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ABSTRACT

One of the strategies for efficient transport service management is to implement advanced technologies for managing urban transport systems. Countries develop and exist under different socio-economic conditions. As a result, there is no universally accepted system of evaluation indicators for the smart mobility system and its infrastructure that can be applied in any country or city. Nowadays, there is a little research on comparing smart mobility systems in different cities. This article proposes a framework for comparing the smartness level of the mobility system and its infrastructure. The literature analysis was performed and the most important factors and indicators having the greatest influence on the smart mobility system and its infrastructure were selected. The influence of individual factors and indicators describing the smartness level of the mobility system varies. Moreover, different authors distinguish different factors and indicators when evaluating a smart city mobility system, which usually do not duplicate. The paper divides the factors of the smart mobility system into five groups: motor travel and congestion reduction measures; pollution abatement measures; travel safety and accident reduction measures; traffic management tools and services; smart infrastructure measures. Each of the listed group is distinguished by a number of specific measures. A model has been developed to compare the smart mobility system of individual cities and their infrastructure.

Keywords: Smart mobility, multicriteria analysis, smartness index, infrastructure, ITS, evaluation model

Introduction

The continuous growth of the urban population and the complexity of urban management encourage local authorities to use technologies that support higher quality urban spaces and better delivery of public services. In recent years, smart city projects have become increasingly popular and widespread worldwide, although the concept of smart cities is far from unambiguous. Rapid urban population growth has had a negative impact on the urban connectivity system, with the need to address the problems of improving transport services and increasing demand for public transport. However, the increase in transport supply is often accompanied by undesirable results. The cities are facing challenges such as traffic jams, rising property prices, environmental pollution, overpopulation and reliance on private vehicles (Farooq et al., 2019). Thus, the right strategy to effectively manage urban transport services is a major concern for cities around the world. While the world population is increasing, it is declining in the Baltic States. Nevertheless, the number of cars is growing and cities are facing the same problems.

Since the advent of Information and Communications Technology (ICT) in the mid-1990s, cities in many countries have harnessed the potential of technological development. The Smart City concept has been unveiled as an urban development concept that uses ICT as a basis for initiatives and programs that facilitate socio-economic activities in the city. The city wishing to become smart has to have a favorable infrastructure (high-speed comprehensive Internet, sufficient number of wireless internet access points, availability and accessibility of classifiers, necessary registers databases, access to open databases and visualization tools, etc.) (Patašienė et al., 2014).

Despite various initiatives to promote smart transport systems in urban areas, little is known about how these systems work in cities, and even less about how to be a flagship city with intelligent transport systems (ITS), if any. (Debnath et al., 2014). Therefore, it is necessary to formulate a proper concept of smart mobility system and to select the indicators of smartness describing it. It can be assumed that the lack of appropriate harmonized concepts and indicators may be the reason for the lack of comprehensive comparative research on ITS in cities.

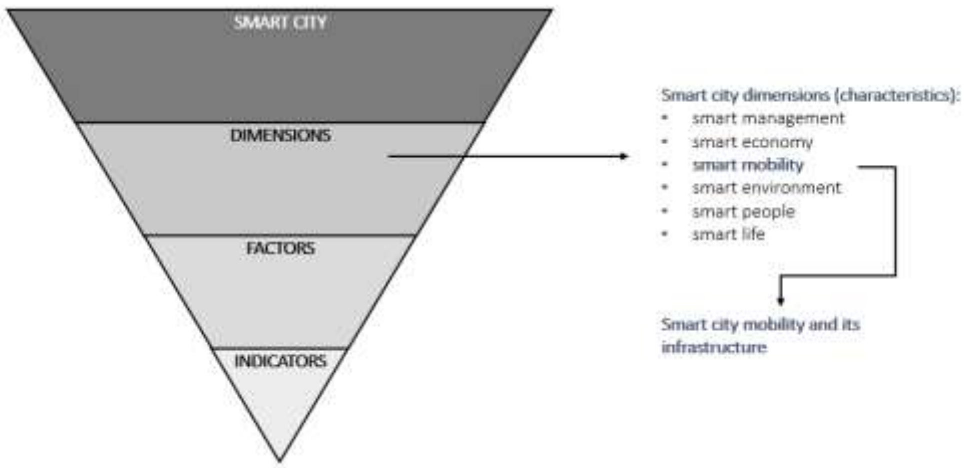
Literature Review

Not only does the smart city itself provide services in the cyber space, its inhabitants actively contribute to its management and the creation and improvement of these services. In other words, a smart city is an integral part of feedback, innovation, active citizenship, and collective intelligence (Šiupšinskas, 2014).

