ddots & \vdots \\ ss_{\mathrm{l}1} & \cdots & ss_{\mathrm{ln}} \end{pmatrix} \; ss_{ik} : \begin{cases} \text{Frequency of stopping} \\ \text{bus i at bus stop k} \end{cases} \tag{9}$$

Let $\boldsymbol{pb_{max}}$ be the maximal allowed charging power for the buses and $\boldsymbol{x} \in [0,1]^{|\mathrm{S}|}$ a decision vector then the energy $\boldsymbol{e}^{+} \in \mathrm{R}^{+|B|}$ which can be taken in each cycle is

$$\boldsymbol{e}^{+} = diag(\boldsymbol{p_{max}}) \cdot (\boldsymbol{SS} \circ \boldsymbol{TS}) \cdot \boldsymbol{x} \quad e_{ik}^{+} = p_{\max_i} \cdot ts_{ik} \cdot sw_{ik} \cdot x_k \tag{10}$$

The multiplication element wise is expressed by the Hadamard operator $\circ$

$$x_k = \begin{cases} 1 & \text{if a bus stop k becomes a charging station} \\ 0 & \text{otherwise} \end{cases}$$

From these equations we derive a linear optimization model:

$$\boldsymbol{A} \cdot \boldsymbol{x} \geq \boldsymbol{b} \quad \boldsymbol{c^T} \cdot \boldsymbol{x} \rightarrow \min \tag{11}$$

In a first step we only consider the charging stations and the objective vector $\boldsymbol{c_1}$ consists only of the cost for purchase and installation of the charging devices.

$$\boldsymbol{A_1} \cdot \boldsymbol{x_{ds}} \geq \boldsymbol{b_1} \quad \boldsymbol{c_1^T} \cdot \boldsymbol{x_{ds}} \rightarrow \min \tag{12}$$

$$\boldsymbol{A_1} = diag(\boldsymbol{pb}_{\max}) \cdot (\boldsymbol{SS} \circ \boldsymbol{TS}) \quad \boldsymbol{b_1} = \boldsymbol{e}^{-} \quad c_1 = \boldsymbol{c_{charge}} \tag{13}$$

$\boldsymbol{c_{charge}}$ is the vector for installation costs for charging devices at different bus stops.

In the second step we consider the costs for wiring the selected bus stops with existing transformer stations. Whenever a bus stop is selected as a candidate for a charging station, a power line to at least one transformer station becomes necessary. Let $\boldsymbol{CST} \in R^{+|\mathrm{S}|\times|\mathrm{T}|}$ be the matrix of wiring costs from charging point k to transformer station p and $\boldsymbol{X_{dst}} \in \{0,1\}^{|\mathrm{S}|\times|\mathrm{T}|}$ an decision matrix that indicates if a connection is required or not.

$$\boldsymbol{CST} = \begin{pmatrix} cst_{11} & \cdots & cst_{1w} \\ \vdots & \ddots & \vdots \\ cst_{n1} & \cdots & cst_{nw} \end{pmatrix} \tag{14}$$

$$\boldsymbol{X}_{dst_{k,p}} = \begin{cases} 1, & \text{if a connection between stop k and trafo station p is required} \\ 0, & \text{else} \end{cases} \tag{15}$$

For the optimization model the cost matrix $\boldsymbol{CST}$ an the decision matrix $\boldsymbol{X_{dst}}$ must be converted to a vectors $\boldsymbol{c_2}$ and $\boldsymbol{X_{dst}}$. This can be done by connecting all rows successively:

$$\boldsymbol{c}_{2_{|\mathbf{T}|\cdot(k-1)+p}} = \boldsymbol{CST}_{k.p} \quad x_{dst_{|\mathbf{T}|\cdot(k-1)+p}} = \boldsymbol{X}_{dst_{k,p}} \tag{16}$$

The optimizing model for the planning process is now complete:

$$\begin{pmatrix} \boldsymbol{A}_1 & 0 \\ \boldsymbol{A}_{21} & \boldsymbol{A}_{22} \end{pmatrix} \cdot \begin{pmatrix} \boldsymbol{x}_{ds} \\ \boldsymbol{x}_{dst} \end{pmatrix} \geq \begin{pmatrix} \boldsymbol{b}_1 \\ 0 \end{pmatrix} \quad \boldsymbol{c} = \begin{pmatrix} \boldsymbol{c}_1 \\ \boldsymbol{c}_2 \end{pmatrix} \tag{17}$$

$$\boldsymbol{A}_{21} = -\boldsymbol{I}_{|S|} \quad \boldsymbol{A}_{22} = \begin{pmatrix} a_{22_{11}} & \cdots & a_{22_{1w}} \\ \vdots & \ddots & \vdots \\ a_{22_{n1}} & \cdots & a_{22nw} \end{pmatrix}, \quad a_{22_{kp}} = \begin{cases} 1, & cst_{kp} \neq 0 \\ 0, & cst_{kp} = 0 \end{cases} \tag{18}$$

After solving the optimization problem the solution vector $\boldsymbol{x}$ must split into $\boldsymbol{x}_{ds}$ and $\boldsymbol{x}_{dst}$. Finally $\boldsymbol{x}_{dst}$ can be rearranged to the decision matrix $\boldsymbol{X_{dst}}$.

This very basic model can be extended by additional constraints e.g. for avoiding overcharging the batteries.

5 Dynamic View

A simulation shows the dynamic behavior of the system. Even if the optimizer has calculated a solution, it is possible that one or more buses ran out of energy. In this case the constraints are relaxed and a new optimizer run is started. This works in a loop, until all buses complete their runs.

The relaxing process increases the values for power consumption for all buses which ran out of energy. With these assumptions the offered power increases in every loop run. The procedure stops when all buses terminate their trips and all batteries never drop their charge below the specified minimal energy e_{min}. The results are a plan for installing charging devices, a plan for connecting charging stations to transformer stations and the sum of all invest.

At run time there is a decision procedure which estimates an amount of power that is to transfer at the current point of charge. This value depends on the currently available power and that depends on the charging requests of the other buses. This requires a communication with all other buses in the system. An adaption to a smart grid that makes an offer of energy and a price offer is possible. Additionally the current state of charge of the battery, the remaining time for charging and the assumed energy consumption until reaching the next charging station are the main input parameters. After all, it is important that no bus is left because of a lack of energy.

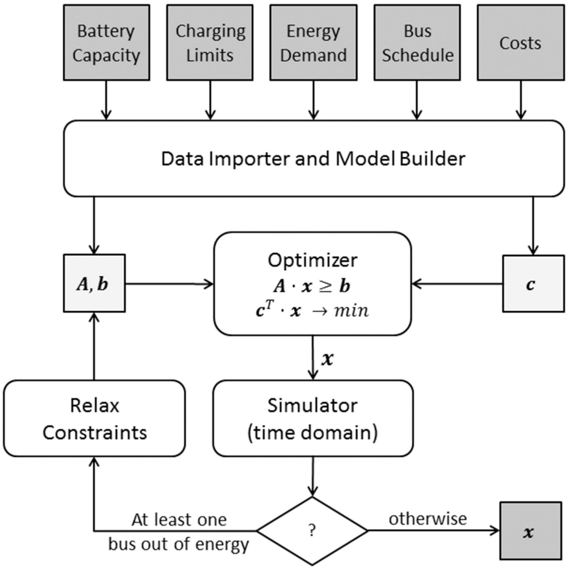

Fig. 2. Two step iterative planning procedure.

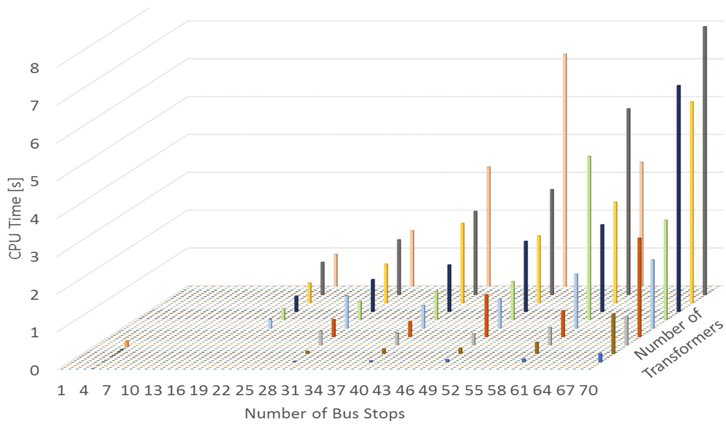

Fig. 3. CPU time for the optimizing procedure with different model sizes.

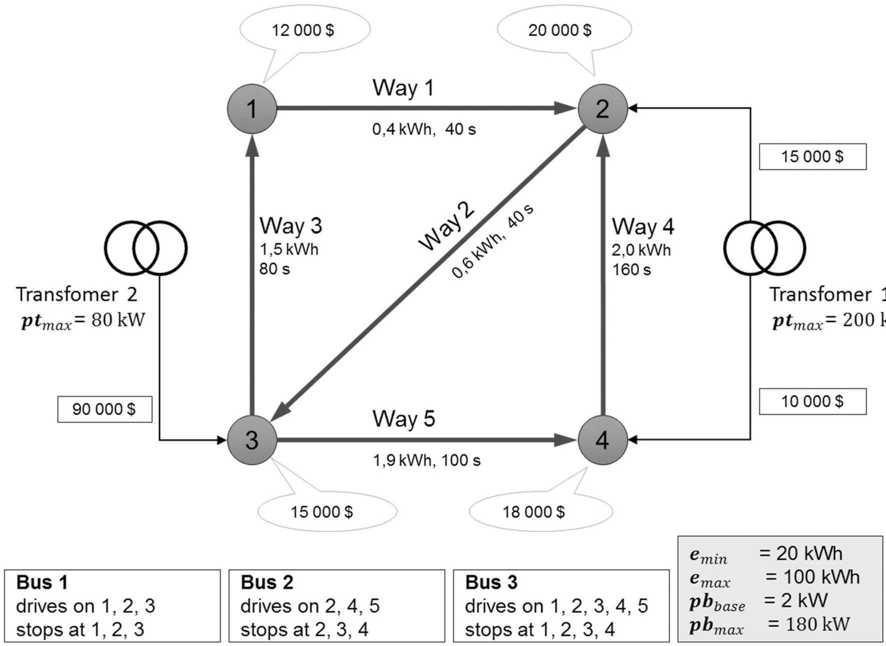

Fig. 4. A tiny example for a system with two transformer stations, three buses, four bus stops and five ways.

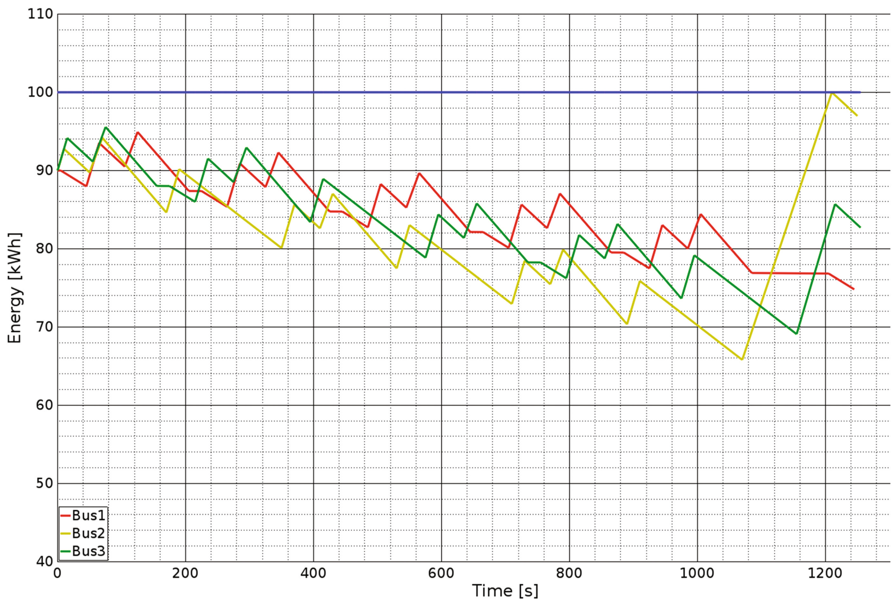

Fig. 5. Typical plot for the bus energies over the time axis for the method of point charging. The initial energy is 90 kWh and the maximum is 100 kWh.

6 Conclusion

The introduced models are implemented in GNU Octave which uses the GNU Linear Programming Kit (GLPK) for solving the optimizing problems. The simulator is implemented in C++ and integrated as a function in the Octave runtime environment.

This system was used to solve some generated models to measure the run time demand and to test the convergence behavior of the loop. Figure 3 shows the CPU time for models of different sizes. The number of transformer stations has more influence to the run time than the number of bus stops.

A very small example (see Fig. 4) is used to show all parameters and to illustrate some numerical results. Finally the transformer 1 feeds the charging stations at bus stop 2 and 4 while transformer 2 supplies power to station 3.

The next step is an evaluation of a real world system with more some thousand bus stops and more than one hundred busses. This ongoing work and this publication are funded by the German Federal Ministry for Economic Affairs and Energy (BMWi).

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A Case Analysis of Electrical Energy Recovery in Public Transport

Konrad Kawałkowski[1], Jakub Młyńczak[2], Zbigniew Olczykowski[1], and Jerzy Wojciechowski[1(✉)]

[1] Faculty of Transport and Electrical, Kazimierz Pulaski University of Technology and Humanities in Radom, Radom, Poland
{k.kawalkowski, z.olczykowski, j.wojciechowski}@uthrad.pl
[2] Faculty of Transport, Silesian University of Technology, Katowice, Poland
jakub.mlynczak@polsl.pl

Abstract. In the past few years the interest in electrical energy recovery process in the traction systems has significantly grown. At the same time, the number of devices designed for this system and a modern traction rolling stock, with the ability of regenerative braking, has gone up. Despite the huge interest in this topic, there are still problems in implementing new technologies. The cause of this lies in different exploitation conditions of each of the implemented solutions. Achieving highest electrical energy recovery indicators without the occurrence of negative side effects and with lowest financial outlays can be a problem. Because of these reasons, one should continue to analyze various cases of using the process of energy recovery and draw general conclusions. The authors of this work have presented the results of the analysis of energy consumption and recovery process in public tram traction system. Measuring data for units without and with the ability for regenerative braking has been analyzed. Results, with reference to various types of vehicles and different manners of driving have been presented. In the summary, the authors have given conclusions arising from the conducted research.

Keywords: Public transport · Electrical energy recovery · Electrical energy usage · Energy efficiency · Traction unit

1 Introduction

Electrical energy consumption and related to it issue of rational management of energy constitute an important area of actions of transport companies and administrative authorities. The cause of this situation is the leading role of economic efficiency, which main component is the efficient energy use. Additional factor is the growth of social awareness of ecology and exhaustion of mineral resources, which serve for producing electrical energy. A solution to the problem of efficient energy use mostly lies in energy-saving technology and energy recovery. An ideal environment for the latter is the public transport.

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_11

Electrical energy recovery in public transport can be effected in a few ways [1–4]. Their common and basic denominator is the occurrence of traction units, which have the ability to regenerative brake. Electrical energy produced in the process of braking can directly power another traction unit, can be kept in the energy storage or can be given back to the electrical grid of the commercial power. When specific conditions are fulfilled, the regenerated energy passed on to another traction unit is the most desired option.

Modern public transport vehicles, despite using energy saving technologies, have bigger and bigger demands for power and electrical energy. It is caused by ride's dynamics connected to tight timetable, a large amount of passengers and an increased number of receivers installed in vehicles (heating, air-conditioning, devices increasing safety and comfort of the ride in public transport). Using energy recovery in traction systems of public transport, because of a large number of bus stops and stations, which, as a consequence, leads to frequent stops and starts of the vehicles, reduces their energy consumption. Reducing the energy consumption of the traction system is equal to the improvement of its efficient energy usage and to the reduction of the demand for energy from an external power source.

Very important in the process of electrical energy recovery of electricity are also security issues and modern information technologies [7, 8].

2 Electrical Energy Recovery Systems in Public Transport

2.1 Using Electrical Energy Recovery Systems

Choosing the method for using electrical energy, coming from the regenerative braking of public transport traction units depends on the following factors [5, 6, 9]:

- power system of the catenary construction,
- parameters of traction units and of traction substations and their location,
- timetable,
- distance between stops and their number,
- permissible speed on a given line,
- terrain's topography.

The above factors and the technological development of power engineering have contributed to the creation of the following groups of solutions in the area of energy recovery in the energy recovery process [5, 6, 9]:

- Direct use of energy recovery – immediate use of the recovered energy, sent via an overhead line from one of the units (during regenerative braking) to another, during its start or drive on the same power track.
- Indirect – used for the accumulation of electrical energy of the storages installed on the traction units, substations or on the route. These storages are electrical or mechanical.
- Energy transfer to the AC power system – transfer of the recovered energy from the DC system to the AC power system with the use of frequency inverters.

2.2 Direct Usage of the Recovered Energy

Energy recovery is manly used on routes, in which there is slight excess of recovered energy, in comparison to energy that can be obtained by other units on the same power supply track. Another condition is that, on the railway electric traction, there always have to be units that can mutually recover energy. That is why, it is a good method that can be used in public transport. Depending on the factors mentioned in Sect. 2.1, the described method can be combined with others, but usually it is uneconomic.

With the lack of energy storage devices and frequency inverters sending this energy to the AC system [3], recovered electrical energy coming from regenerative braking takes place on the unit braking – unit starting level. The frequency inverters installed on the unit serve as the initiators of energy recovery. They heighten or lower the voltage in order to maintain optimal conditions for energy recovery (PN-EN 501636 [13, 14]).

2.3 Electrical and Kinetic Energy Storages

Energy storages allow to keep energy and constitute an element of the whole energy recovery system [1]. The usage of the storages allow to avoid situations, in which it is necessary to lose the excess of energy on the unit's resistors or the traction's substation. Such situation can take place when the value of the energy given back to the railway electric traction exceeds the capacity for its reception. In this case, a carrier will not gain the expected profit connected to the usage of regenerative drives.

Energy storages used in the railway electric traction can be divided into: static ones (batteries, capacitors, SMES - Superconducting Magnetic Energy Storage) and mechanical ones (low-speed, high-speed). Because of the place of the installation, energy storages are divided into: storages installed on the traction units and the ones installed in the electric power systems [4].

Fig. 1. GIGACELL batteries system. (Source: Kawasaki Rail Car [15])

The most famous electrical energy storages are batteries. Figure 1 presents stand-alone battery cabinets for railway – GIGACELL [15], based on the nickel-metal hydride batteries (Kawasaki Heavy Industries, Ltd.). Second, where it comes to popularity among energy storages are supercapacitors [11, 12]. They are used as modules of series connected elements. A storage of this type was installed on a modernized trolleybus Skoda 14TR. It consists of eight series connected BMOD0165 modules by Maxwell. A stationary supercapacitor was installed, among others, on a trolleybus traction substation - Północna Gdynia [9] and in the Warsaw underground.

Storages for storing kinetic energy are mechanical, rotating on their axis, flywheels [10]. Because of their dimensions, they are mainly used on traction substations, however they can also be found on vehicles. An example is a flywheel made of carbon fiber (GTR system), developed by the Kinetic Traction company [17], which purpose is to store energy obtained during regenerative braking of the traction units.

2.4 Electrical Energy Transmission to the Electrical System

A way assuring that all energy coming from regenerative braking is used, is its return to the AC power system [3]. It is possible thanks to the electrical bypass system of the electrical energy. Such a converter supplies energy to the AC system with parameters suiting quality standards for electrical energy (e.g. PN-EN 50160 standard "Voltage Characteristics of Public Distribution Systems" [14]). Here, the most crucial parameter is the content of harmonic multiples in voltage, which is independent of the value of the received current (Fig. 2).

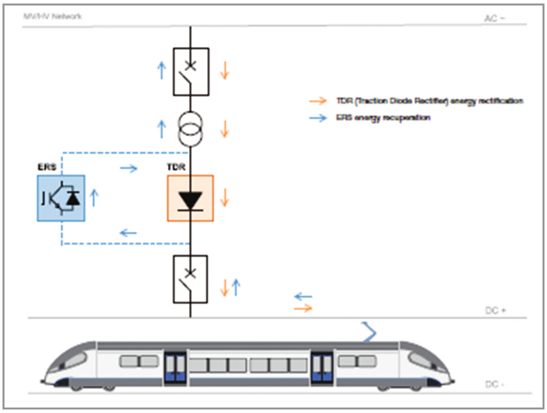

Fig. 2. ERS system by ABB – electrical energy flow. (Source: ABB [16])

At the moment, there are a few traction modules for the transmission of the recovered energy to the AC system on the market. An example is the Enviline ERS system [16], designed for being built in on the traction substations in the form of ready inverters, which diagram has been presented above.

3 An Analysis of Electrical Energy Recovery in a Chosen Public Transportation System

3.1 Parameters of the Analyzed Public Transport System

The analyzed public transport tramway system consists of nearly 200 km of tracks, which together contribute to 25 routes. In this system there are about 400 tram stops, depots and termini. The routes are radial, coming from the city center to the particular districts. Trams move around in a mixed traffic, meaning on the ascribed tracks and on the tracks built-in public roads, used by other road users.

Electrical power supply of the analyzed transportation system is the DC power system with the 0,6 kV voltage. Where it comes to its construction, it is very similar to the classical power supply of the railway traction – DC 3 kV. It consists of a few dozens of traction substations, powered from the SN (15 kV) commercial power. The machinery park consists of various types of traction units. They use a few kinds of drive systems, allowing the change from the kinetic energy of the vehicle to the electric energy during the braking cycle, meaning during regenerative braking. These units are: ANT100-600 (tramway-105 WrAs, 204 WrAs, 205 WrAs), FT130-600 (tramway-2010 NW PESA), SFT-100-600 (tramway-Moderus Beta MF19 AC), NSC 128 GE 03 M (tramway SKODA 16T, SKODA 19T).

The recovered energy is transmitted to the overhead line through the appropriate transistor module and regenerative resistor, which are integral components of the drive system used in a given unit. The flow of the regenerative current takes place on the unit – overhead line – unit level.

3.2 Energy Usage Analysis

An Analysis of the traction energy regeneration has been conducted on the basis of two trams (units A, which do not have the ability to recover energy and units B which do have this ability). Measuring data (energy taken, used and recovered) has been obtained from the electrical energy meters installed in the units. The data has been ascribed to a given line, distance covered and a given tram driver. The analysis was based on the usage of the electrical energy for the period of 6 months (summer and autumn months).

The maximum energy consumption for both types of units A and B was during the autumn months. It was related to the fact that there were more passengers transported and that there were worse conditions for driving a tram. Supposing that the mean usage of energy used by the A units was 100%, the usage of the B units was calculated, which was 78% (all energy taken). Considering recovered energy thanks to the energy recovery mechanism, one received a real energy usage per vehicle, the usage was 55,5%. Recovered energy, thanks to the energy recovery mechanism was 22,5%.

Figure 3 presents a graph of mean percentage values of energy taken and taken per unit – vehicles type A (which do have the ability for energy recovery), in the analyzed period of time, for the chosen transportation lines. Figure 4 shows a similar dependency, but for vehicles type B (having the ability for energy recovery). For B units only data for energy per unit has been shown: taken, consumed and recovered. All values shown in the graphs relate to the biggest values and are shown in percentage.

On the basis of the above data, standard deviation, shown in the Table 1, has been calculated.

Table 1. Standard deviation for energy taken, used and recovered for units type A and B – data Figs. 3 and 4.

Unit type	Energy taken	Energy used	Energy recovered
A	0,215	–	–
B	0,227	0,154	0,156

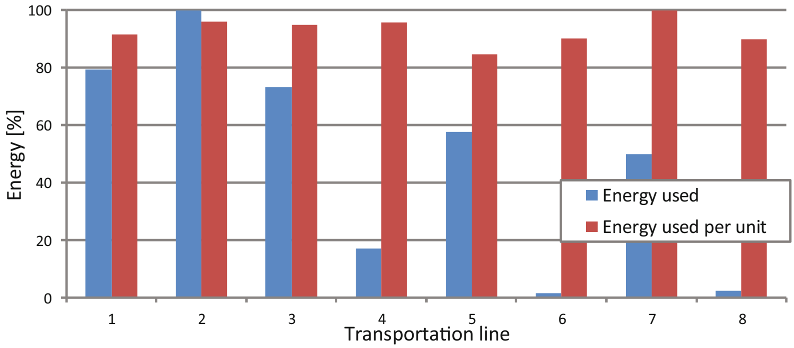

Fig. 3. Energy taken by vehicles A (percentage values and percentage per unit) for the chosen transportation lines

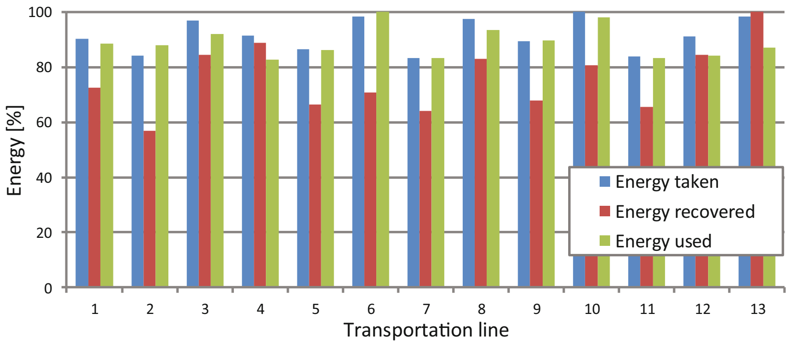

Fig. 4. Energy taken, used and recovered by vehicles B (percentage values per unit) for the chosen lines

Deliberations on energy consumption (usage) are best when based on the per unit energy. For units A (Fig. 3) the difference between the biggest and the smallest value of the per unit of energy use was about 15%. If one takes additionally the standard deviation into account δ = 0,215, then the results prove that there is a small variation in the value of the energy consumed by the units A, meaning that there is a repeated way of operation on different transportation lines. For units B, analogically, the differences are: energy taken 16,7%, recovered – 43,3% and used – 17,4%. Values of the standard deviation are as follows: δ = 0,227; 0,154; 0,156. The biggest difference (43,3%) takes place for the recovered energy on the line 11, but it is connected to an incidental, big value of the recovered energy on the line 13. Standard deviations in units B have also a small value. This leads to similar conclusions as with units A.

Figure 5 Presents a comparison between energy taken by units A and B (and consumed by B) for the same transportation lines. The biggest values of energy taken for a given line (these have always been units A) serve as 100%.

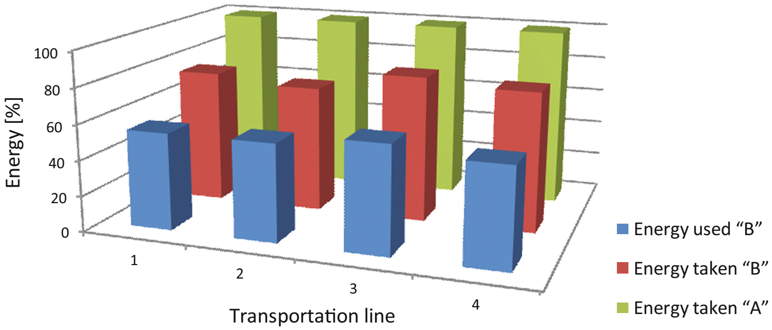

Fig. 5. Energy taken (units A and B) and used (units B) for the same transportation lines.

In all lines, units A had a bigger energy consumption. A percentage difference of the energy consumption by units A and B was from 45% to 50%. Another thing analyzed was the value of the consumed energy depending on the vehicles driven by particular tram drivers. 4 transportation lines were taken into account. Data was presented with reference to the biggest energy consumption on a given line. Characteristics of the energy taken for units A has been shown in the Fig. 6, for B units on the Fig. 7. Figure 8 shows the value of energy consumed of the vehicles type B.

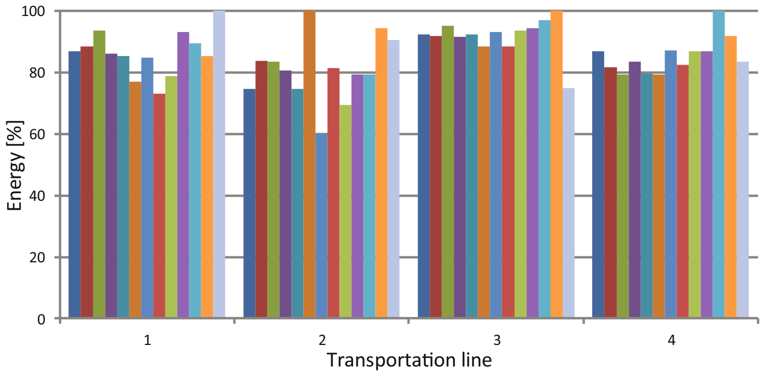

Fig. 6. Energy taken by units type A, driven by a given group of tram drivers on the chosen transportation lines

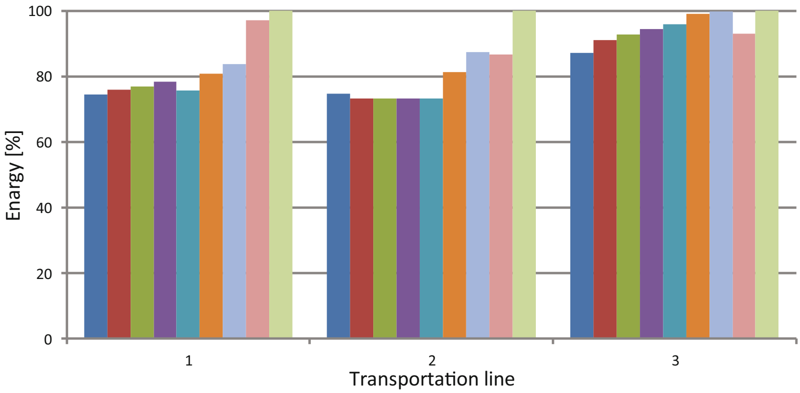

Fig. 7. Energy taken by units type B, driven by a given group of tram drivers on the chosen transportation lines

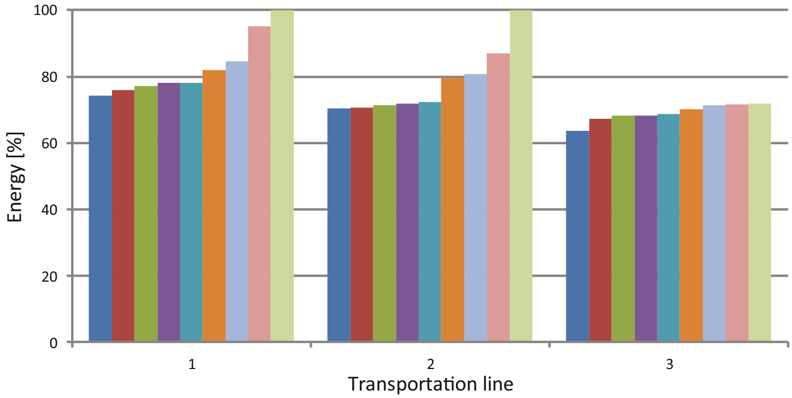

Fig. 8. Energy consumed by units type B, driven by a given group of tram drivers on the chosen transportation

The value of the standard deviation for the particular lines has been presented in the Table 2, and for particular tram drivers in the Table 3. The biggest values of the deviation are: 0,55 and 0,59. These are, however, incidental cases, most of the time the values are much smaller. Examples of big standard deviation values do not have to imply an improper manner of driving a vehicle by the driver, but difficult traffic conditions in a given case. Generally, deviations are small and suggest an energetically effective manner of driving the units.

In all comparisons, units type A had better results than units type B. Units A have a different power technology installed, than units B, which are far more modern than units A. Units A are equipped with direct current motors, which work based on the resistance start. Units B are trams with power supply systems equipped with induction

Table 2. Standard deviation values for energy taken and consumed for a given line.

	Line 1	Line 2	Line 3
	Energy taken		
Unit “A”	0,28	0,34	0,26
Unit “B”	0,42	0,42	0,14
	Energy consumed		
Unit “B”	0,27	0,30	0,08

Table 3. Standard deviation values of the energy taken and consumed for a given tram driver.

	Tram driver								
	1	2	3	4	5	6	7	8	9
	Energy taken								
Unit “A”	0,16	0,33	0,42	0,25	0,28	0,77	0,42	0,38	0,27
Unit “B”	0,23	0,18	0,17	0,17	0,10	0,19	0,29	0,55	0,59
	Energy consumed								
Unit “B”	0,08	0,08	0,09	0,09	0,09	0,08	0,10	0,23	0,33

motors, based on choppers. From the analysis of the tram drivers’ work it seems that the trams are driven in a way to reduce energy consumption of public transport.

4 Summary

In the past few years there has been a significant growth of interest in electrical energy recovery from regenerative braking of the traction systems. This process has taken place mostly in public transport, because regenerative braking is the most effective in this area. When introducing traction units with regenerative braking systems into the traffic, one usually deals with an existing technical infrastructure of transportation lines. Thus, in this system, there are also vehicles without regenerative systems. In cases of simultaneous occurrence of a big amount of traction units, electrical energy usage coming from regenerative braking on the level of unit-overhead line-unit is well visible. An example of such usage has been presented in this article. Results obtained in the conducted analysis prove that it is worth investing in energy recovery during regenerative braking. It is especially significant to carriers, whose vehicles participate in public and agglomerative traffic. Lines of these type are characterized by small distances between stops, meaning a big number of stops and starts, which, as a consequence, generates a substantial amount of recovered energy. Energy recovery process and related to it technologies should be continuously intensively developed.

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Solutions to Improve the Efficiency of Freight Transport

First and Last Mile Delivery – Problems and Issues

Elżbieta Macioszek(✉)

Faculty of Transport, Silesian University of Technology, Katowice, Poland
elzbieta.macioszek@polsl.pl

Abstract. "First and Last Mile Delivery" stands for freight transport logistics over the first and the last part of the way to the customer, accordingly. In freight transport, the first and the last mile are most cost intensive. In the last phase of transport, it is difficult to gather and put shipments together, which results in the costs in that area usually being disproportionately high. The problems of last mile delivery usually stem from the fact that deliveries are composed of individual orders and from a significant level of dispersal of destinations, as each order must be delivered to a different address. Similar problems are related to first mile freight transport. This article addresses the problems and issues connected with first and last mile delivery.

Keywords: First mile delivery · Last mile delivery · Freight transport logistics · E-commerce

1 Introduction

The first mile of the transport process involves initiation of freight transport using the initial (first in order) means of transport. The last mile, on the other hand, is related to freight transport over the last section of the route using the last (in order) means of transport. The problem of first/last mile logistics is broadly discussed in the source literature.

Logistics is one of the basic areas of operation in a modern enterprise. It gains more and more meaning today, both in theory and in practice. Consumers tend to buy more goods on the Internet, which has already become a common practice. Not only do they buy small goods on the web, but also larger products, such as household appliances, building materials, furniture, fragile goods and many more. Online stores are expected to provide the same level of service as in the case of smaller parcels. Delivering large or non-standard shipments to a customer requires detailed planning of every stage of delivery and it involves a much more complex process. Online stores, willing to create their positive image and to build customer loyalty, try to make sure that e-consumers have positive experiences at every stage of order processing, from the moment of buying the goods to their collection. What they use for that purpose is known as "customer experience". Therefore, the role of a logistics company is not only the very delivery, providing maximum flexibility in selection of the best possible place and time for the parcel delivery, but also care for a whole range of other factors which affect the customer's positive experience of services rendered by online stores. In such

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_12

circumstances, gradually and rapidly developing e-commerce market turns the problem of last mile logistics into a huge challenge for logistics operators. According to [1–3], the last mile delivery problem is mainly related to distribution in the retail chain, where the function of logistics is to deliver physical goods to a broad and very diverse group of customers. It is also a problem connected with collection of goods that are subject to complaints, that are unwanted or delivered to a wrong end customer.

