Methods for evaluation of mobility in modern cities

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Abstract. The paper presents approach to the study methods and key performance indicators for evaluation mobility in smart cities. This approach based on strategy of sustainable urban transport system. A methodological framework for assessing urban mobility has been proposed. As a case study, there is data about the feature of transport systems development in cities with a high quality of mobility. Analyzed examples confirmed the validity of idea sustainable mobility. Achieving the strategic goals of sustainable mobility is impossible without the use of modern technologies of intelligent transport systems. This paper shows importance of intelligent transport system in the urban mobility policy. In this paper also formulate the requirements to performance indicators for evaluate the mobility in urban transport system.

Introduction
Currently, one of the most important urban development trends is the transition to the formation of sustainable transport systems. This is due to the fact that traditional approaches to solving the problems of congestion only increasing network capacity are ineffective. Growth in travel demand is concentrated on certain parts of the network at certain times. The increase in network capacity and construction of new roads only leads to a temporary improvement. Trade and industrial companies construct new commercial and residential areas where near new roads are added traffic to road network. At finally, in few years, these new roads become congested. Key barrier for evolution of urban mobility systems is current situation do not adapt to changing demands and has limited possibility to integrate single steps to a whole value chain.

We need new development strategy and it include the strategy of smart cities and cities with a sustainable transport system. There are different definitions sustainable transport system. One of them focuses on the economic side of the problem. L. Schipper used following term: “Sustainable transport is transportation where the beneficiaries pay their full social costs, including those that would be paid by future generations” [10]. There is also a definition of sustainable mobility. For example, as “the ability to meet the needs of society to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values today or in the future.” [2].

Therefore, sustainable mobility allows travel from one location to another using a multimodal approach with the highest standards of safety and security, offers choice of transport mode, provides affordable access to freight and passenger service, limits emissions and minimizes the use of land. In order to design efficient and sustainable transport system, the city must change transport policy from
moving vehicles to moving people and goods. This includes taking into consideration multimodal trip from origin to destination, which is generally accomplished through different kinds of transport.

**Analysis urban mobility methods and experiences**

In depend on the state of urban transport system can be used following development strategies to the sustainable mobility:

- **Reforming of urban transport system**: necessary to implement the program of development of public transport in order to put the system of mobility with a high share of traffic on individual cars to the mobility system with the priority use of public transport, which is one of the main feature of a sustainable urban transport system;

- **Creating an integrated route network**: for increase the attractiveness of public transport and the extension of service is necessary to create conditions for multimodal mobility, integrating transportation on all forms of urban passenger transport with a uniform payment system and a coordinated timetable. The main attention should be paid to the quality of transport services and information support of passengers because, first of all, to the quality associated branded product or service and all of the operators emphasize the importance of formation brand;

- **Creating a stable kernel**: for cities with insufficiently effective public transport systems necessary to create conditions for sustainable mobility based on those modes of transport that can satisfy the demand in a relatively short period of time at a reasonable cost. These technological islands are the basis for the development of advanced mobility systems in these cities.

In this case very important use experience of cities, which has best transport systems. Many cities have implemented sustainable mobility strategy [1, 2, 3, 10, 12]. London's example is very attractive [11]. London demonstrates effective transport policy - investment in public transport, priority for buses and cyclists, a local freight strategy, and congestion charging. From 2000 to 2006 the number of trips by public transport has increased by 42%. More trips are made by cycle and on foot, average traffic speeds in central and inner London have increased since 2003 (reversing a long-term trend) and road casualties across London have declined faster than in the rest of the country. The congestion pricing scheme in the city decreased the number of vehicles entering the city by 25 percent and the amount of circulating traffic fell by 15 percent. London Construction Consolidation Center (LCCC) Consolidation Center was established in London for construction materials. Some of the benefits the traffic and environmental benefits of this consolidation center are:

- 68 percent reduction in construction vehicles for deliveries to sites served by consolidation center;
- Better control over sizes of vehicles entering City of London;
- About 75 percent reduction of CO2 emissions for deliveries from consolidation center to sites;
- 120 minutes average reduction in journey time for contractors.

In the Vienna one of the highest uses of urban public transport, share public transport, walking and cycling in modal split is 69%. Annual volume transportation all kind of public transport is about 870 million passengers. Everyday mileage of Vienna public transport is 180,000 km. Mean travel time to work in Vienna is 28 minutes and it is very good result for big city. In Vienna very high level of satisfaction of public transport, therefore more than 450 thousand people own a yearly ticket. Vienna's program for development of public transport system include innovative approaches to ensure the ecological, economic and social sustainability of transport. Vienna's public transport is committed to efficient and environmentally friendly mobility [7].

One of the main features of the smart city is barrier-free access to transport and facilities. Population of Vienna has barrier-free access and public transport operator, has acquired vehicles for people with impaired mobility. In Vienna uses following seven principles at designing free-barrier access:

- **Equitable Use** - The design is useful and marketable to people with diverse abilities.
- **Flexibility in Use** - The design accommodates a wide range of individual preferences and abilities.
- **Simple and Intuitive Use** - Use of the design is easy to understand, regardless of the user’s experience, knowledge, language skills, or current concentration level.
- **Perceptible Information** - The design communicates necessary information effectively to the user, regardless of ambient conditions or the user’s sensory abilities.
- **Tolerance for Error** - The design minimizes hazards and the adverse consequences of accidental or unintended actions.
- **Low Physical Effort** - The design can be used efficiently and comfortably and with a minimum of fatigue.
- **Size and Space for Approach and Use** - Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user’s body size, posture, or mobility.

