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Transport Solutions and Indicators in Smart Cities – Part I

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Summary
The subject of the article is the analysis of solutions and applications of modern information and communication technologies (ICT) in urban centers and the measurement of transport quality indicators, taking into account the requirements of the ISO 37120 standard: Sustainable cities and communities – indicators for city services and quality of life. The article consists of two parts. In part I of the article, the subject of smart cities was introduced, including the functioning concepts of smart city. A description of the shaping of urban spaces and the quality of life in the smart aspect was made, taking into account the issues of sustainable development. The characteristics of the ISO 37120 standard, used to measure the level of services and living conditions in cities, are presented. The basic and auxiliary indicators in the field of city services and quality of life, including those related to transport, were presented. Polish cities that received the smart city certificate were listed. At the end of part I, there was a review of experiences and solutions that improve mobility that operate in selected cities around the world and in Europe.

Keywords: smart cities, quality of city services, ISO 37120 standard, urban transport, quality indicators in transport

1. Introduction

The last decade of the 20th century and the beginning of the 21st century marked the emergence and development of the so-called information society. This term refers to a community at an advanced level of technological development, where information is the most valuable and widely exchanged commodity, extensively used in economic, social, cultural, and political aspects of life. It is regarded as a special intangible resource, equivalent, and in some cases even more valuable than material goods. The information society possesses abundant means of communication and information processing, which form the basis for generating the majority of the national income and provide a source of livelihood for the majority of the population.

The advancement of civilisation has led to the contemporary society being saturated with technology and innovation, which have become an integral part of its nature, essential for functioning. New and increasingly advanced methods of information transmission have permeated virtually every aspect of human life, and nowadays, it is challenging to imagine a world without the internet, computers, smartphones, and all the information and digital techniques. Harnessing the potential of modern civilisation can successfully serve to improve the functionality of cities.

The issue of *smart cities*[5] encompasses modern, ecological, cost-effective, and efficient urban management. It is a relatively new approach that uses the application of modern information and communication technologies (ICT) for sustainable urban development, involving the improvement of activities in the following categories: citizens, government, energy, buildings, transport, infrastructure, communications and health.

The trend of innovation across different spheres of life serves as a catalyst for socio-economic progress, and it also finds application in the transport sector, including railways. Innovations and enhancements in

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[5] The phrases Smart City 1.0, 2.0 and 3.0 were first used by Boyd Cohen, a smart city researcher from the Universidad del Desarrollo in Santiago de Chile.

infrastructure, superstructure, and transport services positively impact accessibility and increase the mobility of residents. Modern transportation technologies support policies for a resource-efficient, environmentally friendly and sustainable economy.

2. Definitions of *smart city*

The term *smart city* literally translates to an intelligent city. This concept started gaining prominence in the early 21st century. The name „smart" is an acronym for five words:

- **s**pecific
- **m**easurable
- **a**ttractive / **a**chievable
- **r**ealistic
- **t**imely defined / **t**ime-bound

The word "smart" also means clever, sensible or resourceful.

It should be noted that there is no single, specific definition of a *smart city*. This concept, in its macro sense, referring to an urbanised territorial unit, is relatively new, and different researchers focus on various aspects of it.

One of the definitions is proposed by Swiss scholar Robert Horbaty. He considers a city to be smart if it offers its residents the highest quality of life while simultaneously minimising the use of available resources through a proper combination of infrastructure systems (e.g., transport or energy transmission) [1]. According to British researchers Mark Deakin and Husam Al Waer, a distinctive feature of smart cities is their use of a wide range of digital and electronic technologies, including information and communication technologies (ICT) [2]. Jennifer Belissent, on the other hand, points out that a smart city uses information and communication technologies to make key services and elements of urban infrastructure (administration, education, public safety, transport, etc.) more efficient [1]. Nicos Komninos considers a smart city to be an area (commune, district, cluster, city, city-region) consisting of four main elements [3]:

1) a creative population engaging in knowledge-intensive activities or a cluster of such activities,
2) efficiently functioning institutions and procedures for knowledge creation, enabling its acquisition, adaptation, and development,
3) developed broadband infrastructure, digital spaces, e-services and online tools for knowledge management,
4) a proven ability to innovate, manage and solve problems that arise for the first time, as innovation and effective management under uncertainty are crucial for assessing intelligence.