In practice, one may distinguish between several methods related to shipment delivery over the last mile. The first method is referred to as the pragmatic performance method. According to the assumptions underpinning this method, orders are accepted by a central unit and then passed on to the closest branch where they are processed according to a waiting list and finally, after phone consultation, they are delivered. The advantage of this variant is conscious abandonment of an information system. The service must operate due to well-structured organisation. The second method consists in restricting deliveries to a specific time period and region. Under this method, a certain number of orders is accepted through a call centre or an online order handling system for a particular region and a specified period of time. By that means, transport resources are not excessively encumbered with the orders they are assigned. Transfers are set together in the best possible way using dedicated software. Another method is connected with ordering shipments under the so called Milk Runs. In this case, there is a pre-scheduled framework timetable of transfers servicing a particular delivery area. Orders are distributed when customers become connected to a delivery planning server via the Internet or a call centre which provides suggested times of delivery for the customer's town depending on when the delivery vehicles are scheduled to be in that area. The customer selects one of the proposed options while the software books the right date.

The problems of the first and last mile freight transport organisation have been the subject of many multi-faceted studies, addressed from the perspective of economics and logistics (e.g. [4–7]) as well as from the point of view of transport organisation in the given area (e.g. [8–21]). In this article, the problems and issues connected with first and last mile delivery have been discussed.

2 Selected Good Practices in Last Mile Delivery Logistics

Efficient and well-planned transport may facilitate and improve the functioning of a city, thus increasing its competitiveness. Last mile delivery is quite often performed within a dense transport network, overloaded with streams of traffic. This fact does not only make it difficult for logistics operators to deliver goods on time, but it also causes additional nuisance for inhabitants due to higher emissions, noise or traffic congestion. In the literature, a number of good practices are specified with regard to delivery of goods, aimed at eliminating these inconveniences and promoting green solutions as well as sustainable development of transport. These are e.g. [22, 23]:

- night-time (or early morning) deliveries aimed at quiet distribution. Night-time deliveries must meet noise requirements imposed by local authorities. The level of noise produced by machinery in operation should not exceed 60 dB at the distance of 7.5 m from the noise source, which corresponds to the level of noise generated during a regular conversation. It is assumed that equipment used in freight transport, e.g. forklift trucks, tractor units, wheeled pallets, refrigerated semitrailers or tail lifts which meet the aforementioned requirements can be used for night-time deliveries without curfew violation,
- intermodal transport, i.e. transferring part of deliveries from road transport to railway transport at short distances, as long as there is access to the railway network without disturbing the daily train timetable. In this variant, it is necessary to build sidings along with goods handling hubs and to organise shipped goods into wagons,
- multi-function lanes where traffic organisation is supported by variable message signs. The outermost lanes on multi-lane roads can be used for many purposes, depending on the time of the day, e.g. for the traffic of cars, busses, delivery vehicles, for a halt, as a parking space for inhabitants. Such a solution favours undisturbed traffic during the morning and afternoon rush hours and it organises distribution of goods in-between the rush hours, when there is less traffic. At night, the lanes are used by local inhabitants as a parking area. Such a solution favours optimum use of street space,
- micro-consolidation centres located downtown, used as freight handling spots for more environment-friendly forms of transport, such as freight bicycles or electric cars which perform the last mile freight delivery. Micro-consolidation centres are fed by large suburban warehouses. This type of solution has been introduced e.g. in London as a response to growing traffic, pollution, exhaust emissions and noise.

Using the above described good practices in last mile delivery makes it possible to achieve significant economic benefits, such as lower total cost of transport and reduction of environment pollution with nitrogen oxides and carbon dioxide.

3 Road Freight Transport in Poland

According to the Central Statistical Office [24], in 2015, 1,803.8 million tonnes of goods were transported by all means of transport in Poland (i.e. 2% less than in 2014), while the freight transport work performed amounted to 360.6 billion tonne-kilometres and was 3.6% higher than in 2014. When analysing road transport in terms of shipping distance, one can see that as much as 50% of all the goods carried accounts for short-distance transport, i.e. transport up to 49 km. This group comprises last mile freight transport as well. Figure 1 illustrates the 2015 national road transport of goods according to distance.

Moreover, when analysing road transport of goods in the area of Silesian Voivodeship, one can claim that most of these shipments are those dispatched and collected internally, i.e. within the voivodeship (including last mile deliveries). In terms of dispatched shipments, their share reaches 73.5%, while for collected shipments, it is 70.5% of all the goods transported. The above specified shares of shipments dispatched and collected within the voivodeship are higher than the share of shipments dispatched and collected from other voivodeships and the share of shipments delivered to and from other countries, accordingly. The Silesian Voivodeship balance of goods delivered by road transport in 2015 is presented in Fig. 2, and the Silesian Voivodeship balance of goods received by road transport in 2015 is presented in Fig. 3. One can observe a similar situation in terms of road freight transport in other Polish voivodeships (the only exception being Podkarpackie Voivodeship, where shipments dispatched to other voivodeships prevail).

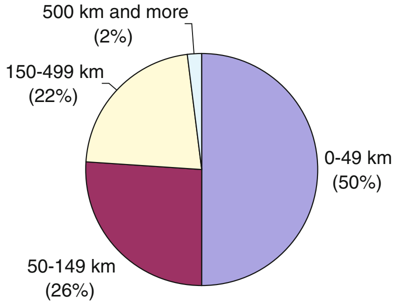

Fig. 1. National road transport of goods by distance in 2015. (Source: own elaboration based on data presented in [24])

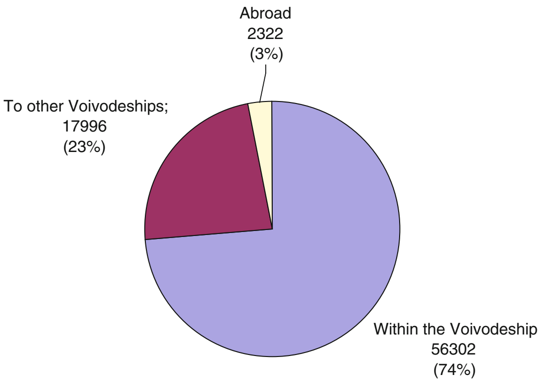

Fig. 2. The Silesian Voivodeship balance of goods delivered by road transport in 2015. (Source: own elaboration based on data presented in [24])

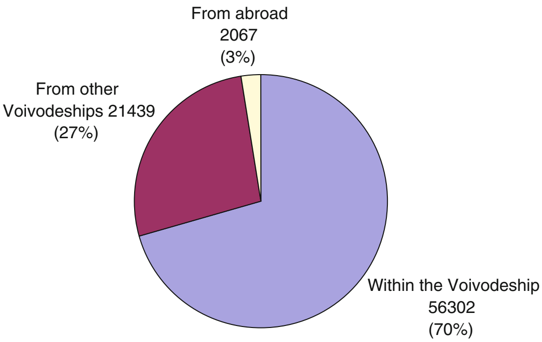

Fig. 3. The Silesian Voivodeship balance of goods received by road transport in 2015. (Source: own elaboration based on data presented in [24])

4 Main Reasons for Last Mile Delivery Problems

Goods purchased by e-customers can be delivered in three ways. They can be collected personally at the store or from an agent involved in the delivery of goods, they can be delivered to the customer by an external courier company or they can be delivered by the seller's own means of transport. Problems related to last mile freight transport may be caused by the online store, the carrier, the customer, or they may be due to external reasons. According to reference literature, the main reasons behind the last mile delivery problems include [24]:

- waybill printed out incorrectly, waybill incorrectly fixed to the parcel, wrong address in the waybill or improper packaging,
- too many parcels per one courier, too large delivery area per one courier, time-consuming process of parcel receipt confirmation by the customer, unreliable courier, courier not equipped with accurate and up-to-date maps or navigation devices,
- bad organisation of parcel sorting facilities,
- highly worn fleet of the carrier's vehicles,
- inaccurate or wrong address provided in the registration form,
- lack of doorbell, broken intercom at the receiver's,
- lack of access road to the receiver's,
- lack of parking space near the receiver's,
- unfavourable weather conditions: snow, black ice etc.,
- road events: accidents, car crashes, car breakdowns,
- road repairs, detours,
- and many more.

5 Conclusions

In the entire transport process, the opportunities for process optimisation aimed to minimise the number of transfers as well as for complete loading of means of transport with the goods shipped are most limited over the first and the last mile of delivery. These sections of the route often force high frequency of transfers of particular means of transport with a relatively low load capacity (due to the fact that goods are very often delivered to highly urbanised areas), and combining these factors is the main task of logistics operators.

The volume of the Polish e-commerce has been growing year over year, and it is actually not different from the global level, therefore the problem of first and last mile logistics will continue to be a subject of interest to many companies and logistics operators. There are already some specialised companies on the market which provide services for online stores while cooperating with carriers, and one can observe specific methods and habits which have already been established, related to logistics management, aimed at enhancing last mile transport, e.g. by informing the customer about the stage of order processing or providing the customer with the possibility of tracking the route of their shipment. All the foregoing elements along with the first and last mile delivery good practices contribute to ongoing improvement of transport within this cost-intensive and problematic section of transport routes.

Acknowledgements. The present research has been financed from the means of the National Centre for Research and Development as a part of the international project within the scope of ERA-NET Transport III Programme "Smart platform to integrate different freight transport means, manage and foster first and last mile in supply chains (S-MILE)".

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Multiple Criteria Evaluation of Global Transportation Systems - Analysis of Case Study

Barbara Galińska(✉)

Lodz University of Technology, Łódź, Poland
barbara.galinska@p.lodz.pl

Abstract. The paper presents the evaluation and selection of the most desired finished goods transportation corridor of delivery for the company which operates in the household appliances industry. To decrease the production costs, the company relocated manufacturing process to China. That is the reason why it is necessary to find a transportation and logistics solution how to supply finished goods from China to the warehouses in central Poland (Lodz) on the most preferable conditions for the company and its customers. The top management of this international company (acting as a Decision Maker DM) is responsible for finding the most suitable supply chain of manufactured goods. To solve the problem the author of this paper implements the Multi-Criteria Decision Making/Aiding methodology. The decision problem is formulated as a multiple criteria ranking problem. Thus, the author designs alternative global transportation corridors between China and Central Europe (Poland) based on a multimodal transportation process. On this basis she defines different alternatives of delivering goods and evaluates them by a consistent family of criteria. The author models the DM's preferences and carries out a series of computational experiments with the application of selected MCDM/A ranking methods, especially Electre III/IV and AHP methods. As a result it generates the final rankings of transportation options and gives the DM the most accurate transportation solution.

Keywords: Global transportation system · Supply chain · Logistics corridors · Transportation · Multi-criteria decision making/aiding · Electre III/IV method · AHP method

1 Introduction

Still changing economy and growing competition on the Polish market substantially influence the relevance of the delivery process in production companies. Enterprises strive for minimizing production costs of the components and shortening the flow of goods and information but at the same time trying to preserve the value of goods and services so important for the customers. The cooperation with the suppliers, who operate in developing countries, is one of the strategies to decrease manufacturing costs. That is the reason why more and more products offered on the European and United States markets come from China. However, decreased manufacturing costs,

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_13

achieved by relocation of production to China, may lead not only to increase in the transportation and storage costs but also to the extension of delivery time. These are main purposes for dynamic development of the supply chains which has been observed for a couple of years. To reduce the number of goods frozen in the warehouses, it is necessary to analyze the duration of order, the time of delivery and the time of storage. Therefore, it is vital to improve the flow of goods delivered from China by implementation of the proper way of transportation, which would directly influence the decrease of costs and shorten the time of storage.

Herein, the author describes the process of construction and evaluation of the global transportation systems, which is a hot topic of the current transportation. The author considers the real world case study of global sourcing and presents a universal methodology of constructing and selecting the most desirable transportation – logistics corridors for global suppliers. The case study refers to the analysis of these corridors between China and Europe. Since China is a very active, global supplier, that delivers raw materials, components and finished goods on a large scale, worldwide, the analysis of the Chinese market makes, in the author's opinion, the presented results quite interesting.

The author analyzes and evaluates different transportation systems in the industry of household appliances. The delivered finished goods - small parts installed in household appliances - are manufactured in China and transferred to the central warehouses located in Central Europe (Poland/Lodz).

The author investigates different options of shipping the goods between China and Central Europe (Poland). She designs alternative, multi-modal transportation solutions that constitute the considered variants of delivering goods in industry. The transportation corridors are constructed heuristically, based on the author's intuition and expert knowledge. They may involve the transportation by road, by rail and by sea. The author simulates the behavior of generated solutions and evaluates major characteristics/ parameters of their performance (costs, time, safety, reliability, timeliness). The evaluation of global transportation – logistics corridors is formulated as multiple criteria ranking problems. The author recognizes different stakeholders and their interests, defines consistent family of evaluation criteria, models the preferences of the decision makers (DMs) and stakeholders and finally performs a series of computational experiments. In the computational phase, she applies different MCDM/A methods, including Electre III/IV and AHP. As a result she generates final rankings of transportation options. Using the methods, the author compares the rankings generated by different computational algorithms and draws final conclusions regarding their stability. Finally, she recommends the best option of the transportation system.

The overall research goal of this paper is to develop a universal, generic methodology of evaluating global transportation systems and select the most desirable ones regarding the considered business environments, supply conditions and external circumstances. The author of this paper claims that the problem selection of transportation system has a multiple criteria character, and thus develops the proposed approach based on the principles of Multiple Criteria Decision Making/Aiding [1–4]. The challenge and the novelty of this work is to present the comparison of the multiple criteria evaluations of the alternative options - transportation systems and selection of the most desirable solution. The originality of this work consists also in the description and confrontation of all components of multiple criteria analysis of transportation variants. The presented approach can serve as a decision support tool for the logistic managers of companies performing the global sourcing. To the best of the author's knowledge such a contribution has not been reported in the literature, so far.

The paper is composed of 5 sections. In the first one the background of the analysis is presented. The second section includes the description of the methodological background of the research. It presents the principles of Multiple Criteria Decision Making/Aiding, the applied MCDM/A methods and the analysis of the transportation systems – with respect to transportation from China. Section 3 is focused on the description of decision making, especially on the characteristic of some ways of transportation and the criteria which are used for evaluation of those ways. Section 4 includes the results of computational experiments generated by the application of Electre III/IV and AHP methods. In Sect. 5 the final conclusions are presented. The paper is supplemented by a list of references.

2 Methodological Background of Research

2.1 Global Transportation System Considering the Chinese Market

Transportation is the set of activities connected with relocation of people and shipments in time and space with proper means [5, 6]. It is covering a distance or a change of place of goods/people using the transport facilities [7]. In another definition, the transportation is the technological process of each and every relocation in the distance, so the relocation of people, items and energy [8]. In economy, transportation is the service provision for consideration which results in relocation of people and shipments [9]. The general definition of the transportation defines it as a process which is the finite sequence of activities necessary to relocate people and shipments [10]. Its efficiency is determined by delivery of goods on time, to the right place, consistent with the decision of a person who assigns a transport service [11]. The set of transportation processes creates the transportation system. In this paper, the global transportation system is the main focus. The global transportation system is defined as the system which covers at least two national transportation systems. It has huge influence on functioning the international trade exchange where costs and time of transportation are very important. Costs and time of transportation depend on the branch and technologies of transportation used [12].

These days, when globalization and strong market competition shape functioning of companies, transportation system is the key issue. It is necessary to look for solutions which will increase competitive advantage of one company over another. Minimizing the prices for the goods by means of lowering the manufacturing costs is one of the ways to achieve the advantage [13]. It is often inevitable to transfer manufacturing to another countries or acquire materials from suppliers who come from countries where the labour force is low-priced [14].

China is the market which performs a vital role taking into account the migration of manufacturing to the developing countries (especially, keeping in mind those countries where the labour costs are lower). China, for the last thirty years, has recorded constant economic growth – on the average 10%. Such results are unprecedented in any other economy [15]. Besides, the forecasts present further development and economic growth of China caused by increasing trade activity between Asian and Pacific countries (the United States in particular) and number of investments in China and India. Still, the trade between the United States and the European Union will be the most important but the biggest growth in that respect will be designated to the trade with Asia [14]. China would be able to approximate or even catch up with the United States in the following decades according to the forecasts [15]. That is why China is the very interesting supply region which advantages are used more and more often by European (including Polish) manufacturers.

In China it is possible to purchase simple, mass products for very affordable prices [16, 17]. In that region is located the production of goods for which demand is constant and easy to predict and have long validity period. It is profitable solution for less innovative companies which manufacture the goods using common technologies [14].

Until recently, the transportation by sea has been exploited as the most preferable transportation system from China. However, this mean of transportation poses a lot of difficulties for companies, especially with respect to placing orders and planning the supplies. Another disadvantage of this way of transportation is the long term of delivery which is more than thirty days. Therefore, companies need to place orders a couple of weeks earlier which may cause planning stocks on the basis of forecasts and result in increase of stocks stored in the warehouses with the simultaneous lack of flexibility in case of changing demand [18]. Such a rationale is the ground for seeking the alternative ways of transportation in the case study described in this paper.

2.2 Characteristics of the MCDM/A Methodology: Major Features of the Applied MCDM/A Methods

Multiple Criteria Decision Making/Aiding (MCDM/A) is a field of study that develops rules, tools and methods supporting the DM in solving complex decision problems, in which several – often contradictory – points of view must be taken into account [1–4]. According to B. Roy [19, 20] Multiple Criteria Decision Making/Aiding is the activity of an analyst who helps to a DM, during a decision making process, to find answers for questions asked to find the most desired solutions, taking into consideration multiple aims (criteria) which are formulated by the DM. The methodology of MCDM/A has a universal character and can be applied in various cases when a DM solves a so called multiple criteria decision problem (MCDP). MCDM/A simplifies the process of carrying out most of the stages of the decision process, starting from formulation of decision aims, through creation of options and finally choosing the best of them [21].

MCDP is a situation in which, having defined a set of actions/variants/solutions (A) and a consistent family of criteria (F) the DM tends to: [1–3, 22]

- determine the best subset of actions/variants/solutions in A according to F (choosing problem),
- divide A into subsets representing specific classes of actions/variants/solutions, according to concrete classification rules (sorting problem),

- rank actions/variants/solutions in A from the best to the worst, according to F (ranking problem).

The set of A can be defined directly in the form of a complete list or indirectly in the form of certain rules and formulas that determine feasible actions/variants/solutions, e.g. in the form of constraints [3, 4]. The consistent family of criteria F should be characterized by the following features: [2, 19, 23, 24]

- it should provide a comprehensive and complete evaluation of A,
- each criterion in A should have a specific direction of preferences (minimized – min or maximized – max) and should not be related with other criteria in F,
- the domain of each criterion in F should be disjoint with the domains of other criteria.

In this paper the multiple criteria evaluation of transportation systems is defined as a multiple criteria ranking problem. The transportation options constitute the considered variants A. They are evaluated by a standardized, consistent family of criteria F and finally ranked from the best to the worst. The criteria evaluate various aspects of the considered variants, which are believed to be important from the perspective of different stakeholders, including the DM.

To solve MCDPs multiple methods can be used. Those methods can be generally divided into:

- The methods of American inspiration [25] based on the utility function; e.g. AHP [26, 27] or UTA [1].
- The methods of the European/French origin, based on the outranking relation (e.g. Electre methods [19, 23], Promethee I and II [1].

In this paper – in the case study described – the Electre III/IV method and AHP method are applied to rank the global transportation systems.

Major Features of Electre III/IV Method

The Electre III/IV method belongs to a family of multiple criteria ranking procedures based on the outranking relation. It is based upon building the preference model by comparing in pairs all decision variants considering thresholds which define the relation between those variants [28]. It generates the final rankings of a definite set of variants and orders them from the best to the worst, taking into account the following relationships between variants: indifference (I), preference (P) and incomparability (R). The calculation algorithm comprises following stages:

- I – creation of the evaluation matrix and definition of the DM's preferences model, (matrix of performances comprises the evaluation of each variant by each criterion; the DM's preference model is constructed with the application of indifference (qj), preference (pj) and veto (vj) thresholds as well as the weight (wj), defined for each criterion. The thresholds define the sensitivity of the DM to the changes of the criteria values and the weight (wj), expresses the importance of each criterion).

- II – creation of the outranking relation.
- III – usage (operation) of the outranking relation.

The final ranking is made on the basis of preorders: a descending and an ascending, in compliance with the following rules:

- The a variant is considered to be better than the b variant (aPb), if at least in one finite preorder a is placed before b, and in the other one a is at least as well classified as b is.
- The a variant is evaluated equally to the b variant (aIb), if both variants belong to the same class in each of two rankings.
- Variants a and b are incomparable (aRb), if in one of two rankings the a variant is placed higher than b and the b variant is placed over the a variant in the other ranking.

In the descending distillation the variants are ranked from the best to the worst, while in the ascending distillation they are ranked in the inverse order. The intersection of two preorders gives the final ranking, which is usually presented in a graphical form. It corresponds to a relation matrix that includes final relations between variants, expressed in the following form: indifference (I); preference (greater than ">"); non-preference or inverse of preference (less than "<") and incomparability (R) [22, 29].

Major Features of Analytic Hierarchy Process (AHP) Method

The AHP method was formulated by Saaty [26, 30], who claimed that human judgments are always relative and depend on characteristic of a DM, his role and the system of values that the DM upheld. As the result one may observe various approaches to the decision problem (the object of evaluation) and manifest itself in different importance wages of partial utilities of specific variants which are the same with the evaluation criteria. The above statement points to consistency of AHP method with utility theory [31].

Similarly to Electre III/IV method the AHP is also a multiple criteria ranking procedure that ranks a finite set of variants from the best to the worst. It is focused on the hierarchical analysis of the decision problem. Through the definition of the overall objective, evaluation criteria, sub-criteria and variants the method constructs the hierarchy of the decision problem. As opposed to Electre III/IV method the AHP is based on a multi-attribute utility theory [25] and generates final rankings of variants based on their aggregated evaluations represented by a utility function. In the final rankings generated by the AHP method the possible relationships between variants are limited to: indifference (I) and preference (P). All variants evaluated by the AHP method are comparable [22].

The AHP method consists of following stages: [32, 33]

- making of hierarchical structure,
- evaluation of the structure.

The procedure of the AHP method is based on the pair-wise comparisons of criteria, sub-criteria and variants. This model of preferences is expressed in the form of relative weights (wr), which represent relative strength of the compared element against another, expressed on the 1 to 9 point scale [26].

The result of the AHP method is a set of vectors containing normalized, absolute values of weights (wa) for criteria, sub-criteria and variants. The sum of the elements of the vector is 1 (100%). The absolute weights (wa) are aggregated by an additive utility function. The utility of each variant (i) – Ui is calculated as a sum of products of absolute weights (wa) on the path in the hierarchy tree (from the overall goal, through criteria and sub-criteria) the variant is associated with. The utility (Ui) represents the contribution of variant (i) in reaching an overall goal and constitutes its aggregated evaluation that defines its position in the final ranking [22].

In Sect. 4 one can find more specific description of each stage in both methods and the results of computational experiments which have been carried out.

The author of this paper has chosen these two methods, as suitable for solving the multiple criteria ranking problem but at the same time handling it in a different manner. She wants to demonstrate how the representatives of two alternative schools of MCDM/A can deal with the global transportation systems evaluation and selection problem. The choice of Electre III/IV and AHP methods allows the author to compare the computational results generated by two methods based on different methodological (axiomatic) principles, alternative ways of defining and structuring criteria and different techniques of modeling the DM's preferences.

3 Characteristic of the Decision Situation

3.1 Verbal Description and Definition of Variants

The object of considerations is evaluation and selection of the most suitable transportation and logistics variant for the company operating in the household appliances industry. The entity is a part of the international corporation which is the leading producer of such appliances. At present, the group comprises of 42 manufactures in 13 countries in Europe, the United States and Asia. Altogether, the sale and customer service network involves 80 companies in 47 countries. The corporation employs about 50,000 people 70% of whom work in Europe. The entity specializes in sale of fridges, ovens, cookers, hoods, washing machines, clothes dryers, dishwashers and small kitchen appliances.

The case study refers to the company located in central Poland – Lodz. The enterprise specializes in the sale of household appliances and its annual production in 2015 was 1.5 pieces and keeps increasing every next year. The company's customers are the so called local warehouses which distribute appliances to the particular stores. Products are sold all over the world, especially on the European markets (Germany, France, Italy, Spain, Great Britain in particular, less frequently in Scandinavia and East Europe), as well as in the United States, Australia and Asia.

Most of the company's suppliers are located in Europe, nevertheless, some of the components are delivered from the Far East. Materials purchased from the supplier whose manufacture is located in China constitute the highest share. It is one type of materials which stands for five different goods (which differ in specification and technical parameters). These components are used in about 67% of manufactured appliances, one item per one appliance.

The process of materials delivery from China is connected with some obstacles caused by distance what results in high delivery time. It influences the quantity of materials stored in the warehouses. The company aims to minimize the stocks by looking for solutions which will make it possible. Therefore, 5 Why analyses were carried out to find the reason why the share of materials delivered from China is so high in the overall quantity of stocks. The analyses have shown that such situation is caused by usage by the company only one transportation solution that is combined variant of two branches: sea and road transportation (V2 variant described in the Table 1). Such model of delivery process was suggested by the shipping agency that cooperated with the company. Director of logistics, acting as the DM, selected the above delivery variant in compliance with the agreement with the shipping agency whereby the agency was responsible for delivery. Besides, the company has never before analysed various transportation variants, taking into account such criteria as costs, duration, timeliness, reliability, flexibility, safety or value-added services offered by the suppliers.

The DM is determined to rationalize the supply chain of purchased goods due to growing, strong competition so that it would be possible to reduce costs and time of delivery as well as improve such crucial parameters as safety and timeliness. To achieve the above mentioned added value of services, the DM finds it necessary to reassess the transportation system used so far and evaluate other options of delivery. After first analyses, the DM considers reduction of sea-road combination chain of delivery and implementation of transportation variant which employs other transportation branches

Table 1. Variants – global transportation systems – verbal description of decision problem.

Variant	Type	Verbal description
V1	Sea transport+sea transport+road - rail transport	Stages: • sea transport from port in Qingdao to Hamburg port • sea transport from Hamburg to Gdynia port • rail transport from Gdynia to container terminal in Strykow • road transport from Strykow to company's central warehouse
V2	Sea transport+sea transport+road transport	Stages: • sea transport from Qingdao to Hamburg port • sea transport from Hamburg to Gdynia port • road transport from Gdynia to company's central warehouse
V3	Sea transport+road transport	Stages: • sea transport from Qingdao to Hamburg port • road transport from Hamburg to company's central warehouse
V4	Road-rail transport	Stages: rail transport from Chengdu to Lodz railway station road transport from Lodz railway station to company's central warehouse
V5	Rail transport+rail transport	Stages: • rail transport from Chengdu to reloading terminal in Lodz • rail transport from Lodz railway station to company's central warehouse (the company owns its siding)

or different combination of them. In the times of strong competition, the DM needs to find better transportation variant having regard to price and duration of delivery. At the same time the DM would like to carry out comprehensive and objective evaluation of transportation options.

Decision problem of choosing the global transportation systems is defined as multicriteria variant ranking task. The variants taken into consideration indicate the ways of covering the distance between China/Qingdao or Chengdu and Poland/Lodz V1–V5 (Table 1).

The above mentioned variants entail the supplier's responsibility for delivery either to Qingdao sea port or to Chengdu railway station. The air transport is intentionally omitted, as it implies too high costs for the investigated company. Since the DM has not used any other transportation systems so far, thus the selection of the new system shall be well-thought and based on the detailed analysis. The following criteria will apply in the selection of the system: time, cost, transportation timeliness and reliability. They are believed to be the most crucial from the DM's perspective.

3.2 Evaluation Criteria for Variants

The decision process of selecting the most desired transportation system is based on 5 variants. Thus, on the basis of the interview and DM's preferences and aspirations the adequate criteria have been formulated. Finally, criteria K1–K7 have been specifically described in Table 2.

Table 2. Evaluation criteria for variants – global transportation systems – decision problem presentation.

Criteria	Verbal description
K1: Transportation cost	It is one of the fundamental criterion for variants evaluation, which defines overall costs of transportation operations of container 40′ from China to the warehouse of the company, expressed in monetary units [PLN]. The criterion has been formulated on the basis of data provided by the company and the shippers' offers. This criterion is minimized
K2: Transportation time	It is the second fundamental criterion for transportation variant evaluation. The criterion is expressed in days and it represents the duration from the release of materials by the supplier to the delivery to the company's warehouse. This criterion is minimized
K3: Transportation timeliness	The criterion defines the variance between actual and pre-defined delivery due date. It resulted from the statistical data provided by the potential carriers. It is a maximized criterion defined as a percentage [%] of deliveries carried out on time
K4: Transportation reliability	This criterion measures the number of damaged packages in delivery process, in a month period. It is a minimized criterion defined as a percentage of damaged shipments

(*continued*)

Table 2. (*continued*)

Criteria	Verbal description
K5:Transportation flexibility	The criterion measures the variant's reaction time (including: operating carrier) to unexpected events. It represents several aspects including: K5.1 – frequency of delivery (defined as a number of potential deliveries in a month period), K5.2 – minimal size of shipping quantity (expressed on the 1 to 10 point scale) and K5.3 – packaging ability (percentage of held container capacity). It is a maximized criterion
K6: Transportation safety	The criterion involves aspects such as: possibility of loss or damage of the goods comprising transshipment or temporary storage. It is pressumed that safety of the delivery decreases not only with the increasing number of transshipments during the transportation process (K6.1 – number of indirect operations) but also with the extension of the storage period in the transshipment terminals (K6.2 – total period of the storage in the transshipment terminals, expressed in days). It is a minimalized criterion
K7: Customer's comfort	The criterion includes such transportation aspects as ability to monitor the package and its status information (K7.1 – expressed on the 1 to 10 point scale). It also includes K7.2 – additional service: number of free of charge storage in port and due date of the payment (K7.3). It is a maximized criterion

The selection of the desired transportation system shall be thoughtful and established on the basis of various criteria, crucial for the DM's perspective. The most important (the highest value) are cost, time and timeliness. On the basis of the seven abovementioned evaluation criteria of the variants and original raw data, the evaluation matrix has been constructed (Table 3).

In the described case study the raw data has been properly processed. Due to the fact that the selection of global transportation systems has been based on the application of two alternative multiple criteria ranking methods (Electre III/IV and AHP) the presented raw data has been handled and adjusted to the requirements of these methods. In all computational experiments based on the application of AHP method the raw data, including the evaluations of variants/transportation systems on all criteria and sub-criteria has remained unchanged. At the same time the raw data for the computational experiments with the application of Electre III/IV method required certain adjustments. For all instances in which single, separate criteria have been applied to evaluate variants (criteria K1, K2, K3 and K4) all the evaluations remained unchanged. For all the remaining criteria (K5, K6 and K7), structured as quantities composed of sub-criteria, the sub-criterion evaluations have been normalized, i.e. transformed into 0–1 intervals and then aggregated (arithmetically or weighted averaged) within each criterion. As a result for all criteria composed of sub-criteria standardized and normalized evaluations have been computed [22]. The detailed computational experiments are presented in the next section of this paper.

Table 3. The Evaluation Matrix based on raw data in described case study (selection of global transportation systems).

Criteria	Variants				
	V1	V2	V3	V4	V5
K1 [PLN]	5650	6250	6550	28400	29100
K2 [Days]	56	51	45	21	23
K3 [%]	0.70	0.80	0.85	0.90	0.85
K4 [%]	0.05	0.04	0.03	0.02	0.03
K5					
K5.1 [Points]	3	4	5	5	4
K5.2 [Points]	3	6	6	3	3
K5.3 [%]	0.45	0.90	0.95	0.50	0.50
K6					
K6.1 [Points]	3	2	1	1	1
K6.2 [Days]	12	8	8	7	10
K7					
K7.1 [Points]	3	5	5	8	8
K7.2 [Days]	12	10	8	2	5
K7.3 [Days]	60	45	45	30	30

4 Computational Experiments

4.1 Ranking of Variants with the Application of Electre III/IV Method

The ranking of the variants has been performed with the application of the MCDM ToolKit programme, which is the implementation of Electre III/IV method, presented in the second section of this paper. In accordance with the algorithm of the applied method, the evaluation matrix (Table 4) of each variants (V1, V2, … V5) of global transportation systems has been constructed. Matrix of performances have been aggregated in accordance with the abovementioned computational procedure.

Table 4. The Evaluation Matrix based on transformed data, used in computational experiments with the application of Electre III/IV.

Criteria	Variants				
	V1	V2	V3	V4	V5
K1 [PLN]	5650	6250	6550	28400	29100
K2 [Days]	56	51	45	21	23
K3 [%]	0.70	0.80	0.85	0.90	0.85
K4 [%]	0.05	0.04	0.03	0.02	0.03
K5 [0–1]	0	0.80	1	0.37	0.20
K6 [0–1]	0	0.65	0.90	1	0.70
K7 [0–1]	0.67	0.57	0.50	0.33	0.43

Then DM's preference model has been constructed including weights of criteria and indifference (qj), preference (pj) and veto (vj) thresholds which define the sensitivity of the DM to the changes of the criteria values. The model has been presented in Table 5. It presents subsequent criteria, preferences direction (including maximalized criterion – increasing (gain) and minimalized criterion – decreasing (cost), weights of the criteria (expressed on the 1 to 10 point scale, where 1 is the lowest value of criterion and 10 is the highest value of criterion) and indifference, preference and veto thresholds.

Table 5. The final model of preferences characteristic for the Electre III/IV method applied in case study.

Preference information					
Criteria	Preference direction	Weight	Indifference threshold	Preference threshold	Veto threshold
K1	Decreasing (Cost)	9	1000	20000	50000
K2	Decreasing (Cost)	8	5	20	50
K3	Increasing (Gain)	7	0.05	0.10	0.50
K4	Decreasing (Cost)	6	0	0.03	0.05
K5	Increasing (Gain)	5	0.20	0.50	1
K6	Decreasing (Cost)	3	0.20	0.50	1
K7	Increasing (Gain)	4	0.20	0.50	1

In the second stage of algorithm the outranking relation has been constructed. The computational procedure starts with the concordance and discordance matrix. On this basis the credibility matrix is acquired (Table 6). Matrix is expressed by the degree of outranking and credibility d(a, b) which are the aggregated evaluations of variants and outranking relation S(a, b) representation. Each degree of credibility defines the degree where 'a substantially outranks b'. For instance, as presented in the table, degree of credibility d(V4, V3) = 0.463 means that variant V4 is likely to outrank variant V3, whereas d(V1, V3) = 0 means that variant V1 will not outrank variant V3.

Table 6. Credibility matrix generated in the computational procedure based on the application of Electre III/IV method in case study.

