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Modeling the Effectiveness of Intelligent Systems in Public Transport That Uses Low-Carbon Energy: A Case Study

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Abstract: Cities have been struggling for many years with many transport problems, including the impact of carbon monoxide emitted by vehicles on the environment, traffic jams, high energy consumption, numerous accidents or high infrastructure costs. There is also a dynamic growth of vehicles on the roads, which is why an increasing number of cities are introducing intelligent transportation systems (ITS), which is part of the concept of smart cities. This paper proposes a new matrix to assess the effects of the ITS implementation in the context of a concept Smart City, which consists of five criteria: (1) movement speed; (2) safety; (3) environmental; (4) economic; (5) satisfaction and amenities for society/passengers. In this new approach the benchmark values of the indicators assigned to the criteria are involved and, therefore, it is possible to determine the level of effectiveness of the ITS in public transport that uses low-carbon energy. This research used literature studies to establish the criteria of effectiveness of ITS as well as a case study, namely public transport that uses low-carbon energy in a Polish city, which had the largest fleet of electric buses in Poland and implements and uses an ITS. Both, the theoretical and the empirical research results demonstrate the usefulness and potency of the proposed matrix to assess the effects of the ITS implementation in cities in the context of the development of a smart city. In that way, the proposed approach may be a useful tool for measuring the effects of ITS implementation in cities.

Keywords: electric buses; intelligent transportation system; public transport; smart city; smart mobility

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1. Introduction

According to the smart city concept, it is necessary to design and implement changes in urban systems, both logistically, economically and environmentally. The smart city concept combines the necessary urban activities into a single logical multi-branch management system. Sustainable management of urban areas is becoming one of the most important challenges of the 21st century and the concept of the smart city is proposed as a possible solution. The smart city includes different aspects of city management: building, energy, environment, government, living, education and mobility [1]".

There are many definitions of the smart city in the literature, one of the more interesting ones presented in [2] claiming that a smart city is a sustainable and efficient urban centre that provides a high quality of life to its inhabitants through optimal management of its resources." Another definition is presented by [3] claiming that a city can be described as "smart" when social capital, traditional and modern (ICT) communication infrastructure encourage sustainable economic development and high quality of life". It can therefore be noted that the smart city concept is closely linked to the implementation of the 17 Sustainable Development Goals adopted by the United Nations (UN). It should be pointed out that a plethora of urban development projects that target 'smartness' as a social, economic, environmental and urban governance goal" [4]. A smart city is the interaction between technological, organizational and political innovations and the achievement of sustainable development (SD) challenges. It can therefore be assumed that smart cities play a key role in achieving the SD objectives and also have a major impact on their, A smart city system comprises of six key building blocks: smart people, smart city economy, smart mobility, smart environment, smart living, and smart governance [5]". It is these six closely related elements that allow you to create a system in a smart city. The characteristics of the six elements that make up a smart city are shown in Table 1.

Table 1. Smart City characteristics [6].

City Dimension	Context
Smart Economy	Highly advanced economy through Information and Communications Technology (ICT), focused on developing new products, services and business models.
Smart Mobility	Use of integrated transport and logistics systems that mainly use clean energy.
Smart Environment	Increase the use of Environmental Education (EE); control of urban networks (street lighting, water, electricity, etc.) for financial and environmental benefits; constant control and monitoring of pollution in the city; thermomodernization and renovation of buildings in order to reduce their energy-intensive.
Smart People	Creating high-quality human capital in a environment of social engagement and creativity, as well as tolerance and diversity.
Smart Living	Ensuring a high quality of life by providing wide access to ICT infrastructure that will enable safe and healthy behaviour, consumption and lifestyles.
Smart Governance	Smart public governance, where joint decision-making by society plays an important role, taking into account strategic decisions.

On the basis of Table 1, we define the smart city a holistic approach to integrating new intelligent technological solutions into a platform providing interaction within cities [7].