The MIT (*Massachusetts Institute of Technology*) *smart city* research centre defines this concept as intelligence that arises from the integration of increasingly effective digital telecommunications networks (comparable to nerves), omnipresent intelligence (comparable to brains), sensors and tags (comparable to sensory organs) and software (comparable to knowledge and cognitive competence). This intelligence does not exist in isolation from other urban systems. Instead, there is a growing network of overlapping connections to mechanical and electrical systems found in buildings, systems embedded in household appliances, transport systems (ITS, P+R), electrical networks, water supply and sewage networks, and systems that provide security for urban residents [3].

It is also worth noting the academic definition of a *smart city*, considered one of the most complete, cited by the Vienna University of Technology, which states that "*smart city* is a city that achieves good results now and in the future (...), created through a smart combination of resources and decision-making activities, independent and involved citizens" [1]. On the other hand, according to Wikipedia [4], a smart city is defined as a city that uses information and communication technologies to increase the interactivity and efficiency of the urban infrastructure and its components, as well as to raise the awareness of its residents. This part of the definition mainly draws attention to the role of IT in a broad sense. A city can be considered "smart" when it undertakes investments in human and social capital and communication infrastructure to actively promote sustainable economic development and a high quality of life, including wise management of natural resources, through citizen participation. This definition is taken from the study by I. Azkuna, Smart Cities Study: International study on the situation of ICT, innovation and knowledge in cities [3].

Based on the cited descriptions and characteristics of *smart cities*, it can be observed that the fundamental differences in the applied terminology lie in the emphasis placed on various aspects. Some terms draw attention to the technological issues used in the creation of smart cities, others to the functionality that such cities should realise, while yet others focus on the benefits for residents of living in a smart city (social aspects) and their necessary participation in the creation and development of such a place. Despite these differences, some common elements can be observed. Experts agree that *smart cities* are cities that are well organised and useful and that, through the organisation of processes, offer: service to the needs of the residents, the development of public space and growth potential, the most favourable conditions for increasing the quality of life of the residents and the realisation of the goals of their stakeholders [5].

3. Shaping urban spaces and quality of life in the context of smart cities

Cities are like living organisms. They have their strengths, opportunities, potentials, and aspirations, but they also face numerous limitations and grapple with problems and challenges. Therefore, urban development depends on many factors and is a complex, multi-dimensional, and multi-faceted process that requires a forward-looking perspective, planning, and management.

Expectations towards cities are for them to provide easy and fast access to services, energy, housing resources, transport, education, and healthcare. They should expand and enhance opportunities for leisure activities, including cultural and sports offerings. Moreover, cities should attract new residents and investors, which requires creating a favourable job market situation, access to a skilled workforce, and availability of knowledge and technology. A friendly administration plays a crucial role, as well as coexistence with other businesses in the market, whose presence ensures a suitable atmosphere for business development.

Contemporary shaping of urban space, including public space, in a way that is friendly and attractive to residents while also beneficial from the perspective of investors and business stakeholders, and serves future generations, requires consideration of various concepts and processes. This includes sustainable development, quality of life, attractiveness, and the competitiveness of cities, which are used to conduct policies for urban development and functioning of urbanised areas. Thus, according to [6]:

- sustainable development – pertains to ensuring economic growth in conjunction with principles of social justice, while respecting environmental protection. It serves as a starting point for planning future civilisational development, including urban development (sustainable urban development).
- high quality of life – is a sustainable development objective for urban development and a soft location factor with a significant impact on the attractiveness of cities;
- sustainable urban regeneration – is one of the instruments for achieving sustainable development and improving quality of life, contributing to a city's attractiveness;
- city attractiveness – is a positive potential for future development, raising its position in competition between cities at the appropriate level (global, national, regional).

The interrelationships and interactions of these concepts and processes influence urban development and guide the creation of new urban design and planning solutions and the adaptation of new technologies in urban areas that will support decision-making and resource management tailored to the specific functional conditions and needs of the territorial unit.

Currently, cities strive for smart sustainable development, understood as a balance between environmental, economic and social governance. This fits in with the idea of the *smart city*, i.e. the development of urban areas using information and communication technologies (ICT). Thanks to modern methods, tools and solutions, the smart city adapts to the needs of the residents and the space becomes user-friendly for all users. A smart city is supposed to operate like an efficient organism in which the individual elements work together to ensure harmonious development. An important element in the smart city concept is concern for the environment and the use of green solutions. In particular, the *smart city* should provide:

- favourable conditions for investing in the city,
- efficient settlement of matters in city offices and institutions,
- universal access to information about the city, development plans, etc,
- efficient communication,
- effective operation of municipal services,
- safety of inhabitants,
- care for the environment,
- a wide range of leisure activities (cultural events, sporting events, etc.),
- active involvement of residents in improving the city through cooperation with the administration.