Slowly, however, smart cities are becoming a reality and changing the existing urban environment. The goal of a smart city is to promote a sustainable environment that is safe and comfortable for citizens. A smart city is primarily about people, not technology. Every major city is unique in its way and faces many of the same or very similar problems.

Smart cities around the world are quite diverse in their characteristics, requirements and components (Mohanty et al., 2016). R. Giffinger et al. (2007) identified four components of a smart city: industry, education, governance and technical infrastructure. This list was expanded by the Regional Science Center project at the Vienna University of Technology (Albino et al., 2015). After examining smart city models, six dimensions of a smart city are highlighted: smart management, smart economy, smart mobility (see Figure 1), smart environment, smart people and smart life. Each has its specific structure, which forms an integral holistic vision for creating, managing and maintaining a smart city quality of life. A smart city can consist of any combination of advanced components. A city does not have to have all the smart components, its number may depend on city funds and technology availability (Mohanty et al., 2016). Smart mobility system or transport is a critical subsystem of the city. The transport sector consumes a lot of energy and is one of the biggest polluters in cities (Miloševi´c et al., 2019).

Figure 1. *Smart Mobility in the Context of Smart City*



Source: Compiled by the Author.

ITS that use information and communication technologies, including infrastructure, vehicles and users, to manage traffic and mobility, as well as interfaces between different modes of transport, play an important role in the development of a smart urban communication system. The development of ITS ensures efficient reduction of congestion and accidents, traffic control and solves public transport problems. The goal of ITS is to achieve traffic efficiency by reducing traffic problems.

The loads on transport systems are constantly increasing. The Communication from the European Commission entitled "Action Plan for the Deployment of ITS in Europe" foresees there will be such changes in years of 2000-2020:

road freight transport will increase by 50%;
public transport will increase by 35%.

Traditional solutions cannot solve this problem and new solutions must be sought. One of the ways to address the challenges facing the transport sector is to deploy ITS.

Different countries have their own ITS architecture, divided into separate activities. Each identified ITS activity has many subgroups. This means that ITS activities can address a wide range of problems in different transport sectors. In this paper ITS Architecture of the USA (United States Department of Transportation), Canada (Transportation Association of Canada), India (Mohan, 2008), Croatia (Mandžuka et al., 2013), Poland (Modelewski, 2008), and Lithuania (Paulauskas et al., 2011) were investigated (see Table 1).

Table 1. *Comparison of ITS Architecture in Different Countries*

Activities	USA	Canada	India	Croatia	Poland	Lithuania
Commercial Vehicle Operations	+	+	+		+	+
Data Management	+	+				
Maintenance and Construction	+	+				
Parking Management	+					
Public Safety	+		+		+	+
Public Transportation	+	+	+	+	+	+
Support	+					
Sustainable Travel	+					
Traffic Management	+	+	+	+	+	+
Traveler Information	+	+	+	+	+	+
Vehicle Safety	+	+	+	+	+	
Weather and Environmental Monitoring	+			+		+
Emergency Management		+	+	+	+	+
Electronic Payment			+	+	+	+
Vehicle services						+
Commercial Vehicle			+	+		
Coordination and control of natural disasters				+		+
National Security				+		+
Vehicles				+		

Source: Compiled by the Author.

Some of the activities are mentioned in the ITS of all the countries considered Public Transportation, Traffic Management, Traveler Information, Vehicle Safety.

Lithuanian ITS Architecture has as many as eight out of eleven activities that correspond to those in other countries.

Selection of Factors and Indicators

Scientists do a lot of researches about the smart city mobility system, but little work has been done to differentiate the smart mobility system's evaluation indicators. In addition, different researchers distinguish different indicators. More than 20 scientific papers with one or another classification of indicators have been analyzed in order to select smart mobility system and its infrastructure indicators. More than 90 different indicators were found describing the smartness of the urban transport system. Twenty-three indicators were selected using the exclusion method (see Table 2).