The literature of the subject [8] indicates that one of the measures showing the legitimacy of the implementation of the smart city concept is effectiveness. The effectiveness of a smart city can be mainly due to the resulting joint connections from both the private and public sectors. Many scientific papers focused on the notion of efficiency in a smart city solely in terms of energy effectiveness [9,10]. Mora et al. [11] described this trend as the "European Path: Smart City for a Low-Carbon Economy". Effectiveness in the context of a smart city also means environmental and transport effectiveness [12,13]. Other benefits of implementing a smart city identified in [8] are: improving quality of life, ensuring integration and equality in society, connectivity, joint creation and sharing of knowledge, etc. Our research is limited to assessing effectiveness in the context of a smart city focused on the use and the implementing of Intelligent Transportation Systems.

Cities have been facing transport problems for many years, including the impact of carbon monoxide emitted by vehicles on the environment, traffic jams, high energy consumption, numerous accidents or high infrastructure costs. There is also a dynamic growth of vehicles on the road, which is why an increasing number of cities are introducing intelligent transportation systems (ITS), defined as "combining information and communication technologies with transport infrastructure and vehicles to improve safety, increase the efficiency of transport processes and protect the environment" [14]. Its main tasks include improving transport quality and reducing pollution by improving fuel efficiency, accessibility and safety. ITS is also a solution to improve air quality and reduce traffic jams without the need to design and implement changes in urban infrastructure. ITS covers a number of software solutions, including [1]:

- traffic management systems, e.g., motorway and incident management systems, electronic toll collection;
- advanced information systems for travellers, e.g., real-time traffic, information and navigation systems;
- advanced public transport systems;
- information and navigation systems, etc.

These information systems for travelers can be found at stops, stations or vehicles. In modern vehicles, systems taking the form of boards, liquid crystal displays (LCD) and monitors and audio messages transmitted to passengers. It is also pointed out that "providing accurate and real-time information (RTI) on services can be an effective way of encouraging passengers to shift from private to public transport (PT)" [15]. However, it is worth noting that the expectations of passengers are primarily the reliability of the means of transport. RTI systems are expected to improve travel experience, affect users' perception in terms of reliability of service [15,16]. RTI systems are assumed to allow passengers to make more informed decisions.

The transportation system condition has a significant effect on the economic and social development of the region [17]. Three essential components are necessary for any ITS to perform its function(s): data collection, data analysis, and data/information transmission [18]. The collection of data for ITS purposes consists in the collection of information, e.g., the volume of traffic for a particular road network, the average journey time on a specified section of road, the number of passengers using the transit lines concerned, the number of public transport available, etc. This allows for constant control and analysis of traffic conditions. Smartphones, advanced communication technologies, Global Positioning System (GPS), Wi-Fi, Bluetooth and mobile phone data [19,20] are increasingly being used in the context of ITS to adapt to the current needs of society. The collected data are used to analyze traffic conditions and even travel activity.

The basic elements of the system are fixing facilities, information transfer telecommunications, databases, data processing and processes control applications, hardware components of control mechanisms [21]. It has also developed standards and related activities for ITS systems. Its scope in public transport includes [22]: ISO/TR 14806, which sets out the requirements for TP to use the application for paying for the journey, ISO 17185 (group), where the information addressed to the TP user is contained.

This work defines a new matrix to assess the level of effectiveness of the implementation of ITS in the example of public transport that uses low-carbon energy in a Polish city, which had the largest fleet of electric buses in Poland and implement and use ITS. Based on the literature review we created a tool so called a matrix, to assess the effects of introducing ITS in the context of a concept of the smart city, that consists of five criteria: (1) movement speed; (2) safety; (3) environmental; (4) economic; (5) satisfaction and amenities for society/passengers. In this new approach the benchmark values of the indicators assigned to the criteria are strictly defined an involved and therefore it is possible to determine the level of effectiveness of the ITS in public transport that uses low-carbon energy.