The key role in creating "smart cities" is played by the skillful implementation of technology that supports urban development and serves the needs of residents, as well as the creation of universal and user-friendly urban spaces. Increasingly, modern technology assists daily life in urban areas, making them more convenient and efficient. In a nutshell, a smart city is a dream place to live.

4. Application areas and examples of smart city solutions

The *smart city* concept distinguishes six functional areas, comprehensively covering the smart city issue. These are [cf. 7, 8]:

1. *Smart economy* – is a knowledge-based, high-tech, well-connected economy with strong local and global ties, in which innovation-supported entrepreneurship ensures high productivity, prosperity and employment. It also includes the development of future-oriented business, with the promotion of innovation, investment, new industries, the

expansion of services and support for an ecosystem of new ventures (*start-ups*[6]).
2. *Smart environment* – includes issues related to climate protection, management of natural resources and optimisation of environmental costs. Environmental issues relate to appropriate water and energy management, including the use of renewable energy sources and energy efficiency solutions, waste recycling or reduction of pollutant emissions.
3. *Smart governance* – transparency of public administration, citizen and supplicant orientation, openness and service of public services and social needs, accessibility to information and offers for the whole population, public participation in decision-making.
4. *Smart mobility* – signifies the implementation of an efficient transport system in the city, based on an extensive network of public transport and mass transit, where mobility processes and traffic management are supported by smart transport systems. The fundamental aim is to optimise vehicle traffic and the provision of transport, benefiting from the integration of public transport and promoting modes of transport other than the car. The use of ITS systems helps to increase road capacity, serves to better coordinate traffic and reduce travel times, as well as provides more comprehensive information and safety for road users.
5. *Smart people* – this is a community of aware, mindful people who are open to knowledge and education. Access to educational services and offers, as well as equal opportunities policies, provide possibilities for labour market and business development. Social and human capital supported by a system of further education, improvement of qualifications and competences, also in terms of new technologies, provides the basis for maintaining employability and prevents social exclusion of citizens.
6. *Smart living* – this is an area related to quality of life in terms of safety, culture and recreation or health care. Providing a friendly place to live and spend time is achieved through a wide range of public services, modern technical and social infrastructure, cultural and leisure offerings and leisure time activities.

Smart city tools are modern technologies, products and services for creating a better managed, greener and more citizen-friendly city. Manufacturers and distributors offer many solutions for entities and decision-makers directly responsible for investments in public spaces in urban areas. The audience interested in the *smart city* segment also includes representatives of the private sector (developers, investors, designers, architects and urban planners), with the largest groups being from the IT, energy, transport and logistics industries. Examples of solutions for individual smart city areas are summarised in Table 1.

However, it is important to emphasize the fact that the *smart city* concept is not just about electronics and IT solutions. It is a concept for the full development of the city, which provides stability and living comfort. With increasing demands for rational energy management, the use of renewable energy sources and care for the environment, the implementation of the smart concept is inevitable in the long term. Such a centre is a place that becomes safe and friendly for its residents, making them live more comfortably, healthier and longer. By implementing modern technologies, the city becomes a developing, modern place, and, as a result, attractive and open to business and investors [8].

5. City services and quality of life in cities

One of the defining features of the 20th century was the dynamic urban growth that affected various regions of the world. The reasons for this growth were the establishment of new industrial plants in urban agglomerations and the associated influx of people employed in these plants, as well as the post-war baby boom. The dynamic development of cities has resulted in many negative phenomena, the most important of which are:
- underdevelopment of technical and municipal infrastructure,
- air and water pollution,
- the phenomenon of wild urbanisation, i.e. cities „spilling over" into neighbouring areas in a chaotic manner and not in line with urban development priorities,
- water scarcity,
- traffic difficulties (traffic jams),
- excessive noise,
- higher cost of living,
- crime and related insecurity,
- isolation and loneliness of people fending for themselves in their neighbourhoods,
- increase in the number of homeless people,
- the emergence of shantytowns,
- lack of land reserves for green areas or car parks,
- the emergence of "subcultures".

Uncontrolled urban growth is a negative phenomenon and therefore ways are being sought to monitor it. In order to manage urban development effectively, it is necessary to obtain a variety of city data that

[6] Start-up – an undertaking created with the purpose of developing a new product or service under conditions of risk and uncertainty.