Credibility matrix					
Alternative	V1	V2	V3	V4	V5
V1	1	0.267	0	0.162	0.272
V2	0.650	1	0.940	0.365	0.559
V3	0.186	0.988	1	0.660	0.756
V4	0	0.600	0.463	1	0.976
V5	0.373	0.483	0.244	0.952	1

In the final stage of the algorithm the outranking relation S(a, b) has been applied and on the basis of qualitative characteristics of each variant, both ascending and descending distillations have been performed. It resulted in complete preorders of the variants. Then, they have been averaged in the median ranking and the intersection of preorders resulted in the final ranking. The results of these calculations are presented in Fig. 1.

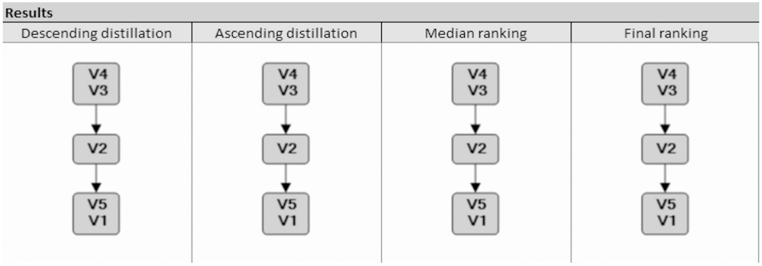

Fig. 1. The results of case study – analysis of global transportation systems – generated by a computational procedure based on the application of Electre III/IV method

The tabular form of the final ranking is outranking matrix also known as relation matrix, presented in Table 7 of this paper. The matrix includes final relations of the variants, expressed in the following form: indifference (I), preference (>), inverse of preference (<) and incomparability (R).

Table 7. Relation matrix generated in the computational procedure based on the application of Electre III/IV method in case study.

Relation matrix					
Alternative	V1	V2	V3	V4	V5
V1	I	<	<	<	I
V2	>	I	<	<	>
V3	>	>	I	I	>
V4	>	>	I	I	>
V5	I	<	<	<	I

Final ranking and relation matrix clearly indicate that equally V3 and V4 are the most desired variants and they outperform the others. The high value of system V3 is created by: low cost (K1), accurate timeliness (K3), flexibility (K5) and high ranking of criterion K7 – comfort for the customer. The major strengths of variant V4 are low delivery time (K2), excellent timeliness (K3) and reliability (K4) as well as safety of delivery (K6). It is worth pointing out that both variants V3 and V4 offer the average but not the cheapest price of transportation, which means that this aspect is compensated by other values.

The least desired systems are variants V1 and V5. Although the variant V1 offers the lowest costs of delivery, the other aspects of this variant have poorer performance than the winners of the ranking. The similar situation is with variant V5, which in addition offers the highest price of transportation.

4.2 Ranking of Variants with the Application of AHP Method

In the AHP method the pair-wise comparisons of criteria, sub-criteria and variants/global transportation systems have been applied to generate the preference model. This model of preferences is expressed in the form of relative weights (wr) on the 1 to 9 point scale. Each evaluation represents relative strength of the compared element against another. All weights have a compensatory character, i.e.: the value that characterizes the less important element (1/2, 1/4, 1/9) is the inverse of the value assigned to the more important element in the compared pair (2, 4, 9) [22].

Based on the AHP method algorithm the consistency indexes CI for each matrix of relative weights (wr) at each level of the hierarchy (criteria, sub-criteria and variants) have been generated. In the analyzed case study 16 CI-s have been computed, including 1 for criteria level, 3 for the sub-criteria levels and 12 for variants compared against each criterion.

In the next step of the AHP method computational algorithm 16 normalized, absolute values of weights (wa) for criteria, sub-criteria and variants have been produced. Due to space limitation the results of these calculations are not presented in this paper.

Table 8. The values of utility of each variant generated in the computational procedure based on the application of AHP method in case study.

Alternative	Score
V3	0.726
V4	0.720
V2	0.632
V5	0.614
V1	0.512

Table 8 presents the computed utilities (Ui) of each variant – transportation system with its absolute and normalized values. Figure 2 shows the classification of variants based on their generated utilities in the graphical form. Each variant – transportation system, presented in the graph, is featured by the level of computed utility (from 0.512 – V1 to 0.726 – V3 in the absolute values). The winner of the ranking generated with the application of AHP method is variant – global transportation system V3, followed by variants V4 and V2 (current system). The weakest variant V1 occupies the bottom position of the ranking.

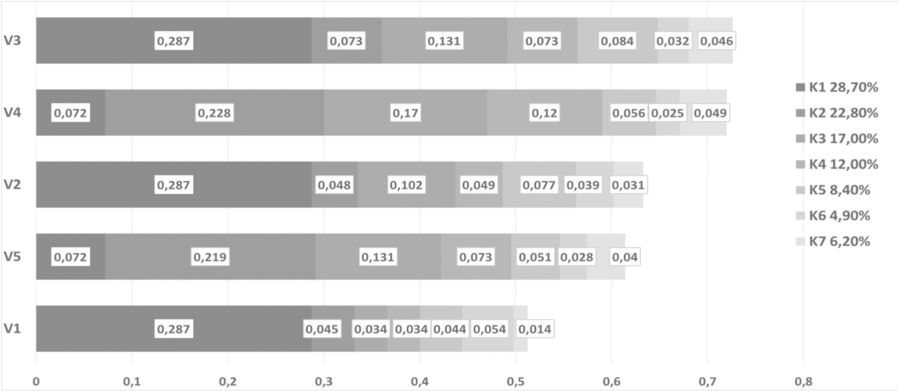

Fig. 2. Graphical representation of the final ranking generated with the application of AHP method in case study

Based on the ranking generated by the AHP method algorithm one can also conclude about the distance between the variants – global transportation systems (Table 8 or Fig. 2). The utility (Ui) of variant V3 is 0.726 and is not much larger than (Ui) of variant V4 (which makes these two variants comparable). But, what is transparent, the utility (Ui) of variant V3 is substantially larger than utilities of the remaining variants. For example the difference between V3 and V2 is 0.094 and between V3 and V1 is 0.214 (in the absolute values). The important feature of the ranking is its ability to demonstrate the contribution of each criterion to the final score and position of each variant – transportation system. Each distinctive colour on the graph represents the share of each criterion contribution in the utility (Ui) of each global transportation system.

The results generated with the application of AHP method are identical to those produced by the application of Electre III/IV method. Electre III/IV method indicates the equal importance of variants V3 and V4. Calculation results of AHP indicate slight difference of utility (Ui) between variants (0.006) so it can be assumed that they are comparable. Thus, the author of this paper recommends the transportation system V3 as the most universal and desired. For the DM of lower sensitivity on cost criterion, system V4 can be also taken into consideration, as it is characterized by a very low delivery time.

5 Summary

The presented paper is a comprehensive study concerning the evaluation and selection of global transportation systems for the company in the industry of household appliances. It proposes universal methodology based on the selection of global transportation system with application of the principles of Multiple Criteria Decision Making/Aiding (MCDM/A) and algorithm of solving the multiple criteria decision problem. Decision problem is defined as a multiple criteria ranking problem. The Electre III/IV and AHP methods have been applied in order to obtain the final ranking of global transportation systems. This research is an extension of the author's previous works [6, 22, 29].

The paper has both methodological and utilitarian character. It indicates the way of analysis and assessment of global transportation systems in order to rank solutions from the best to the worst, in compliance with the multiple criteria methodology. The methodological approach is based on the presentation of multiple criteria decision making procedure (ranking of the variants) in order to enable the optimum selection of global transportation systems. The author demonstrates the process of selecting and defining the variants (global transportations systems), specifies DM's model of preferences and finally carries out a series of computational experiments with the application of selected multiple criteria ranking methods. Based on the generated rankings, the author recommends the selection of the most desired transportation system.

In practical terms the author demonstrates the best variants which appear to be V3 and V4. They are both variants characterized by a lot of values, even though they do not provide the lowest cost of transportation. Variant V3 presumes to be favourable in aspect of costs, timeliness, flexibility and reliability of delivery. It is also featured by a high rank in aspect of comfort for the customer, ensuring the option of monitoring the package during transportation process, eight days of free of charge storage in port and convenient 45-days payment period for transportation service. Variant V4 is advisable in situation where DM expects low delivery time (this variant offers the lowest delivery period) regardless of the costs, which in this case is not the cheapest option. Nevertheless, it is also valuable for accurate timeliness, reliability and safety of delivery.

In conclusion, the author of this paper recommends the selection of V3 global transportation system as the most universal and desired. At the same time for the customer of lower sensitivity on costs but aimed at the short period of delivery, the author indicates variant V4 as considerable.

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Urban Freight Transport Demand Modelling and Data Availability Constraints

Daniel Kaszubowski(✉)

Road Engineering Department, Faculty of Civil and Environmental Engineering, Gdansk University of Technology, Gdańsk, Poland
dankasz@pg.gda.pl

Abstract. The paper provides a review of urban freight transport demand modelling approaches confronted with constrains regarding adequate data provision from a perspective of the local authorities. Demand estimation models has been selected as a reference because they are the most representative in terms of inclusion of urban freight indicators which can be transformed into a decision-support tool for evaluation of freight measures. The main concern is to find a balance between an effort required to create a reliable urban freight analysis framework and transport policy's objectives. Delivery-based models has been considered as the most promising in terms of possible results and ability to represent different aspects of urban supply chains in a coherent way. As they use a vehicle movement as a descriptor, the results can be presented in measurable way in terms of general transport planning framework.

Keywords: Urban freight modelling · Freight demand · Freight surveys

1 Introduction

To respond to challenges related to urban freight activity a city requires reliable analysis and forecasting tools providing comprehensive overview of all aspects of transport operations. Urban freight transport system consists of multiple stakeholders: producers, shippers, retailers, distributors and receivers. As a consequence of the multiple stakeholders presence no single entity can provide a complete picture of the freight system [1]. The basic step of typical analysis approach is a determination of what goods are being moved and delivered, where they come from, what are the most used type of vehicles and transport services used. This allows for estimation and modelling of freight demand and then simulating and forecasting results of possible policy measures.

Ability to analyse urban freight transport is restricted by the availability of freight data. This factor affects all steps in transportation modelling (generation, distribution, modal split and traffic assignment) which are critical for (1) developing improvements in freight policy, (2) forecasting of system performance, (3) mitigating impacts of freight traffic, (4) determining transport externalities, (5) improving traffic safety. Policy oriented models help public decision making about the main stakes associated with and urban sustainable development [2]. Therefore it is essential to develop efficient and cost effective data collection procedures.

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_14

The main objective of this paper was to investigate what are the most important interdependencies between urban freight demand modelling and data provision techniques in order to find which approach would be the most appropriate to start development of coherent approach to urban freight issues when no previous experience on this field is available. Section 2 of the paper reviews existing approaches to freight demand modelling with regards to their data requirements. Section 3 follows with an analysis of relevant data sources and their capture system with regards to the requirements identified in Sect. 2. In the final chapter, general conclusions and recommendations are provided discussing which approach would be the most feasible in terms of a balance between data complexity and expected functionality.

2 Urban Freight Transport Demand Modelling

2.1 Freight Demand Models Within Different Freight Analysis Approaches

All modelling approaches consist of reducing the object studied in order to understand the mechanism involved. The main categories of urban freight models related to their function include [3]:

- Demand estimation models. Their main objective is to estimate the demand for freight in an urban area or its part and to relate this demand to socio-economic and spatial characteristics of chosen area.
- Fixed-demand optimisation models, which are related to optimisation research. Their function is not to estimate the demand to be distributed but to optimise the transportation process. These models derive from the well-known families of location-routing and vehicle routing problems. The demand is known or estimated with other categories of models.
- Multi-actor simulation models, which main function is to simulate the behavior of the involved stakeholders instead of estimation the demand.
- Macro-economic and public decision support models. They evaluate action and solutions for urban goods distribution and in the most cases are dependent on the other categories of proposed models.

Review of urban modelling efforts provided by Duin and Tavasszy [4] shows that the most used descriptors were traffic flow, trip generation, vehicle loading and commodity flow. This aligns well with previous research done by Feliu and Routheir [3], where the most common modeling unit was commodity, trip and route of delivery vehicle, used in demand generation and O/D estimation methodological framework. This should drive attention to demand estimation models, because are the basis on any freight modelling approach.

2.2 Characteristics of Freight Demand Modeling Methods

Despite different approaches to urban freight modelling a general methodology for simulation can be identified allowing to [5]:

- Forecast how the key land-use activities and the use of transport systems may change over time, taking account of the transport infrastructure and its performance.
- Forecast the freight quantities demanded by end-consumers (demand models).
- Simulate the distribution process of different stakeholders (retailers, stakeholders, carriers, etc., supply models).
- Represent the transportation infrastructure and their general characteristics.
- Assign the multi-commodity flows to the multimode network (assignment models).
- Estimate and evaluate the performance and the impacts of a given city logistics measures.

The demand models are fundamental for an *ex-ante* assessment of policies and measures that can be implemented by local administration in order to make urban freight system more sustainable and reduce the total cost of transport system operations [6]. The basis for simulation is to estimate freight origin-destination (O-D) flows. This can be achieved by taking as the reference unit either quantity moved or delivery (commodity-based or delivery based) or freight vehicles by which transport is made (truck-based). Also a mixed commodity/delivery-based approach can be considered as shown in Fig. 1.

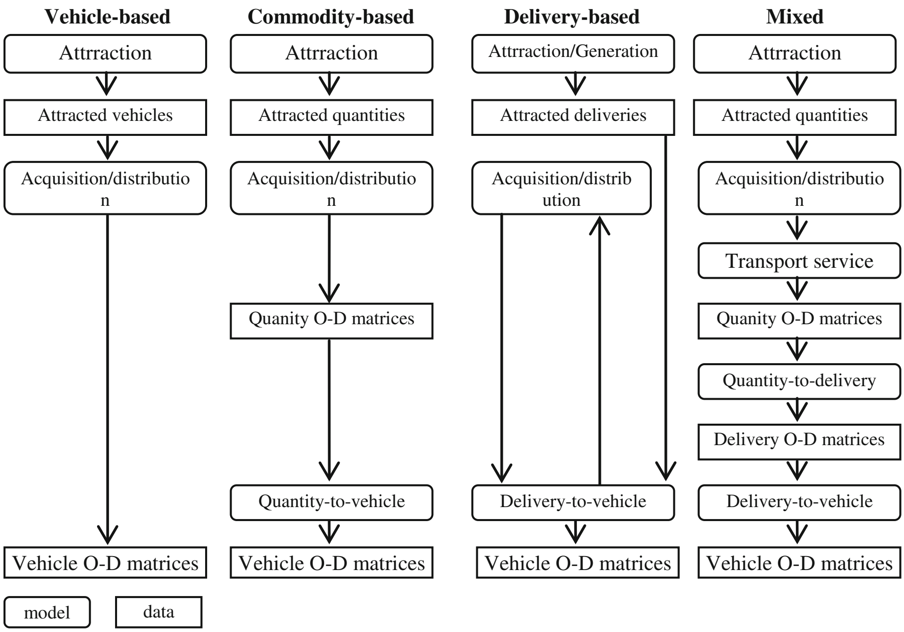

Fig. 1. Different freight demand modeling approaches (Source: [5])

Truck-Based Models

Truck based models follows the least elaborate structure of models presented in Fig. 1. This could indicate their high implementation potential, but this has to be taken with major consideration. Their reference unit is trip of freight vehicle and modelling approach includes two steps. The first one allows estimating the number of freight vehicles attracted or generated by each zone to which city was divided for analysis purposes. The second step provides spatial distribution of the previous estimated flows in the form of O-D matrices. Sometimes model is calibrated for different classes of freight vehicles. Significant number of examples of trip based modes is available in literature [7–13]. The main disadvantage of truck based models is that they perform well regarding round trip (one origin and one destination), but they do not reproduce trip chain (tour) simulation [5]. Based on that assumption a procedure has been developed to combine single trips into tours. It has been implemented within the WIVER [14] software and was applied in several cities in Europe, mainly in Germany. Truck based models are suitable for the simulation of the current state of freight transport system, but they lack the ability to properly reflect changes in the mechanism underlying demand generation, such as spatial patterns and mix of different forms of activity. Moreover, the application of the sequential modelling process appropriate for representing personal travel has been criticised with regards to urban freight [15]. The motivation for and characteristics of person travel are well informed by extensive survey research. Most person travel is characterised by round trips from home to principal destination, however, the factors driving the economy and freight transport are more complex than in case of personal travel and involve multiple entities. On the other hand, truck based models are characterised by relative ease of data gathering, which can be done with in automatic way including use of traffic management systems [16] or for example Weigh-in-Motion systems [17].

Commodity-Based Models

This group of models considers as reference unit the quantity of commodity moved. First, the attraction model estimates commodity flows attracted by defined zones in function of socio-economic data. Then acquisition model determines the O-D matrix by provision of the zone from where commodity flows are originated. Finally, quantity-to-vehicle model converts commodity O-D flows into vehicles. Complexity of this approach suggest that commodity based models are build with several separate models responsible for each step of the modelling process, indicating high demand for reliable data and significant effort to calibrate the model.

At the attraction level inbound quantities are modelled through direct relationships with the attraction power of each zone measured in the number of retailers or sales employees and land use variables [15]. For example, the daily attracted quantities can be described with a regression model as a function of employees in retailing activities [18]. Once the quantities attracted by each zone have been estimated it is necessary to spatialise them in acquisition model according to zone of origin of commodity. The acquisition model simulates the choice of origin (macro areas) among possible areas. This part of modelling procedure is covered completely only in few models because lack of commodity flow data to calibrate the models [19].

Provided that freight origin and destination zones have been identified the next step is to convert these flows from quantity to vehicle. Different factors can be used here to reproduce the composition of vehicle load: shipment size, type of service, vehicle type and restocking journey type (round trip of trip chain/tour). For shipment size the average values of transported goods can be used as proposed by Nuzzolo [18] based on studies in Italian cities. Also a share of empty trips needs to be included to get reliable picture of transport flows. Decision about type of service used for restocking trips can influence the vehicle load factor and characteristics of the vehicle journey. This refers to decision about the potential use of consolidation facilities or restocking in own account by retailer [13]. Vehicle type choice simulation may be done using different approaches. Vehicle type can be a function of freight type and service type [20]. Also specific models for simulation of vehicle choices of a retailer that restocks in own account were implemented [21]. When allocation of the freight quantity to each vehicle type is considered freight type variable should be the main reference unit.

The last steep for converting O-D matrices from quantity to vehicle is investigation of restocking journeys. The comment is that vehicle O-D matrices usually are quite different from quantity O-D matrices because delivery vehicle can service different destination along the same tour [5]. A specific-tour based approach was developed to replace traditional trip-based one [14, 22]. Based on the availability of several well established research examples commodity models can be considered generally as mature. However, only few authors propose a complete modelling framework. The majority of models take a detailed look at some specific stages, making it difficult to combine them into one practical solution.

Delivery-Based Models

Delivery-based models are interesting alternative for complexity of urban freight transport as they provide a direct link between generators and transport operators through the use of the same reference unit which are deliveries. One of the most used models of this type is FRETURB developed in France [22]. It consists of three modules which complete each other: (1) a pick-up and delivery model representing flows between all economic activities of a town, (2) a town management module consisting of transport of goods and raw material for public construction works and maintenance services and garbage, (3) a purchasing trips model, which represents the main last kilometers trips to end-consumers by shopping trips by car. An unique feature of this model is that it allows evaluating the flows of goods generated by economic activities of an urban area without carrying out a specific receivers survey, thus making it affordable for local authorities [23]. However, this statement is true only with regards to situation in France, where a comprehensive local entities database exists as an obligatory part of local authority's responsibilities. Also, an extensive surveys to calibrate a model in advance were required to get reliable information about average number of deliveries per each type of activity. Nonetheless, around fifty French (including Paris, Lyon and Lille) and European cities has adopted this model to simulate the goods movements within its boundaries. Despite using a reference which well fits into the characteristics of freight activities, the delivery-based models are mainly static-descriptive [5]. They are able to reproduce the actual scenario but cannot be used for forecasting analysis where the effects of city logistics policies have to be evaluated.

Mixed Quantity-Delivery-Vehicle Based Models

Review of previous categories of freight demand estimation may lead to a conclusion that current models were mainly developed to simulate particular aspects of urban freight but are not able to forecast many impacts of implementing freight policies at an urban scale [24]. They do not consider all the three fundamental factors describing urban freight activity (i.e. quantity, delivery and vehicle) that allow the actors' behavior to be captured. Hence there is a need for behavioral models derived from assumptions about stakeholders' choices. This would allow to simulate the effects of current decisions and to forecast the future scenarios according to network attributes that can be modified by implementation of logistics measures. Nuzzolo and Comi [24] presented results of this type of modelling approach with regards to evaluation of selected measures in the city of Rome. The general structure of the mixed approach is presented in Fig. 1 and it includes three subsequent modules: (1) the average quantity O-D matrices by transport service (e.g. retailer on own account or wholesaler on own account or by carrier), (2) the average delivery O-D matrices by delivery time period, (3) he average vehicle O-D matrices by delivery tour, departure time and vehicle type. The model's aim was twofold: one to evaluate the effects of the new regulation of freight traffic and the other to support *ex ante* assessment of future scenarios. It was supported by surveys at considered inner city area of 6 km^2: traffic counts (600 interviews) at the boundary of study area in order to investigate the supply chain and about 500 interviews of retailers for each freight type. Despite the model was based on several calibration specific solely for the analysed area it accounted well for its the economic characteristics, attracted and generated freight traffic for each zone and the pattern of delivery tours. Results proved feasibility of such approach, but future research should go further in development of its components, such as better behavioral models for simulating attraction and acquisition considering various socio-economic variables.

3 Data Availability Constraints for Urban Freight Demand Modelling

All urban freight demand modelling efforts presented so far aimed at better understanding of the nature of this phenomenon to facilitate rational decision-making process responding to local authorities requirements. But these efforts face one universal problem which is the availability and quality of information about urban freight movements. This problem is getting critical when main issues related to urban goods movements are mentioned [25]: (1) the economic dynamics of urban activities is weakened by risk of congestion and increasingly restricted space, (2) logistics flows are increasingly driven by consumer demand, following just-in-time principle, but not by the productive system, (3) the consideration of environmental requirements has become a major issue at every level of the transportation activity, at both local (noise and pollution) and global levels. These issues may take a form of concrete application areas where freight data are required [26]: (1) investigation of specific projects and initiatives, (2) development of national and local estimates, (3) government monitoring and performance measurement, (4) freight transport modelling and forecasting, (5) meeting the requirements of EC Directives, (6) commercial monitoring, (7) introduction of regulatory setup, (8) defining legal requirements for licensing and safety controls, (9) offence investigation (i.e. overloaded vehicles, speeding). Variety of reasons for freight data collection brings confusion in methodological approach and makes results comparison difficult. It applies not only to comparison of results and methodologies between countries, but sometimes between each city. Allen et al. [27] have found significant differences in freight surveys' review in UK resulting in problems with direct data interpretation. Ibeas et al. [6] analysed transferability of surveys results comparing between two European cities (Rome and Santander) and found that quantities of goods attracted can be generalised, but other steps required for reliable modelling are case-specific and cannot be directly transferred between cities even if very similar data acquisition methodology had been used. This reduces a chance for using external data especially when a city has not developed its own freight related database and only starts defining its framework [28]. To set-up an effective data provision system necessary to answer the problems described above three main objective should be followed [25]:

- To understand how and by whom goods flows are generated - what is the importance of the different urban activities in the generation of pick-ups and deliveries?
- To obtain a detailed description of all the urban logistics aspects: how many pick-ups and deliveries are carried out in the city and its surroundings? Who is ensuring the transport? How many kilometers are generate by these activities, which vehicles are used, who is running these vehicles, what goods and packaging are most often used, how many empty trips are made, how deliveries are organised (direct trips, rounds of different sizes, etc.).
- To help authorities in their decision-making: build decision-support models in order to answer how much traffic will be generated by new activities in the city. How can the indicators for urban freight be assessed in order to compare different areas and policy measures? How can the impacts of different future scenarios be compared?

There are two main categories of tools that can be used for collection of urban goods movements [29]. The first is that of urban goods surveys and the second are data estimation tools which are scarce and include already mentioned FRETURB approach and Viver tool. First, the main gaps in urban freight data collection should be identified [30]: (1) data about light goods vehicle activity, (2) data about the supply chain as a whole, (3) data about freight and logistics infrastructure attracting and generating freight flows, (4) data about loading and unloading operations and infrastructure for goods vehicles, (5) geographical data about goods vehicle trips in urban areas, (6) data about trips carried out by consumers for the purpose of shopping, (7) speed and route data for goods vehicles, (8) data for non-road modes. When these gaps are confronted with aforementioned requirements for data collection systems it is evident that there is a high demand for well structured and policy driven freight surveys. Table 1 presents selected methodologies for data collection in urban freight [1].

In general, data about urban goods movements can be collected using different techniques [31]:

- General surveys: they objective are to collect global information of generation variables and information how transport flows are generated. In most cases they have national and local coverage.
- Stakeholder specific surveys, which focus on extracting information from a given category of stakeholder, mainly establishment, shippers, retailers and freight operators. Each survey of this category refers to only one of those types of stakeholders.

Table 1. Selected data collection methodologies in urban freight

Type	Description	Application	Collection methods	Strengths	Weakness
Establishment based					
Receiver	Targets the final receivers of the shipments	Freight/freight trip demand generation models	Self-administered or staff-assisted surveys	Can provide excellent data about the goods received	Receivers are unaware of the cargo transportation aspects
Carrier	Widely used approach to collect freight data	Freight movements surveys	Based on vehicle registration samples or CATI interviews	Target population relatively easily defined. Good travel patterns data.	Questionable quality of cargo related data. Mismatch between vehicle registration list and commercial vehicle population in urban area
Shipper	Measures of sales, quantity, cost, modes, production hours, location	Commodity flow survey	Self-administered or staff-assisted surveys	Capture data on cargo, may include shipment tracking	Questionable validity about routes, intermediaries, transfer points etc. data
Vehicle based	Collect: origin, destination, trip mileage, travel time, routing, commodity, truck type, land use, activity at trip end	Trip chaining, trip generation and trip routing	Travel diaries from sample of trucks operating in the selected area May use GPS to track the routing patterns	Useful for understanding internal truck trips in an urban area	Difficult sampling process. Low response rates GPS cannot provide all data
Cordon	Collect travel pattern data: O-D at a perimeter of an area, routing patterns, truck/commodity type, vehicle/cargo weight, shipper/carrier/receiver information	Modelling/planning: O-D freight flow matrices, commodity tonnage distribution to truck classes, empty and through truck factors	Roadside postcard survey to be mailed back License plate recording/matching out to be returned	Less likely to disrupt traffic than roadside interviews, requires fewer personnel Does not disrupt traffic	Usually low response rate, which could result in significant non-response bias Lag between observation and survey reception may lead to low response rates

- Vehicle specific surveys: they follow vehicle, its usage and driver practices using different methods, such as drivers' interviews or surveys, vehicle observation, vehicle trip diaries and data from GPS.
- Area specific surveys, which focus on a defined area and are in general very descriptive. The main examples of such category of surveys are roadside interviews, parking observations and traffic counts. The latter approach is used in conjunction with the above techniques to give complementary information.

The general surveys are the most complete and complex data collection methods. These surveys are the most expensive as require significant amounts of material and human resources to survey the entire supply chain activity at an urban area. The inconvenient of global surveys is usually the lack of accuracy on urban freight operations, especially when commodity flows are surveyed on national or regional level and urban areas are considered only as a hub generating flows without detailed of their internal structure. It is also difficult to generate the interest of the stakeholders in participating in these not statutory surveys. There are new approaches to urban freight surveys specifically designed for the urban area. One of them is the survey developed in France for the FRETURB model application [26].

Stakeholders' surveys are closely related to the previous category as they can be a part of general surveys. They facilitate understanding freight transport operations within urban area. The shippers and establishment surveys provide more information on shipment and handling operations. Freight operators and service providers surveys are better in provision of information on vehicle operations while still holding data on shipment and handling operation, but sometimes with lesser quality on the latter. Those surveys are very accurate but this is followed by substantial resources demand if carried out on large scale [31]. The vehicles surveys mainly concern the behavior of fleets and vehicles in urban areas. Driver survey can give information on pick-up and delivery and shipment and GPS survey that can only identify the path taken but with high accuracy regarding routes and speeds. The area specific surveys can play complementary role in surveying urban freight movements. They help in understanding the environment in which they take place. The limit of these surveys is they do not capture organisation of transport and only give information on the use of the road network and O-D flows. Despite the limitations these surveys are still useful to understand the influence of external elements on urban freight operations.

4 Conclusions

The objective of this paper was to investigate interdependencies between urban freight demand modelling and data capture procedures in order to find which approach would be the most appropriate to start development of effective approach to urban freight issues. It may be assumed that city without experience with urban freight movements analysis has very limited information about its characteristics and its transport planning system relies on general techniques related primarily to passenger mobility. However, urban freight is one of the most complex parts of urban transportation system and requires much more reliable data to be properly understood and forecasted. The most widely used models applicable for local authorities are demand estimation models based on indicators directly related to urban freight activities such as commodity flow, vehicle flow and delivery structure. Vehicle-based models seem to be relatively the easiest in implementation due to potential accessibility of data which can be gathered without developing extensive studies. However, they do provide static insight into urban freight movements rather poorly linked to mechanism underlying demand generation. They also do not provide an opportunity to forecast changes due to implementation of freight measures. Commodity-based and delivery-based models are much better suited as a decision-aid tools for local authorities. But this comes at a price of very high input data requirements. Extensive and resource consuming surveys of each part of urban logistic chain are required (shippers, carriers and receivers) to estimate commodity types and volumes, origin-destination matrices, types of vehicles used and their routing patterns. This is why there is no unified methodology of data capture and surveys' approach varies not only between countries by also between cities in the same country, depending on funding and research objectives.

Local authorities facing problems with freight activities needs scalable support tools reflecting as much aspects of this issue as possible at acceptable cost and time of response. Despite relatively high level of complication the delivery-based models have a potential to meet this challenge. They are based on common indicator for both the receiver and the shipper which is the delivery. Data about deliveries can be obtained at an acceptable cost using somehow complicated, but still manageable direct establishment surveys complemented with on-street observations and vehicle drivers' questionnaires about trip pattern (origin and number of stops in round). A movement of vehicle (delivery or pick-up) used as main indicator may also be considered through the road occupancy as a trip and parking time, what assures the measurability of objective and possibility to compare it with existing traffic counts. When properly calibrated, the surveys' results may be transferred to other city's areas to estimate their demand for deliveries (vehicle movements) without repeating the survey. This approach gives only estimated results, but still this at acceptable level of detail for general evaluation.

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Estimating the Number of Dispatchers of a Freight Forwarding Company on the Base of Computer Simulations

Vitalii Naumov(✉)

Transport Systems Department, Cracow University of Technology, Kraków, Poland
vnaumov@pk.edu.pl

Abstract. The number of dispatchers, servicing requests for forwarding operations, determines the effectiveness of a freight forwarding company: lack of dispatchers would lead to losses of possible profits and decrease of the quality of servicing, but an excessive number of operators will generate additional costs. In this paper, the functional dependencies of technological parameters from the dispatchers' number are determined on the basis of computer simulations. Using the obtained dependencies, the mathematical model for estimation of the optimal dispatchers' number was developed.

Keywords: Freight forwarding · Dispatchers' number · Requests flow · Computer simulations

1 Introduction

A freight forwarding company acts in a macro-logistics system of the transportation market as an organizer of logistics chains used for deliveries of goods. Accordingly, the main functions of freight forwarders are receiving of requests for goods' deliveries from cargo owners and carriers, processing of these requests, searching for optimal variants for implementation of the clients' needs, selecting the participants of the delivery chain, etc. Dispatchers of a freight forwarding company are elements of the logistics system that directly implement functions of servicing the flow of incoming requests for goods' deliveries.

Freight forwarding is a complex technological process, and its management is characterized by a large number of alternatives at different stages of the decision-making process. Costs of a mistake in making a decision during freight forwarding operations are quite high, which is explained by relatively high costs of the vehicles downtime, significant possibility of cargo damages and losses of possible incomes of freight forwarders due to the declined requests. The problem of determining the optimal dispatchers' number for a forwarding company is particularly relevant in the management of logistics chains involving road transport since this segment of the transport market is characterized by the significant volatility of demand.

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_15

The goals of this paper are to present an object-oriented approach to modeling of freight forwarding operations and to propose the method for estimation of the dispatchers' number, based on the results of computer simulations.

The paper has the following structure: in the second section the most relevant problems related to freight forwarding processes are discussed; in the third part the problem of the optimal dispatchers' number estimation is stated and the respective mathematical model is proposed; the fourth section depicts a class library developed by the author for simulations of freight forwarding technological processes; the fifth part discusses the results of the simulation experiment, on which basis the dependencies of resulting characteristics from demand parameters are defined; the sixth section contains description of the proposed method for estimation of the dispatchers' number; the last part offers conclusions and directions for future research.

2 Literature Review

Freight forwarding processes include numerous technological operations of stochastics nature conditioned by random demand parameters and a variety of alternatives in the clients servicing. It causes a large number of problems related to ensuring an effective operation of forwarding companies.

The conducted review of recent publications in the field of freight forwarding management allows us to identify the most relevant problems to solve:

- forecasting of demand and the transport market situation [1, 2];
- measuring the quality of the freight forwarding services [3–5];
- optimizing the technological processes, including the provider selection [5–7], the number of suppliers estimation [8], the supply chain formation [9, 10];
- estimating an impact of different technological solutions on the performance of a freight forwarder, [5, 11–13].

The problem of estimation of the dispatchers' number could be attributed to the group of optimization tasks, however, in order to obtain proper data for the optimization model, the demand forecasting should be performed, and the estimation of the technological solutions influence on the performance and quality of forwarding operations should be provided as well.

A choice of a mathematical method depends on the problem to solve and the available data (or available resources for obtaining the data). Solving of problems related to freight forwarding processes is performed by scientists with the use of such contemporary methods of applied mathematics as artificial intelligence methods [1, 3, 14, 15], an apparatus of the decision-making theory [3, 4, 11, 12], methods of mathematical optimization [5–7, 10], etc. The mentioned approaches could be used in order to develop the freight forwarding process model which makes possible to estimate the dispatchers number: artificial intelligence methods allows researchers to consider complexity of technological processes and its stochastic nature, optimization methods yield a solution for the given initial data, and methods of the decision-making theory substantiate the proper solution.

It should be underlined that due to calculus complexity of the noted mathematical methods in most cases for their proper use, the specialized software is needed.

3 Problem Statement

The efficiency of a freight forwarding company at the market of transport services could be estimated on the grounds of technological and economic parameters: e.g., the servicing level, the total number of serviced requests, the company's profit, operational costs, profitability rate, etc. However, the most appropriate way for measuring the efficiency of freight forwarding services is to use some integral indicator, which would include a set of technological and economic indices. In the paper [13], its author mentions that forwarders select the optimal alternative concerning only the criteria related to the economic effectiveness and, as a rule, transport companies are not aware of the concept of sustainable transport and harmful effects they generate. Thus, an integral criterion of the forwarding operations efficiency should also provide some measure of the forwarding activities sustainability. As such a criterion, we propose to use a difference between the forwarding company profit and an economic expression of a harmful impact of transport on the environment:

$$E_{FF} = P_{FF} - H_E, \tag{1}$$

where: E_{FF} – criterion of the freight forwarding efficiency, \$; P_{FF} – profit of a freight forwarding company, \$; H_E – economic expression of the road transport's harmful impact on the environment.