2. Materials and Methods

2.1. A New Matrix to Assess the Effects of the ITS Implementation in the Context of a Smart City Concept

ITS main tasks include providing a way to move quickly, safety and minimise environmental damage. The ITS effectiveness criteria can, therefore, be divided into three groups [21]:

- The criterion of movement speed;
- Indoor safety;
- Environmental criterion.

The authors of the study, based on the literature research results and also on the opinions of experts involved in the implementation of the "Sustainable Cities" program in Poland propose two additional criteria that should also be taken into account:

- Satisfaction and amenities criterion for the public/road passengers;
- Economic criterion.

It is assumed that ITS efficiency can be measured through selected key performance indicators (KPIs) for ITS. The literature of the subject [23,24] recommends as KPIs:

- the costs of building and implementing the system,
- change in the capacity of roads and junctions,
- change in inter-stop driving times of public transport vehicles,
- an appreciable (subjective, surveyed) assessment of changes in travel conditions (including in particular time) of drivers of passenger cars, drivers of public transport vehicles, public transport passengers (tz) and cyclists,
- change in the share of public transport, bicycles and pedestrian journeys in transport,
- the number and % of public transport stops where dynamic travel information is made available to travellers, whenever possible separately depending on the mode of public transport.
- the number and % of new vehicles equipped with elements enabling the use of smart services, change of travel time during peak hours on routes where ITS has been implemented, reported by vehicle type, where possible,
- change in % of annual CO_2 emissions on routes where ITS has been implemented.

Therefore, we propose a new matrix to assess the effects of the ITS implementation in the context of a smart city concept. The effectiveness should be calculated by the criteria proposed by the authors and the KPIs specified for them:

- C1: Movement speed criterion:
  - time needed to change route/plan detours (SR1)
  - number of buses in motion (SR2)
- C2: Safety criterion:
  - number of electric bus failures (S1)
  - line throughput/line congestion (S2)
  - number of communication collisions (S3)
- C3: Environmental criterion:
  - average number of passengers per day (EV1)
  - number of downloaded e-cards (EV2)
- C4: Economic criterion:
  - number of persons employed in the operation of the systems (EC1)
  - ticket/travel price (EC2)
- C5: Criterion of satisfaction and facilities for society/passengers:
  - average passenger quality of service assessment (SP1)
  - number of complaints made by passengers (SP2)
  - number of mobile app downloads (SP3)
  - the number of public transport stops where dynamic travel information is made available to travellers (SP4).

The following rules have been defined, the application of which will allow the assessment of the level of its effectiveness depending on the value of the defined indicators (Table 2).

Factors for the evaluation of ITS effectiveness in a city in the context of a concept smart city were based on feedback surveys experts and their sources are listed here: ITS effectiveness: the degree to which a city achieves the benchmark values of the indicators assigned to the criteria in Table 2, using the scale: Level1: not effective; Level2: rather effective; Level3: effective; Level4: very effective; Level5: excellent.

Table 2. A new matrix to assess the effects of the intelligent transportation systems (ITS) implementation in the context of a smart city concept.