Table 1

Solutions and technologies in urban functional areas

Functional area	Examples of solutions, technologies, and services in cities
Smart economy	• Development of business spaces • Start-up ecosystem • Technology parks • Business incubators, cluster initiatives • Promotion of innovation (*high-tech* industry) • Industry 4.0 • Last mile logistics • Retail 2.0 • E-commerce, e-services • Digital tourism offers
Smart environment	• Renewable energy sources • Photovoltaic systems • Smart metering systems (*e-metering*) • Smart grid • Small wind turbines • Water management • Environmental sensors • Closed-system economy and modern raw material processing methods (recycling, upcycling)
Smart governance	• Digital services for citizens and businesses • E-administration (e-government) • Open data • Maintenance of order and cleanliness • Smart street lighting • Public safety – city surveillance • Broadband Internet • Free Wi-Fi
Smart mobility	• Transport optimisation and road safety • Intelligent Transport Systems (ITS) • Electric mobility (electric cars and charging systems) • Integrated traffic management • Cycling infrastructure • Shared mobility • Smart parking • Low emission urban transport (hybrid, electric hydrogen, CNG/LNG solutions)
Smart people	• Increase in community competences • Digital inclusion • Digital education • Lifelong learning (e-learning, distance learning) • Development of sciences (technology, engineering, mathematics) • Digitisation of the labour market
Smart living	• Services for enhancing quality of life • Smart buildings and smart homes • Mobile applications for residents • E-payments • Digital healthcare • Culture • Green spaces • Libraries • Innovative solutions for small infrastructures

Prepared on the basis of [7].

characterise the city and which will serve as input for the methods and tools developed to help analyse and report on the state of the city and its services.

Another phenomenon becoming apparent today and affecting cities is globalisation. In the age of globalisation, the world has become a field of competition between entities that in the past were never direct competitors to each other. This applies not only to businesses, but also to local governments. Among other things, cities compete with each other for residents, investments, the location of events and organisations as well as tourists and students.

The competition between cities manifests itself in the development of various rankings in different fields, which aim to highlight the advantages of one city over another in a given area. These rankings were often created spontaneously to satisfy immediate objectives.

5.1. Characteristics of the ISO 37120 standard

As a result, there was a need to create a universal set of indicators for all local governments in order to reliably compare their potential in a variety of areas, which in turn makes it possible to create new development strategies for local governments based on inferences from large data sets.

As the management of large data sets can lead to the phenomenon of 'information overload', the need to standardise this type of data has also arisen. The response to these needs is the ISO 37120 standard.

Its genesis was the perceived lack of a coherent and properly prepared standard for assessing the performance of cities, while at the same time there was an increased interest from various stakeholder groups in the performance of cities. This led to the International Organisation for Standardisation's decision to create ISO 37120, which includes a set of indicators developed and tested by the Global City Indicators Facility (a sister organisation of the WCCD, World Council on City Data) and its more than 250 member cities around the world [9]. In turn, the WCCD, in collaboration with the Global Cities Registry™, has developed the first ISO 37120 certification scheme [10].

The ISO 37120:2014 standard (Fig. 1) was finally defined in 2014 [11]. It is divided into the part necessary for certification and contains additional, optional requirements. The standard identifies and defines how to measure individual indicators for steering and measuring the performance of city services and quality of life, and where to get the necessary data from. However, it does not specify minimum values that the city must achieve.

The standard can be applied in any city, commune or local government that undertakes to measure its own performance in a comparable and verifiable way, regardless of size and location. In Poland, the standard has been published by the Polish Committee for Standardisation under the title: "Zrównoważony rozwój społeczny – Wskaźniki usług miejskich i jakości życia" (Sustainable development in communities – Indicators for city services and quality of life) [11]. It defines and establishes the measurement methodology for a set of indicators. For each indicator, two fundamental principles were followed: data reliability and usability, ensuring that the data accurately describe the city's situation and, at the same time, serve as a useful tool for city governance.

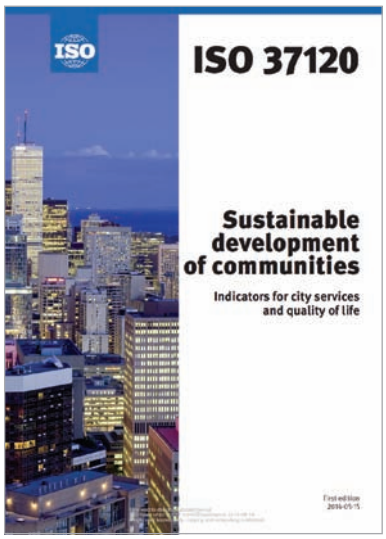

Fig. 1. Cover of ISO 37120 standard [10]

5.2. Specification of city indicators

The ISO 37120 standard [10] contains a set of 100 indicators that characterise the level of city services and the standard of living (46 indicators are basic and 54 are auxiliary), which are divided into 17 thematic areas. Table 2 summarises all the indicators defined in ISO 37120, by thematic area, taking into account the rank of the indicator – the basic indicators in the table are marked in bold.