In Amsterdam, the creation of sustainable mobility is carried out in accordance with the program of Smart Mobility [5]. The goals of this action program Smart Mobility contribute to the goals of the Executive agenda Mobility and Agenda Sustainability: improving the safety, accessibility, quality of life and attractiveness of Amsterdam.

The Stockholm Urban Mobility Strategy provides the urban policies for priorities in development of transport system to promote a more efficient, safe, attractive, environmentally friendly and healthy city [8]. In the Stockholm is implementing smart-choice measures that helps inhabitants and that encourage city travelers to plan their journeys in a smarter manner, to reduce congestion, environmental impact. The city’s strategy for how Stockholm is based on three interacting parts - urban planning, infrastructure planning and traffic planning:

- Urban planning: a dense and mixed urban development that reduces the need to travel;
- Infrastructure planning: a substantial expansion of public transport and a road network that leads away major traffic flows;
- Traffic planning: optimizing use of existing infrastructure.

The Urban Mobility Strategy establish following planning aims for the city’s roads and streets:

- An increasing number of people and amount of goods need to be moved, through greater use of high capacity transportation means; that is, public transport, bicycles and walking as well as goods vehicles with a high load factor.
- Accessibility in the road and street network is to be enhanced by increasing speeds for high-capacity transportation means and raising travel-time reliability for all road users.
- The role of roads and streets as attractive areas is to be strengthened through improved walkability in the walkable city.
- The negative effects of road and street traffic must be minimized through promoting car use for journeys that generate the most public good.

Observing examples confirm the validity of idea sustainable mobility which based on master plans for smart cities; public transport less environmentally harmful, sufficient infrastructure supply and convenient access, high-end technologies of Intelligent Transport Systems.

### Key Performance Indicators of Mobility

In forming the transport policy and evaluation of urban transport systems inevitably arises the problem of comparative evaluation indicators of the functioning of public transport and the transport system as a whole in various cities. There are variety of criteria for evaluating the quality of mobility. For the criteria, it is necessary to formulate the requirements, which they must meet to evaluate the mobility of the system as a whole. It is also necessary to take into account the criteria adaptation to modern information and communication technologies for collecting and processing traffic information, since this circumstance greatly affects the functionality of the criteria. Development of methods and criteria for evaluating the effectiveness of urban transport system should be carried out with the following requirements:
Beyond the technical requirements, applicable indicators should evaluate the satisfaction of users of the road network, the public perception of urban transport policy;

- Indicators should diagnose the problems of traffic management and transportation, to assess the quality and effectiveness of mobility for both the current situation and predict future changes;
- Indicators must necessarily be focused on the ability to collect information in real time for operational use of the proposed quality assessment methods and efficiency;
- Indicators should allow evaluating the situation at both the operational and the long-term levels, ensuring a balance between obtaining the short-term results and preservation effectiveness for the future.

Therefore, various methods are used to assess the quality of mobility in projects smart cities. International Association of Public Transport recommend used two-level system of indicators for complex estimation of urban mobility. The first level represents the level of development indicators, which include the share of transportation by public transport, cycling and walking, number of carpooling, penetration rate of smart cards, and strategy for future mobility. Performance indicators include number of accidents, Average travel time, level of motorization, level of traffic emissions, and degree of satisfaction with public transport. According to the Arthur D. Little Mobility Index, cities with a total index more than 75 points, are of high quality of mobility [9]. Cities with scores below 55 points has significant deficiencies in the mobility system.

A large number of performance indicators can be used for the evaluation of traffic efficiency. Structures of such indicators is shown on the figure 1.

![Key Performance Indicators Urban Transport System for Smart-City](image)

**Figure 1.** Key performance indicators urban transport system for smart city

One of the most important is indicators of evaluating mobility. It is travel time index, mobility index (total and separately for public and private transport), reliability index, average travel time to relevant points of interest, travel delay time, etc.

Mobility index can be determined by various parameters, but typically includes the average travel time by public and individual transport, taking into account the weighting factors:

\[
I_M = w_{PV} \left( \frac{1}{|R_{PV}|} \sum_{r \in R_{PV}} \frac{t_{PV}}{d_r} \right) + w_{PT} \left( \frac{1}{|R_{PT}|} \sum_{r \in R_{PT}} \frac{t_{PT}}{d_T} \right)
\]

where:
- \( r \) a route (specific OD pair) among a set of selected routes \( R_{PV} \) and \( R_{PT} \) on the road and public transport respectively;
- \( t_{PV} \) average travel time for route \( r \) on the road network;
- \( t_{PT} \) average travel time route \( r \) on the public transport network;
- \( d_r \) length of route \( r \);
- \( w_{PV} \) represents the weight of the travel time on the road network;
$w_{PT}$ denotes the weight of the travel time in public transport.

The weighting factors for the average travel time should range from 0 to 1, but the sum of their values should in any case be 1. The set of routes should include the main routes of public transport and road traffic routes for the respective individual points of origin and destination.

A reliability index included different parameters for estimate congestion:

$$I_{REL} = 1 - \sum_{l \in L} \left( w_{PT} \sum_{p_t \in PT} w_l t_{w_1}^{p_t} + w_{PV} \sum_{p_v \in PV} w_l t_{w_1}^{p_v} \right),$$

(2)

Summary

Traffic congestion and incident in urban transport system is one of the important problems in modern society. New quality of mobility can be achieved through the application of smart city strategy and the transition to a sustainable urban transport system. The main conditions for the creation of a sustainable transport system are development of integrated public transport network that ensures efficient multimodal trip, development non-motorized mode, development of freight distribution and city logistic, improvement intelligent transport system. Important topic for smart city projects is determine key performance indicators for different kind of urban mobility. In a future, it will be possible to develop set of mobility models for cities with different level of urban transport system.

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