	Motion Speed Criterion	Safety Criterion	Environmental Criterion	Economic Criterion	Satisfaction and Amenities Criterion for Society/Passengers
Level 1 effectiveness (LE1)	If SR1 = (0.5/min) and SR2 = (100%)	If S1 = (0/month) and S2 = (100%/0%) and S3 = (0/month)	If EV1 = (70% city population) and EV2 = (720/month)	If EC1 = (2) and EC2 = (no price change in the last year)	If SP1 = (4,9) and SP2 = (0/month) and SP3 = (90% passengers) and SP4 = (80%)
Level 2 effectiveness (LE2)	If SR1 = (5/min) and SR2 = (95%)	If S1 = (3/month) and S2 = (90%/10%) and S3 = (4/month)	If EV1 = (50% city population) and EV2 = (684/month)	If EC1 = (5) and EC2 = (2x price change in the last year)	If SP1 = (4,5) and SP2 = (30/month) and SP3 = (80% passengers) and SP4 = (60%)
Level 3 effectiveness (LE3)	If SR1 = (10/min) and SR2 = (90%)	If S1 = (5/month) and S2 = (80%/20%) and S3 = (8/month)	If EV1 = (40% city population) and EV2 = (650/month)	If EC1 = (7) and EC2 = (3x price change in the last year)	If SP1 = (4,0) and SP2 = (60/month) and SP3 = (60% passengers) and SP4 = (50%)
Level 4 effectiveness (LE4)	If SR1 = (15 min) and SR2 = (85%)	If S1 = (7/month) and S2 = (70%/30%) and S3 = (12/month)	If EV1 = (30% city population) and EV2 = (617/month)	If EC1 = (9) and EC2 = (4x price change in the last year)	If SP1 = (3,5) and SP2 = (90/month) and SP3 = (40% passengers) and SP4 = (30%)
Level 5 effectiveness (LE5)	If SR1 = (30/min) and SR2 = (80%)	If S1 = (10/month) and S2 = (50%/50%) and S3 = (15/month)	If EV1 = (20% city population) and EV2 = (586/month)	If EC1 = (11) and EC2 = (5x price change in the last year)	If SP1 = (3,0) and SP2 = (120/month) and SP3 = (20% passengers) and SP4 = (15%)

Thanks to cooperation with experts, rules have also been created to define the overall level of ITS efficiency (LE):

If $C1\epsilon L1 \wedge C2\epsilon L1 \wedge C3\epsilon L1 \wedge C4\epsilon L1 \wedge C5\epsilon L1$ then LE = 1
If 3 $C\epsilon L1 \wedge$ two $C\epsilon L2$ then LE = 1
If 3 $C\epsilon L1 \wedge$ one $C\epsilon L2 \wedge$ one $C\epsilon L3$ then LE = 1
If 4 $C\epsilon L1 \wedge$ one $C\epsilon L3$ LE = 1
If $C1\epsilon L2 \wedge C2\epsilon L2 \wedge C3\epsilon L2 \wedge C4\epsilon L2 \wedge C5\epsilon L2$ then LE = 2
If 3 $C\epsilon L2 \wedge$ two $C\epsilon L3$ then LE = 2
If 3 $C\epsilon L2 \wedge$ one $C\epsilon L3 \wedge$ one $C\epsilon L4$ then LE = 2
If 4 $C\epsilon L2 \wedge$ one $C\epsilon L4$ LE = 2
If $C1\epsilon L3 \wedge C2\epsilon L3 \wedge C3\epsilon L3 \wedge C4\epsilon L3 \wedge C5\epsilon L3$ then LE = 3
If 3 $C\epsilon L3 \wedge$ two $C\epsilon L4$ then LE = 3
If 3 $C\epsilon L3 \wedge$ one $C\epsilon L4 \wedge$ one $C\epsilon L5$ then LE = 3
If 4 $C\epsilon L3 \wedge$ one $C\epsilon L5$ LE = 3
If $C1\epsilon L4 \wedge C2\epsilon L4 \wedge C3\epsilon L4 \wedge C4\epsilon L4 \wedge C5\epsilon L4$ then LE = 4
If 3 $C\epsilon L3 \wedge$ two $C\epsilon L5$ then LE = 4
If $C1\epsilon L5 \wedge C2\epsilon L5 \wedge C3\epsilon L5 \wedge C4\epsilon L5 \wedge C5\epsilon L5$ then LE = 5
If more than 3 $C\epsilon L4$ then LE = 5