Assuming that tariff T_{FF} for freight forwarding services is some constant (average) value per a request, the forwarder's profit could be defined in a following way:

$$P_{FF} = T_{FF} \cdot n_{sr} - (c_0 + c_d \cdot N_d), \tag{2}$$

where: n_{sr} – number of serviced requests; c_0 and c_d – constant and specific costs of freight forwarding operations, \$ and \$/dispatcher; N_d – number of dispatchers serving an incoming flow of requests.

In general, the harmful impact of transport on the environment could be defined on the basis of the total distance L_Σ covered by vehicles servicing clients of the freight forwarding company:

$$H_E = L_\Sigma \cdot c_e, \tag{3}$$

where: c_e – average specific costs of a harmful impact, \$/km.

The efficiency criterion also should reflect characteristics of production resources of a forwarding company, i.e. the number of dispatchers servicing an incoming flow. As it's defined in (2), operational costs of a forwarder depend linearly on the number of dispatchers. But also it's obvious that resulting technological parameters (number of serviced requests and the total distance) are functions of the dispatchers' number.

In such a way, the problem of estimation of the optimal dispatchers' number could be formulated as finding of such a value N_d that maximizes the following function:

$$T_{FF} \cdot n_{sr}(N_d) - L_\Sigma(N_d) \cdot c_e - c_d \cdot N_d - c_0 \to \max. \quad (4)$$

The function (4) would be considered as a known one if functional dependencies $n_{sr} = f(N_d)$ and $L_\Sigma = f(N_d)$ are defined. In order to determine these functional dependencies, computer simulations of the forwarding process should be performed.

4 Software for Simulations of the Freight Forwarding Servicing Process

For development of simulation models of interactions between the transport market participants, we propose to use a specialized class library implemented in Java programming language (its code is available at [16]). The general structure of the developed specialized class library is presented as the UML-diagram in Fig. 1.

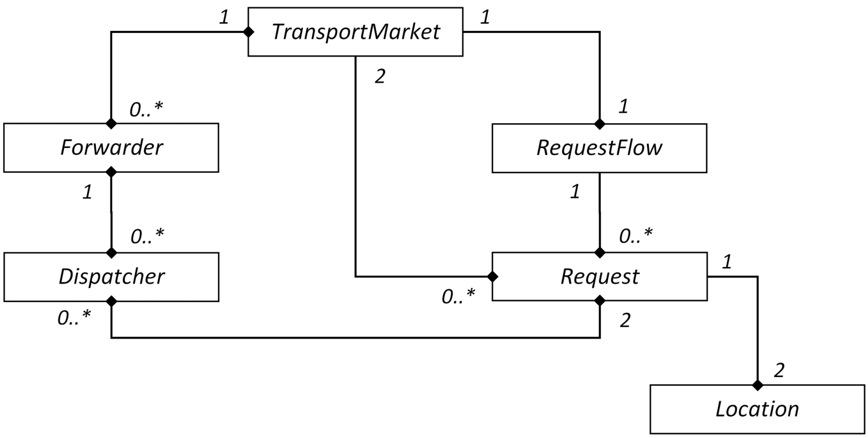

Fig. 1. UML-diagram of the developed class library

The proposed class library contains the following basic classes, which could be used by developers in order to model entities and technological operations of freight forwarding processes:

- *Request* is used for modeling of requests for freight forwarding services arriving from cargo owners;
- *RequestFlow* is a software abstraction describing demand for freight forwarding services as a stream of consecutive requests;

- *Location* is used in order to model the geographical location of cargo owners as the characteristics of requests for transport services;
- *Forwarder* allows a researcher to simulate a forwarding company as a subject of the transport market;
- *Dispatcher* is a software abstraction of the forwarding company's dispatcher servicing requests from freight owners;
- *TransportMarket* is used for development of software models of the transport market as a macro-logistics system, which elements are freight forwarders and consumers of freight forwarding services.

To model the transport market parameters as random variables (e.g., demand parameters), in the frame of the class library the Stochastic class was implemented.

The main class used for development of simulations models for processes of interactions between the transport market participants, is the *TransportMarket* class. This class is created in the model in a single instance; on its basis, the basic procedure that imitates the processes of forwarding services is launched directly.

A set of all forwarding companies at the market of transport services is defined in the model on the basis of a collection of the *Forwarder* type elements, which is defined in a single instance as a field of the *TransportMarket* class: if this collection is empty, then none of the forwarders is available at the market for servicing of clients. A model of a freight forwarding company contains a field which is a collection of all the company dispatchers involved in servicing of requests from freight owners (accordingly, if this collection is empty, then none of the dispatchers is available for servicing).

For simulations of demand for forwarding services, as a field of the *TransportMarket* class, one instance of the *RequestFlow* class is created, which, however, may not contain requests (i.e., may contain an empty list of requests – of elements of the *Request* type). For each instance of the *Request* class, two fields of the *Location* type are defined; these fields contain information about locations of the consignor and the consignee for this request.

For description of the simulation results, fields of the *TransportMarket* class are used – two collections of elements of the *Request* type: one collection contains requests serviced as the result of the model launching (this list could be empty if none of the requests was served), and the other collection contains a list of the unserved requests (accordingly, this collection could be empty if all the requests were served). During the process of simulation of the requests flow servicing, for each requests, a collection of elements of the *Dispatcher* type is specified; the collection contains models of dispatchers of different forwarding companies, who were involved in servicing of this request: if the collection does not contain items after the simulation is done, then the request remains unserved. For a dispatcher's model, during the simulation process, two fields of the *Request* type are defined; these fields contain references to a couple of requests combined into a pendulum route (if such requests were found by dispatchers). The respective procedure (a method of the *RequestFlow* class), merging requests into a route, has the following implementation:

```
public Request aPair(Request req, double aD) {
  for (Request r : this.flow) {
    if (req.getVehicleBody() == r.getVehicleBody()
     && req.getOriginPoint() == r.getDestinationPoint()
     && req.getDestinationPoint() == r.getOriginPoint()
     && Math.abs(1-r.getVolume()/req.getVolume())<=(1+aD)
     && Math.abs(1-r.getVolume()/req.getVolume())>=(1-aD)
     ) return r;
  }
  return null;
}
```

This procedure for the request, given as the first argument, searches such a paired request, which is characterized by the same body type of a vehicle and which destination is the same as the origin point of the given request, and vice versa. Furthermore, the cargo volume for the paired requests shouldn't differ more than it specified by the second argument of the method. The *aD* argument sets allowable bounds of difference between the volume of shipments for the paired requests: the lower bound of the difference is equal to $(1 - aD)$, and the respective higher bound is equal to $(1 + aD)$.

5 Simulation Experiment and Its Results

The simulation experiment was carried out in order to define dependencies of the number of serviced requests and total distance covered by vehicles from the number of dispatchers processing the requests for forwarding services. As these parameters depend on demand as well, the experiment also covered studies of demand parameters' influence on number of serviced requests and total distance.

The case of servicing a set of requests, obtained at the information logistics portal lardi-trans.com, was simulated in the experiment. A set of requests is serviced simultaneously by freight forwarders registered at the portal (more than 5 thousands of companies). As an intensity of the requests flow at lardi-trans.com is quite high (about 500 requests per minute), the servicing of the requests' sample obtained during one minute is considered. The number of available dispatchers for competing forwarding companies is taken as a random value with exponential distribution and the scale parameter equal to 1.

In the experiment, demand for road transport deliveries at the territory of Ukraine was simulated: the respective OD-matrix, the structure of the demanded vehicles' body types and distributions of the demand parameters (exponential distribution of the shipment volume up to 18 tons, lognormal distribution of the shipment volume over 18 tons and exponential distribution of the delivery term) were used for the simulations of the requests' parameters [17]. As significant numerical parameters of demand, varying in the experiment, the share δ of requests with the shipment volume less than 18 tons (equal to 0,2769) and the scale parameter λ for the stochastic variable of the delivery term (equal to 0,605 $days^{-1}$) were considered.

In the frame of the experiment, two alternatives for the requests' processing technology were examined: processing with the use of specialized software allowing dispatchers to form pendulum routes and processing without the use of the decision support tools. The duration of the request processing is taken as the normally distributed variable; for the first of the described alternatives, its location parameter equals 2 min per request, and for the manual processing – 10 min per request.

As the varying input factors of the experiment, the following parameters were considered: the number of dispatchers in the range from 1 to 20 with the step equal to 1, the share of requests with the volume under 18 tons and the scale parameter of the delivery term variable (three varying levels were considered for the demand characteristics: 80%, 100% and 120% of the nominal parameter value). In this way, the total number of series in the experiment is amounted to 180. To ensure the adequacy of the simulation data, 500 runs of the model were performed for each of the series (afterwards, the sufficiency of such a number of launches was checked for a significance level of 0,05).

On the grounds of data, obtained as a result of simulations, with the use of regression analysis, hypotheses on the linear and power-law dependence for functions $n_{sr} = f(N_d, \delta, \lambda)$ and $L_\Sigma = f(N_d, \delta, \lambda)$ were tested for each of the alternative variants of the requests flow processing.

For the requests processing with the use of specialized software, the following regression models fit the best:

$$n_{sr}^{ws} = \delta^{0,416} \cdot N_d^{0,982}, \tag{5}$$

$$L_\Sigma^{ws} = 302,921 \cdot \delta^{0,365} \cdot N_d^{0,994}. \tag{6}$$

In the case of processing without software, the respective models look as follows:

$$n_{sr}^{ns} = \delta^{0,501} \cdot \lambda^{0,066} \cdot N_d^{0,979}, \tag{7}$$

$$L_\Sigma^{ns} = 266,654 \cdot \delta^{0,366} \cdot N_d^{0,991}. \tag{8}$$

The obtained models are characterized by the determination coefficient values higher than 0,99, so they could be considered as functional dependencies. However, it should be mentioned that obtained models are valid only for conditions of Ukrainian market of transport services. For other markets, the simulations must be performed for the respective demand parameters and the regression coefficients should be estimated on the grounds of the obtained results.

6 Model for Estimation of the Dispatchers' Number

Using the obtained regression models, the efficiency criterion (1) as a function from the dispatchers number could be calculated. The case with numeric parameters typical for the transport market of Ukraine is presented in Fig. 2.

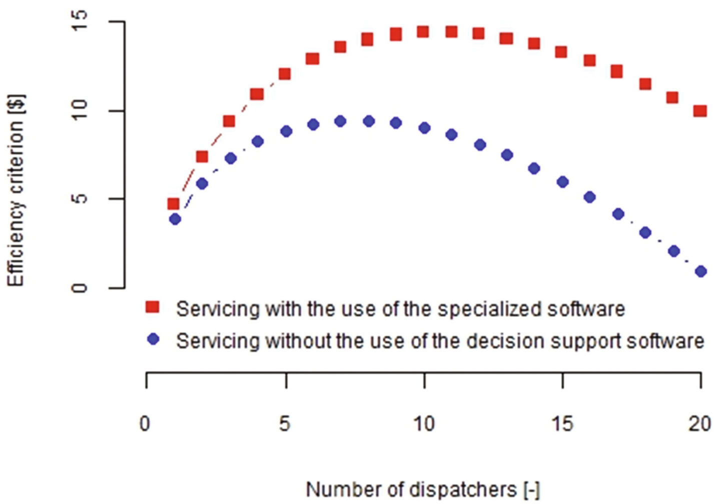

Fig. 2. Dependence of the proposed efficiency criterion from the dispatchers' number

As it's shown in Fig. 2, the function $E_{FF}(N_d)$ has an extremum which characterizes its maximum. Thus, the optimal dispatchers' number should be defined as an argument of the extreme value of the function and could be determined as a root of the following equation:

$$\frac{\partial E_{FF}}{\partial N_d} = 0. \tag{9}$$

Differentiating function (4) for the variants of servicing with the use of decision support software and without it, we obtain the following respective equations:

$$\frac{0,982 \cdot T_{FF} \cdot \delta^{0,416}}{N_d^{0,018}} - \frac{301,06 \cdot \delta^{0,365} \cdot c_e}{N_d^{0,006}} - c_d = 0, \tag{10}$$

$$\frac{0,979 \cdot T_{FF} \cdot \delta^{0,501} \cdot \lambda^{0,066}}{N_d^{0,021}} - \frac{264,36 \cdot \delta^{0,366} \cdot c_e}{N_d^{0,009}} - c_d = 0. \tag{11}$$

The equations given above could be solved with the use of any of the known numerical methods, for example, using the Newton method. For the situation shown in Fig. 2, the integer root for the Eq. (10) would be equal to 10 (the case of processing with the use of supporting software), and for the Eq. (11) – 8 (the case of processing without decision-supporting tools).

7 Conclusions

The proposed efficiency criterion of freight forwarding services includes a set of resulting technological and specific economic indices. It reflects the features of the forwarding process, thus, it could be used for estimating the optimal number of dispatchers involved in the requests flow processing.

The developed class library could be used for the creation of simulation models of interactions between the transport market participants. The models developed with the use of the presented library would allow researchers to consider stochastic nature of the transport demand and random parameters of the forwarding technological operations.

The obtained regression models could be considered as functional dependencies of the serviced requests number and total distance covered by vehicles from the number of dispatchers servicing the requests because these models are characterized by the determination coefficient values higher than 0,99.

A dependence of the proposed efficiency criterion from the dispatchers' number is a function that has an extremum characterizing its maximum. Thus, the optimal number of a forwarding company dispatchers should be defined as an argument of the extreme value of this function.

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Open Street Map as a Source of Information for a Freight Transport Planning System

Grzegorz Sierpiński(✉)

Faculty of Transport, Silesian University of Technology, Katowice, Poland
grzegorz.sierpinski@polsl.pl

Abstract. Route planning systems are indispensable means of support for freight transport. Combing deliveries into chains and route optimisation provide grounds for efficient transport. In order to be able to find optimum solutions, travel planners require being fed with external data in large volumes. This article is an attempt to identify the capabilities of Open Street Map (OSM) used as source of information. Utility of this database is often limited to the transport network itself. This article provides numerous examples showing how the functionality of a freight transport planner may be expanded owing to OSM data. It is the specific and pre-defined data storage standard that contributes to the universal nature of the data which can be used in different parts of the world. However, it should also be noted that even though the standard generally applies, some features of individual areas have not yet been properly developed (which is where one must rely on other data sources).

Keywords: Open street map · Freight transport planning · Open data sources

1 Introduction

Transport efficiency may be increased through route planning. Travel planners should follow a multi-criteria approach to the problem in question, suggesting the available optimum solutions against specific input data. The criteria primarily taken into consideration by various route planning systems are those of distance and time [1, 2]. Some less popular criteria include costs and environmental impact [3–5]. With regard to freight transport, route optimisation should also encompass seeking the best attainable sequence (order) of transfers to be made in the chain of deliveries. What also proves important for companies running a fleet composed of different vehicle types is an optimum choice of vehicles against specific commodity groups. Where the latter is the case, one typically seeks an optimum alternative between using a smaller number of larger vehicles and a larger number of smaller vehicles (which, depending on the input criteria, may translate into disparate final results).

Besides the user (transport company) defined data, also other sources of information as well as their availability are growing in importance. A considerable obstacle one may encounter in this respect is the lack of pre-defined standards in different information systems. Every route planning system makes use of its own data sources which are not compatible with other systems. These data may include results of extensive transport studies covering a specific territory or road solution type (see [6–9] among

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_16

others) as well as information acquired directly from vehicles (see [10–16] among others) and subsequently accumulated and converted into formats which the planner can read. The basic set of data required to initiate the process of seeking an optimum solution (i.e. setting a transfer route) comprises the transport network and its parameters [17]. Other important input elements include, for instance, address database items, information concerning locations of various points of interest (POI) etc.

The solution proposed in this article is to use data from Open Street Map (OSM) [18], being an abundant source of information for the route planning systems used in freight transport. Individual options of using the chosen OSM features have been identified in the paper. Following further analyses, also specific weakness and deficiencies which, in spite of the OSM capabilities, lack sufficient data have been highlighted.

The conclusions provided in the article constitute partial results of the international project entitled "Smart platform to integrate different freight transport means, manage and foster first and last mile in supply chains (S-MILE)" [19] implemented under the ERA-NET Transport III Sustainable Logistics and Supply Chains programme and co-financed by the National Centre for Research and Development.

2 Opportunities for Using OSM Information in Freight Transport Planners

Open Street Map is a free-of-charge source of data on geographic locations, developed by volunteers from all over the world. What proves to be the main advantage of its map over other data sources is primarily the high frequency of updates (Fig. 1), but also the uniform global standard of data storage.

Fig. 1. Map validity comparison (the roundabout was commissioned at the end of 2016): (**a**) OpenStreetMap, (**b**) GoogleMaps, (**c**) car navigation system map updated in March 2017 (no roundabout) (*source*: own research based on [20, 21])

Table 1 summarises the most useful features for different OSM components which may find practical application depending on the specificity of the freight transport planning system. Besides the basic characteristics directly connected with the transport network, also other properties considered relevant and contributing to the efficiency of route planning have been described. Some of the following features may also prove useful when planning courier freight of smaller size cargo. Others, in turn, will be considered important for vehicles transporting large-size goods using pallets.

Table 1. Features of OSM components and their usefulness in freight transport planning (*source*: own research based on [22])

Name of OSM feature	Meaning	Capacity to be used in freight transport planning
`highway` (limited to road types)	Determines the road type for linear data (road sections)	Basic variable used for route planning, related to time-based optimisation. Every road type corresponds to different generally defined speed limits and different route standards (e.g. lower rank roads, dirt roads –track)
`crossing`	Determines locations of intersections between a walking path and a vehicle traffic road	Having identified such locations, one can set routes involving minimised risk of collisions with pedestrians
`mini_roundabout`	Identifies mini-roundabout intersections (with a painted circle at the centre)	From the route planning support perspective, such intersections are difficult to pass for larger lorries
`traffic_signals`	Location of traffic lights	The feature enables planning of routes with minimised number of traffic lights on the way (which may decrease delivery time)
`Barrier` (different values/types):	Location of road barriers of different types (four examples below)	Information about barriers enhances route planning
`bollard`	Prevents cars from passing, but at the same time, it does not deny passage to persons on foot or using bicycles	Insufficient information in this respect may cause incorrect route planning. The above data also make it easier to pick the right vehicle type for a specific group of deliveries
`height_restrictor`	Restricts passage to vehicles of specific height	
`lift_gate`	Restricts access (gate)	
`sump_buster`	Restricts passage to vehicles of specific minimum wheel base	
`charge`	Defines the required tool amount	The feature is particularly important when planning routes by following the cost criterion

(*continued*)

Table 1. (*continued*)

Name of OSM feature	Meaning	Capacity to be used in freight transport planning
maxheight maxlength maxwidth maxweight	Features which limit the available options depending on vehicle dimensions and weight	The information is crucial when planning transport, as it makes it possible to choose appropriate vehicles types for specific routes or to avoid a section with restrictions
maxspeed minspeed	Features which set the upper and lower running speed threshold	Relevant when planning routes in line with the time criterion
maxstay	Waiting time restriction	The parameter is particularly important for freight transport on account of the required unloading time
parking parking_space parking_entrance motocycle_parking parking:condition	Parking area location, respectively for all vehicles and for motorcycles only	When transporting smaller parcels by courier services, this parameter makes it easier to plan a route by locating parking places next to successive destination points (delivery addresses) Additionally, the latter feature may help establish if parking is paid
charging_station fuel	Location of a charging or a petrol station	Relevant when planning routes, particularly for electric cars. A charging station on the way can extend the route and enable a larger number of deliveries to be made with one-time vehicle loading (without having to return to the departure point)
protected_area	Sets boundaries of a protected area	The information proves useful when choosing means of transport, since a protected zone is often access-restricted depending on the vehicle size or emission parameters
access	Defines accessibility for a specific group, e.g. of vehicles	
building	Feature defining a building type	Building type may be of relevance when applying the heuristic approach to seeking routes for courier services
office (different values/types)	Place of business activity	Feature which makes it possible to plan transport by grouping shipments according to pre-set business activity types

3 Selected Examples of OSM Data Deficits

The data storage standard established for OSM makes it possible to define an abundance of infrastructure elements within a selected area and set characteristics of individual structures at the same time. Unfortunately, due to the nature of the OSM initiative (it is a public initiative, where users from all over the world can enter data into maps), one must be aware of two risks when using the map. The first one concerns validity of individual pieces of information. In this respect, specific procedures have been implemented under the OSM initiative, and by way of a multi-stage supervision, they make it possible to minimise the number of invalid information being entered. Depending on the area, data accuracy may very closely correspond to the reality. OSM data have been assessed for various regions of the globe (see [23–27], among others). Bearing in mind that the number of objects in the OSM database is above 4 billion, and the number of roads alone approaches 400 million [28], one may claim that the error is not significant on a global scale. The second issue is the lack of complete information about numerous territories. The basic layer of information available on the map, i.e. the transport network represented as sections of roads with assigned capacity for automotive vehicle, pedestrian or bicycle access, has been prepared very meticulously. The foregoing results from the fact that OSM maps are primarily used by different navigation programs (more and more frequently by those running on Android mobile phones). However, deficiencies are clearly noticeable for other (more specific) features of the picture displayed. Selected examples of incomplete information retrieved from OSM have been described below. The first one pertains to information being important for travel time estimation and application of the time criterion in travel planning. In this respect, the maxspeed feature is undefined for many road sections covered by OSM. Percentage rates for three chosen territories have been compared in Table 2. On a global scale, only 7% of sections with the highway attribute have been assigned the maxspeed feature [29], however, the intensity with which the speed limit parameter is applied in not uniformly distributed. One should bear in mind that, in a majority of cases, the absence of a value assigned to this feature means that there is no local speed limit for the given road section. The relevant sections also include walking paths. In the event that there is no feature determining the speed limit, travel planning systems apply a generalisation by defining the maxspeed parameter as equal to the permissible speed for the given road type set as highway. Route planning is possible in such cases, yet the results the system delivers may be encumbered with inaccuracy resulting from the potential local speed limitations.

Table 2. Comparison of percentage shares of road sections with the maxspeed feature defined against the given territory's entire network (*source*: own research based on data from [20])

Territory	Percentage share of road section with pre-set maxspeed
Berlin (Germany)	24.17%
Amsterdam (Netherlands)	24.11%
Dortmund (Germany)	15.44%
Budapest (Hungary)	14.09%
Paris (France)	14.05%
Silesian Province (Poland)	7.96%
Tokyo (Japan)	3.85%

Another example of incomplete information is connected with locations of electric car charging stations (feature charging_station). The OSM data source has been compared for several cities with other available data (EV-Charging Stations in Europe [31] and PlugShare [32]). Figure 2 show significant deficiencies in this respect for some municipal areas (e.g. Amsterdam and Dortmund), which may effectively limit the future utility value of OSM maps on account of the trend characterising the development of transport systems oriented towards e-mobility [33, 34]. At the same time, it should be noted that this deficiency does not pertain to all cities. The cases of Berlin and Budapest prove high accuracy of data.

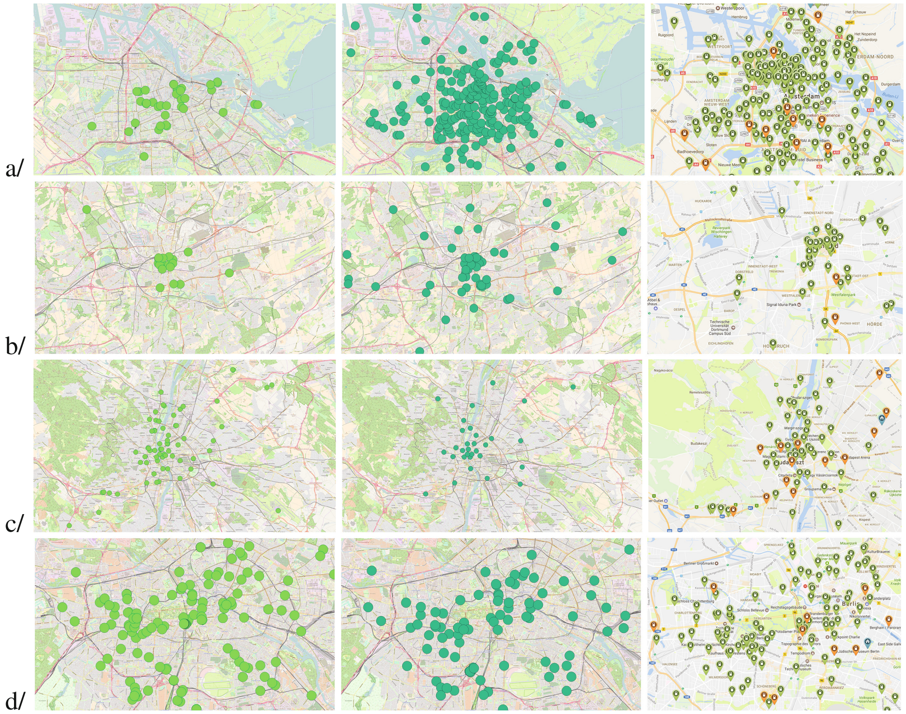

Fig. 2. Comparison of three data sources in terms of locations and number of charging stations (OpenStreetMap, EV-Charging Stations in Europe and PlugShare): (**a**) Amsterdam (Netherlands), (**b**) Dortmund (Germany), (**c**) Berlin (Germany), (**d**) Budapest (Hungary) (*source*: own research using QuantumGIS based on data from [18, 31, 32])

The OSM database may also contain formal errors arising from incorrect information entry, and these may include the following examples:

- no connection between a road section and other transport network sections,
- area not closed,
- unnamed POIs (Points of Interest),
- intersections without a junction assigned,
- duplicated elements etc.

Errors such as these often result from inappropriate information entry by users and are gradually eliminated by more experienced persons. On account of the popularity of OSM [35], special information websites have been established to enable identification of selected errors in the current OSM database (e.g. KeepRight [36] shown in Fig. 3).

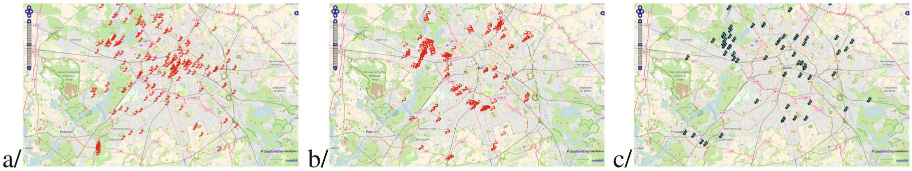

Fig. 3. Errors and deficiencies in the OSM data covering the vicinity of Berlin (Germany): (**a**) intersection without a junction, (**b**) missing values of the maxspeed feature, (**c**) duplicated information (*source*: own research using [36])

4 Conclusions

A route planning system dedicated to freight transport requires information whose scope extends beyond that used by traditional navigation systems. In this respect, one should mind the larger number of optimisation criteria as well as their simultaneous application. There is also a need for combining deliveries into chains, thus triggering further specific needs pertaining to information about the given area and the structures it contains. The studies addressed in the article, exploring the potential of OpenStreetMap to be used as a source of information, have revealed numerous advantages offered by this solution. The OSM system features a pre-defined data structure, and this assumption allows for its universal application regardless of the location in the world. The multitude of features which can be entered in the OSM standard is yet another undeniable benefit. OSM has been designed as a transparent and frequently updated database which also ensures sufficient accessibility of documentation. Nevertheless, the article has also highlighted certain flaws of this information source. Despite having a suitable standard deployed, data available for many territories are limited to the mere transport network layout. To recapitulate the foregoing, it may be claimed that OSM can function as the basic data source for route planning systems intended for freight transport. However, when it is to be applied on a broader scale, one should consider the necessity for complementary sources of local information to be added to a system being developed. The missing information may also be fed into the system by means of data processing programs dedicated to the OSM standard (e.g. JOSM [37]).

Further research works are planned to increase the number of utility features of the freight transport route planning system discussed in the paper and to perform a case study for several chosen areas where the problem of data completeness will be investigated.

Acknowledgements. The present research has been financed from the means of the National Centre for Research and Development as a part of the international project within the scope of ERA-NET Transport III Programme "Smart platform to integrate different freight transport means, manage and foster first and last mile in supply chains (S-MILE)".

The National Centre for Research and Development

S mile

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Optimization of Multimodal Transport Technologies Selection for Packed Non-climacteric Vegetables and Fruits

Paweł Leleń and Mariusz Wasiak(✉)

Faculty of Transport, Warsaw University of Technology, Warsaw, Poland
{plelen,mwa}@wt.pw.edu.pl

Abstract. Optimizing the selection of transport technology for transport tasks is of particular importance while the improper technology can lead to significant reduction in safety of transported cargoes or in extreme cases to loss of cargo and reduces transport efficiency. This issue is particularly important for perishable products and cargoes. Up until now, there have not been developed any optimization tasks of the selection of multimodal transport technologies for perishable products that would adequately address the transportability of cargo. This paper presents the optimization task for the selection of multimodal transport technologies for perishable products on the example of non-climacteric fruits and vegetables carried in gas, light and liquid impermeable packaging. The task takes into account the criterion of maximizing cargo safety and the criterion of minimizing transport costs. The solution of the exemplary problem of technology selection o with the proposed optimization task is presented.

Keywords: Perishable cargoes · Optimization in transport · Selection of transport technology · Multimodal transport

1 Introduction

Up to 35% of worldwide food production, which is a primary group of perishable cargoes, reach recipient with reduced quality and not meeting the requirements of the final customer or even spoiled. In many cases, the direct cause of food spoilage is improper transport technology, and in particular the failure to take into account the characteristics and requirements of perishable goods [1].

Selection of transport technologies should be done in a way guaranteeing safety of transported goods and ensuring efficiency of transport [2]. Appropriate choice of coupling technologies with a specific groups of products requires considering their characteristics and properties. The transportability is a property of a high importance for all groups of products. So called natural transportability related to physical and chemical characteristics of carried materials is particularly important in case of perishable foodstuff. The transportability was introduced as crucial for transport technology selection as early as 1949 by C. Pirath [3]. Pirath didn't attempt to prescribe it by numerical values. Afterwards, transportability was addressed in numerous publications. Often, despite the authors underlined the importance of proper setting cargo

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_17

transportability while selecting transport technologies, they didn't try to define it in quantitative way [4, 5]. First attempts to numerical description of transportability were undertaken by Madeyski [6], Bogdanowicz [7], and Tylutki [8]. Nevertheless, so far proposed indexes are very general and in some cases are not related directly to transport but for other areas like geology [7]. So far developed models for the design of perishable products supply chains have been very detailed in terms of cost analysis, vehicle designation or vehicle selection [9–11]. None of the papers offers the detailed analysis of cargo transportability under optimization of selection of transport technology for perishable foodstuff. Considering this fact, attempts were made to formulate optimization tasks for the selection of transport technologies for perishable cargoes with particular regard to their transportability. Perishable cargoes are specific according to the fact that their characteristics and properties encourage a significant or total loss of usefulness due to improper composition of surrounding atmosphere, lack of adequate airflow, light and sunlight or too long carriage [12, 13].

It was assumed that perishable cargoes comprise all those which allowable carriage and storage time, notwithstanding the implementation of appropriate conditions, is no longer than 185 days. The presented author's optimization task can be used to select transport technologies for particular groups of perishable cargoes, including fragile food products, medicines, etc. In this paper we consider non-climacteric vegetables and fruits portioned and packed into packaging impermeable for gases, light and fluids. Proposed optimization task includes selected features of perishable cargoes that fundamentally influence their transportability. It also uses selected parameters of transport forms (loading units) determining transportability of cargoes [12–15]. The requirements for international transport of perishable food products are set out in the Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be used for such Carriage (ATP). In this document the temperature of the immediate vicinity of the load is considered as the most important parameter to be observed when transporting perishable products. Therefore, this temperature cannot be neglected when designing the transporting technology for perishable products. The ATP Agreement also notes the permissible carriage time, which should also be considered while selecting transport technology for all perishable product groups. The permissible carriage time can be determined only when remaining requirements for atmospheric parameters in the immediate vicinity of the cargo are met, and when acceptable static and dynamic effects on cargoes are not exceeded [16, 17].

In addition to the above, the parameters of the humidity in the immediate vicinity of the cargoes are very important. Too low air humidity in the immediate vicinity of the cargoes causes excessive water loss from the products and in many cases leads to product deterioration. On the other hand, too high humidity leads to water absorption by cargoes or the accumulation of water droplets on the surface of cargo. As a result of these phenomena excessive breeding of microbes leading to microbial spoilage of transported products can occur. Excessive humidity fluctuations expedite spoilage of products and contribute to a significant reduction in the acceptable time of carriage and the quality of the delivered products. The sensitivity to ethylene and the volume of production of this gas is very important for the group of perishable products.

The presence of this element in the surroundings of cargoes sensitive to its effect causes a gradual decrease in the quality of these products. Additionally, the task complies with the fact that most of perishable cargoes are the groceries intended for human consumption. Therefore, when selecting transport technologies, the potential contamination of cargoes by other substances or risk of cargo deterioration must be minimized since it will have negative consequences for consumer's life and health.

2 Optimization Task of Selecting Multimodal Transport Technologies for Perishable Cargo

2.1 Input Data

It was assumed that set $\boldsymbol{B} = \{1, \ldots, b, \ldots, B\}$ of types of perishable cargoes is given. The characteristics of cargoes include: dimensions of cargo packaging $w_{bx}(b)$, $w_{by}(b)$, $w_{bz}(b)$, weight $m_b(b)$ and cubic capacity $V_b(b)$, as well as cryoscan temperature $t_{kr}(b)$, maximal temperature $t_{\max}(b)$, minimal temperature $t_{\min}(b)$, permissible temperature fluctuations $\Delta t_{dop}(b)$, permissible time of transport and storage $t_{pt}(b)$, permissible pressure on the package surface from static effects $f_{\max}(b)$ and from dynamic effects $f_{\max d}(b)$ and unit price of cargo $k_b(b)$. Due to the fact that the packaging is a barrier to a light, water and gases, the characteristics of fruits regarding the light and water resistance as well as the atmosphere composition, including air humidity, are not taken into account. In such a way, the set of characteristics of types of perishable cargoes $\mathbf{F_B}$ is defined as follows:

$$\boldsymbol{F_B} = \{(w_{bx}(b), w_{by}(b), w_{bz}(b), m_b(b), V_b(b), t_{kr}(b), t_{kr}(b), t_{\max}(b), t_{\min}(b),\\ \Delta t_{dop}(b), t_{pt}(b), f_{\max}(b), f_{\max d}(d), k_b(b)) : b \in \boldsymbol{B}\}$$

Moreover, it was assumed that the set of transport forms (loading units) $\boldsymbol{P} = \{1, \ldots, p, \ldots, P\}$ is given. Characteristics of loading units include: particular external dimensions $w_{px}(p)$, $w_{py}(p)$, $w_{pz}(p)$, cubic capacity $V(p)$ and dimensions of space available for cargo $w_{lx}(p), w_{ly}(p), w_{lz}(p)$, as well as privileged dimensions of cargo $w_{lxp}(p), w_{lyp}(p), w_{lzp}(p)$, cubic capacity available for cargo $V_p(p)$, resistance to static effects $f_{p\max}(p)$ and to dynamic effects $f_{p\max d}(p)$, maximum ambient temperature of cargo $t_{\max p}(p)$, minimal ambient temperature of cargo $t_{\min p}(p)$, maximal temperature fluctuations $\Delta t_{rzp}(p)$ and the possibility of its regulation $w_t(p)$. Therefore, the set of characteristics of transport forms $\boldsymbol{F_P}$ is defined as follows:

$$\boldsymbol{F_P} = \{(w_{px}(p), w_{py}(p), w_{pz}(p), f_{p\max}(p), f_{p\max d}(p), w_t(p), t_{\min p}(p), \Delta t_{rzp}(p), t_{\max p}(p),\\ m_p(p), Q(p), V(p), w_{lx}(p), w_{ly}(p), w_{lz}(p), w_{lxp}(p), w_{lyp}(p), w_{lzp}(p), V_p(p)) : p \in \boldsymbol{P}\}$$

The set of types of means of transport is defined as $\boldsymbol{U} = \{1, \ldots, u, \ldots, U\}$ and it is decomposed to the sets of types of vehicles $\boldsymbol{U}1$ and types of loading devices $\boldsymbol{U}2$.