Table 2. *Smart City Mobility System and its Infrastructure Indicators*

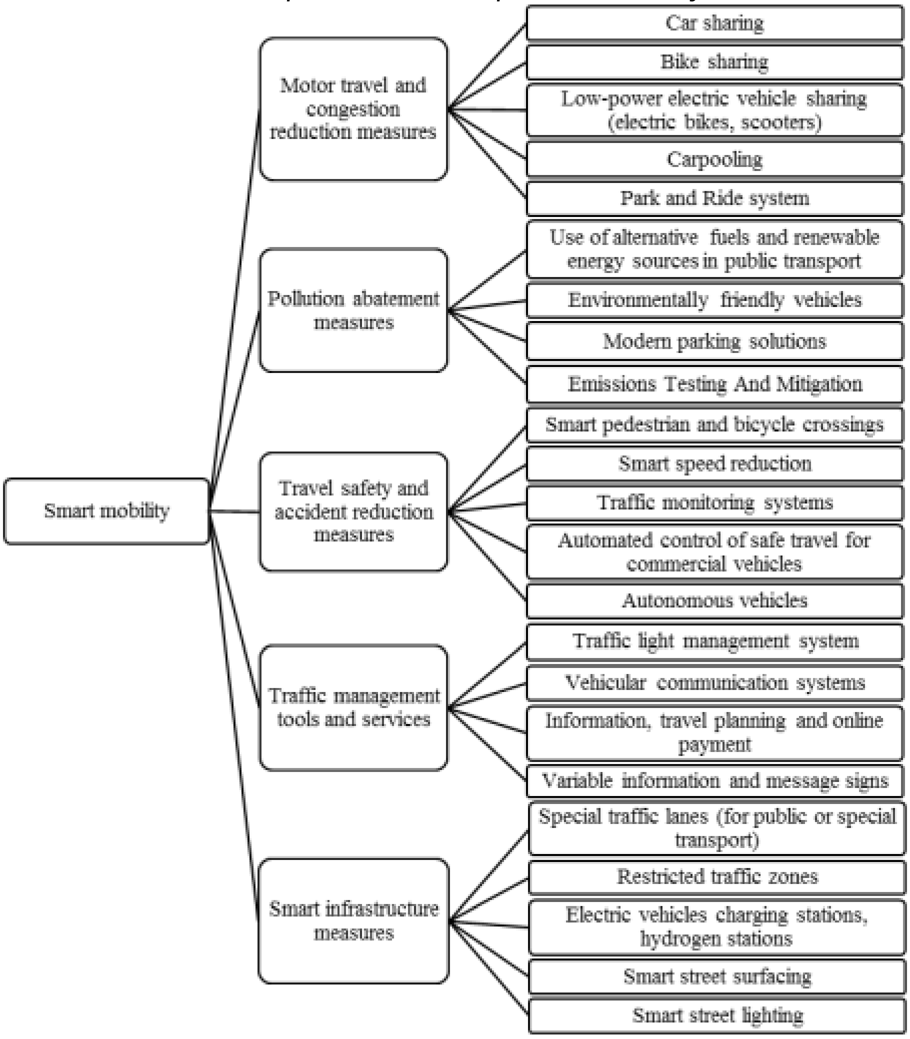
Indicators	**Sources**
Car sharing (8)	Yadav et al., 2017; Garau et al., 2016; Balducci & Ferrara, 2018; Battarra et al., 2018a; Battarra et al., 2018b; Girardi & Temporelli, 2016; Reiber & Huang, 2018; Benevolo et al., 2016
Bike sharing (9)	Yadav et al., 2017; Garau et al., 2016; Balducci & Ferrara, 2018; Battarra et al., 2018a; Battarra et al., 2018b; Girardi & Temporelli, 2016; Reiber & Huang, 2018; Benevolo et al., 2016; Alexopoulos et al., 2019
Low-power electric vehicle sharing (electric bikes, scooters) (2)	Benevolo et al., 2016; Battarra et al., 2018b
Carpooling (2)	Benevolo et al., 2016; Li et al., 2019
Park and Ride system (3)	Balducci & Ferrara, 2018; Benevolo et al., 2016; Carli et al., 2013
Use of alternative fuels and renewable energy sources in public transport (4)	Balducci &Ferrara, 2018; Benevolo et al., 2016; Carli et al., 2013; Lopez-Carreiro & Monzon, 2018
Environmentally friendly vehicles (6)	Balducci & Ferrara, 2018; Battarra et al., 2018a; Benevolo et al., 2016; Carli et al., 2013; Neirotti et al., 2014; Petrova-Antonova & Ilieva, 2018
Modern parking solutions (7)	Yadav et al., 2017; Girardi & Temporelli, 2016; Wibowo & Grandhi, 2015; Debnath et al., 2014; Reiber & Huang, 2018; Benevolo et al., 2016; Alexopoulos et al., 2019
Emissions Testing And Mitigation (4)	Wibowo & Grandhi, 2015; Debnath et al., 2014; Benevolo et al., 2016; Carli et al., 2013
Smart pedestrian and bicycle crossings (3)	Benevolo et al., 2016; Alexopoulos et al., 2019; Battarra et al., 2018b
Smart speed reduction (1)	Benevolo et al., 2016
Traffic monitoring systems (4)	Wibowo & Grandhi, 2015; Debnath et al.,