In addition to a set of indicators, the standard also includes profile indicators, i.e. basic statistical data and information about the city – mainly demographic and city budget data.

5.3. Certification of cities for compliance with the standard

The certification process consists of several stages. If a city decides to use ISO 37120 to measure its level of service and quality of life, it proceeds to collect the relevant data, measures the indicators defined in the standard and submits a corresponding application to the authorised certification body. In the application, it is indicated which indicators the city presents for assessment.

Table 2

Indicators according to ISO 37120 [10]

Indicator number according to the standard	Name of the indicator
	ECONOMY
5.1	**Unemployment indicator**
5.2	**Commercial property value as a percentage of the value of all properties in the city**
5.3	**Percentage of residents living in poverty (minimum subsistence level)**
5.4	Percentage of full-time employees
5.5	Percentage of employed young people
5.6	Number of economic entities per 100,000 residents
5.7	Number of new patents per 100,000 residents per year
	EDUCATION
6.1	**Percentage of school-age girls**
6.2	**Percentage of students completing primary education**
6.3	**Percentage of students completing secondary education**
6.4	**Number of students per teacher**
6.5	Percentage of school-age boys
6.6	Percentage of young people attending school
6.7	Number of professional and scientific degrees and titles awarded per 100,000 residents
	ENERGY
7.1	**Total household energy consumption per resident (kWh/year)**
7.2	**Percentage of city residents with access to a legal source of electrical energy**
7.3	**Energy consumption of public buildings per year (kWh/m^2)**
7.4	**Percentage of energy derived from renewable sources in the city as a proportion of total energy consumed in the city**
7.5	Total energy consumption per resident (kWh/year)
7.6	Average number of energy supply interruptions per customer per year
7.7	Average duration (in hours) of energy supply interruptions
	ENVIRONMENT
8.1	**Concentration of PM2.5 fine particulate matter (small particles)**
8.2	**Concentration of PM10 particulate matter**
8.3	**Greenhouse gas emissions in tonnes per person**
8.4	Concentration of nitrogen dioxide
8.5	Concentration of sulphur dioxide
8.6	Concentration of ozone
8.7	Noise
8.8	Percentage change in native species
	FINANCE
9.1	**Local government budget deficit**
9.2	**Investments as a percentage of total budget expenditure of the local government**
9.3	Own revenue of the local government as a percentage of total revenue
9.4	Tax collection
	FIRE PROTECTION AND COMBATING THE EFFECTS OF NATURAL DISASTERS
10.1	**Number of firefighters per 100,000 population**
10.2	**Number of fire-related deaths per 100,000 residents**

Table 2 cd.

Indicator number according to the standard	Name of the indicator
10.3	**Number of disaster-related deaths per 100,000 residents**
10.4	Number of members of Volunteer Fire Brigades per 100,000 residents
10.5	Average response time of services to a notification (112)
10.6	Average response time to a notification of fire
GOVERNANCE / ORGANISATIONAL ARRANGEMENTS	
11.1	**Voter turnout in recent local elections**
11.2	**Percentage of women in leadership positions in the local government office**
11.3	Percentage of women employed in local government office
11.4	Number of final convictions for corruption or bribery for local government officials per 100,000 residents
11.5	Representation of residents: number of people elected to a local government office per 100,000 residents
11.6	Number of registered voters as a percentage of total population eligible to vote
HEALTH	
12.1	**Average life expectancy**
12.2	**Number of hospital beds per 100,000 residents**
12.3	**Number of doctors per 100,000 residents**
12.4	**Mortality rate of children under 5 years of age per 1,000 live births**
12.5	Number of nurses and midwives per 1,000 residents
12.6	Number of mental health practitioners per 100,000 residents
12.7	Suicide rate per 100,000 residents
RECREATION	
13.1	Number of square metres of indoor recreation spaces per resident
13.2	Number of square metres of outdoor recreation spaces per resident
SAFETY	
14.1	**Number of police officers per 100,000 residents**
14.2	**Number of murders per 100,000 residents**
14.3	Property crime per 100,000 residents
14.4	Police response time to reports of possible crimes
14.5	Number of violent crimes per 100,000 residents
SOCIAL ASSISTANCE	
15.1	**Percentage of city population living in slums**
15.2	Number of homeless people per 100,000 residents
15.3	Percentage of households living in dwellings without legal title
SOLID WASTE	
16.1	**Percentage of the city's population from whom solid waste is regularly collected**
16.2	**Total weight of solid waste collected per resident**
16.3	**Percentage of solid waste that is recycled**
16.4	Organised (with special preparation) landfill sites
16.5	Percentage of solid waste that is incinerated in a waste incineration plant
16.6	Percentage of solid waste that is incinerated in the open air
16.7	Non-organised (without special preparation) landfill sites
16.8	Percentage of municipal waste that is managed in another way
16.9	Production of hazardous waste per resident in tonnes