2.2. Smart City Development Level

The pillars of smart city construction are reducing the need to have their own means of transport by increasing the mobility of available means of transport (operating permits, transport data and interfaces, public service obligations, taxes and auditing, certifications, and reporting), increasing road safety (for both road users and pedestrians) and minimising environmental pollution (route optimisation, infrastructure development, geoinformation). The interest in digital interventions is often underpinned by smart knowledge claims: claims with regard to smart data's contributions towards an improved understanding of urban systems and towards better governance of these systems [25]". Urban mobility claims indicate that the use of new real-time data collection practices allows for more effective understanding, better predictability and traffic management. It also includes more efficient infrastructure planning, reducing negative environmental impacts and, importantly, increasing road safety. It is indicated that the data collected through smart mobility increases the level of decisions taken to initiate actions aimed at improving mobility and quality of life [26].

Smart mobility has a number of features in the smart city concept, including among others [5]:

- a smart city focuses on the mobility of people, and not only that of vehicles.
- a smart city effectively manages vehicular and pedestrian traffic, and traffic congestion.
- a smart city has balanced transportation options.
- a smart city has seamless mobility for differently-abled (often incorrectly called, disabled) people.

In our approach, smart mobility is affected by criteria (Table 2) that include:

- number of buses in motion (C1-SR2),
- line throughput/line congestion (C2-S2),
- number of communication collisions (C2-S3),
- number of e-cards downloaded (C3-EV2),
- number of mobile app downloads (C5-SP3).

The smart economy (SE) is also a component of the smart city system. The literature review identifies a number of different definitions of SE: (1) a smart economy involves the knowledge economy, where innovation and technologies are considered as the most important driving force [27]; (2) a smart economy is a networking economy, developing new cooperation models in production, distribution, and consumption [28]; (3) a smart economy is a green economy; it encourages reduction of the amount of carbon dioxide in industry and suggests investing in the 'clean economy [29]. The SE covers economic competitiveness, taking into account factors such as entrepreneurship, innovation, entrepreneurship, productivity, adaptability, economic promotion. To build a smart economy, cities should be highly productive, innovative and labour market flexible. A number of smart economy functions are indicated in the context of the smart city among others [5]:

- A smart city offers its citizens diverse economic opportunities.
- A smart city knows that all economics works at the local level.
- A smart city is prepared for the challenges posed by and opportunities of economic globalization.
- A smart city develops and supports compelling national brand/s.
- A smart city insists on balanced and sustainable economic development.
- A smart city is a destination that people want to visit (tourism).
- A smart city is resourceful, making the most of its assets while finding solutions to problems.
- A smart city's inhabitants strive for sustainable natural resource management and understand that without this its economy will not function indefinitely.

In our approach the functions described above have allowed the selection of defined criteria (Table 2), including:

- number of persons employed in the operation of the systems (C4-EC1).
- tickets/travel price (C4-EC2).

The criteria and indicators characteristic of smart mobility and a smart economy were named for the purposes of the article smart indicators (SI). Therefore, we defined the smart city development level (SC) according to the rules:

If $SR1 \epsilon L1 \wedge S2 \epsilon L1 \wedge S3 \epsilon L1 \wedge EV2 \epsilon L1 \wedge EC1 \epsilon L1 \wedge EC2 \epsilon L1 \wedge SP3 \epsilon L1$ then $SC = 1$
If 5 $SI \epsilon L1 \wedge$ two $SI \epsilon L2$ then $SC = 1$
If 6 $SI \epsilon L1 \wedge$ one $SI \epsilon L3$ then $SC = 1$