	2014; Battarra et al., 2018b; Lazaroiu& Roscia, 2012
Automated control of safe travel for commercial vehicles (3)	Benevolo et al., 2016; Wibowo & Grandhi, 2015; Debnath et al., 2014
Autonomous vehicles (3)	Benevolo et al., 2016; Boukerche & Coutinho, 2019
Traffic light management system (9)	Yadav et al., 2017; Balducci & Ferrara, 2018; Battarra et al., 2018a; Garau et al., 2016; Benevolo et al., 2016; Boukerche & Coutinho, 2019; Alexopoulos et al., 2019; Orlowski & Romanowska, 2019; Petrova-Antonova & Ilieva, 2018
Vehicular communication systems (3)	Battarra et al., 2018a; Wibowo & Grandhi, 2015; Debnath et al., 2014
Information, travel planning and online payment (15)	Yadav et al., 2017; Vidiasova et al., 2017; Balducci & Ferrara, 2018; Battarra et al., 2018a; Battarra et al., 2018b; Reiber & Huang, 2018; Benevolo et al., 2016; Boselli et al., 2015; Li et al., 2019; Neirotti et al., 2014; Alexopoulos et al., 2019; Orlowski & Romanowska, 2019; Garau et al., 2016; Petrova-Antonova & Ilieva, 2018; Lopez-Carreiro & Monzon, 2018
Variable information and message signs (12)	Dudzevičiūtė et al., 2017; Balducci & Ferrara, 2018; Battarra et al., 2018a; Battarra et al., 2018b; Reiber & Huang, 2018; Benevolo et al., 2016; Boselli et al., 2015; Alexopoulos et al., 2019; Orlowski & Romanowska, 2019; Garau et al., 2016; Petrova-Antonova & Ilieva, 2018; Lopez-Carreiro & Monzon, 2018
Special traffic lanes (for public or special transport) (3)	Yadav et al., 2017; Battarra et al., 2018a; Benevolo et al., 2016
Restricted traffic zones (5)	Yadav et al., 2017; Balducci & Ferrara, 2018; Battarra et al., 2018a; Battarra et al., 2018b; Benevolo et al., 2016
Electric vehicles charging stations, hydrogen stations (5)	Yadav et al., 2017; Balducci & Ferrara, 2018; Girardi & Temporelli, 2016; Benevolo et al., 2016; Petrova-Antonova & Ilieva, 2018
Smart street surfacing (2)	Reiber & Huang, 2018; Boukerche & Coutinho, 2019
Smart street lighting (4)	Balducci & Ferrara, 2018; Reiber & Huang, 2018; Boukerche & Coutinho, 2019; Battarra et al., 2018b

Source: Compiled by the Author.

The selected indicators are grouped into five groups (factors) according to their influence on the mobility system. The model for evaluation of the smart city mobility system and its infrastructure was created (see Figure 2).

Figure 2. *Hierarchical Model for Evaluation of Smart Mobility*



Source: Compiled by the Author.

Car sharing. The system allows people to borrow cars. In a smart app, the user can see available cars in the area and reserve a vehicle for some time. The user can leave the vehicle within the service area specified in the app.

Bike sharing. The system allows people to borrow bikes from a rental point and return it to the same or another rental point in the same system. Mobile apps show nearby bikes and open rental locations.

Low-power electric vehicle sharing (electric bikes, scooters). The system allows people to borrow electric scooters, bikes and more. With the mobile app, users will be able to see the location of low-power electric vehicles on the map and pick them up and then leave them elsewhere.

Carpooling. The purpose of the system is to bring users together, who travel in the same direction with the same vehicle.

Park and Ride system. Park and Ride parking lots are ideally located at city entrances, through public transport terminals, or at high-speed city transit routes (subways, express buses, etc.). The system provides drivers with information about available parking areas and alternatives for their onward journey.