Indicator number according to the standard	Name of the indicator
16.10	Percentage of hazardous municipal waste that is recycled
	TELECOMMUNICATIONS
17.1	**Number of Internet connections per 100,000 residents**
17.2	**Number of mobile phone calls per 100,000 residents**
17.3	Number of calls from landlines per 100,000 residents
	TRANSPORT
18.1	**Kilometres of high-capacity public transport system per 100,000 residents**
18.2	**Kilometres of urban public transport network per 100,000 residents**
18.3	**Annual number of public transport travels per resident**
18.4	**Number of passenger cars per resident**
18.5	Percentage of commuters using another means of transport than their own passenger car
18.6	Number of single-track motor vehicles per resident
18.7	Length of cycle paths and lanes per 100,000 residents
18.8	Number of fatalities in transport per 100,000 residents
18.9	Number of scheduled air services
	AREA DEVELOPMENT AND PLANNING
19.1	**Green areas (in hectares) per 100,000 residents**
19.2	Number of trees planted per year per 100,000 residents
19.3	Size of illegally settled areas/wild settlements as a percentage of city area
19.4	Ratio of number of jobs to number of dwellings
	SEWAGE
20.1	**Percentage of residents who have access to a sewage system**
20.2	**Percentage of wastewater that is untreated**
20.3	**Percentage of wastewater that is subject to preliminary treatment**
20.4	**Percentage of wastewater that is subject to further treatment**
20.5	**Percentage of wastewater that is subject to final treatment**
	WATER AND SANITARY CONDITIONS
21.1	**Percentage of city residents with access to drinking water**
21.2	**Percentage of city residents with access to improved water quality**
21.3	**Percentage of city residents with access to a sewage system**
21.4	**Total household water consumption per resident**
21.5	**Total water consumption per resident**
21.6	Average number of hours per year associated with water supply interruptions to households
21.7	Percentage of water supply losses (water supplied but not billed)

The application is accompanied by documentation for the audit. The certification body verifies the relevance and reliability of the data used and the correctness of the calculations themselves. However, it is not the values of the indicators themselves that are assessed, but only the appropriateness of the interpretation and correctness of the measurement of the indicators [12].

While ISO 37120 does not define certification levels and only outlines the conditions to be met for compliance with this standard, in practice, certification is conducted at five levels, which vary depending on the number of indicators submitted by the city for certification and are named accordingly [13]:

- aspiring level includes: 30–45 basic indicators,
- bronze level: 46 basic indicators and 0–13 auxiliary indicators,
- silver level: 46 basic indicators and 14–29 auxiliary indicators,

- gold level: 46 basic indicators and 30–44 auxiliary indicators,
- platinum level: 46 basic indicators and 45–54 auxiliary indicators.

Certification under the ISO 37120 standard at international level is handled by the World Council on City Data (WCCD). When a city is certified by the WCCD, the name of the city is added to the organisation's Global Cities Registry database. The certification is renewed annually and it is a mandatory requirement to maintain a valid certificate and remain in the database.

National certification bodies can also assess compliance with the standard. The verification process and awarding of the certificate in such a case is faster and cheaper, but it lacks the image benefits of being compared to European and world cities. In Poland, five cities hold the ISO 37120 certificate: Gdynia, Kielce and Warsaw (certified by the World Council on City Data), Lublin (certified by the Polish Committee for Standardisation) and Gdańsk (certified by the Polish Register of Shipping) [12].

6. Overview of foreign smart solutions for the transport sector

Many foreign cities feature innovative solutions aimed at improving mobility. Among the solutions used in modern and sustainable transport in Europe, other continents, and increasingly in Poland, we should mention, for example:

Florida (USA) – in Miami-Dade County, there is an *Advanced Traffic Management System* (ATMS) that covers the city of Miami and its surrounding areas. It operates more than 2,700 signal intersections and street crossings, the number of which increases each year. The system is designed to reduce congestion and delays and improve mobility. It uses Digi 4G mobile routers, which, being part of the communications infrastructure, have been installed in road cabinets across the county [14].