If SR1ϵL2 $\wedge$ S2ϵL2 $\wedge$ S3ϵL2 $\wedge$ EV2ϵL2 $\wedge$ EC1ϵL2 $\wedge$ EC2ϵL2 $\wedge$ SP3ϵL2 then SC = 2
If 5 SIϵL2 $\wedge$ two SIϵL3 then SC = 2
If 6 SIϵL2 $\wedge$ one SIϵL4 then SC = 2
If SR1ϵL3 $\wedge$ S2ϵL3 $\wedge$ S3ϵL3 $\wedge$ EV2ϵL3 $\wedge$ EC1ϵL3 $\wedge$ EC2ϵL3 $\wedge$ SP3ϵL3 then SC = 3
If 5 SIϵL3 $\wedge$ two SIϵL4 then SC = 3
If 6 SIϵL3 $\wedge$ one SIϵL5 then SC = 3
If SR1ϵL4 $\wedge$ S2ϵL4 $\wedge$ S3ϵL4 $\wedge$ EV2ϵL4 $\wedge$ EC1ϵL4 $\wedge$ EC2ϵL4 $\wedge$ SP3ϵL4 then SC = 4
If 5 SIϵL4 $\wedge$ two SIϵL5 then SC = 4
If SR1ϵL5 $\wedge$ S2ϵL5 $\wedge$ S3ϵL5 $\wedge$ EV2ϵL5 $\wedge$ EC1ϵL5 $\wedge$ EC2ϵL5 $\wedge$ SP3ϵL5 then SC = 5
If more than 5 SIϵL4 then SC = 5

2.3. A Case Study

The Municipal Department of Transport (MDT) in a Polish city (Zielona Góra) is a municipal body serving public transport in the area and within Zielona Góra. It has been operating and providing transport services in Zielona Góra since 1954.

The organizer of public transport in Zielona Góra is the Mayor of Zielona Góra, while the Department of Enterprise and Municipal Economy is responsible for the implementation of public transport policy and cooperation with the MDT. The only operator operating on urban lines is an internal entity—the MDT in Zielona Góra. It currently employs 296 people and has 89 buses in operation. The MDT is constantly implementing measures towards the implementation of Green Kand Low-emission public transport [30]. As a result, MDT purchased low-floor electric buses, which are powered by energy produced in the green mountain heat and power plant, obtained by the cogeneration of burned gas. MDT also took care to reduce water consumption, as the bus depot was rebuilt in such a way as to obtain and use rainwater for washing buses.

MDT in Zielona Góra is involved in green solutions and in building an intelligent public transport strategy based on ITS.

ITS Solutions

Since 2004, the MDT in Zielona Góra has been constantly implementing new IT systems, which are designed to improve the quality of services provided and reduce the negative impact of public transport on the environment (Table 3).

Nowadays all described processes are usually thoroughly supported by IT systems [5].

2.4. Data Collection

The results of the analysis of effectiveness of the implementation of ITS and based on the opinions of experts from 34 cities involved in the implementation of the "Sustainable Cities" program in Poland and also four internal experts from public transport that uses low-carbon energy in a Polish city: Zielona Góra.

The data necessary for the calculation of ITS effectiveness on the basis of criteria and indicators set by the authors were obtained from the Municipal Department of Transport in the Polish city, which had the largest fleet of electric buses in Poland and implements ITS.

Table 3. Information technology (IT) solutions implemented in the Municipal Department of Transport (MDT).