The characteristics of vehicles include expected maximal $t_{\max r}(u)$ and minimal $t_{\min r}(u)$ temperature, maximal temperature fluctuations $\Delta t_{rz}(u)$, dimensions of available cargo space $w_{ux}(u), w_{uy}(u), w_{uz}(u)$ and privileged dimensions of loading units $w_{uxp}(u)$,$w_{uyp}(u), w_{uzp}(u)$, permissible loading capacity $Q_{dop}(u)$, maximal space available for cargoes $V_{dop}(u)$, as well as unit costs of operation related to distance travelled $k_{ts}(u)$, unit costs related to the worktime $k_{tt}(u)$, costs related to exposure to damage due to static effects $f_{u1\max}(u)$ and dynamic effects $f_{u1\max d}(u)$. Additionally, the set of work resources which can cooperate with the device $\boldsymbol{UU}(u)$, set of served loading units $\boldsymbol{P}_{U1}(u)$ and set of workplaces required for servicing particular devices $\boldsymbol{LSP}(u)$ are defined. Consequently, the set of characteristics of vehicles $\boldsymbol{F}_{U1}$ is defined as follows:

$$\begin{aligned}\boldsymbol{F}_{U1} = \{(&t_{\min r}(u), t_{\max r}(u), \Delta t_{rz}(u), Q_{dop}(u), V_{dop}(u), w_{ux}(u), w_{uy}(u), w_{uz}(u), w_{uxp}(u), w_{uyp}(u)\\ &w_{uzp}(u), v_{sr}(u), k_{ts}(u), k_{tt}(u), f_{u1\max}(u), f_{u1\max d}(u), \boldsymbol{UU}(u), \boldsymbol{P}_{U1}(u), \boldsymbol{LSP}(u)) : u \in \boldsymbol{U}1\}\end{aligned}$$

Significant features of loading devices comprise: maximum lifting capacity/load capacity $F_Q(u)$, theoretical yield $W(u)$, coefficient correcting the theoretical yield $g_t(u)$, unit (hourly) cost of work $k_{j2}(u)$, the highest permitted static effects $f_{u2\max}(u)$ and dynamic effects $f_{u2\max d}(u)$ on which the cargo is exposed, maximal dimensions of cargo unit on which loading operations can be performed $w_{u2x}(u)$, $w_{u2y}(u), w_{u2z}(u)$, privileged dimensions of cargos $w_{u2xp}(u), w_{u2yp}(u)$,$w_{u2zp}(u)$. The set of supported transport forms is defined as $\boldsymbol{P}_{U2}(u)$ and workplaces to be filled as $\boldsymbol{LSP}(u)$. In such a way, the set of characteristics of loading devices $\boldsymbol{F}_{U2}$ is defined as follows:

$$\begin{aligned}\boldsymbol{F}_{U2} = \{(&F_Q(u), W(u), g_t(u), k_{j2}(u), \boldsymbol{P}_{U2}(u), f_{u2\max}(u), f_{u2\max d}(d), f_{u2\max d}(d),\\ &\boldsymbol{LSP}(u), w_{u2x}(u), w_{u2y}(u), w_{u2z}(u), w_{u2xp}(u), w_{u2yp}(u), w_{u2zp}(u)) : u \in \boldsymbol{U}2\}\end{aligned}$$

Then, it was assumed that set of human-work categories is described as $\boldsymbol{L} = \{1, \ldots, l, \ldots L\}$. Appropriate unit costs of work of workers of particular categories $k_l(l)$, and possible assignment to specific workplaces $\boldsymbol{SLU}(l)$, are defined. Set of characteristics of categories of workers is defined as $\boldsymbol{F_L} = \{k_l(l), \boldsymbol{SLU}(l)) : l \in L\}$.

Model includes also the set of transport paths $\boldsymbol{T} = \{1, \ldots, t, \ldots T\}$ characterized by their length $s(t)$, set of means of transport that can operate on them $\boldsymbol{TU}(t)$, as well as charges for using the infrastructure $k_{dod}(t, u)$. Then, set of characteristics of transport paths is defined as follows $\boldsymbol{F_T} = \{(s(t), \boldsymbol{TU}(t), k_{dod}(t, u)) : t \in \boldsymbol{T}, u \in \boldsymbol{U}$.

It was also assumed that the set of transport tasks – to which optimal multimodal technologies are – selected is defined as $\boldsymbol{Z} = \{1, \ldots, z, \ldots, Z\}$. Each transport task is described by set of cargoes types $\boldsymbol{B}(z)$, set of weights of cargoes $\boldsymbol{M}(z)$, origin place $m_p(z)$ and destination point $m_d(z)$, required loading time $t_p(z)$ and delivery deadline $t_d(z)$, set of numbers of accepted types of loading units $\boldsymbol{P}(z)$, and set of types of means of transport that can be engaged to perform transport task $\boldsymbol{U}(z)$.

Multimodal technologies are represented by set of numbers of technologies $\boldsymbol{D} = \{1, \ldots, d, \ldots, D\}$. Each technology was depicted as a technological process $PT(d)$ composed of ordered fives for each e-th operation (type of cargo transport form $pt_e(d)$, type of operation $nt_e(d)$, transport path $tt_e(d)$, set of accepted means of transport

$\boldsymbol{UT_e}(d)$ and set of work categories $\boldsymbol{LT_e}(d)$ which can be assigned to the operations). According to that the technological process can be defined as follows:

$$PT(d) = \langle (pt_e(d), nt_e(d), tt_e(d), \boldsymbol{UT_e}(d), \boldsymbol{LT_e}(d)) : e \in \boldsymbol{I}(d), pt_e(d) \in \boldsymbol{P}$$
$$tt_e(d) \in \boldsymbol{T}, \boldsymbol{UT_e}(d) \subseteq \boldsymbol{U}, \boldsymbol{LT_e}(d) \subseteq \boldsymbol{L} \rangle, d \in \boldsymbol{D}$$

2.2 Decision Variables

Three types of decision variables are determined in the problem. Variables are interpreted as assignment of transport technologies to particular transport tasks, types of transport means assigned to particular tasks within selected technology, and work categories assigned to serve selected means of transport. Waiving last two types of variables would simplify the formal form of the model, but it would require preparation of significantly more variants of technology. Hence, such an approach was abandoned. And that's because such a model – unlike the developed one – would be difficult to accept in practical applications.

Given binary variables are defined as follows:

$$x(z, d) = \begin{cases} 1, \\ 0, \end{cases}$$

where: when $x(z, d) = 1$ then z-th transport task must be realized under d-th transport technology, and when $x(z, d) = 0$, otherwise.

$$y(z, d, e, u) = \begin{cases} 1, \\ 0, \end{cases}$$

where: when $y(z, d, e, u) = 1$, then e-th operation of z-th transport task performed under d-th transport technology must be done by u-th mean of transport, and when $y(z, d, e, u) = 0$, otherwise.

$$z(z, d, e, u, lsp(u), l) = \begin{cases} 1, \\ 0, \end{cases}$$

where: when $z(z, d, e, u, lsp(u), l) = 1$ then e-th operation of z-th transport task under d-th transport technology performed by u-th mean of transport on $lsp(u)$-th workplace must be served by worker of l-th work category, and when $z(z, d, e, u, lsp(u), l) = 0$, otherwise.

2.3 Constrains

Depending on the nature of the problem, and in particular the type of perishable cargo, a number of constraints must be taken into account. Constrains result from the physical and chemical properties of cargoes, characteristics of loading units, characteristics of multimodal transport technologies, and transport tasks. For selected groups of perishable cargoes, some restrictions may not be taken into account, which simplifies the problem. This article discusses non-climacteric vegetable and fruit groups in impermeable for gases, light and fluids packages. There are no significant constraints associated with a range of atmospheric parameters in the immediate vicinity of the cargoes like maximum and minimum humidity and its possible changes, composition of the atmosphere, or the possibility of removing ethylene from the cargo space. Also, constrains protecting cargoes from sunlight, water, and cargo leaks are not included.

Taking into account above, assumptions constraining optimization of selection of multimodal transport technology for analyzed case are defined as follows:

$$\bigwedge_{z \in \boldsymbol{Z}} \sum_{d \in \boldsymbol{D}(z)} x(x,d) = 1 \tag{1}$$

$$\bigwedge_{z \in \boldsymbol{Z}} \bigwedge_{d \in \boldsymbol{D}(z)} \bigwedge_{e \in \boldsymbol{I}(d):\boldsymbol{UT_e}(d)=\varphi} \sum_{u \in \boldsymbol{UT_e}(d)} y(z,d,e,u) = x(z,d) \tag{2}$$

$$\bigwedge_{z \in \boldsymbol{Z}} \bigwedge_{d \in \boldsymbol{D}(z)} \bigwedge_{e \in \boldsymbol{I}(d):\boldsymbol{UT_e}(d)=\varphi} \bigwedge_{lsp(u) \in \boldsymbol{LSP}(u):u \in \boldsymbol{UT_e}(d)} \sum_{l \in \boldsymbol{SUL}(u,lsp(u))} z(z,d,e,u,lsp(u),l) = x(z,d) \tag{3}$$

$$\bigwedge_{z \in \boldsymbol{Z}} \bigwedge_{d \in \boldsymbol{D}(z)} \bigwedge_{e \in \boldsymbol{IP}(d)} \bigwedge_{u \in \boldsymbol{U1} \cap \boldsymbol{U}(z) \cap \boldsymbol{UT_e}(d)} t_{\min r}(u) \cdot [1 - w_t(pt_e(d))] + t_{\min p}(pt_e(d)) \cdot w_t(pt_e(d)) > y(z,d,e,u) \cdot \max_{b \in \boldsymbol{B}(z)} \{t_{\min}(b)\} \tag{4}$$

$$\bigwedge_{z \in \boldsymbol{Z}} \bigwedge_{d \in \boldsymbol{D}(z)} \bigwedge_{e \in \boldsymbol{IP}(d)} \bigwedge_{u \in \boldsymbol{U1} \cap \boldsymbol{U}(z) \cap \boldsymbol{UT_e}(d)} y(z,d,e,u) \cdot [t_{\max r}(u) \cdot [1 - w_t(pt_e(d))] + t_{\max p}(pt_e(d)) \cdot w_t(pt_e(d)] \le \min_{b \in \boldsymbol{B}(z)} \{t_{\max}(b)\} \tag{5}$$

$$\bigwedge_{z \in \boldsymbol{Z}} \bigwedge_{d \in \boldsymbol{D}(z)} \bigwedge_{e \in \boldsymbol{IP}(d)} \bigwedge_{u \in \boldsymbol{U1} \cap \boldsymbol{U}(z) \cap \boldsymbol{UT_e}(d)} y(z,d,e,u) \cdot [\Delta t_{rz}(u) \cdot [1 - w_t(pt_e(d))] + t_{rzp}(pt_e(d)) \cdot w_t(pt_e(d)] \le \min_{b \in \boldsymbol{B}(z)} \{t_{dop}(b)\} \tag{6}$$

$$\bigwedge_{z \in \boldsymbol{Z}} \bigwedge_{d \in \boldsymbol{D}(z)} \bigwedge_{e \in \boldsymbol{IL}(d)} \bigwedge_{u \in \boldsymbol{U2} \cap \boldsymbol{U}(z) \cap \boldsymbol{UT_e}(d)} \max\{f_{p\max d}(pt_e(d)); \min_{b \in \boldsymbol{B}(z)} \{f_{\max d}(b)\} \ge y(z,d,e,u) \cdot f_{u2\max d}(u) \tag{7}$$

$$\bigwedge_{z \in \mathbf{Z}} \bigwedge_{d \in \mathbf{D}(z)} \bigwedge_{e \in \mathbf{IP}(d)} \bigwedge_{u \in \mathbf{U1} \cap \mathbf{U}(z) \cap \mathbf{UT_e}(d)} \max\{f_{p\max d}(pt_e(d)); \min_{b \in \mathbf{B}(z)} \{f_{\max d}(b)\} \ge y(z,d,e,u) \cdot f_{u1\max d}(u) \tag{8}$$

$$\bigwedge_{z \in \mathbf{Z}} \bigwedge_{d \in \mathbf{D}(z)} \bigwedge_{e \in \mathbf{IL}(d)} \bigwedge_{u \in \mathbf{U2} \cap \mathbf{U}(z) \cap \mathbf{UT_e}(d)} \max\{f_{p\max}(pt_e(d)); \min_{b \in \mathbf{B}(z)} \{f_{\max}(b)\} \ge y(z,d,e,u) \cdot f_{u2\max}(u) \tag{9}$$

$$\bigwedge_{z\in\mathbf{Z}}\bigwedge_{d\in\mathbf{D}(z)}\bigwedge_{e\in\mathbf{IP}(d)}\bigwedge_{u\in\mathbf{U1}\cap\mathbf{U}(z)\cap\mathbf{UT_e}(d)}\max\{f_{p\max}(pt_e(d));\min_{b\in\mathbf{B}(z)}\{f_{\max}(b)\}\geq y(z,d,e,u)\cdot f_{u1\max}(u) \quad (10)$$

$$\bigwedge_{z\in\mathbf{Z}}\bigwedge_{d\in\mathbf{D}(z)}\bigwedge_{e\in\mathbf{IP}(d)}\bigwedge_{u\in\mathbf{U1}\cap\mathbf{U}(z)\cap\mathbf{UT_e}(d)}\min\{Q(pt_e(d))-m_p(pt_e(d));Q_{dop}(u)\}\geq y(z,d,e,u)\cdot\max_{b\in\mathbf{B}(z)}\{m_b(b)\} \quad (11)$$

$$\bigwedge_{z\in\mathbf{Z}}\bigwedge_{d\in\mathbf{D}(z)}\bigwedge_{e\in\mathbf{IL}(d)}\bigwedge_{u\in\mathbf{U2}\cap\mathbf{U}(z)\cap\mathbf{UT_e}(d)}y(z,d,e,u)\cdot Q(pt_e(d))\cdot g\leq F_Q(u) \quad (12)$$

$$\bigwedge_{z\in\mathbf{Z}}\bigwedge_{d\in\mathbf{D}(z)}\bigwedge_{e\in\mathbf{IP}(d)}\bigwedge_{u\in\mathbf{U1}\cap\mathbf{U}(z)\cap\mathbf{UT_e}(d)}\min\{V_p(pt_e(d));V_{dop}(u)\}\geq y(z,d,e,u)\cdot\max_{b\in\mathbf{B}(z)}\{V_b(b)\} \quad (13)$$

$$\bigwedge_{z\in\mathbf{Z}}\bigwedge_{d\in\mathbf{D}(z)}\bigwedge_{e\in\mathbf{I}(d)}\bigwedge_{u\in\mathbf{U}(z)\cap\mathbf{UT_e}(d)}w_{ui}(u)\geq y(z,d,e,u)\cdot\max\{w_{pi}(pt_e(d));\max_{b\in\mathbf{B}(z)}\{w_{bi}(b)\}\} \quad (14)$$

$$\bigwedge_{z\in\mathbf{Z}}\bigwedge_{d\in\mathbf{D}(z)}x(z,d)\cdot t_c(z,d)\leq\varepsilon\cdot\min_{b\in\mathbf{B}(z)}\{t_{pt}(b)\} \quad (15)$$

$$\bigwedge_{z\in\mathbf{Z}}\bigwedge_{d\in\mathbf{D}(z)}\bigwedge_{e\in\mathbf{IP}(d)}\bigwedge_{u\in\mathbf{U1}\cap\mathbf{U}(z)\cap\mathbf{UT_e}(d)}\min\{uu(u,ut_{e-1}(d));uu(u,ut_{e+1}(d))\}\geq y(z,d,e,u) \quad (16)$$

$$\bigwedge_{z\in\mathbf{Z}}\bigwedge_{d\in\mathbf{D}(z)}\bigwedge_{e\in\mathbf{IP}(d)}\bigwedge_{u\in\mathbf{U1}\cap\mathbf{U}(z)\cap\mathbf{UT_e}(d)}y(z,d,e,u)\leq\kappa(u,pt_e(d)) \quad (17)$$

$$\bigwedge_{z\in\mathbf{Z}}\bigwedge_{d\in\mathbf{D}(z)}\bigwedge_{e\in\mathbf{IL}(d)}\bigwedge_{u\in\mathbf{U2}\cap\mathbf{U}(z)\cap\mathbf{UT_e}(d)}y(z,d,e,u)\leq\kappa_2(u,pt_e(d)) \quad (18)$$

$$\bigwedge_{z\in\mathbf{Z}}\bigwedge_{d\in\mathbf{D}(z)}\bigwedge_{e\in\mathbf{I}(d)}\bigwedge_{u\in\mathbf{U}(z)\cap\mathbf{UT_e}(d)}y(z,d,e,u)\leq\tau(tt_e(d),u) \quad (19)$$

Constrain (1) concerns the implementation of transport tasks, constrain (2) is for selection of transport means to particular operations, while (3) is for selection of work categories. Constrains (4–6) are related to the temperature values in the immediate vicinity of the cargo.

Subsequent constrains are for resistance to mechanical damage (7–10), weight (11–12) and cubic capacity (13) of cargoes. Constrain (14) concerns the dimensions of cargoes. It should be fulfilled for particular dimensions of cargo $w_{bi}(b)$ for $i=(x,y,z)$, dimensions of available space within loading unit $w_{pi}(pt_e(d))$ for $i=(x,y,z)$ and available dimensions of loading unit on the means of transport $w_{ui}(u)$ for

$i = (1x, 1y, 1z, 2x, 2y, 2z)$. Next constrain is for allowable carriage and storage time (15). The last group of constrains is for possible cooperation between specific means of transport (16), accepted loading units (17, 18), and admitting transport means to move on specific transport paths (19).

2.4 Criteria Functions

Evaluation of the quality of solutions in proposed optimization task is done through criteria of maximal safety and minimal costs. Criterion of maximal safety includes 12 partial criteria. Each of them is related to the value of partial coefficient of transportability, which is determined on the base of selected characteristics of perishable cargoes, types of loading units, multimodal transport technologies and transport tasks. Values of partial criteria are set on the base of mathematic formulas. Partial criteria take values from 0 to 1. Numbers close to 1 means a higher level of cargo safety according to the investigated criterion. Analyzed partial criteria of safety cover maximal ($w1 \equiv w(1, z, d)$)and minimal ($w4$) temperature of the air in the immediate vicinity of the load and temperature fluctuations ($w5$), maximal size of cargo ($w2$), value of privileged dimension ($w3$), loading capacity utilization ($w9$), weight ($w10$) and cubic capacity ($w11$) of single piece of cargo or single unit package with foodstuff, allowable carriage time ($w12$), the cargo resistance to mechanical damage caused by static effects ($w13$) and dynamic effects ($w14$) and the value (price) of carried goods ($w16$). Due to the fact that in analyzed example perishable cargoes are placed in unit packets impermeable to gases, it is not necessary to take into account the criterion of moisture fluctuations in the immediate surroundings of cargo ($w6$), as well as the criterion forcing using modified atmosphere ($w15$). Criteria related to volume of released ethylene ($w7$) and sensitivity to this gas ($w8$) have also been omitted since non-climacteric vegetables and fruits do not produce ethylene. The general form of criteria function describing safety of cargoes is following:

$$\mathrm{F1}_k(\mathbf{X}) = \sum_{z \in \mathbf{Z}} \sum_{d \in \mathbf{D}(z)} x(z, d) \cdot w(k, z, d) \longrightarrow \max \tag{20}$$

where $w(k, z, d)$ is the partial coefficient of transportability set for k-th criterion for z-th transport task performed under d-th transport technology.

Apart from maximizing the safety of cargo, the minimization of transport costs was included in the task. Optimization task covers four basic types of costs which sum is minimized: operating costs of transport means related to performing specific carriage operations $\mathrm{KU1}(z, d, e, u)$, operating costs of loading devices related to performing specific loading operations $\mathrm{KU2}(z, d, e, u)$, cost of employment of workers to handle vehicles performing specific carriage operations $\mathrm{KL1}(z, d, e, u, lsp(u), l)$ and cost of employment of workers to handle loading devices performing specific loading operations $\mathrm{KL2}(z, d, e, u, lsp(u), l)$.

Criterion function minimizing costs of transport takes form:

$$\mathrm{F2}(\mathbf{Y},\mathbf{Z}) = \sum_{z\in\mathbf{Z}}\sum_{d\in\mathbf{D}(z)}\sum_{e\in\mathbf{I}(d)}\left[\sum_{u\in\mathbf{UT_e}(d)\cap\mathbf{U1}} y(z,d,e,u)\cdot \mathrm{KU1}(z,d,e,u) + \sum_{u\in\mathbf{UT_e}(d)\cap\mathbf{U2}} y(z,d,e,u)\cdot \mathrm{KU2}(z,d,e,u)\right] + \sum_{z\in\mathbf{Z}}\sum_{d\in\mathbf{D}(z)}\sum_{e\in\mathbf{I}(d)}\sum_{u\in\mathbf{UT_e}(d)\cap\mathbf{U1}}\sum_{lsp(u)\in\mathbf{LSP}(u):u\in\mathbf{UT_e}(d)}\sum_{l\in\mathbf{SUL}(u,lsp(u))} z(z,d,e,u,lsp(u),l)\cdot \mathrm{KL1}(z,d,e,u,lsp(u),l) + \sum_{z\in\mathbf{Z}}\sum_{d\in\mathbf{D}(z)}\sum_{e\in\mathbf{I}(d)}\sum_{u\in\mathbf{UT_e}(d)\cap\mathbf{U2}}\sum_{lsp(u)\in\mathbf{LSP}(u):u\in\mathbf{UT_e}(d)}\sum_{l\in\mathbf{SUL}(u,lsp(u))} z(z,d,e,u,lsp(u),l)\cdot \mathrm{KL2}(z,d,e,u,lsp(u),l) \longrightarrow \min \tag{21}$$

3 Case Study

Application of the proposed approach to optimal selection of multimodal transport technologies for perishable cargoes was illustrated by example of two types of perishable cargoes (lemons and peppers) $\boldsymbol{B} = \{1, 2\}$ of known characteristics. Transported lemons are edible citrus fruits of yellow color, oval shaped, with an average width of single fruit 6–7.5 cm and height of 6–9 cm. The minimum transport and storage temperature is 283 K, the maximum temperature is 287 K, while the permissible temperature fluctuation is 1.5 K. The relative air humidity in the immediate vicinity of the product should be not less than 90% and not more than 95%, and its fluctuations should not exceed 3%. 1 kg of lemons produce a maximum of 10 μl of ethylene within 1 h. Lemons are sensitive to sunlight and water. No modified atmospheric composition is required during carriage; however, it is recommended. The permissible carriage time, under appropriate conditions, is 100 days. Estimated allowable pressure per unit area is 55 N/m^2, for dynamic and 100 N/m^2 for static effects. The price/value of 1 kg of product is about 2 PLN. Transported peppers have different colors and oval shapes, with medium sizes 8–12 cm wide and 10–14 cm high. The permissible storage and transport temperature is between 280 K and 284 K, while the temperature fluctuations must not exceed 0.7 K. The maximum air humidity is 95%, the minimum is 90% and the permissible variation is 3%. Peppers generally do not emit ethylene, it is sensitive to sunlight and also to water. The modified composition of the atmosphere is required during carriage. Permissible transport time is 1000 h, and the estimated permissible pressure per unit area is 34 N/m^2, for dynamic and 55 N/m^2 for static effects. The price/value of 1 kg of the product is about 2.50 PLN [12, 15].

Both, lemons and peppers are packed into plastic 0.6 m × 0.4 m × 0.3 m containers. The weight of one package with lemons is 20 kg and with the peppers is 18 kg. Packaging is impermeable to gases, liquids and light. Unit packages are of low mechanical strength and do not ensure protection against damage to transported fruits. Due to the fact, that the cargo is fruits in unit packages, it is characterized by the external dimensions, mass and volume of the unit packages, not the individual fruit.

Packages are a barrier against the effects of light and water, so the parameters of the fruits are not taken into account.

Considering above, the set of characteristics of cargoes takes the form:

$$\boldsymbol{F_B} = \{(0,6; 0,4; 0,3; 20; 0,072; 271; 287; 1,5; 283; 2400; 100; 55; 2), \\ (0,6; 0,4; 0,3; 18; 0,072; 272,1; 284; 0,7; 280; 1000; 55; 34; 1)\}$$

It was assumed that cargoes can be formed into loading units of two types $\boldsymbol{P} = \{1, 2\}$ (boxes or pallet-boxes) with known characteristics:

$$\boldsymbol{F_P} = \{(0,6; 0,4; 0,3; 100; 55; 0; 270; 50; 295; 0; 20; 0,072; 0,6; 0,4; 0,3; 0,6; 0,4; 0,3; 0,072); \\ (1,2; 0,8; 1; 180; 100; 0; 270; 50; 295; 43; 300; 0,96; 1,1; 0,7; 0,9; 0,6; 0,4; 0,5; 0,693)\}$$

Specific operations can be done by four types of vehicles $\boldsymbol{U}1 = \{1, 2, 3, 4\}$ and four types of loading devices of $\boldsymbol{U}2 = \{3, 5, 6, 7\}$ with known characteristics:

$$\boldsymbol{F_{U1}} = \{(265; 40; 286; 17500; 88,11; 13,2; 2,5; 2,67; 0,4; 0,2; 0,3; 44; 12; 3; 10; 14; \\ (3,5,6,7); (1,2); (1,2)); (283; 1; 285; 16000; 69,12; 12; 2,4; 2,4; 0,8; 0,4; 0,3; 44; 44; 8; 12; \\ (3,5,6,7); (1,2); (1,2)); (284; 1,2; 286; 3500; 8; 2; 2; 2; 0,4; 0,6; 0,3; 50; 15; 17; 17; 22; \\ (3,5,6,7); (3,5,6,7); (1,2); (1,2)); (265; 40; 285; 800; 32; 8; 2; 2; 0,15; 0,15; 0,15; 58; \\ 24; 22; 22; 18; (3,5,6,7); (1,2); (1,2))\}$$

$$\boldsymbol{F_{U2}} = \{(4500; 1200; 0,55; 13; (1,2); 10; 43; 2; 3; 2; 1; 1; 1); (4200; 555; 0,55; \\ 12; (1,2); 10; 44; 1; 1; 1; 0,8; 1,2; 0,5); 4000; 400; 0,58; 11; (1,2); 14; 73; \\ 4; 4; 4; 1,2; 1,2; 1,2); (3300; 500; 0,66; 13; (1,2); 32; 22; 5; 5; 5; 1; 1; 1)\}$$

Vehicles and devices engaged in technological process can be handled by workers of two categories $\boldsymbol{L} = \{1, 2\}$ with known characteristics:

$$\boldsymbol{F_L} = \{(1400; (1,2); 0); (70; (3,4); 0)\}$$

Set of transport paths is formulated as $\boldsymbol{T} = \{1, 2, 3, \ldots, 14, 15\}$, while sets of characteristics of particular paths are formulated as follows:

$$\boldsymbol{F_T} = \{(1400; (1,2); 0); (70; (3,4); 0); (1350; (1,2); 0); (120; (3,4); 0); (1000; (3,4); 0); (300; \\ (1,2,3,4); 0); (0,1; (3,5,6,7); 0); (0,04; (3,5,6,7); 0); (0,2; (3,5,6,7); 0); (0,1; (3,5,6,7); 0); (0,2; \\ (3,5,6,7); 0); (0,1; (3,5,6,7); 0); ?(0,3; (3,5,6,7); 0); (0,25; (3,5,6,7); 0); (0,2; (3,5,6,7); 0)\}$$

Analyze takes into account one transport task $\boldsymbol{Z} = \{1\}$ for which multimodal technology of transport must be selected to maximize safety of perishable cargoes and minimize costs of transport.

Analyzed transport task concerns carriage of two types of cargoes $\boldsymbol{B}(1) = \{1, 2\}$, in amounts respectively $\boldsymbol{M}(1) = \{1200, 800\}$ from Antwerp $m_p(1) = 1$ to Warsaw $m_d(1) = 2$. Three possible transport technologies have been pre-defined $\boldsymbol{D}(1) = \{1, 2, 3\}$ for which technological processes are defined as follows:

$$\mathrm{PT}(1) = \langle[1;0;7;(3,5,6,7);(1,2)];[1;1;1;(4);(1,2)];[1;0;8;(3,6,7);(1,2)]\rangle,$$

$$\mathrm{PT}(2) = \langle[1;0;9;(3,5,6,7);(1,2)];[1;1;2;(3,4);(1,2)];[1;0;10;(3,5,7);(1,2)];$$

$$[1;1;3;(1,2);(1,2)];[1;0;11;(5,7);(1,2)]\rangle$$

$$\mathrm{PT}(3) = \langle[2;0;12;(6,7);(1)];[2;1;4;(3,4);(1,2)];[2;0;13;(3,6,7);(1,2)];[2;1;5;(2);(2)];$$

$$[2;0;14;(6,7);(1,2)];[2;1;6;(3,4);(1,2)];[2;0;15;(6,7);(1)]\rangle$$

It was assumed that cargoes are to be taken at the earliest moment $t_p(1) = 0$, while the latest moment of delivery $t_d(1) = 168$. Two types of loading units are accepted in the task – boxes and pallet-boxes $\boldsymbol{P}(1) = \{1, 2\}$. The task can be performed by the following means of transport $\boldsymbol{U}(1) = \{1, 2, 3, 4, 5, 6, 7\}$.

As a result of the optimization task, the first variant of technology was rejected as infeasible and second variant was indicated as the best.

The selection of means of transport and workers performing particular operations was done in each variant. The selection of resources was done in a way maximizing safety criteria and minimizing cost criteria. The values of safety criteria, except the criterion of allowable carriage time, for whole transport process are set as the lowest value of particular criteria among the values set for each operation. The values of criteria functions for subsequent technological solutions are gathered in Table 1.

Table 1. The values of partial criteria for particular technologies

Partial criterion	d = 1	d = 2	d = 3
$F1_1$ (**X**)	0,3679	0,1353	0,1353
$F1_2$ (**X**)	1,0000	1,0000	0,5455
$F1_3$ (**X**)	0,5000	0,3333	0,3333
$F1_4$ (**X**)	**0,0000**	1,0000	1,0000
$F1_5$ (**X**)	0,0175	0,5833	0,5833
$F1_9$ (**X**)	0,8333	0,1250	0,1250
$F1_{10}$ (**X**)	1,0000	1,0000	1,0000
$F1_{11}$ (**X**)	1,0000	1,0000	0,9351
$F1_{12}$ (**X**)	1,0000	1,0000	1,0000
$F1_{13}$ (**X**)	1,0000	1,0000	1,0000
$F1_{14}$ (**X**)	1,0000	1,0000	1,0000
$F1_{16}$ (**X**)	0,6376	0,4382	0,1042
F2 (**Y, Z**)	35064	21702	22900

When some of the partial criteria from $F1_1$ (**X**) to $F1_{16}$ (**X**), takes zero-value (values bolded in table), the technological solution is rejected due to failure to meet certain safety condition. This is the reason why technology of 1-st type is not considered in further study. Of the other two, the technology of 2-nd type is characterized by lower cost of transport. Comparing values of partial safety criteria, it must be stated that according to all partial safety criteria technology of 2-nd type ensures higher or equal safety of cargoes as technology of 3-rd type. On the basis of the presented solution, it should be stated that the realization of given transport task under the multimodal transport technology of the 2-nd type is optimal in these conditions.

4 Summary and Conclusions

The presented formal model is used to optimize the selection of multimodal transport technology for a selected group of perishable products. The optimization task for other types of products and cargoes may vary, in particular in formulated constrains and the number of partial criteria considered, depending on the type of problem. Selecting the type of optimization task according to the type of problem solved, limits required calculations. The optimum solution is based on a number of partial criteria – maximally 18, related to transportability and cargo safety and one criterion for transport costs. In order to guarantee the safety of perishable cargo, if any of the cargo safety related criteria takes zero-value, the solution is considered infeasible.

Correct use of presented optimization task should help to increase the efficiency of selection of multimodal transport technology for perishable products. The selected technology will then be characterized by the lowest cost of transport and will ensure the safety of transported cargoes, as well as meet other requirements determined by the transport task. Applying optimization of transport technology, based on the analysis of load characteristics affecting transportability, should contribute to reducing the percentage of spoiled cargoes throughout the supply chain. Using proposed tool by companies will improve their competitiveness by improving their ability to provide high-quality perishable products with an optimal cost and to meet growing demands of consumers. The proposed model is a universal tool that can be modified depending on the type of decision problem to be solved. The paper presents an example of using a model to design a transport technology for a specific perishable product group, but the model can be adapted to a variety of design problems in transporting different groups of perishable products.

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Information as a Component of Intelligent Transport Systems

Improving Bicycle Mobility in Urban Areas Through ITS Technologies: The SaveMyBike Project

Antonio Pratelli[1(✉)], Massimiliano Petri[1,2], Alessandro Farina[1], and Marino Lupi[1]

[1] Department of Civil and Industrial Engineering, University of Pisa, Pisa, Italy
{antonio.pratelli,alessandro.farina, marino.lupi}@unipi.it, m.petri@ing.unipi.it
[2] TAGES Soc. Coop., Pisa, Italy
petri@tages.it

Abstract. This paper describes some ITS solutions and rewarding policies to increase the use of sustainable transport means in urban areas. Firstly, existing policies are described, and the advantages of rewarding systems are presented. Afterwards, the ITS technologies application to monitor mobility modes is described. In this context, the paper presents the SaveMyBike prototypical project and its solutions. SaveMyBike is an anti-theft monitoring system, based on RFID technologies and made of three modules. The first module creates secure urban areas through installed alarms where owners can leave their bike safely. The second module uses fixed RFID gates to monitor journeys and detect stolen bikes. The third module uses portable RFID readers that, during the parking and street control, read in-bike tags, detecting: the stolen bikes, and origins/destinations of bicycle trips. The system is based on rewarding policies, to incentivize people to use their private bikes and public transport modes.

Keywords: Sustainable mobility · Rewarding · Citizen behavior · Bike · ITS · Anti-theft system · Peer-to-peer bike-sharing

1 Introduction

Private car mobility registers a high accident rate: in 2014 it was responsible for over 25,000 fatalities in the EU-28, while 3,400 fatalities occurred in Italy in the same year [1]. In addition, in 2014 in the EU-28, around 70% of the overall CO2 emissions from transport were generated by road mode; in Italy this percentage was even higher: around 83% [1]. Moreover, in urban areas they occur 38% of the overall fatalities from road transport, and 23% of the overall CO2 emissions [2]. As a result, a modal shift of at least a part of passenger transport in urban areas, from private car to sustainable transport systems is desirable.