Philadelphia (USA) – the *Southeastern Pennsylvania Transportation Authority* (SEPTA) [3], which manages the city's light rail, subways and buses, operates there. With over a million passengers daily, these services must be reliable and safe every time a vehicle embarks on its route. For this reason, SEPTA has built a Positive Train Control (PTC) system to signal trains, prevent derailments and accidents, and monitor speed and signal violations. SEPTA accomplishes this using the Digi WR44-RR mobile access router. The device installed on the train allows remote communication with sensors along the tracks via a radio link. It sends signals with train movement data while also receiving information about closures and other factors that would require schedule changes. As a result, trains are not exposed to danger [14].

Detroit (USA) – operates the SMART (*Suburban Mobility Authority for Rapid Transit Authority*) system, which manages more than three hundred buses throughout the city. To manage the dispatching and tracking of bus locations, the city used an analog radio network with three radio towers located throughout the city. Utilising this system enables punctual, safe, and reliable operation of the city's bus fleet. The system uses a Digi WR44 R mobile cellular router. The transition from an analog to a digital network has enabled much better management and tracking of buses. The new technology allowed the SMART system to not only locate the vehicle, but also monitor its speed and maintenance data for each bus. This provided greater fleet availability, prevented delays, and facilitated preventive maintenance to reduce breakdowns and major repairs, saving around 70,000 dollars annually [14].

Portland, Oregon (USA) – local authorities are collaborating with a Pittsburgh-based start-up called Rapid Flow to prevent pedestrian accidents using an artificial intelligence-based system that automatically optimises traffic conditions. This system can communicate with neighbouring intersections and all nearby smart vehicles. This technology helps reduce the number of pedestrian-involved accidents [15].

San Francisco (USA) – the city uses smart ticket to streamline processes related to public transport and smart parking. This allows authorities to adjust parking prices in a particular area based on the number of available spaces and helps people move more freely around the city [15].

State of Wyoming (USA) – an innovative program using *Vehicle to Infrastructure* (V2I) technology has been introduced here. The programme is designed to help car and lorry drivers navigate safely through congested and dangerous areas. The programme utilises V2I technology to send drivers weather and road alerts. Drivers receive traffic information sent by 75 short-range communication devices placed at designated points. Thanks to these systems, on stretches of road where the described technologies have been deployed, drivers are informed about road conditions: upcoming weather phenomena or other obstacles that may affect driving (including possible accidents), they are also informed about the time of arrival at a specific destination. Drivers can plan their route rationally and in advance, which in turn helps to reduce traffic and increase safety. The municipal authorities expect that, as a result of the programme being implemented, there will be a significant increase in the local economy and overall safety, among commuters in the area [15].

Christchurch (New Zealand) is transforming its current bus network into a smart transport network by implementing a modern Real-Time Information (RTI) system to accurately track and inform passengers about bus schedules and public transport options. The city uses information and communication technologies to address issues such as road congestion and to increase the utilisation of public transport. These technologies enable the introduction of a multimodal integrated ticket, an automated fare collection system, a passenger information system, and also improve public safety (monitoring through video systems). Smart transport networks are also safer as they are connected, flexible, and capable of responding quickly to emergencies, partly due to video technology and sensors that allow operators of urban transport systems to continuously monitor traffic flow and respond to potential disruptions before they occur [15].

Auckland (New Zealand) – the city aspires to become the most liveable city in the world for its residents. Smart lighting and smart urban elements have been installed on the streets surrounding Wynyard Quarter's Innovation Precinct. This technology enables the generation of pedestrian traffic heat maps, allowing for better control of lighting in the immediate surroundings. As a result, energy consumption is reduced, and air and noise pollution levels are monitored. Some street lighting control systems are equipped with industrial television connected to the 5G network, enabling high-resolution monitoring of the environment, even at night. The system can enhance the detection of criminal activities and remotely adjust the lighting intensity at the installation site and its immediate vicinity to help reduce energy consumption. Smart solar-powered benches allow for charging electric scooters, bicycles, and smartphones. Information and communication technologies have also been used to build smart waste bins, allowing the recognition of the level of waste fillings and preventing overflow, thus optimising the work of municipal cleaning companies [14].