Use of alternative fuels and renewable energy sources in public transport. The alternative to fossil fuels: electricity, liquefied gas, methane, hydrogen, biodiesel, fuel cells.

Environmentally friendly vehicles. These include electric, hydrogen vehicles and others that use alternative fuels to fossil fuels.

Modern parking solutions. These are the parking lots with a routing system and/or reservation of parking space.

Emissions Testing and Mitigation. The system uses advanced sensors to monitor areas of polluted air and control access to such areas. For example, in tunnels, in case of excessive air pollution, ventilation systems are activated.

Smart pedestrian and bicycle crossings. Built-in hardware detects pedestrians and activates roadside light panels and vertical panels on either side of the road. It can be equipped with a laser STOP strip at waist level or a STOP wall for drivers to warn that there are people in the crossing. At that time, a 2-meter-high illuminating red barrier with human silhouettes is formed across the street with the aid of laser lights. Sensor-driven cycling signal management, creating “green waves”.

Smart speed reduction. The sensors of the automatic speed reduction system detect when the number of cars exceeds the set limits on the streets and automatically reduce the speed limit.

Traffic monitoring systems. The travel safety system helps to create a safe environment for passengers, drivers and support staff. The sensors monitor the environment in vehicles, stations, parking lots and generate alarms (automatically or manually) as needed. The system also monitors basic transit infrastructure (rail tracks, bridges, tunnels, bus rides, etc.).

Automated control of safe travel for commercial vehicles. This is a system that gives drivers alerts on their driving characteristics, vehicle condition and road condition. The system monitors the performance of components such as tires and brakes and warns of impending failure. A start-up compatible alcoblock can be installed.

Autonomous vehicles. The equipment installed in the cars tracks the environment, has databases of the road and surrounding areas that are constantly scanned. The system provides information to the driver and helps to drive safely. Autonomous driving is also possible in some sections.

Traffic light management system. These are the “smart traffic lights”, which improve traffic conditions for public transport by giving it a priority in junctions, prioritizing special motor vehicles (ambulances, fire trucks).

Vehicular communication systems. Vehicle-to-everything (V2X) system components monitor the environment. The system incorporates vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies, which detect and prevent potential obstacles and alert other road users. 5G internet connectivity provides autonomous car development opportunities.

Information, travel planning and online payment. These are the mobile apps that help users to choose the time and convenience of their trip by one or more modes of transport and make payment for the trip.

Variable information and message signs. Traffic signs at stops inform road users about the state of transit in real-time (street events, traffic delays, re-routing, and more). The information displays show information relevant to drivers - air and road surface temperatures, air pollution indicators, instantaneous speeds for drivers and traffic congestion messages.

Special traffic lanes (for public or special transport). Only vehicles meeting the lane marking requirements (buses, 4+, electric cars, taxis) can drive in these lanes. Smart special lanes must be equipped with sensors to detect offenders - the ANPR system is used.

Restricted traffic zones. Smart restricted traffic zones capture vehicles entering the area. If the system does not find a specific vehicle in the list of vehicles allowed to enter the area, a fine will be imposed.

Electric vehicles charging stations, hydrogen stations. These include electric vehicles charging and hydrogen filling stations, and other smart electric vehicles charging applications. For example, rechargeable smart road surfaces.

Smart street surfacing. These are the surfaces: illuminated, heated, de-icing, charging electric vehicles, etc.

Smart street lighting. Smart street lighting controls work with climatic conditions, time of the day, traffic volume, and more. The main advantage of this system is the centralized control of all luminaires connected to the system, remote lighting level change, information on luminaire malfunctions, pavement, traffic conditions.

Conclusions

The goal of a smart city is to promote a sustainable environment that is safe and comfortable for citizens. A smart city is primarily about people, not technology.

The implementation of Intelligent Transport Systems in cities can be considered as one of the ways to solve the problems of the mobility system. This would ensure an effective reduction of congestion and accidents, traffic control and help solve public transport problems.

It can be assumed that the lack of appropriate harmonized concepts and indicators may be the reason for the lack of comprehensive comparative research on ITS in cities. In order to carry out comprehensive comparative studies of smart mobility systems in cities, it is necessary to develop appropriate benchmarks to describe the smartness level of the smart mobility system.

The developed hierarchical model of smart mobility system evaluation will be used in expert research for further analysis and evaluation of smart cities.

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