"Sustainable mobility", that is disconnecting mobility from its harmful effects, is the element around which gravitates the EU transport policy [2]. The Communication n. 433 [3] lists several strategies to increase sustainable mobility in urban areas. Among these, systems of payment for the use of roads (e.g. Pricing) or systems for rewarding

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_18

for good practice (e.g. Mobility credits) allow to act on the mobility behavior. However, currently only a few rewarding policies have been put in practice; moreover they act on occasional basis.

In this field, the project SaveMyBike, funded by the Tuscany region, has been developed in order to improve the bike mobility in urban areas. The project regards the development of an ICT platform capable of: monitoring systematically bicycle trips inside the city, creating secure areas for bike parking, tracking stolen bicycles, rewarding people who perform the majority of their trips by bike.

In this paper, firstly an overview on existing transport demand management policies, with a focus on accessibility restrictions and on rewarding policies, is exposed. After, the main characteristics of the project SaveMyBike are described. Conclusions follow.

2 Transport Demand Management Policies

2.1 Classical Accessibility Restriction Policies

A study made for DG TREN by the Italian ISIS - Institute of Studies for the Integration of Systems [4] in December 2010 analyzes various systems of restriction accessibility in 417 different European cities. The two policies of restriction used in most cases are the Access Restriction Scheme (ARS) and the Low Emission Zone (LEZ). ARS can broadly be classified into four types:

(1) Point based (e.g. restriction to cross a bridge or to enter a small section of city)
(2) Cordon based: a restriction is applied for crossing a cordon, and may vary with time of day, direction of travel, vehicle type and location on the cordon. There could be several cordons in the same urban area with different rules or prices. This scheme is the typical form of road pricing; the main advantage is the flexibility in eventual variation by time of day and vehicle type.
(3) Area license based pricing: a restriction is applied for driving within an area during a period of time; restrictions may vary with time and vehicle type. In alternative to a restriction, the access to a given area may be charged. The main field of application of this restriction policy is the inner core of cities. Restrictions may vary with time and vehicle type. An application of this policy is the London Congestion Charge.
(4) Distance or time based: it is essentially a pricing restriction based upon the distance or time a vehicle travels along a congested route or in a specified area, and may vary with time, vehicle type and location.

2.2 Rewarding Demand Management Policies

In Europe in a few cases alternative systems to the current simple accessibility limitation policies, such as pricing, have been introduced. Three different levels of complexity, in the management of transport demand for modal split, have been studied.

The first level ranges from a simple reward, for those who use public transports or shared means, to a system of penalties, for those who carry out certain modes of transport, to a real credits market managed by the public administration, similar to the 'Carbon credits' market in relation to emissions.

The second level of complexity regards a system which uses the internal GPS traces of the black boxes installed in cars, whose installation incentive is due to the discounts made by several insurance companies. In this system, incentives gained in the usage of public transport can be exchanged, creating a sort of incentives "market". In a similar way, the Mobility Credits can be exchanged among drivers with a negative balance of credits to buy extra-credits from other credit-positive drivers. The only limitation is that the total amount of credits must remain the same avoiding the distribution of "new credits", which will be not coherent with the purpose of reducing carbon footprint.

The third level of complexity regards a system, called "Mobility Credits Model", which allows to create a behavioral context where travelers and transport operators can experience the effects of changing attitudes and choices in mobility within a range of possible implementations, from a "pedagogic tool" to a "mandatory demand management scheme". The mechanism of this context is to set a quantitative target of Sustainable Environmental Footprint (SEF), for example an allowable threshold for each type of externality (e.g. energy consumption or CO2 production), to make the approach path to the target measurable (e.g. how much CO2 is not produced on account of a different mobility behavior) and to apply a driving force (incentive or obligation) from the current status to the target.

For the second rewarding system, it is complex and expensive to have car GPS data (to buy from insurance) and to solve legal problem linked to the penalty system while the third system is always too much at theoretical state. Then, we project to apply the first rewarding system, with a real application in Pisa. The project is illustrated in Fig. 1.

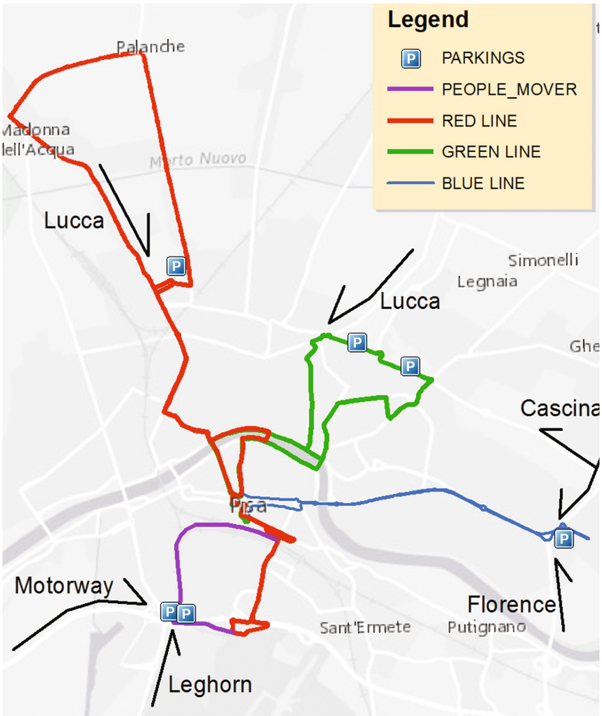

Fig. 1. The general Pisa municipality rewarding project (source: own research).

The Pisa project tries to decrease the commuters entering in the city every day applying a rewarding system to those leaving their car in the cordon parkings and taking sustainable transport means to enter the city. In cordon parkings are located bike-sharing station and bike-lanes, and are crossed by high frequency bus lines that bring directly to the city-center. Regarding bike users, there is always a bottleneck disabling the application of rewarding policies: i.e., the inexistence of a systematic daily monitoring system. From this evaluation, it starts the SaveMyBike system.

3 The SaveMyBike System

As demonstrated from the TEMS-The EPOMM Modal Split Tool, there are several cities where bike mobility is very low: several EU cities such as Bilbao, Brno, Paris, Warszawa, London, Madrid, Budapest, Stockholm, Geneva, Nice and Porto reported a bike use between 0 and 3%. This trend is mainly due to local habits and to the high theft rate. Italian cities in particular suffer from high cars density.

The SaveMyBike system aims at breaking the economic circle created around the private car replacing it with a remuneration system based on the cycle usage. Moreover, SaveMyBike aims at decreasing the operating costs of bike-sharing systems, currently too high also for medium-little cities: in Pisa a system with 18 bike-sharing stations costs every year about 200.000€ with annual operating costs for each bike of about 1.000€; in Mexico City bike sharing systems costs are even higher, equal to 2.594$ [5]).

SaveMyBike therefore creates an urban service, for the first time, also for occasional city users like tourists but also asking citizens an annual fee subscription and giving, in exchange, an antitheft, monitoring, recovering and rewarding system.

Recent researches show that bike theft is up 25 % in many cities and that up to a million bikes get lifted annually, without considering those not reported. The average stolen bicycles and their parts sum up to about 300 million Euro per year. Notice that there are two types of bike thieves. In many cases, they are occasional thieves, but some others are professionals who steal large amounts of bikes, using effective lock-breaking tools, and resell them in other cities or countries.

Unfortunately, most of the proposed countermeasures result almost ineffective as the consequence of the current unavailability of unique and irremovable (in a few words, completely reliable) identification systems. Public officers cannot demonstrate that a bike has been stolen in almost all cases. Besides, removing a bike from the street is fast and easy, even when locking tools impede the movement. Some producers (see for instance [6]) propose a complete set of locking belts that can be used to fasten wheels, handles and other parts. An appropriate key is then needed to release the bike, but still thieves can remove the whole bike and work on it later.

However, in the last years, due to the gravity and the growing frequency of bicycles thefts, different systems to prevent them have been proposed over time. In Italy, for example, a public register has been created in 2007, while in the UK a register of stolen bicycles already existed. It consists of a system of software applications, often web-based, and hardware tools that try to help owners to signal the theft, identify the stolen bike and verify if those available on the market have been previously looted elsewhere. It is noteworthy that tracking devices are not an anti-theft solution. Because no bike lock can offer total protection, tracking devices offer a last-resort, post-theft recovery support.

Referring to all the above mentioned aspects, some approaches to bike security can be identified, each with its own strengths and weaknesses:

- Metallic plates: these, reporting unique numbers, can be fixed or welded onto the frame. Similar solutions have been adopted since many years in Switzerland and Denmark. Recently, in some Italian cities plates, among them Pisa, have been tested to the aim, but results have been rather poor mainly due to the fact that removal is all but difficult.
- Adhesive plates: similarly, some cities in northern Italy have adopted adhesive plates. However, these can be easily removed.
- QR codes: this is a solution that has been tested mostly in northern Europe. Codes can be punched onto the metallic parts of the bicycle, but removal, covering or hiding is almost easy.
- GPS-GPRS and Bluetooth systems: these are advanced and costly solutions (an interesting program using GPS tools has been proposed by both the Taiwan University and the Copenhagen municipality) that allow the identification and also the tracking of the bicycle within a given area (Bluetooth) or almost without restrictions (GPS). Unfortunately, they are heavily affected by the short life of batteries and by the easiness with which the emitting sources can be removed from the frame. Besides, the cost of the anti-theft system is often burdensome.

Finally, the main aims of the SaveMyBike project are:

- Encourage citizens to use bicycles through a rewarding system and a bike insurance. Currently, there are still no examples of rewarding systems for citizens based on bike's usage. Moreover, Zurich insurance company would guarantee the theft insurance for the bikes using SaveMyBike system (end user = citizen).
- Create an efficient anti-theft system (end user = citizen).
- Monitor cyclists trips (and their origin and destination) to implement an effective decision support system to plan bike mobility (end user = municipalities) without obligate them to use an App for smartphone [7].
- Monitor bike stolen trends and locations to prevent future ones (end user = police).
- Develop a peer to peer bike-sharing system which is managed by the citizens themselves who, also, could receive a revenue. Therefore, users can rent or borrow bikes hourly or daily from the other citizens, providing therefore also a revenue for private bike owners. Although it is very popular, peer-to-peer bike sharing has not yet applied to real urban center for the absence of a proper technology [8].

The SaveMyBike approach is meant to deal with all the previously mentioned issues and, in detail, it is intended to provide an anti-theft monitoring system based on the well-known RFID technology and built mainly upon three different modules.

- The first module is intended to create secure urban areas with installed alarms, where owners can leave their bike safely. In case of theft an alarm is sent to the management system, to the owner and to all the registered members of the SaveMyBike network: this works as a fully cooperative control, delineating the

SaveMyBike system as a Cooperative-ITS platform (see Fig. 2) [9]. Besides, the creation of well delimited secure areas constitutes a particularly strong feature of the whole project, because it provides the town administrators a valuable mean to avoid the annoying “wild parking”. Actually, users often park their bicycles almost everywhere. While parking is properly regulated both for cars and motorbikes, nothing has been conceived yet for bicycles. This is why the secured areas may come useful. Moreover, while it is certain that covering with RFID signals the entire metropolitan areas would be rather impossible (or at least extremely expensive even for small towns), the dedicated areas represent truly economic, closed and controlled parking areas for bicycles. A well-thought rewarding mechanism is suitable/necessary to stimulate the citizens to use such areas, in order to make the implementation effective in a reasonable time.

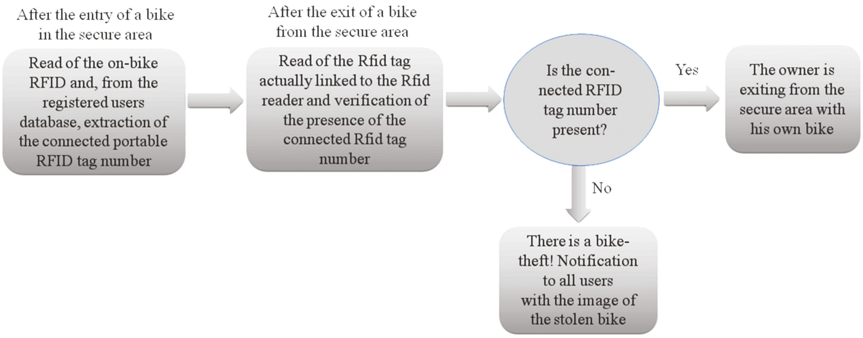

Fig. 2. A chart flow describing the first module (source: own research).

- The second module, aimed at the identification and tracking of bicycles, uses fixed RFID gates to monitor daily journeys and to detect stolen bikes. This module is built upon the newest UHF passive RFID technology, that has grown enough in the last years to grant the capability of identifying the bicycles when they are within the protected areas. The reading range goes up to some meters and this allows to effectively cover the closed and secured zones. RFID gates cover an entire road section, as bicycles could be identified until a distance greater than 20 m. Fixed readers will be also available in different locations within the metropolitan areas, to track and trace bicycles while they are moving on the roads. These readers provide a valuable tool both to determine the zones were bicycles have been stolen and to analyse the most/less used paths in the bike-sharing programs. The passive tags will be built and installed using a specific technology, therefore they are immovable and protected from damaging and manumissions. In the ideal situation, when a bicycle producer inserts the tag within the bike body, a visible and characteristic marking should be applied on the metallic structure of the bike itself, for example, by a punching process. Obviously, removing the marking is possible (for instance, by abrasion), but in this case the metallic surface of the bicycle will be visibly damaged, signaling immediately that it is a possible bike suspected of theft. Fixed or

portable RFID readers can be then used to verify the current state of the vehicle. Even if the passive tag has been somehow damaged, removed or tampered, the marking or the missing-marking can be used as further significant signals.
Finally, the system is capable of recognizing which bikes leaving the secure urban area in the following way. During the registration, the system users provide not only the bicycle data but also a photo of the bike itself. This photo allows an unique identification of the bike in case of theft.

- The third module uses portable RFID readers. Such instruments will be given to each policeman or parking enforcement officer, allowing them to read the "in-bike" tags and to detect stolen bicycles. Since the RFID tags will be hidden and immovable, the system can be used to rapidly verify the state of any "suspected" bicycle, as explained within the last point. Furthermore, it allows the system to control those areas where fixed readers cannot be installed.

To resume, the SaveMyBike system uses, for the first time, immovable sensors in the bike and it is based on a rewarding system elaborated on the routes monitored and on the travelled kilometers. Moreover, each citizen can leave their bike in the nearest secure area, where other users can take it, simply booking the service by means of the smartphone. As a result, SaveMybike will allow the implementation of the first real peer-to peer bike-sharing linked to a rewarding system. In addition, SaveMybike will enable several travel demand policies, basing: on incentives to switch from private car to bike mode, or on rewarding policies for citizens who use bus, bike or car-sharing modes, or electric cars, in performing their trips. In Fig. 3 it is possible to see a summary of the problems of the users and their solutions offered from the system.

Finally, this project will encourage the development of bike-sharing systems also in small and medium cities due to the low-cost of the system, that can be totally amortized from the annual registration fee in about 2–3 years, and it will provide citizens a central role in the development of bike-sharing solutions [10].

The SaveMyBike system related privacy concerns will also be addressed. Actually, tracking data at individual level will be visible only to the single user (i.e. each user is capable to access only his own data), while only aggregated data will be available to public administrators which are therefore able to efficiently implement the rewarding policies.

In Fig. 4, the results of the cost-revenues analysis are represented, regarding Pisa scenario, including the bike-sharing capital and the actual operating costs. The analysis takes into account revenues coming from annual citizen fees (about 5 euros), the company subscribed to the rewarding system that give discount based on the credit points collected, from occasional users of the bike-sharing systems/tourists, from insurance companies (for example Zurich one will subscribe a contract with the service company manager to make an insurance against theft at 15 euro/3 years for each bike, from publicity. The costs are divided in capital costs for the first year and in operating costs for each year based on the number of users. The analysis shows that, comprising the bike-sharing operating costs, for the first 3 years there is a negative balance between revenues and costs, mainly due to the initial investments, while, after the third year, the balance becomes positive, therefore it is possible to break in a few years the private car economic hegemony.

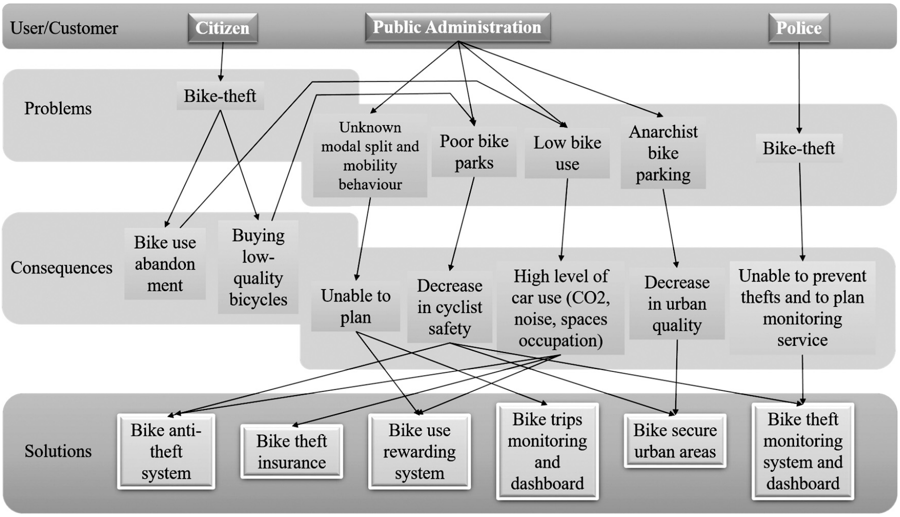

Fig. 3. Users' problems and their solutions offered from the SaveMyBike system (source: own research).

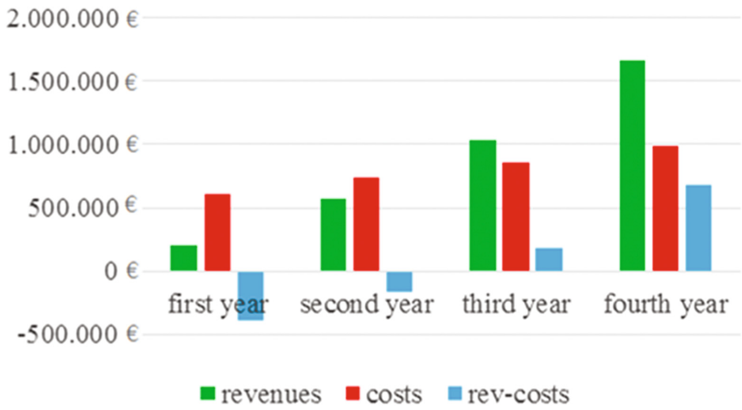

Fig. 4. The results of the cost-revenues analysis applied to Pisa scenario (source: own research).

4 Conclusions

Currently, urban areas register a high transport accident rate; moreover urban mobility is responsible for a relevant quota of pollutant emissions and fuel consumption. As a result, a shift of at least a part of urban transport, from private car to greener means of transport, is desirable. While the usage of public transport is not negligible, specially by commuters, the bicycle is still used, as a transport mean, by only 0–3% of citizens in Europe, and this occurs both in big and medium sized cities. The reduced use of bicycle is due to mainly two reasons. Firstly, the high rate of bike thefts in Europe discourages citizens from bike mobility. Secondly, a “green” mentality among citizens is still lacking, while private car still occupies a central role in the overall urban economy.

The project SaveMyBike has been developed in order to encourage bicycle mobility in urban areas. As a result, the project has the following main targets.

Firstly, the project aims at discouraging the bikes theft, through the usage of RFID tags and detectors. The project therefore proposes the development of “secure areas” where bicycles could be parked safely: if a bike is stolen, an alarm signal, directed to the bike owner and to the police, is activated. Moreover, mobile RFID detectors provided to policemen and parking enforcement officers, allow, in case of theft, the recovery of bicycles. Furthermore, a bike insurance is however offered to citizens.

Secondly, the project proposes rewarding policies to encourage bike mobility in urban areas. In order to detect the actual kilometers travelled by bike users, a monitoring system, through fixed gates placed in the roads, is proposed: this however helps also in recovering the stolen bike.

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Implementation Factors of Automated Fare Collection Systems: Case Study Based on Silesian Public Services Card Example

Anna Urbanek(✉)

Department of Transport, University of Economics in Katowice, Katowice, Poland
anna.urbanek@ue.katowice.pl

Abstract. The implementation of automated fare collection systems for urban public transport services, in particular in big cities and metropolises, is a complex process. A new solution, especially at the very beginning, on the users side is related to fears or additional actions, which previously did not exit – in the case of paper carriers. It is possible to specify here the necessity to perform actions related to ordering and collecting the card, reading the card when entering and leaving vehicles, or the fear of safe processing of data originating in the card systems. At the same time the new solution is a source of real benefits – new fares are available and the ticket purchase is much easier. The acceptance of the solution being implemented depends on many factors that should be considered. The paper, based on the data related to cards issuing and ticket sales, presents the process and factors conditioning the implementation of one of largest IT projects in the urban public transport.

Keywords: Automated fare collection system · Implementation · E-tickets · Smart card · Urban transport · Public transport

1 Introduction

The implementation of an automated fare collection system for the urban public transport services is a project not just changing, but requiring to establish a brand new system for services distribution and sales. It is necessary to ensure the distribution of smart cards and to create and equip a network for tickets selling and charging with e-money, moreover settlement models and rules of tickets sales and validity will change. The automated system allows to expand the ticket offer and to introduce new ticket types, which could be easier matched to individual travel plans, including the travel start time, the distance, and the number of travels. It is also important to have a possibility of buying the tickets via e.g. Internet, i.e. without the need to go to a point of sales. Because of the implementation of a fare collection system based on an e-card, additional actions will occur on the service users side. It is possible to mention here actions related to ordering and collecting personalised cards, which require going to one of 40 Passenger Service Points, or during the service use - the necessity to register the entry to and possibly the exit from a vehicle.

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_19

The implementation of an automated fare collection system requires some strategy for action, so as to smoothly move from the paper tickets system to the system using smart cards [1]. Such project is the more difficult, the larger is the scope and scale of specific urban public transport system. In the case of the Municipal Transport Union of the Upper-Silesian Industrial District (KZK GOP) – 29 municipalities making the Union and nearly 2 million people living within its boundaries – it is possible to refer to a very large system, in Poland comparable only to Warsaw and ranked also among large on the European or global scale. Hence this example is a kind of a case study, allowing to draw examples of strategy and of the implementation course for other large metropolises, which are planning to carry out such projects. The paper focuses on the significant part of the Silesian Public Services Card (SKUP), namely on the payments and tickets for the urban public transport services. However, the SKUP system is much larger, enabling to pay for car parking or for various public services [2, 3].

2 E-Tickets Prices and Rules of Use

A draft tariff and price list was prepared in mid-2015, taking into account the introduction of e-cards and e-tickets. Apart from provisions specifying the rules of electronic tickets using, promotional e-ticket prices were established – lower than their paper ticket equivalents. The determination of lower prices was aimed at encouraging the e-tickets use via a measurable and concrete benefit gained by passengers. The solution was viable due to falling fuel prices, because the implementation coincided with the period, when the KZK GOP expenditures related to payments for the transport services were going down because of that. The ticket price reduction and the introduction of price promotions resulted in reduced revenue on the sales of services. Because it should be considered that the demand for the urban public transport services is inflexible, hence it is typical that in the case of price cuts the obtained revenue will diminish [4].

The cards issuing started in October 2016 and the use of season tickets recorded on cards on the 2nd November 2016. Tables 1 and 2 present prices of paper tickets and corresponding e-tickets.

Table 1. KZK short-term ticket prices (electronic and paper) (Source: Own study based on the KZK GOP figures)

Single travel/short-term tickets	Paper ticket price (PLN)	E-ticket ticket price (PLN)	% price reduction
Single travel within one city or during 15 min from validation	3.20	3.10	3.13
Single travel within two adjacent cities or during 30 min from validation	3.80	3.70	2.63
Single travel within three or more cities or during 1 h from validation	4.80	4.60	4.17

Table 2. KZK GOP medium- and long-term season ticket prices (Source: Own study based on the KZK GOP figures)

Medium-term tickets	Paper ticket price (without a limit of travels) (PLN)	E-ticket price without a limit of travels for a personalised/ non-personalised card (PLN)	% of price reduction for a personalised/non-personalised card	
24-hour ticket	18	16/17	11.11/5.56	
48-hour ticket	28	26/27	7.14/3.57	
5-day ticket	44	42/43	4.55/2.27	
7-day ticket	50	48/49	4/2	
14-day ticket	88	85/86	3.41/2.27	
24-hour ticket	18	16/17	11.11/5.56	
Long-term tickets	Paper ticket price (PLN)	E-ticket price (without a limit of travels) (PLN)	E-ticket price (without a limit of travels) with a discount (PLN)	% price reduction before/after discount
Personal monthly/30-day ticket authorising to travel only by bus lines or only by tram lines in the area of one selected city	110	104	98.80	5.45/10.18
Personal monthly/30-day ticket (only bus lines or only by tram lines in the area of two or more cities)	134	126	119.70	5.97/10.67
Personal monthly/30-day ticket authorising to travel by all lines in the area of one selected city	126	122	115.90	3.17/8.02
Personal monthly/30-day ticket (all lines in the area of two or more cities)	150	144	136.80	4/8.8
Bearer monthly/30-day ticket (all lines in the area of two or more cities)	174	168	159.60	3.45/8.28
Personal quarterly/90-day ticket (all lines in the area of one selected city)	322	310	294.50	3.73/8.54
Personal quarterly/90-day ticket (all lines in the area of two or more cities)	376	358	340.10	4.79/9.55

The amount of price reduction for e-tickets as compared with the paper ones is visible for individual ticket types. For example, the short-term (single travel) ticket prices were reduced by 3.13–4.17%, and medium-term ticket prices by 2.27–5.56%. In a similar way the long-term ticket prices were also reduced - the price of a 30-day SM ticket for one traction was reduced by 5.45%, of a 30-day SC ticket by 5.97%, of a 30-day SM/AT ticket by 3.17%, of a 30-day SC/At ticket by 4%, and of a 90-day ticket by 4.79%.

Irrespective of paper ticket equivalents, new types of tickets were introduced in the KZK GOP ticket offer as well as a distance tariff, where the paid fares are related to the distance of a single travel. E.g. the fare paid by the SKUP card for a travel up to 1 km is now PLN 2.20, for a distance from 1 km to 2 km – PLN 2.80, from 2 km to 5 km – PLN 3.10 and appropriately more for the next distance sections.

Before the SKUP introduction the travel at specified distances required validating the cheapest single travel ticket, PLN 3.20. Also an independent change of tariff type was enabled, as a result it is always possible to choose this tariff system, which is most favourable for the specific travel. In addition a promotion was introduced, consisting in 5% of discount when purchasing the next season ticket in the case of regular registration of exits from a vehicle (so-called check-out). Tables 3 and 4 present new types of tickets and the comparison with those, which were previously bought by the people.

Table 3. KZK distance ticket prices (electronic and paper) system (Source: Own study based on the KZK GOP figures)

Distance	E-ticket ticket price (PLN)	Paper ticket price (PLN)	% price reduction
Up to 1.0 km	2.20		31.25
From 1.0 km to 2.0 km	2.80	3.20	12.50
From 2.0 km to 5.0 km	3.10		3.13
From 5.0 km to 9.0 km	3.70	3.80	2.63
From 9.0 km to 14.0 km	4.20		12.50
From 14.0 km to 20.0 km	4.40	4.80	8.33
More than 20.0 km	4.60		4.17

Note: So far passengers did not have a possibility to use a distance tariff, which is favourable especially for persons travelling short distances. For example, a person willing to travel 2 stops at a distance of 900 m had to validate a ticket for PLN 3.20, now the amount of PLN 2.20 will be charged, giving the passenger savings of PLN 1 during one travel.

Two types of cards are available in the SKUP system - personalised and non-personalised. The obtaining of a personalised card requires fulfilling additional formalities, which do not exist in the case of a non-personalised card. At the same time the personal ticket prices – available on a personalised card – are lower, which is more favourable in particular for persons systematically using the public transport services.

Table 4. KZK GOP medium- and long-term season tickets system (Source: Own study based on the KZK GOP figures)

Fare/ticket type*	Limit	Price (PLN)	Paper ticket price (PLN)	% price reduction
Medium-term tickets for passengers using a personalised/non-personalised SKUP card with a limit of travels				
24-hour ticket	5 travels	13/14	18	27.78/22.22
48-hour ticket	9 travels	23/24	28	17.86/14.29
5-day ticket	16 travels	39/40	44	11.36/9.09
7-day ticket	20 travels	44/45	50	12/10
14-day ticket	40 travels	79/80	88	10.23/9.09
Season tickets for passengers using a personalised SKUP card with a limit of travels				
Personal 3-day bus (tram) ticket authorising to travel in the area of one selected city (SM)	66 travels	96	110	12.73
Personal 30-day bus (tram) ticket authorising to travel in the area of two or more cities (SC)	80 travels	114	134	14.93
Personal 30-day bus & tram ticket authorising to travel in the area of one selected city (SM/AT)	66 travels	114	126	9.52
Personal 30-day bus & tram ticket authorising to travel in the area of two or more cities (SC/AT)	Limit of 80 travels	132	150	12.00
Bearer 30-day bus & tram ticket authorising to travel in the area of two or more cities (SC/AT)	Limit of 80 travels	156	174	10.34
Personal 90-day bus & tram ticket authorising to travel in the area of one selected city (SM/AT)	220 travels	286	322	11.18
Personal 90-day bus & tram ticket authorising to travel in the area of two or more cities (SC/AT)	266 travels	328	376	12.77

*Passengers using season e-tickets recorded on the SKUP Card, who registered at least 95% of travels both when entering and leaving a vehicle during the ticket validity period or in a similar period preceding the date of ticket purchase, when buying the next season ticket for a period not longer than that indicated on the previously used ticket are entitled to a 5% discount in the price of appropriate ticket, specified in the Tariff.

The obtaining of a non-personalised card is easier, it does not require any formalities, also those cards distribution network is larger – apart from 40 Customer Service Points they can be obtained at 6 Passenger Service Points, from more than 100 ticket machines and 800 points of sales. A lower interest in non-personalised cards results from the need to pay a deposit and from higher prices of medium- and long-term season tickets. Table 5 presents the number of cards issued in individual months from October 2015 to December 2016.

Table 5. Number of SKUP cards issued (from October 2015 to December 2016) monthly and cumulative, broken down into personalised and non-personalised cards (Source: Own study based on the KZK GOP figures)

Year	Month	Cumulative number of issued SKUP cards	Monthly number of issued SKUP cards	Of which		Share of issued non-personalised cards (%)
				Personalised cards	Non-personalised cards	
2015	October	4,703	4,703	4,255	448	9.5
	November	10,898	6,195	5,610	585	9.4
	December	19,707	8,809	8,507	302	3.4
2016	January	28,145	8,438	7,681	757	9.0
	February	33,372	5,227	4,675	552	10.6
	March	38,983	5,611	5,077	534	9.5
	April	48,931	9,948	8,964	984	9.9
	May	71,051	22,120	20,163	1,957	8.8
	June	110,460	39,409	37,694	1,715	4.4
	July	141,342	30,882	28,981	1,901	6.2
	August	171,761	30,419	28,752	1,667	5.5
	September	200,894	29,133	27,790	1,343	4.6
	October	218,208	17,314	16,103	1,211	7.0
	November	228,052	9,844	9,089	755	7.7
	December	234,861	6,809	6,188	621	9.1
	Total	234,861	234,861	219,529	15,332	6.5

Till the introduction of SKUP Card passengers could buy only tickets with unlimited travels. The introduction of a card with a limit of travels is favourable in particular to passengers, who do not use the urban transport frequently and at the same time buying single travel tickets is not profitable for them.

A significant increase in the number of collected cards has been visible from May, this is related to a systematic withdrawal of medium- and long-term season paper tickets from the network. And so [5, 6]:

- on the 1st of May 2016 the following tickets were withdrawn from the offer of paper bearer season tickets: 24-hour, 48-hour, 5-day, 7-day, 14-day as well as paper personal season tickets: quarterly, reduced-fare and holiday monthly school tickets as well as monthly bearer tickets,
- on the 1st June 2016 paper personal season tickets were withdrawn, authorising to travel only by bus lines or only by tram lines in the area of two or more cities (municipalities),
- on the 1st July 2016 paper personal season tickets were withdrawn, authorising to travel only by bus lines or only by tram lines in the area of one selected city (municipality),
- on the 1st August 2016 paper personal bus & tram monthly tickets were withdrawn, authorising to travel by all lines in the area of one selected city (municipality) and authorising to travel by all lines in the area of two or more cities (municipalities).

The interest in the SKUP cards and thereby the number of issued cards is affected by many factors. Definitely, it is the image of the project itself, which despite a good information policy, promotional prices and the introduction of additional promotions for persons buying tickets for the next period of time (5% promotion), has also elements deteriorating the image. Many elements of the system may be positively assessed, including the availability of new tariffs, the e-money functions, promotions, starting 110 multifunctional Stationary Card Charging Machines, establishing and equipping a network of 800 points of tickets sales, a possibility to charge the card and to buy tickets via an Internet site. The delay of the project implementation and thereby a shift of previously planned dates of cards issuing start and introducing e-tickets into circulation may be mentioned among elements deteriorating the project's image. Moreover, there were notifications of cases – in particular during the first travels – of system stopping in certain vehicles, of queues, especially at month's turns in Customer Service Points, related to filing applications or collecting cards. Also fears of personal data protection were expressed – with paper tickets such data was not acquired. Moreover the obligation of validation (check-in) was extended onto all ticket types, which in the case of season tickets with unlimited travels could be perceived as an additional and not entirely necessary action. It could be assumed that to some extent this resulted from the fare collection system in force previously for many years, in which there was no validation whatsoever of monthly and quarterly tickets.

The check-in and check-out system enables automatic identification of passenger flow volumes in individual sections of routes. The necessity to acquire and process such quantities enables adapting the time tables to the demand on a current basis and planning and settling subsidies contributed by municipalities forming the KZK GOP. Most generally, the amount of subsidy is settled based on the financial results of individual lines and this forces to identify the transport volumes and the obtained ticket revenue. At the same time the cost of line operation is known, because it results from the contracts concluded by the KZK GOP on the performance of bus/tram public transport, rates paid for a vehicle-kilometre and from the operating performance of carriers [7].

The data on the travels' purchase and registration in a vehicle is available in the SKUP system, however, the identifier is only and solely the card number, there is no information about such card's user and hence it is not possible to connect the data on the card use with the user personal data, because the personal data is not recorded in the SKUP IT system. Also on-board readers in vehicles identify the card number and recorded rights to concessionary or free travels, while they do not read from the card and do not register in the system the information about specific card user. Thereby in such cases there is no personal data processing. Personal data of personalised (personal) cards users is collected in the process of cards ordering and processes for the needs to conclude and execute the contract on the card use. During the filing of application for a personalised card, be it via the Customer Portal or in service points, a form is filled, which is automatically transferred via the SKUP IT System to the Settlement Agent system, while the data is not saved in the SKUP system. KZK GOP, as the SKUP system administrator, and other entities participating in the project implementation do not have access to the Settlement Agent system. Thereby there is no possibility to connect the data used among others for settlements with the personal data of the Settlement Agent system.