Atlanta (USA) – in order to ensure the safety of residents, the **Metropolitan Atlanta Rapid Transit Authority** (MARTA) has created the MARTA See & Say app. Travelers who notice incidents or suspicious behaviour can use this app to directly contact the police. The app allows for two-way communication – travelers can exchange messages with emergency services and provide them with additional information when requested. This not only provides additional assistance to city services but also makes travelers feel much safer [16].

Singapore – the city is investing in smart parking solutions. A number of sensors have been installed throughout the city to collect and monitor large amounts of data, which are used to improve parking, traffic and keep the city clean. The use of sensors to identify empty parking spaces in large multi-storey car parks helps reduce the time drivers spend looking for a vacant space, and with the help of warning lights and information boards [15], they also receive information on the number of vacant spaces to park their vehicle.

Seoul (South Korea) – the underground has completely eliminated cash payments and replaced them with smartphone payments. The underground operator has also implemented an app that provides access to real-time information on timetables, travel disruptions, so travellers can plan, book and pay for their journey using a single device [16].

Dublin (Ireland) – the Dublin Bus company has implemented the *Real-Time Passenger Information* (RTPI) system to provide travelers with personalised travel advice based on the current road situation. Dublin Bus is able to provide passengers with information on bus delays, arrival times and information on which buses will pass specific stops. The stops are equipped with sensors, and the buses have GPS, radio, and onboard computers that report their positions to a central computer. The data obtained from all this communication is useful for optimising bus schedules and the occupancy level of individual bus lines [16].

London (United Kingdom) – the city is testing bike-sharing systems to encourage more people to opt for bicycles over cars and increase the use of two-wheelers. Traffic management has been implemented by introducing a congestion charging system for driving in the city centre and the SCOOT traffic management system, which controls traffic lights at intersections [18]. An innovative transport system has also been introduced at the Heathrow airport, i.e. self-service pods that allow travellers transferring from a local flight to an intercontinental flight to quickly move between terminals. The pods, which can accommodate up to 4 people with luggage, are equipped with a touch screen. After selecting the destination (such as a terminal or parking area), the pods autonomously find their way there and deliver passengers to specified location within minutes [17].

Vienna (Austria) – to achieve zero emissions in the city center, conventional buses have been replaced with 12 innovative microbuses that mainly use energy from renewable sources. These vehicles are twice as expensive and require infrastructure modernisation for charging, but in the long run, they generate benefits such as fuel cost reduction, noise reduction, improvement of public health, and zero emissions of pollutants [8].

Copenhagen (Denmark) – the city utilises an integrated pedestrian, cycling, and car transport system. Additionally, the city centre (an area of 96,000 m^2) has been closed off for car traffic [8].

7. Conclusions

The growing demands in the field of rational energy management, utilisation of renewable energy sources, and environmental care make the implementation of smart ideas in urban areas a necessity in the longer time perspective. The ISO 37120 standard [10] is a valuable tool for monitoring urban development and the level of city services. The set of indicators included in this standard allows for both analytical observation and assessment of changes occurring over time in various fields and functional areas of the city, as well as enabling the comparison of results, implementation of changes, and the creation of development policies [13].

The assumption behind implementing a smart transport system in cities is the pursuit of reducing the consumption of natural resources and minimising the emission of harmful substances into the atmosphere, which has the potential to make the cities more attractive, healthier, and more comfortable places to live and conduct activities. The response to these challenges is a system that involves the collaboration of three components: a smart road, a smart vehicle (equipped with devices that maintain continuous information exchange with devices installed along transport routes), and a smart management centre.

The fundamental element that distinguishes the concept of a *smart city* from previous models of sustainable urban development is "mobility," treated as a separate and essential dimension that defines transport accessibility, teleinformation infrastructure, and innovative and secure transport systems. The cooperation of these three factors in smart mobility is intended to primarily serve [18]:

- improving traffic flow efficiency,
- increasing the comfort of moving,
- reducing the stress associated with traffic,
- supporting eco-friendly forms of transport.

Changing commuting behaviours requires a wide range of actions, often involving bold decisions by city authorities and close cooperation with local communities – starting from initiatives promoting alternative forms of public and eco-friendly transport, integrating transport systems, and ending with investments in transport infrastructure. The measures taken and the concrete implementations cited in the examples from various cities (global and European) can effectively improve the functionality of the entire urban area, contribute to cost reductions, save resources and improve the quality of life in cities.

The development and implementation of innovative solutions for urban transport also require cooperation with scientific institutions, the construction of sustainable transport infrastructure supporting innovative mobility solutions, and ensuring an adequate level of funding. It can be expected that the expenses incurred for investments will only pay off after several years and will bring tangible benefits in the longer term.

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