IT Solution	Year of Implementation	Description	Planned Development
Electronic Payment System			
E-Card	2012	Non-contact electronic card, which is a carrier of electronic tickets, valid for public transport in Zielona Góra [31]. The fare is designed in a way that benefits the passenger, as the introduced season tickets with a limit of quantity and the need to register journeys are relatively cheaper than season tickets without a travel limit and the electronic purse function allows you to pay for one-time trips depending on the number of stops traveled and this cost will never exceed the price of a single paper ticket. The advantage for Municipal Department of Transport in the city of Zielona Góra is the data from the e-card system determining the number of trips and relationships (the system requires a touchdown at the entrance and at the exit of the vehicle).	Lifting the limit of accumulated funds, e-card on a smartphone
Road Traffic Management Systems			
Timetable Software	2009	MZK in Zielona Góra uses busman network management software in the process of designing the timetable, which also takes into account the operation of electric buses. This is particularly important in view of the need to take into account the number of buses on charging loops at the same time and to infrastructure constraints on some loops, for example on one of the loops, in order to maintain maximum traffic safety, the first-in first-out (FIFO) departure principle is applied in order of arrival. The most important function of the program is a topographic map, which in a way facilitates and reduces the time in the design of routes, defining travel times or generating inter-stop distances. A special map interface also speeds up the creation of detours.	Simulation of the movement of vehicles—an image of the position of buses on the map within a set time frame in the proposed timetable
Passengers Support Systems			
Passenger App	(zbiletem.pl) 2018 (mPay) 2017 (moBILET)	The mobile passenger app allows you to purchase tickets for public transport. You can pay with Google Pay, Apple Pay, Blik, a payment card, or a quick transfer. The app works on Android and iPhone smartphones. The application offers one-time and daily tickets from the MZK offer in Zielona Góra.	Submitting requests for a VAT invoice, making a complaint without having to contact the Customer Service Point directly. Possibility to report problems in vehicle and inbound infrastructure and vending machines
QR Codes	2013	QR codes have been placed next to the timetables to redirect you to a page that displays current departures in real time. The Traveller system forecasts departures for all stops.	Alternative form of reading information using Near-Field Communication (NFC) technology
Electronic Stop Plates	2006	At the end of 2020, in Zielona Góra, electronic stop boards were located at as many as 73 stops. The operation of the electronic stop plates operated by TRAVELLER system consists in sending information about their location and the necessary identification note by buses whenever they reach a predefined point recognized using GPS. The system receives information about the location of the vehicle and retrieves data from Tarna/Municom (a database with timetables), which allows you to create a forecast of departures from stops in real time and transfer data to the displays of the boards. Depending on the type of board, there are 3 or 5 fields on the displays that indicate: line number, direction of travel, number of minutes remaining until departure or departure time, voice information system for passengers with vision problems.	Extension of displayed information about all operators and carriers

Table 3. *Cont.*

IT Solution	Year of Implementation	Description	Planned Development
Interactive Map	2016	The map shows the current location of all MZK vehicles based on GPS signals. The passenger has the option to choose a stop from the map and view the current departures.	
		Driver Safety and Support Systems	
Electric Bus Surveillance Software	2018	Electric buses, unlike conventional buses, require additional supervision due to the correct charging process of traction batteries in order to carry out the courses smoothly. Battery level signaling is supported on the CNR map. The CNR map performs the following functions: Track the current location of buses control of vehicle speed and deviation from timetable, voice over internet protocol (VOIP) call between dispatcher and driver two-way communication with drivers via SMS sent to vehicle autocomputers, notifying the dispatcher of the delayed departure of the bus from the loop (the system is configured to send a notification to the dispatcher if the bus does not go from standstill to driving state after 2 min after the scheduled departure time),the ability to view on-line images from surveillance cameras in the vehicle, placing information on the boards of internal vehicles (so-called "beads") in the announcement bar, emergency route changes, using the "Diversions" module, emergency communication—information from the so-called "panic" button, punctuality analysis in any time range for any vehicle. Additional supervision of electric buses is also supported by the Open Charge Point Protocol System (OCPPS), known as the telemetry system. OCPPS provides charging processes, loader statuses in the house as well as historical sessions. The system's home screen shows the distribution of chargers in the depot and loops, and clicking on the charger symbol at a given point allows you to view the last active session along with details and graphs showing the charging current value, charge level, temperature and other technical parameters. The system allows you to increase or limit the charging power, interrupt charging or turn off any charging point by the dispatcher. An additional advantage of the systems is also the view of the estimated range of the bus at any given time during an active charging session.	Auto-uploading maps to on-board bus computers, auto-updating maps in case of need of a detour, auto-changes sent to the passenger application and information boards in case of planned changes of arrival/departure. Bug fix history monitoring–reporting the status of each bug. Repair realizations-an indication of the current status. Repair cost reports to analyze repair costs and group fault types.