3 The Process of Replacing Paper Tickets with Electronic Tickets and Payments

Table 6 presents the number of issued/sold short-term (single travel) paper and electronic tickets. Short-term e-tickets, recorded on the SKUP card, were valid starting from the second decade of January 2016, hence the single travel e-tickets included in the specification in Q4, 2015, were only SMS tickets.

Table 6. Number of issued for sales/sold short-term (single travel) tickets (Source: Own study based on the KZK GOP figures)

Specification	Short-term (single travel): paper tickets	Short-term (single travel): e-tickets (recorded on the SKUP card, purchased in the validators, SMS)	Total	E-tickets share in total tickets (%)
October 2015	4,244,177	42,200	4,286,377	1.0
November 2015	4,360,469	38,800	4,399,269	0.9
December 2015	4,239,752	51,200	4,290,952	1.2
Total Q4, 2015	12,844,398	132,200	12,976,598	1.0
Monthly average for Q4, 2015	*4,281,466*	*44,067*	*4,325,533*	*1.0*
January 2016	4,090,863	53,916	4,144,779	1.3
February 2016	4,351,958	70,312	4,422,270	1.6
March 2016	4,549,588	78,297	4,627,885	1.7
April 2016	4,619,667	91,103	4,710,770	1.9
May 2016	4,174,983	111,162	4,286,145	2.6
June 2016	5,307,812	136,819	5,444,631	2.5
July 2016	5,058,565	171,055	5,229,620	3.3
August 2016	4,788,409	199,201	4,987,610	4.0
September 2016	4,266,309	248,398	4,514,707	5.5
October 2016	5,787,470	239,352	6,026,822	4.0
November 2016	4,005,587	218,898	4,224,485	5.2
December 2016*	4,896,529	229,125	5,125,654	4.5
Total 2016	55,897,740	1,847,638	57,745,378	3.2
Total Q4, 2016	14,689,586	687,375	15,376,961	4.5
Monthly average for Q4, 2016	*4,896,529*	*229,125*	*5,125,654*	*4.5*

*Estimated data

When analysing the volume and dynamics of individual ticket type sales, an increase in the sales of short-term paper tickets is a surprise – quite clearly visible from June 2016 and still a small number and share of e-ticket sales as compared with the paper tickets, and in general with the season tickets sales.

In the last months of 2016, despite an increase in sales of this segment tickets – the share of short-term e-tickets did not exceed 10%. At the same time, comparing Q4, 2016 with Q4, 2015 in terms of paper tickets sales, an average monthly increase by approx. 600,000 tickets is visible, which means a relative increase by 15%. The number of travels by the KZK GOP urban transport during that period has not increased, hence it means changes in the ticket types purchased by passengers. In general, and the issue will be discussed further on, the increase in the number of short-term tickets sold results from a decline in the volume of purchased medium- and long-term tickets. The reasons can include habits to use paper tickets, which – distributed in various forms – were used in the urban public transport from the beginning of its existence, hence from the turn of the 19th and 20th century. Another reason is certainly the fact – in the case of a small group of persons – of a systematic decrease of the number of travels carried out with season tickets, which at the moment of the need to shift to a season ticket recorded on the SKUP card resulted in giving up the purchase of a season ticket in favour of short-term (single travel) tickets. This may be confirmed by the fact of a quite large share in the sales of tickets with a limited number of travels. A significant average monthly increase in the e-tickets sales draws attention - in the period from January 2016 to December 2016 by nearly 420%, however, despite significant growths their sales are not high. Table 7 presents the n-day ticket sales (i.e. 24-hour, 48-hour, 5-, 7-, and 14-day tickets).

Table 7. Number of issued for sales/sold n-day tickets (Source: Own study based on the KZK GOP figures)

Specification	n-day paper tickets	n-day tickets recorded on SKUP card	Total	Share of tickets recorded on SKUP card in total tickets (%)
October 2015	9,362	124	**9,486**	1.3
November 2015	7,857	531	**8,388**	6.3
December 2015	9,012	684	**9,696**	7.1
Total Q4, 2015	26,231	1,339	27,570	4.9
Monthly average for Q4, 2015	***8,744***	*446*	***9,190***	4.9
January 2016	9,070	634	**9,704**	6.5
February 2016	9,778	718	**10,496**	6.8
March 2016	6,158	674	**6,832**	9.9
April 2016	3,773	799	**4,572**	17.5
May 2016	0	2,363	**2,363**	100
June 2016	0	5,068	**5,068**	100
July 2016	0	6,266	**6,266**	100
August 2016	0	6,178	**6,178**	100
September 2016	0	4,960	**4,960**	100
October 2016	0	4,601	**4,601**	100
November 2016	0	4,127	**4,127**	100
December 2016 *	0	4,364	**4,364**	100
Total 2016	**28,779**	**40,752**	**69,531**	58.6
Total Q4, 2016	**0**	13,092	**13,092**	100
Monthly average for Q4, 2016	***0***	*4,364*	***4,364***	100

*Estimated data

Note: The volume of n-day paper tickets given out from the warehouse was proportionally reduced in the period from October 2015 to April 2016 by returns in May (10,308) and June (6,165).

The volume of specified ticket sales – recorded on a paper carrier – on average monthly in Q4, 2015 was 11,362.

The paper form of those tickets was no longer available from May. Their sales already as e-tickets is significantly lower, in Q4, 2016 as against Q4, 2015 a decline to around 4,000 pieces was visible. Albeit in July and August 2016 their sales exceeded 6,000 pieces, but that was caused by the vacation and holiday period. The sales of long-term – 30-day tickets went down then and the sales of n-day tickets grew, primarily of 7- and 14-day tickets. It is possible to refer to low sales of n-day tickets not only with respect to the previous level of those tickets sales, but also taking into account the introduction to the offer of additional ticket types – with a limited number of travels and thereby with a price reduced due to that. Short-term (single travel) tickets are substitutes for such tickets, hence a decline in the n-day ticket sales has translated into increased sales of short-term (single-travel) tickets. It is necessary to consider another aspect of this phenomenon. The n-day tickets, including in particular 24- and 48-hour tickets and 5-day tickets are those, which are purchased by visitors. For such persons a shift to electronic ticket forms means the necessity to obtain a card, personalised or non-personalised. A non-personalised card is related to the payment of a deposit – PLN 20, which at the purchase of a 24-hour ticket for PLN 16 or 17, or a 48-hour ticket for PLN 26 or 27 means a double expenditure. Obviously, the deposit is repayable, however, that means additional actions. Alternatively, a personalised card may be obtained, but there is some procedure in place and the card is issued on the second day, which – for a visitor not having much time and willing to buy the ticket immediately – is not acceptable. So this explains the increase in the sales of tickets that do not require having a SKUP card. Table 8 presents the volume of paper monthly tickets sales and of 30-day e-tickets sales between October 2015 and December 2016.

A drop from nearly 109,000 sold on average monthly in Q4, 2015 to almost 99,000 tickets sold on average monthly in Q4, 2016 is visible. This is a decline by nearly 10%. The drops could be perceived as resulting from the introduction, together with e-tickets, of 30-day tickets instead of monthly tickets. This means that the start of ticket validity period is not defined strictly as the month beginning, but the ticket's validity starts at the moment specified by the user during the ticket purchase or during the first travel by a vehicle of urban public transport. This causes that to some extent the purchased ticket could better used by the elimination of days, in which the transport services are not used. Such effect was considered when the 30-day ticket was offered. The second reason for the drop was referred to earlier, this is a shift of part of people to the segment of short-term (single travel) tickets.

Table 9 presents sales of quarterly tickets in the period of October 2015 - December 2016. In practice the sales are on the same level. The quarterly/90-day tickets are purchased by persons frequently and permanently using the transport services, for those persons any change of ticket type is unprofitable. Because of a long period of ticket validity, the replacement of a quarterly ticket with a 90-day one does not result in decreased sales.

The presented figures show that despite lower prices and additional promotions, the habit of using paper tickets was and is visible. Such situation is not characteristic of only the case of introducing automated collection systems in the public transport, but occurs and applies to all new solutions in the field of e-services in the municipal management. Automated systems require certain change of hitherto habits, part of the public has a very cautious attitude, being afraid of missing some selection function, making a choice not in accordance with expectations or making a mistake and later on having to clarify it. In the ticket segments, which are available both in the paper and electronic version, part of service users are persons trusting more to a traditional validator and to the record on a paper ticket, than to e-cards. The number of short-term e-tickets has been systematically growing, although already now it was possible to expect a larger number of persons using the e-money and the distance tariff. In the next periods of time it is necessary to pay greater attention to this type of fares, so that short-term e-tickets would start dominating the sales in their segment. It can be added that this is a response to the formulated expectation of a cheap ticket for small distances, e.g. a few stops, and also of increased price competitiveness of the public

Table 8. Number of issued for sales/sold monthly tickets (Source: Own study based on the KZK GOP figures)

Specification	Monthly paper tickets	30-day tickets recorded on SKUP card	Total	Share of tickets recorded on SKUP card in total tickets (%)
October 2015	118,886	704	**119,590**	0.6
November 2015	109,170	2,702	**111,872**	2.4
December 2015	99,406	3,886	**103,292**	3.8
Total Q4, 2015	327,462	7,292	334,754	2.2
Monthly average for Q4, 2015	***109,154***	*2,431*	***111,585***	2.2
January 2016	90,605	5,645	**96,250**	5.9
February 2016	98,815	5,732	**104,547**	5.5
March 2016	90,680	8,281	**98,961**	8.4
April 2016	77,883	10,092	**87,975**	11.5
May 2016	55,684	23,251	**78,935**	29.5
June 2016	23,287	36,894	**60,181**	61.3
July 2016	0	45,069	**45,069**	100
August 2016	0	74,616	**74,616**	100
September 2016	0	83,799	**83,799**	100
October 2016	0	99,938	**99,938**	100
November 2016	0	97,269	**97,269**	100
December 2016 *	0	98,604	**98,604**	100
Total 2016	**436,954**	**589,190**	**1,026,144**	57.4
Total Q4, 2016	**0**	295,811	**295,811**	100
Monthly average for Q4, 2016	***0***	*98,604*	***98,604***	100

*Estimated data

Note: The volume of n-day paper tickets given out from the warehouse was proportionally reduced in the period from October 2015 to June 2016 by returns in July (15,886), August (23,543), September (64), and October (91).

Table 9. Number of issued for sales/sold quarterly and 90-day tickets (Source: Own study based on the KZK GOP figures)

Specification	Quarterly paper tickets	90-day tickets recorded on SKUP card	Total	Share of tickets recorded on SKUP card in total tickets (%)
October 2015	7,355	278	**7,633**	3.6
November 2015	2,317	871	**3,188**	27.3
December 2015	7,365	547	**7,912**	6.9
Total Q4, 2015	17,037	1,696	18,733	9.1
Monthly average for Q4, 2015	***5,679***	*565*	***6,244***	9.1
January 2016	4,584	1,007	**5,591**	18.0
February 2016	4,599	1,023	**5,622**	18.2
March 2016	5,198	1,080	**6,278**	17.2
April 2016	416	1,701	**2,117**	80.3
May 2016	0	2,309	**2,309**	100
June 2016	0	3,821	**3,821**	100
July 2016	0	3,355	**3,355**	100
August 2016	0	5,730	**5,730**	100
September 2016	0	7,977	**7,977**	100
October 2016	0	7,236	**7,236**	100
November 2016	0	5,570	**5,570**	100
December 2016*	0	6,403	**6,403**	100
Total 2016	**14,797**	**47,212**	**62,009**	76.1
Total Q4, 2016	**0**	19,209	**19,209**	100
Monthly average for Q4, 2016	***0***	*6,403*	***6,403***	100

*Estimated data

Note: The volume of n-day paper tickets given out from the warehouse was proportionally reduced in the period from October 2015 to April 2016 by returns in May (2,731), June (1,137) and from July.

transport against travels by individual means of transport. The distance tariff allows to implement this postulate. At the same time the sales of tickets with a limit of travels may be assessed very well, within a few months the sales reached more than 20% of total sold tickets. For individual ticket types for 2016 these values are as follows – for n-day tickets 23.5%, for 30-day tickets 22.2%, for 90-day tickets 28.1%. The users obtained a measurable and considerable reduction of expenditures related to the tickets purchase, this is positive because such persons were relatively less using KZK GOP services. With successive issuing of SKUP cards in 2016, gradually more and more people have been using the reduced ticket prices and at the same time have been better adapting the purchased tickets to the number of performed travels.

Presented figures on the sales of individual ticket types, used when travelling by the KZK GOP public transport, show a systematically increasing share of e-tickets. Taking into account the size of SKUP system, measured by the number of devices installed in vehicles and in points of sales, the number of issued SKUP cards and also the number of persons using the KZK GOP services, it is possible to state that during a year both the card itself and e-tickets became widespread. It is worth emphasising here, that the public transport services are used not only by young people, or by social groups easily and fast adopting changes in the field of electronic services and wishing such changes. It is also necessary to consider long-term habits, unwillingness or more generally difficulty in adaptation to new solutions. A fear of e-services, of unauthorised data use, of excessive number of documents or information related to the given service, or of other arduousnesses, which could be experienced in the domain of digital economy, also frequently occur [8]. We should be aware of difficulties or even threats and also we should know how to prevent them, what rules should be observed, which requires both knowledge and continuous learning. The phenomenon of digital exclusion is known, narrowed to a lack of computer or of Internet access, but it has a broader dimension, just of the lack of possibilities and skills to use increasingly common e-services of various types [9]. In the context of various type e-services within the e-administration, which use is not common, the SKUP project may be positively assessed, in particular in the context of the issued cards number and the volume of e-tickets sales achieved since November 2015. It is well related to the fact that the project was implemented under Priority 2. Information society. Measure 2.2. Development of electronic public services of the Regional Operational Programme of Silesian Voivodship for the years 2007–2013.

The e-tickets system, especially at the implementation stage, must consider massive nature of services, such as urban public transport services; it is necessary to consider cumulation of various actions in various periods of day, week or month, which require certain reserves in the service points or in the network throughput. Also expectations and ideas related to possible functionalities differ. Expectations may be and sometime are contradictory, for example they include on the one hand the whole system simplification, and on the other hand many functions and numerous selection possibilities. However, the system should be definitely intuitive in operation and work on-line, despite many thousands of various devices working in the system. The SKUP system equipment has been operating in a few hundred entities, the rules and regime established for the system should be strictly observed, because deviations from them cause negative effects for the service users and later on are the cause for the complaints.

Also the image of the entire project is extremely important. Unfortunately, a very short planned implementation time, resulting from the use of EU funds under the Regional Operational Programme and hence the necessity to complete and settle the project by the externally indicated deadline, and the fact that it is a large project and with respect to its principles – basing on the e-money – innovative, resulted in delays of its implementation. A good positive image of the solution is necessary, because it allows to implement the project on a mass scale and also to cover by it persons, who approach solutions in the field of e-services with scepticism and great fears.

4 Conclusion

The implementation of large IT systems is a difficult and complicated organisational process, in which the hardware vendors and teams of analysts and programmers play a major role. However, in the case of systems managing the provision of common services, as it is in the SKUP case, its acceptance by the system users plays a great and even basic role. According to the assumptions the system shall be common and replace the hitherto paper tickets system. This requires listening to the expectations, but also numerous compromises, because the ideas differ and the expectations are frequently contradictory. This requires creating also a system of broad possibilities and expanded functions, necessary at the given moment, but also anticipated in the future.

Measurable effects are visible in the part related to the implementation of payments and e-tickets after a year from starting the cards issuance and e-tickets sales. Among persons systematically using the public transport the SKUP card became common, at the same time medium- and long-term tickets were entirely replaced with e-tickets. A significant factor, affecting the volume of e-ticket sales, is the fact that the implementation was linked with a new, very attractive services price list and with the introduction of new tariff and ticket types to the offer. A systematic withdrawal of selected paper tickets from the offer was also significant. The next steps should be directed towards a systematic increase in the short-term e-tickets sales, at least to the level, where they will be dominating in the sales volume. Their total liquidation should be approached very carefully, at least due to the previously mentioned digital exclusion or the visitors or persons occasionally using the public transport, Because of that it should be considered to leave the paper tickets sales, e.g. sold by the vehicle drivers.

During the SKUP system implementation a new sales network was established, dedicated to e-tickets, ensuring their availability in all administration units of KZK GOP. In addition, a possibility to purchase tickets all day long through the Internet or in additionally installed machines for card servicing. In practice, the network created for paper tickets is still in operation now, and also that for e-tickets. In part of cases these are the same points. Longer-term, the parallel maintaining of two developed networks will not be justified – actions will be doubled, which in fact will generate unnecessary expenditure. Therefore the previously mentioned reduction of paper tickets sales should be linked with gradual liquidation of the sales network.

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Selected Aspects of the Methodology for Delimitation of the Area of Urban Agglomeration in Transportation Models for the Evaluation of ITS Projects

Grzegorz Karoń[1(✉)], Renata Żochowska[1], Aleksander Sobota[1], and Ryszard Janecki[2]

[1] Faculty of Transport, Silesian University of Technology, Katowice, Poland
{grzegorz.karon, renata.zochowska, aleksander.sobota}@polsl.pl
[2] Faculty of Economics, University of Economics, Katowice, Poland
ryszard.janecki@ue.katowice.pl

Abstract. The article presents the selected issues and the algorithm of methodology for delimitation of the urban area for the needs of construction of four-step transportation model. In the methodology the use of the transportation model for the evaluation of ITS projects has been taken into account. The essence of the presented methodology is to take into account three types of criteria for delimiting the area and different levels of reference. Presented issues became the basis for the development of mathematical formalization of delimitation problem. The examples relate in particular to urban agglomeration with the nature of a conurbation - Upper Silesian Agglomeration in Poland.

Keywords: Urban agglomeration · Four-step transportation model · Delimitation of the area · ITS projects

1 Introduction

Four-step transportation models are now the standard tools of transportation analysis of cities and urban agglomerations, which include:

- diagnoses of functioning of transportation systems [1–3],
- traffic forecasts for specific strategic actions [4–6],
- analyzes within the transportation studies for specific investment projects, among others for the ITS projects - defined in a number of investment variants [7].

Delimitation of the study area - (for example, the impact area of the investment project), carried out during the construction of transportation model, is associated with conducting spatial-demographic and socio-economic analyzes. As a result, they should enable the identification of traffic analysis zones (TAZs), which constitute the basic structure for generating and absorbing movement in the four-step transportation model. The article presents some aspects of the methodology of delimitation of the study area.

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_20

A review of the state-of-the-art revealed that issues of delimitation of urban areas described in foreign literature [4, 9–11] do not take into account, to a large extent, the determinants of the functioning of such areas as polycentric agglomeration (conurbation) [8]. Many authors of various publications describe insufficiently the elements of the developed methodology, which involve such conditions as:

– division of settlement units and TAZ's to those that belong to different organizational structures, related to the organization of urban transport and the possibility of raising funds for the realization of the project,
– division of settlement units and TAZ's into those with one public transport organizer, and those with other public transport organizer located in the immediate vicinity of the study area,
– division of settlement units and TAZ's in terms of the functioning of transportation systems and the planned ITS project, covering in various functional scopes (different ITS services) the transportation subsystems of communes forming polycentric agglomeration.

There is a lack of comprehensive works in the national literature and there are many publications in the national literature that deal with these issues in a fragmentary or superficially manner. Developed methodology with algorithm of delimitation of the study area for transportation modeling with evaluation of ITS project—which uses a systematic approach and a formalization of the key research questions—is an important scientific contribution.

2 The Framework Conditions and Methodological Assumptions

When making the delimitation of the study area for which the transportation model would be constructed one should considered, among others, the following aspects of the issue:

– administrative delimitation of the settlement units - levels: national, regional, voivodeship, sub-regional, metropolitan, urban agglomeration, local,
– structural delimitation of the settlement units - levels: the zone area, transportation macroregion, transportation microregion,
– technical and functional delimitation for the ITS project.

These issues have been presented in the following chapters with regard to the methodology [8] developed for the concept of the ITS project for the agglomeration area and for the urban area of the municipality - the capital of the urban agglomeration. The algorithm of delimitation of the study area (blocks 4a–4d, 5) included in the algorithm of activities during Comprehensive Traffic and Transportation Studies (CTTS) for Transportation Modeling with Evaluation of ITS Project has been presented in Fig. 1.

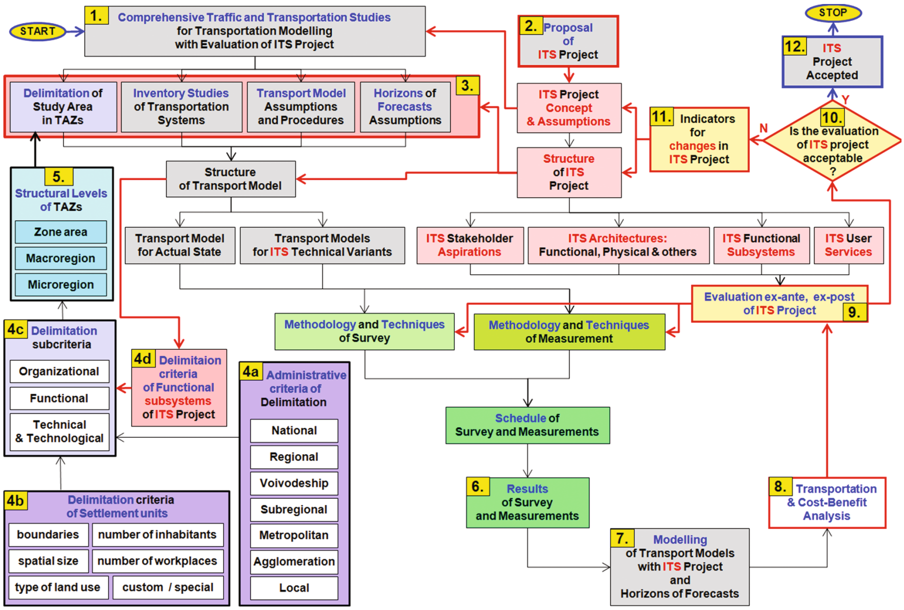

Fig. 1. Algorithm of delimitation of the study area (blocks 4a–4d, 5) included in the algorithm of activities during Comprehensive Traffic and Transportation Studies (CTTS) for Transportation Modeling with Evaluation of ITS Project (in the form of block-scheme)

The methodology and detailed concept of conducting the survey as well as the of the manner of constructing the transportation model for the area of urban agglomeration [8] refers to the area of the Upper Silesian Agglomeration, where the functional conditions allow treating the study area as a metropolis. In the first stage of the process of administrative delimitation of the settlement units of Silesian Voivodeship, divided into four sub-regions (central, northern, southern and western), has been analyzed.

The area of Silesian Voivodeship has been subjected to analysis of functional relationships between the units of the settlement. The result of the analysis is to identify the following units of the settlement network:

– metropolis understood as the main link that concentrates the processes of economic and social development of the voivodeship as well as enhances the competitiveness of the whole region as one of the national development poles of European significance,
– urban agglomerations that are the areas which are mainly focused on the development of the processes of sub-region and on enhancing the competitiveness of the region as center of national and transnational significance,
– the functional areas of the metropolis and urban agglomerations understood as the territories that surround the metropolis or agglomerations and are directly linked in spatial, social and economic layout, absorbing development processes of the central areas,

– local development centers understood as the units that organize the development processes at the local level, focusing the features and services for the population, cities and rural areas located outside the metropolis, metropolitan areas and functional areas.

These settlement units in the Silesian Voivodeship are (Fig. 2): Upper Silesian Metropolis, functional area of Upper Silesian Metropolis, Czestochowa Agglomeration, functional area of Czestochowa Agglomeration, Rybnik Agglomeration, functional area of Rybnik Agglomeration, Bielsko-Biala Agglomeration, functional area of Bielsko-Biala Agglomeration.

3 Principles and Criteria of Delimitation

The division of the area into the zones area results from the system approach to the process of constructing of the transportation model. Such a model for a particular city, agglomeration or region should include their closer and optionally further surroundings that are the zones functionally related to the area for which it is constructed.

Structural delimitation of the settlement units depends primarily on the following factors, that constitute the subcriteria (see Fig. 1 blocks 4C):

– organizational criterion – this criterion is important with respect to the division of settlement units into those that belong to different organizational structures related to the organization of urban transport and possibility of raising funds for the realization of the project:
– participation in the investment structure related to the project (e.g. participation related to the organization of public transport - KZK GOP),
– participation in the institutional structure associated with applying for EU funds (e.g. Association of Municipalities and Districts of the Central Subregion of Silesian Voivodship),
– functional criterion – this criterion is important with respect to the division of settlement units into those with one public transport organizer, and those with other public transport organizer located in the immediate vicinity of the study area:

• the beneficiary of the public transport services on a over-municipal level, functioning on the basis of the ticket-tariff agreement, of the agreement between the municipalities or of the agreement on the realization of public transport on a district or voivodeship level,
• location in the direct functional neighborhood of the city or the agglomeration, for which the transportation model is constructed,

– technical and technological criterion – this criterion is important with respect to the division of settlement units in terms of the functioning of transportation systems and the planned transportation project – in this case ITS project:

• the area operated by the specified transportation system,
• the coverage area of the ITS services supporting the management of the flow of people and goods in the city, agglomeration or region.

In the methodology the following units of administration delimitation—zone areas—have been separated (see Fig. 2):

– Zone 0: the municipalities that are beneficiaries of the project (e.g. ITS project for KZK GOP),
– Zone 1: the municipalities directly neighboring to the zone 0; the municipalities that are not participants of the KZK GOP but are operated by bus lines organized by the Association; the municipalities that are not participants of the KZK GOP but are operated by the bus lines organized by the KZK GOP Katowice and MZKP in Tarnowskie Góry under an ticket-tariff agreement between the Associations,
– Zone 2: the municipalities belonging to the Central Subregion of of Silesian Voivodship that are not elements of previously featured zones.

The zone areas, separated by the above criteria, are further divided into smaller areas (see Fig. 1 block 5): transportation macro- and microregions according to the presented principles.

The transportation macroregion constitutes the area of a large size with a similar demographic, spatial and transportation features. The transportation macroregion may be the area formed by:

– the units of administrative division of the country: municipalities or districts,
– sets of administrative units created in accordance with the needs of the project,
– the individual auxiliary units of the municipality with a high demographic potential (number of inhabitants in these units over 4–5 thousand in large cities, over 1 thousand in small towns),
– certain sets of auxiliary units of the municipalities created in accordance with the needs of the project,
– the groups of the transportation microregions appropriate to the needs of the project.

The zone areas as well as transportation macroregions are further subdivided into the transportation microregions - areas of the defined area and of demographic potential expressed as the number of inhabitants or as the number of workplaces [9–12]. The areas should be homogeneous in term of land use. The smaller the size of the transportation macroregion, of the population in the area and the number of workplaces, as well as the homogeneous nature of zoning, the more accurate representation of real trips in terms of quantity and space. The number of the transportation microregions depends on the size of the area, on the spatial and demographic structure, that is on distribution of trip generators in the area, and on the assumed level of homogeneity of selected areas.

From the point of view of the division of the study area one may determine two types of areas:

– the transportation microregions, covering the areas of individual auxiliary units of the municipality or certain sets of these units which meet quantitative and qualitative criteria of delimitation of areas. This is important within the rural areas where a large number of units with low demographic potential is observed. This requires their combination when determining the transportation microregions,

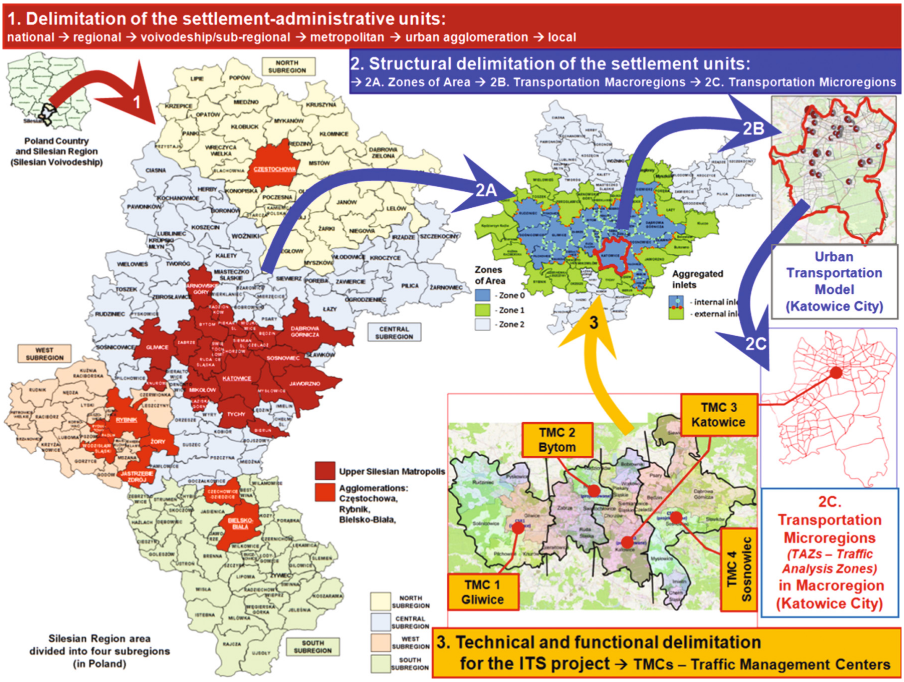

Fig. 2. Stages of delimitation of urban agglomeration having regard to ITS projects: 1. The settlement units, 2. Structure of the settlement units: 2A – zone area, 2B – transportation macroregions, 2C – transportation microregions (delimitation of urban transportation model), 3. Functional and technical areas of the ITS project (areas covered by traffic management centers TMCs). Source: own research based on [8]

– the transportation microregions formed in accordance with generally applicable rules, given later in this article.

During the delimitation of the area in the transportation microregions the following subcriteria should be taken into account (see Fig. 1. block 4b):

– the boundaries of the area: the boundaries should, if possible, run along the boundaries of the natural barriers (e.g. rivers, railways, undeveloped areas, etc.); the boundaries conducted by roads and streets should be carried out on the axis of the road. The numbers of buildings on the street demarcating the area should be also determined,
– the size of the area: the transportation microregion should cover all areas of urban investment; one should aim to the size of the area enable obtain reliable data on the distribution of the population and of the workplaces and thus include e.g. the area of auxiliary unit of the municipality or of the urban unit,
– the size of the area in terms of number of inhabitants: in smaller towns the recommended maximum number in the transportation microregion is to 1.0–1.5 thousand of person; in other cities - respectively to 2.5–3.0 thousand of people,

– the size of the area in terms of number workplaces: in smaller towns the maximum recommended number of workplaces in the transportation microregion is to 0.5–0.8 thousand of person; in other cities - respectively to 1.0–1.5 thousand people,
– land use of the area: the regions with homogeneous functions, such as housing, industry, the public services, recreation, etc.,
– the custom transportation microregions: the inlets of routes on external cordon points; railway stations; bus stations.

The methodology [8] formulates the principle of the division of the study area into the transportation microregions with an accuracy of municipality, street and number of building, and defines the minimum number of the transportation microregions, which has been estimated on the basis of the number of inhabitants. The aim of this approach was primarily to take into account the inhabited areas, in which the Household Interview Survey shall be conducted. Then the additional terms and conditions of the division of the area into the transportation microregions have been indicated:

– the number of the transportation microregions should be increased having regard to the land use of the area associated with the various activities of the users of the transportation system. In this way, the successive transportation microregions with a different land use than housing (e.g. industrial, service and trade, recreational, educational and cultural, etc.) would be separated,
– in the case of the use of data from urban transportation models (e.g. transportation model of the city of Katowice in 2015 - see. stage 2C in Fig. 2), the efforts should be made to ensure that the boundaries of the transportation microregions in the model for agglomeration (zone 0) were consisted with the borders of the aggregated transportation microregions in more developed models of each city of zone 0. This approach would enable the use of existing databases containing the same characteristics of trip generation (e.g. the number of the residents, of the students, of the workplaces etc.). Furthermore, the combination of the models in the future will be possible to carry out,
– the custom transportation microregions on cordons points have been segregated: on external cordon points – aggregated external inlets, including all transportation systems accessible in the immediate neighborhood of the inlet; on internal cordon points – aggregated internal inlets, enabling integrate data between different models of the cities as well as between the model of the agglomeration and the models of the cities.

Presented methodology of delimitation of the area of urban agglomeration in transportation models assumes the development of a transportation model with a delimitation of the area appropriate to evaluate the effects of deployment of the ITS service, described in the concept of the ITS or in the feasibility study of the ITS service in form (see Fig. 2 – block 2 and next):

– logical architecture (functional) with defined operations and functions of ITS services and data flows between them,
– physical architecture with mapping of the logical architecture in necessary technical and human systems and subsystems,
– stakeholders and end-users aspirations.

If the transportation model is constructed or calibrated to evaluate a particular investment project, e.g. the assessment of technical alternatives of the ITS services defined in the concept of the ITS (see Fig. 1 block 2) or in the feasibility study of the ITS service, then in the process of delimitation it is important to consider the functional and technical area of the ITS project (see Fig. 1 block 4d and next). For example, in the methodology [8] the area of the agglomeration covered by the following subsystems of the ITS services has been taken into account:

- system of area traffic control and public transport management system,
- system of information for drivers and passenger information system,
- video monitoring system.

In the process of delimitation the places of installation of external devices of mentioned subsystems, and the location and spatial extent of the traffic management centers (see TMC 1, TMC 2, TMC 3 and TMC 4 in Fig. 2) have been considered. Results of the use of methodology for Upper Silesian Agglomeration (in Poland) – macroregion-administrative level – cities, microregions-settlement level – TAZs with criteria: spatial size and number of inhabitants have been shown in Table 1.

Table 1. Results of the use of methodology for Upper Silesian Agglomeration (in Poland) – macroregion-administrative level – cities, microregions-settlement units – TAZs with criteria: spatial size and number of inhabitants

Administrative criterion of delimitation – cities of urban agglomeration	Spatial criterion – area of city (km^2)	Inhabitants criterion – number of inhabitants	Number of microregions – TAZs
Będzin	37	58 205	20
Bobrowniki	52	11 941	9
Bytom	69	172 306	61
Chełm Śląski	23	6 173	4
Chorzów	33	110 337	35
Czeladź	16	32 666	21
Dąbrowa Górnicza	189	123 376	39
Gierałtowice	38	11 624	7
Gliwice	134	184 415	58
Imielin	28	8 723	5
Katowice	165	301 834	95
Knurów	34	38 859	24
Mysłowice	66	75 037	23
Piekary Śląskie	40	56 755	18
Pilchowice	70	11 451	7
Psary	46	11 859	7
Pyskowice	31	18 563	12
Radzionków	13	17 050	11
Ruda Śląska	78	140 669	44

(*continued*)

Table 1. (*continued*)

Administrative criterion of delimitation – cities of urban agglomeration	Spatial criterion – area of city (km^2)	Inhabitants criterion – number of inhabitants	Number of microregions – TAZs
Rudziniec	159	10 613	7
Siemianowice Śląskie	25	68 634	22
Siewierz	114	12 284	8
Sławków	37	7 135	5
Sosnowiec	91	209 274	66
Sośnicowice	116	8 682	5
Świętochłowice	13	51 494	32
Wojkowice	13	9 033	6
Zabrze	80	177 188	56
SUM	1 810	1 946 180	707

4 The Formalization of the Issues

The development of the methodology and the algorithm (Fig. 1) requires a formal description of the problem for the algorithmic process. This process will allow the transformation of the issues formulated in the form of a verbal description into the algorithm and then into the specialized software - decision support tool when planning activities shown in Fig. 1.

To describe in formal way the issue of delimitation of the study area the methods of mathematical modeling have been used. Accordingly, the set of criteria for delimitation of the area is defined as:

$$\boldsymbol{K} = \{k1, k2, k3\} \tag{1}$$

where:

$k1$ - administrative criterion,
$k2$ - structural criterion,
$k3$ - functional and technical criterion with respect to the ITS project.

These criteria have been illustrated in Fig. 1 ($k1$ - stages 1 and 2A, $k2$ - stages 2B and 2C, $k3$ - stage 3) for an exemplary implementation of the developed methodology [8] for Territory of the Public Transport Operator in Upper Silesian Industrial Region (in Poland).

Within each of the methods of delimitation the levels of aggregation have been specified. The sets containing elements with an interpretation of the numbers of these levels have been defined as:

$$\boldsymbol{L}(k1) = \left\{ l(k1) \quad : l(k1) = 1, \ldots, \overline{L(k1)} \right\}, \qquad k1 \in \boldsymbol{K} \tag{2}$$

$$\boldsymbol{L}(k2) = \left\{ l(k2) \quad : l(k2) = 1, \ldots, \overline{L(k2)} \right\}, \qquad k2 \in \boldsymbol{K} \tag{3}$$

$$\boldsymbol{L}(k3) = \left\{ l(k3) \quad : l(k3) = 1, \ldots, \overline{L(k3)} \right\}, \qquad k3 \in \boldsymbol{K} \tag{4}$$

where:

$l(k1)$ - the number of the level of aggregation of the delimitation of the study area according to $k1$-th criterion (administrative),
$l(k2)$ - the number of the level of aggregation of the delimitation of the study area according to $k2$-th criterion (structural),
$l(k3)$ - the number of the level of aggregation of the delimitation of the study area according to $k3$-th criterion (functional and technical criterion with respect to the ITS project),
$\overline{L(k1)}$ - the number of all levels of aggregation of the delimitation of the study area according to $k1$-th criterion (the size of the set $\boldsymbol{L}(k1)$),
$\overline{L(k2)}$ - the number of all levels of aggregation of the delimitation of the study area according to $k2$-th criterion (the size of the set $\boldsymbol{L}(k2)$),
$\overline{L(k3)}$ - the number of all levels of aggregation of the delimitation of the study area according to $k3$-th criterion (the size of the set $\boldsymbol{L}(k3)$).

The values of $\overline{L(k1)}$, of $\overline{L(k2)}$ and of $\overline{L(k3)}$ depend on the specifics of the study area. For example, for the administrative delimitation (according to $k1$-th criterion) seven levels of aggregation $\left(\overline{L(k1)} = 7\right)$ may be identified. Then subsequent elements of the set $\boldsymbol{L}(k1)$ means: $l(k1)$ = 1- national level, $l(k1)$ = 2- regional level, $l(k1)$ = 3- voivodship level, $l(k1)$ = 4- sub-regional level, $l(k1)$ = 5- metropolitan level, $l(k1)$ = 6- agglomeration level, $l(k1)$ = 7- local level.

Therefore, at each level of aggregation the specific territorial units (called traffic analysis zones - TAZs), which are the subject of the analysis, may be unambiguously defined. Depending on the method of delimitation the traffic analysis zone would be:

- the settlement unit (according to $k1$-th criterion),
- the zone area, transportation macro- or microregion (according to $k2$-th criterion),
- the functional and technical area of the ITS service (according to $k3$-th criterion).

The traffic analysis zones have been presented in the form of sets and defined as:

$$\boldsymbol{TAZ1}(l(k1)) = \left\{ TAZ1_{l(k1)} : TAZ1_{l(k1)} = 1, \ldots, \overline{TAZ1_{l(k1)}} \right\},\ l(k1) \in \boldsymbol{L}(k1),\ k1 \in \boldsymbol{K} \tag{5}$$

$$\boldsymbol{TAZ2}(l(k2)) = \left\{ TAZ2_{l(k2)} : TAZ2_{l(k2)} = 1, \ldots, \overline{TAZ2_{l(k2)}} \right\},\ l(k2) \in \boldsymbol{L}(k2),\ k2 \in \boldsymbol{K} \tag{6}$$

$$\boldsymbol{TAZ3}(l(k3)) = \left\{ TAZ3_{l(k3)} : TAZ3_{l(k3)} = 1, \ldots, \overline{TAZ3_{l(k3)}} \right\},\ l(k3) \in \boldsymbol{L}(k3),\ k3 \in \boldsymbol{K} \tag{7}$$

where:

$TAZ1_{l(k1)}$ - the number of the TAZ separated at $l(k1)$-th level of aggregation according to $k1$-th criterion (administrative),
$TAZ2_{l(k2)}$ - the number of the TAZ separated at $l(k2)$-th level of aggregation according to $k2$-th criterion (structural),
$TAZ3_{l(k3)}$ - the number of the TAZ separated at $l(k3)$-th level of aggregation according to $k3$-th criterion (functional and technical criterion with respect to the ITS project),
$\overline{TAZ1_{l(k1)}}$ - the number of all TAZs separated at $l(k1)$-th level of aggregation according to $k1$-th criterion (the size of the set $\boldsymbol{TAZ1}(l(k1))$),
$\overline{TAZ2_{l(k2)}}$ - the number of all TAZs separated at $l(k2)$-th level of aggregation according to $k2$-th criterion (the size of the set $\boldsymbol{TAZ2}(l(k2))$),
$\overline{TAZ3_{l(k3)}}$ - the number of all TAZs separated at $l(k3)$-th level of aggregation according to $k3$-th criterion (the size of the set $\boldsymbol{TAZ3}(l(k3))$).

5 Conclusions

Verification of the assumptions of described methodology was made during preparation tender documentation (including Specification of the essential terms of the contract as well as Description of the subject of the order) for two areas: Upper Silesian Agglomeration (in Poland) and for the Territory of Central Subregion of Silesian Voivodeship. In both cases, verification was based on prepare the delimitation of each area, as well as to estimate the costs of the project - both by the contracting entity and by the entities that submitted their offers in the tendering procedure. Further research will be focused on the development of the specialized decision support software when planning activities shown in algorithm described in this article.

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Measures for Matching Stereo Images in Road Pavement Diagnostics

Marcin Staniek(✉)

Silesian University of Technology, Gliwice, Poland
marcin.staniek@polsl.pl

Abstract. The paper addresses the overall body of problems related to application of measures for matching stereo images in the measuring instruments used for assessment of road infrastructure condition. Selected stereo vision solutions applied in road pavement diagnostics have been explained. The main problem connected with the subject in question, namely the ambiguity of image matching, has been briefly described, and the matching algorithms commonly used have been characterised. The following measures of matching have been discussed: Sum of Absolute Differences (SAD), Zero Mean Sum of Squared Differences (ZSSD) as well as Covariance-Variance (CoVar). The studies conducted in the field addressed in the article concerned efficiency of stereo image matching for the aforementioned measures of matching. The relevant measurements were performed using images developed as outcomes of field surveys of the road infrastructure condition. The three-dimensional road pavement mapping thus obtained was compared with the mapping based on direct measurements using a dedicated diagnostic station.

Keywords: Evaluation of road pavement · Stereo vision · Image processing · Measures of images matching

1 Introduction

Road pavement diagnostics is a key process in the Pavement Management System (PMS), comprising assessment of such technical and operating parameters of roads as: wheel load capacity, transverse evenness, longitudinal evenness, anti-skid properties and identification of bumps, fractures or patches. Minimisation of the time required to conduct measurements as well as of the impact on other traffic participants and increasing measurement precision and comprehensiveness are the priorities of road pavement diagnostics, which determines the application of state-of-the-art measurement solutions in diagnostics of road infrastructure [1].

The solutions applicable to road infrastructure, its technical condition [2–4] and behaviour patterns displayed by traffic participants [5–7] are all factors affecting traffic safety. By way of analysis and assessment of the descriptive data obtained from measurements, one can draw conclusions concerning the road infrastructure condition and define schedules for repair and overhaul works as well as the scope of the necessary procedures. In a long-term horizon, the foregoing makes it possible to lay down the assumptions for acquisition and distribution of funds required to maintain the road infrastructure operational.

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_21

2 Visual Solutions Applied in Road Pavement Diagnostics

Visual solutions based on image processing and pattern recognition are widely applied in road pavement diagnostics. The computational algorithms adopted for these solutions use a number of different procedures, including segmentation, object detection, thresholding, matching estimation and, last but not least, three-dimensional image mapping. However, despite the broad capabilities of the solutions used in the process of road condition identification and description, vision methods entail certain limitations which require the system to be calibrated, noise filtered out of the image and the surface subject to measurements appropriately illuminated. Using solutions based on image processing and pattern recognition, one is capable of detecting, describing as well as recording such road pavement defects as bumps, patches, fractures of different kind, including longitudinal, transverse, alligator and technological cracks, as well as road surface deformations and chipping of the bitumen-aggregate mixture particles.

In a review of publications commenting upon road pavement diagnostics, one can find numerous references to solutions based on vibration assessment methods [8–10], mechanical measurement methods, methods based on laser properties (cross-section/ surface scanning), and finally visual solutions, including stereo vision methods. With the subject of this paper in mind, selected accomplishments connected with the application of stereo vision solutions in road pavement diagnostics have been discussed in the following paragraphs.

A measuring station designed for purposes of road pavement diagnostics based on the stereo vision method has been addressed in publications [11, 12], describing studies where for the sake of the disparity map determination, being a major step in the road pavement mapping, the measure of Mean Sum of Squared Differences for stereo images was used. The morphological operations undertaken for the foregoing purposes were used to remove noise from images. The efficiency of the stereo image matching increased after suitable means of additional road pavement illumination were installed on the test vehicle.

By extending the assumptions adopted for the above concept with a light pattern forming a line, one could assess the condition of both the road pavement macrostructure and microstructure [13, 14]. However, this solution is encumbered with crucial disadvantages like computational complexity which translates into the considerable amount of time required to complete the mapping as well as the complex procedure of the measuring station calibration.

A similar solution, also based on linear illumination or a projector displaying a rectangular grid pattern on the road pavement, has been proposed in publication [15]. Its operating principle is based on identification and recording of differences between the theoretical light information assuming the form of a line or a grid and the light image created on the road pavement.

The ongoing technological development gives birth to further optoelectronic solutions characterised by increasingly advantageous technical parameters, such as the improved resolution of CCD matrixes or reduced image acquisition time. Application of additional linear cameras in a stereo vision system of a measuring station has been described in papers [16, 17]. Using light information, one can unambiguously link vision data in a one-dimensional description acquired from linear cameras with a two-dimensional description delivered by traditional cameras. An outcome of such a concept is road pavement mapping with 1 mm accuracy.

3 Ambiguity of Object Matching in Stereo Images of Road Pavement

In the process of road pavement mapping, matching of objects in stereo images is a stage of key importance. This is when the chosen points/pixels or objects of the reference image are linked with their equivalents in the image being analysed, where the pair comprising the reference image and the analysed image form a stereo image. This stage also poses one of the most complex problems in the sphere of digital image processing [18].

In the road pavement mapping process, once the images have been acquired from the cameras installed at the measuring station (stage one), it is necessary to adjust and rectify the stereo images (stage two). In the subsequent, third stage, the disparity map is determined using the measures of object matching in stereo images. For the disparity map thus obtained as well as for the assumed optical camera parameters and spatial parameters of the measuring station, the road pavement is reflected in a three-dimensional system (stage four).

The main problem encountered while determining the disparity map is the ambiguity of matching between points/pixels or areas in stereo images, which stems from the imprecision of the reality mapping in the recorded image. With the problem source in mind, one may speak of the ambiguity of matching for the image elements characterised by [18]:

– equal value of intensity (colour),
– image noise,
– deformed image mapping,
– texture duplication,
– identical value of light components.

Assigning elements of stereo images using measures of matching has been widely described in the literature of the subject. From all the available solutions, one should highlight the following types of matching algorithms [18]:

– Algorithms based on feature detection,
– Algorithms of area matching,
– Algorithms based on the energy function,
– Algorithms based on application of transforms.

The algorithms abased on detection of individual features in the matching process use characteristic objects (e.g. edges, corners tec.) identified by means of extraction filters. The characteristic objects present in images make it easier to proceed with mutual assignment in stereo images. Contrary to the foregoing, in the area matching algorithms, one divides stereo images into smaller pieces which are subsequently assigned to one another. What matters in this solution is that the images analysed should be perpendicular towards the camera's direction of view, i.e. perpendicularly to its optical axis. There are also solutions based on using the energy function to establish the appropriate matching of objects. Neural networks provide a good example of such a solution. One can also apply the Fourier transform at the stage of object matching in stereo images [18].

On account of the measures of matching applied in road pavement diagnostics, only the area matching algorithms have been addressed in subsequent paragraphs of the paper. The foregoing stems from the assumptions adopted for the assessment of technical condition of road pavement, perceived as a surface mapped in a rectangular grid with the resolution of 1 cm × 1 cm.

Some of the most popular area matching algorithms include SAD and SDD [19] which can be successfully applied to process images with noises of exponential and normal distribution, respectively. However, with noise of a different function distribution, it is required that the ZSAD or ZSSD measures be introduced [20], with the mean image intensity value being taken into account. The solution suggested for non-uniformly illuminated areas is to apply the CoVar measure [21]. Selected relations describing the measures of matching, i.e. SAD (1), ZSSD (2) and CoVar (3), have been described below.

$$SAD(m,n,d_m,d_n) = \sum\nolimits_{(i,j)\in U} |I_L(m+i,n+j) - I_R(m+d_m+i,n+d_n+j)| \tag{1}$$

where:

I(m, n) – value of intensity of the image pixel at a point of coordinates *(m, n);*

U – pre-defined area of the image analysed in a pixel description.

$$ZSSD(m,n,d_m,d_n) = \sum\nolimits_{(i,j)\in U} \left(\begin{array}{c} \left(I_L(m+i,n+j) - \overline{I_L(m,n)}\right) - \\ \left(I_R(m+d_m+i,n+d_n+j) - \overline{I_R(m,n,d_m,d_n)}\right) \end{array} \right)^2 \tag{2}$$

where:

$\bar{I}_L$, $\bar{I}_R$ – mean values of intensity in a pre-defined point neighbourhood, given by relation (3), (4):

$$\overline{I_L(m,n)} = \frac{1}{25}\sum\nolimits_{(i,j)\in W} I_L(m-i,\ n-j) \tag{3}$$

$$\overline{I_R(m,n,d_m,d_n)} = \frac{1}{25}\sum\nolimits_{(i,j)\in W} I_R(m-d_m-i,\ n-d_n-j) \tag{4}$$

where:

W – pre-determined set of coordinates used to calculate mean intensity value:

$$CoVar(m,n,d_m,d_n) = \frac{L(m,n,d_m,d_n)}{\sqrt{M_L(m,n)\cdot M_R(m,n,d_m,d_n)}} \tag{5}$$

where:

$$L(m,n,d_m,d_n) = \sum\nolimits_{(i,j)\in U} \left(\begin{array}{c} \left(I_L(m+i,n+j) - \overline{I_L(m,n)}\right)\cdot \\ \left(I_R(m+d_m+i,n+d_n+j) - \overline{I_R(m,n,d_m,d_n)}\right) \end{array} \right) \quad (6)$$

$$M_L(m,n) = \sum\nolimits_{(i,j)\in U} \left(I_L(m+i,n+j) - \overline{I_L(m,n)}\right)^2 \quad (7)$$

$$M_R(m,n,d_m,d_n) = \sum\nolimits_{(i,j)\in U} \left(I_R(m+d_m+i,n+d_n+j) - \overline{I_R(m,n,d_m,d_n)}\right)^2 \quad (8)$$

The above measures of matching of pixels in stereo images were subjected to an assessment of algorithm efficiency. The research material included a set of stereo images of the recorded road pavement, taking its typical defects into consideration.

4 Assessment of Measures of Matching for Road Pavement Images

In the process of the road pavement mapping, the third stage consists in matching of pixels of stereo images, i.e. determination of disparity maps, followed by a three-dimensional mapping of the road surface being generated With regard to the goal of this article, namely comparing the measures of matching, this stage was covered by application of three measures: SAD, ZSSD and CoVar, using the stereo images obtained for pre-set test cross-sections. The measuring station used to record the stereo images, featuring a direct measurement function, has been illustrated in Fig. 1.

Fig. 1. Measuring station used for assessment of measures of matching

For the chosen twenty four test cross-sections located in local roads, two types of measurements were conducted using the above measuring station. The first one consisted in taking photographs of road fragments in a stereo vision system in order to map the road pavement. The photographs thus taken were 1,024 × 768 pixel stereo images with 8-bit colour depth. The other type of measurements comprised direct road surface measurements using a laser range finder assumed as reference data for further analyses. A set thus formed consists of altitudes Z set out against a rectangular grid with the dimensions of 1,020 mm × 760 mm, with a 10 mm pitch in the directions of X and Y.

The stereo images recorded in the test cross-sections were adjusted and rectified, and then disparity maps were determined based on the measures of SAD, ZSSD and CoVar. For the disparity maps obtained, three-dimensional road mapping was developed and subsequently compared with the direct measurement results. Table 1 provides a summary of mean values of the differences and standard deviations between the reference values and the results obtained by application of the stereo vision mapping for three measures of matching, i.e. $\Delta\bar{z}_i \phi\Delta z_i$ SAD, ZSSD and CoVar, in specific test cross-sections.

Table 1. The results of analysis of the twenty-four selected measurement cross sections.

i	SAD		ZSSD		CoVar	
	$\Delta\bar{z}_i$	$\phi\Delta z_i$	$\Delta\bar{z}_i$	$\phi\Delta z_i$	$\Delta\bar{z}_i$	$\phi\Delta z_i$
1	−0.27	3.31	0.00	1.74	−0.03	1.41
2	0.47	3.33	−0.43	1.78	−0.54	1.37
3	0.76	3.70	−0.17	1.97	−0.07	1.30
4	−0.67	3.57	0.09	1.94	−0.11	1.24
5	−0.39	3.48	0.01	1.80	0.06	1.22
6	0.16	2.93	−0.09	1.84	0.11	1.28
7	0.33	3.70	−0.20	1.78	0.11	1.29
8	0.24	3.58	0.01	1.92	0.41	1.27
9	−0.34	3.19	0.06	1.81	0.26	1.19
10	0.80	3.40	−0.37	1.72	−0.01	1.31
11	0.37	3.42	−0.06	1.79	−0.14	1.34
12	−0.26	3.21	0.07	1.79	−0.03	1.31
13	0.51	3.31	0.29	1.67	−0.04	1.27
14	−0.20	3.53	0.19	1.63	−0.17	1.19
15	−0.19	3.61	0.24	1.91	0.21	1.38
16	−0.14	3.07	0.01	1.65	−0.19	1.20
17	−0.27	3.24	0.06	1.99	0.23	1.30
18	−0.21	3.31	0.03	1.79	0.07	1.28
19	0.67	3.26	−0.16	1.75	0.30	1.35
20	0.50	3.93	0.40	1.74	0.07	1.35
21	−0.14	3.22	0.04	1.73	0.19	1.25
22	0.43	3.63	0.13	2.08	−0.11	1.32
23	0.37	3.75	0.30	1.67	−0.07	1.28
24	−0.07	3.57	0.20	2.00	0.33	1.32
Mean:	0.102	3.458	0.027	1.826	0.035	1.310

5 Conclusions

Based on the field measurements conducted in twenty four test cross-sections, specific road pavement mappings were obtained. For each test cross-section, four mappings were developed, namely three based on stereo vision conversions and one based on direct in situ measurements. The stereo vision mappings were developed for the following measures of matching: SAD, ZSSD and CoVar.

An analysis of mean differences and of the standard deviation between the reference data obtained in direct measurements and the stereo vision mapping of selected measures of matching has shown satisfactory results of the comparison between the ZSSD and the CoVar measures. From the perspective of road pavement mapping, the best measure is CoVar, however, it is also the most complex one in terms of the calculations it entails. The SAD measure of matching for stereo image points is to be rejected on account of the individual large differences obtained while comparing it with other mapping concepts. The foregoing results from not having regarded the mean intensity value of the stereo image analysed in the computational relations taken into consideration.

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Vehicle Speed Sensor Node for ITS

Wiesław Pamuła(✉)

Faculty of Transport, Silesian University of Technology, Katowice, Poland
wieslaw.pamula@polsl.pl

Abstract. This paper addresses the problem of measuring the speed of vehicles using a single camera. A method is proposed for transforming the camera space coordinates to world coordinates taking as reference the size of a vehicles number plate. Implementation using a megapixel camera is proposed and the measuring characteristics of the method in this case are discussed. The proposed method poses modest computational requirements and is suitable for incorporating into designs of sensor nodes of wireless sensor networks incorporated into ITS for traffic data collection.

Keywords: Image processing · Speed measurement

1 Introduction

Speed is an important parameter characterising the movement of vehicles. The mean speed value and its probability distribution, describing the traffic streams, contributes to the analysis of road traffic conditions. The definition of congestion and levels of service (LOS) includes values of vehicle movement parameters such as speed. Intelligent Transportation Systems collect vehicle speed information for controlling and managing traffic in road networks. Speed measurement systems play an important role in providing accurate and timely data for working out optimal traffic decisions.

The vehicle speed measurement methods fall into two main groups: "active" where microwaves or light is used for probing the speed, "passive" based on devices like inductive loop detectors, magnetic field sensors, videodetectors [1]. Videodetectors take advantage of the vast spectrum of image processing algorithms for analysis of image sequences of moving objects.

The problem of determining parameters of movement in a sequence of images is tackled using several approaches. These are conditioned by the complexity of the algorithms, variability of the observation scene, required accuracy and speed of processing. Methods rely first of all on finding correspondences between the positions of objects on consecutive video frames. The position changes are mapped to real world distances and referenced to time, converted to speed values. The problem of mapping the camera and scene coordinates makes up the core of the processing algorithms.

The natural solution based on stereo vision is frequently proposed. Stereo vision provides depth information, which is scaled, using the distance between the pair of cameras, to real world distances. The algorithms are focused on tracking corresponding feature points, applying triangulation to the points [2, 3]. Authors in [4] discuss the characteristics of a modified solution incorporating particle filtering for handling

G. Sierpiński (ed.), *Advanced Solutions of Transport Systems for Growing Mobility*,
Advances in Intelligent Systems and Computing 631, DOI 10.1007/978-3-319-62316-0_22

nonlinearities arising from perspective projections. The visual tracking processes in the two views are coupled with each other and correlated in the observations. The path constraint reconstructed from stereo views is used to reduce the uncertainty of the vehicles motion and improve the accuracy for both tracking and speed measuring. Results of tests using real world sequences provide speeds with less than 5% errors.

ITS comprise wide area networks of cameras for supervising the operation of the systems. Cameras of various resolution and range of observation work mostly individually. Monovision is the preferable base for traffic observation. Vehicle tracking systems provide the widest range of traffic parameters amongst them: vehicles speeds [5, 6]. The solution developed by Lana et al. [7] is an elaborate example of such a system. Speed is estimated using parameters of trajectories after mapping/alignment with respect to dominant paths learned based on an evolutionary dynamics model. Tracking systems are complex and demanding in the scope of computing power.

Less complex approaches use the specific characteristics of acquiring images of the traffic scenes. Lin et al. [8] propose to use motion blur as a cue for estimating speed. The image of a vehicle is observed from the roadside and the length of the motion blur is evaluated. The length of the vehicle or the distance of the camera to the vehicle are used as reference for calculating the size of the real world movement on the basis of the blur parameters. A pinhole camera model is used for establishing the dependencies.

Without referring to the camera model the authors in [9] present a solution based on assessing the displacement of the view of a vehicles number plate. A high resolution camera is used in the tests. An experimentally derived formula is used for calculating the distance travelled. The formula uses as variables the height of mounting the camera, the height of mounting the number plate on the vehicle above the road and the camera parameters.

A similar approach is discussed in [10]. The proposed solution uses as reference the number plates characters height or the plates width. Two formulas for calculating distances, based on measurements of plates views at different distances, are derived. The sizes decrease exponentially with distance, also the larger the distance the lower the accuracy of distance estimation. The speed is obtained as the change of distances calculated for successive images in time. Various weather conditions of observation are checked for estimating the measurement errors.

The aim of this investigation is to assess the measuring characteristics of a vehicle speed sensor design using a single camera for observing the movement of vehicles. The standard size of the number plate is chosen as reference for deriving the distance of travel of the vehicle in the time lapse of consecutive observations. A pinhole camera model is used and a solution of the projection equations of the number plate image corners is used for determination of distances in the observed scene.

The proposed approach eliminates the need for experimental calibration of the measurement task, which is commonly used in video based methods for speed estimation. Such a solution can be a component of a sensor node of a sensor network for use in ITS. Currently many ITS use ANPR cameras for supervising road traffic and these provide high resolution video data suitable for obtaining traffic parameters.

The paper is organised as follows: the prerequisites for measuring speed are discussed and the concept of speed measuring is elaborated. The next section covers the discussion of the measuring characteristics of the speed sensor design. The concluding part summarizes the results and proposes further research topics.

2 Speed Estimation

Number plate reading devices are mature solutions available from many manufacturers. The methods for extracting the number plate position in the image are well developed and offer a very high reliability of operation [11]. This is additionally enhanced by utilizing infrared illumination.

Number plates in most European countries, in compliance with traffic regulations, are covered with foil highly reflective in the infrared spectrum. Illuminated plates are distinctly visible when the scene is observed using cameras with IR filters. This technique is widely used in video surveillance applications especially for night vision. Right images of Fig. 2 show the effect of IR illumination.

Regulations define also the standard sizes of number plates. This regulated set of sizes is the reference set for determining the real distances in the field of view of the camera. Figure 1 presents the projection of the number plate in the camera coordinate system. A pinhole model of the camera is used.

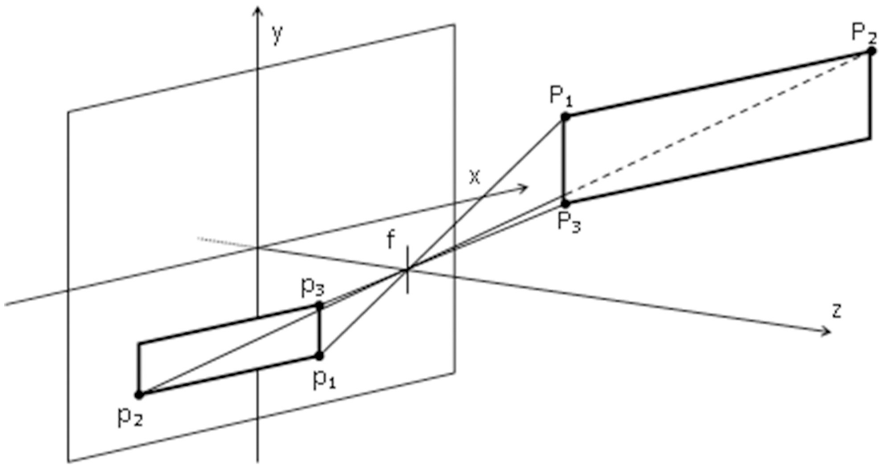

Fig. 1. Projection of the number plate on the camera sensor

The three corners $P_1(X_1, Y_1, Z_1)$, $P_2(X_2, Y_2, Z_2)$, $P_3(X_3, Y_3, Z_3)$ of the number plate are mapped to $p_1(x_1, y_1, z_1)$, $p_2(x_2, y_2, z_2)$, $p_3(x_3, y_3, z_3)$ on the camera sensor. The point coordinates are linked by line segments passing through the focal point of the camera lens.

A non standard approach is used for solving the triangulation problem, which simplifies the calculations and reduces the sensitivity to errors.

The parametric equations of the lines are:

$$\begin{aligned} X_i &= x_i + kx_i = (1+k)x_i = k_i x_i \\ Y_i &= y_i + ky_i = (1+k)y_i = k_i y_i \\ Z_i &= 0 + kf = (k_i - 1)f \end{aligned} \tag{1}$$

f - focal length of the camera lens

In order to determine the parameters of the lines an assumption is made that the squared lengths of the sides of the number plate and its diagonal satisfy:

$$\begin{aligned} a^2 &= \|P_2 - P_1\|^2 \\ b^2 &= \|P_2 - P_3\|^2 \\ c^2 &= a^2 + b^2 = \|P_3 - P_1\|^2 \end{aligned} \tag{2}$$

a, b, c - length, height, diagonal of the number plate respectively

Further the set of Eqs. (2) is expressed using point coordinates (1) of the number plate camera view as:

$$\begin{aligned} a^2 &= a_1 k_1^2 + a_{12} k_1 k_2 + a_2 k_2^2 \\ b^2 &= a_2 k_2^2 + a_{23} k_2 k_3 + a_3 k_3^2 \\ a^2 + b^2 &= a_3 k_3^2 + a_{31} k_3 k_1 + a_1 k_1^2 \end{aligned} \tag{3}$$

where:

$$\begin{aligned} a_1 &= x_1^2 + y_1^2 + f^2 \\ a_2 &= x_2^2 + y_2^2 + f^2 \\ a_3 &= x_3^2 + y_3^2 + f^2 \\ a_{12} &= -2(x_1 x_2 + y_1 y_2 + f^2) \\ a_{23} &= -2(x_2 x_3 + y_2 y_3 + f^2) \\ a_{31} &= -2(x_3 x_1 + y_3 y_1 + f^2) \end{aligned} \tag{4}$$

The set of Eqs. (3) constitutes the core of the processing algorithm for determining the vehicle speed. These are three quadratic equations of three line parameters. The solution of the set of Eqs. (3) comprises eight sets of (k_1, k_2, k_3) out of which one is selected for calculation of the distance of the number plate from the camera. The distance from the camera plane is assumed as the mean of distances to the three corners of the number plate $d = (d_1 + d_2 + d_3)/3$.

$$d_i = \sqrt{k_i^2 (x_i^2 + y_i^2) + (k_i - 1)^2 f^2} \tag{5}$$

Speed is calculated using distance measurements made in consecutive moments of time. The time interval is determined by the method of acquiring images from the observation camera. In the case of common surveillance cameras this is usually 40 ms.

$$v = (d(t + \Delta t) - d(t))/\Delta t \tag{6}$$

Surveillance cameras acquire images using the PAL TV standard. This limits the resolution of observation to 720 × 576 pixels. Such a resolution may be inadequate for measuring the speed with a desired error e.g. for assessing travel conditions on a stretch of a road.

a)
b)

Fig. 2. Number plates (a) observation at t, (b) observation at $t + \Delta t$

The implementation of the measuring algorithm is based on detecting the position of the number plate and precise estimation of pixel coordinates of its corners. Detection algorithms rely on finding quadrangles in the image. Hough transform is used to find lines in the image and a search is done to determine intersections, which belong to quadrangles [12]. It is possible to establish the intersections with subpixel accuracy. In difficult lightning conditions morphological operators are applied for cleaning the image prior to searching for lines. More complex filtering techniques such as SIFT, SURF are not applied as the aim is to implement the design using low power devices.

It is important to take into account the distortion of view introduced by the camera lens during acquisition. The procedure of camera view calibration is required to rectify these distortions, especially in the case of multi megapixel cameras [5, 13, 14].

3 Results

The proposed measurement algorithm is validated using sequences of images of moving vehicles registered on a road with small traffic. A camera with day/night filter is used for acquiring the images. The scene is illuminated with a high power IR source and the camera filter is forced to night operation.

Figure 2 presents an example of a pair of observations. The monochrome images show the positions of the number plates highly exposed by the IR illumination. A 5 Mpx camera is used which is capable of taking images at the top rate of 15 per second in good lighting conditions. These conditions are ensured by the IR illumination.

At first the core of the processing algorithm is implemented in a math processing environment for evaluating the sensitivity to parameter changes. The following algorithm steps are evaluated:

- morphological “cleaning”,
- Hough transform for finding lines,
- search for intersections, which belong to quadrangles - potential number plates,
- distance calculation.

A procedure is used to calculate the calibration matrix of the camera. The validated steps of the algorithm are implemented using open source image processing libraries. Tests are carried out using an ARM based processing platform. This platform is planned for use as a sensor node possibly enhanced with a FPGA based processing accelerator. At this stage no optimisation of the speed nor efficiency is done as the aim is to assess the limitations of the method.

3.1 Measurement Errors

Examination of the performance of the number plate extraction results shows errors. Errors due to imperfect detection of edges of the number plates and to the camera movement are observed. A high resolution camera is sensitive to displacements of its position, when registering images. Vibrations caused by heavy vehicle movements are a serious source of such displacements.

The performed tests provide an estimation of the position errors as ± 5 pixels. This estimation does not take into account possible errors introduced by conditions of heavy traffic or bad weather e.g. wind bending the mounting pole of the camera.

The estimated position error value is used for simulating the accuracy performance of the speed determination algorithm. A model is proposed for pairs of observations. The width of the number plate on the first image of the pair, is one tenth larger than the width on the consecutive image. The focal length is 36 [mm], the size of the number plate is 466×100 [mm]. Speeds are calculated for a range of plate widths seen on the image. The widths range from 1/20 up to 3/4 of the image width.

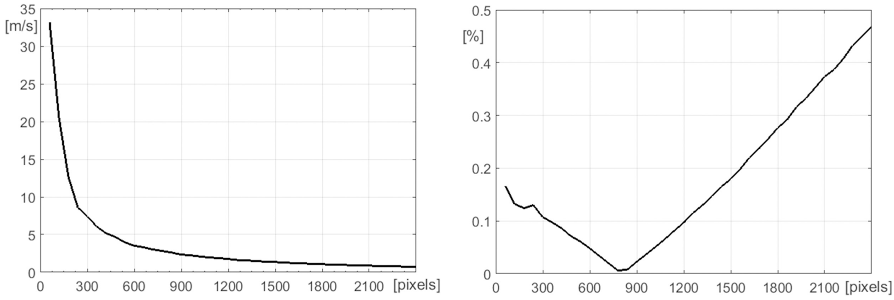

Fig. 3. Speed and speed errors

Small views of the number plate indicate - Fig. 3 that vehicles are far from the camera and small changes of width signify large vehicle speeds. On the other end of the graph the same relative changes in size give insignificant speed changes.

The error graph Fig. 3 is convex with a minimum about the number plate view size of 900 pixels. 900 pixels account for about 1/3 of the width of the image.

3.2 Measurement Bounds

As in the case of measurements done using light or microwave based devices camera observations also determine the speed perpendicular to the sensor. The placement of the camera relative to the road defines the initial error of measurement. Vehicle speeds are defined as parallel to the road axis, so camera observation angles other than parallel to the axis require a scaling factor to compensate the effects.

The focal length of the camera lenses and its relative size to the image sensor determine the range of observation. Lens with focal lengths larger than 4–6 times the sensor diagonal are regarded as tele and are suitable for observations of vehicles over 100 m away from the camera.

4 Conclusions

The experimental results prove the feasibility and usefulness of the proposed method of determining vehicle speeds. A megapixel camera is necessary for observation and its mounting position must be immune to disturbances caused by road traffic. Analysis of errors indicates that the visible width of the number plate being about 1/3 of the size of the image gives the most accurate estimate of the vehicles speed.

The introduction of a vehicle tracking approach for compensating camera displacements may be considered for enhancing the measuring algorithm.

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