3. Research Results

Based on the data received from the MDT, Zielona Góra we assessed the ITS effectiveness in the context of the development of a smart city. In this new approach the benchmark values of the indicators assigned to the criteria are involved and, therefore, it is possible to determine the level of effectiveness of the ITS in public transport that uses low-carbon energy.

BusMan's public transport network management software collected data on the number of buses in traffic and the amount needed tore-route/plan detours. On the other hand, thanks to passengers support systems implemented in MDT, data were obtained in terms of: the average number of passengers per day, thus indicating the overload of individual lines, the number of downloads of the mobile application, the number of e-cards downloaded, the number of available public transport stops, on which dynamic travel information is made available to travelers (electronic stop boards operated by the traveller system).

(1) Time needed to re-route/plan a detour: immediately set an alternative route using the CNR map;
(2) Number of e-cards downloaded as of 01.03.2012:75,702 e-cards issued (as of 31.01.2021), average monthly number of e-cards issued 721 e-cards;

(3) Average number of passengers per day: 60,786, Population of Zielona Góra on 31.12.2019: 140,874;
(4) Average passenger service assessment: according to a spring 2019 survey, the average quality of service assessment is 451;
(5) Number of complaints submitted by passengers: at d the beginning of the existence of the electronic ticket system 01.03.2012 until 31.01.2021, 7814 complaints were considered;
(6) Number of mobile app downloads: data cancer on the number of mobile app downloads. In 2020, the average monthly number of tickets purchased using the app was about 2900;
(7) Number of traffic collisions: 2018—83, 2019—92, 2020—86; data from the last three years have allowed the average number of collisions per year to be set: 87. The average number of collisions is 7.25;
(8) Number of electric bus failures—no data available;
(9) Ticket/travel price;
(10) Line throughput/line congestion: 35 cases of overfilling in 2018 (79.5%) related to the operation of standard 12-metre buses. In 32 cases, the condition of compression was found, while 3 times the excess capacity of the vehicle was found. In 9 cases, the described overruns were found during the execution of the course by an articulated bus (of which 8 cases represented a squeeze, and only 1 case overcapacity).

For all types of rolling stock, the state of compression in October 2018 was set at more than 70% of capacity and the state of dangerous overcapacity was set at 115% of the nominal capacity of vehicles.

As many as 55 cases of border overruns were reported across the green mountain public transport network during marketing studies in October 2018.

On a weekday in October 2018, there were 44 exceedances of the indicated level of border fill-ins in the majority, because there are as many as 18 lines of green mountain public transport: 0, 1, 2, 5, 8, 9, 14, 17, 19, 25, 26, 27, 30, 37, 39, 44, 80 and Z19. Most, as many as 40 cases, represented a compressive state, but 4 cases involved overcapacity of the vehicle.

(11) Number of persons employed in the operation of the systems: number of dispatchers employed unchanged after implementation of ITS—7 dispatchers, including 2 dispatchers responsible for the control of charging stations;
(12) Number of buses on the move: 71 on weekdays/32 on Saturday/29 on Sunday;
(13) Number of public transport stops where dynamic travel information is made available to travellers: 73/422.

As a result, the level of ITS effectiveness, based on the benchmark values of the indicators assigned to the criteria was calculated (Table 4).

Table 4. The level of ITS effectiveness in Polish city.

	Motion Speed Criterion	**Safety Criterion**	**Environmental Criterion**	**Economic Criterion**	**Satisfaction and Amenities Criterion for Society/Passengers**
Level 1 effectiveness	SR1 = (0.5/min) and SR2 = (100%)		EV2 = (721/month)		
Level 2 effectiveness					SP1 = (4.51)
Level 3 effectiveness		S3 = (7.25)	EV1 = (43.2% city population)	EC1 = (7)	
Level 4 effectiveness		S2 = (79.5%)			SP2 = (75/month)
Level 5 effectiveness					SP4 = 17%

According to the adopted rules, the assessment of the level of effectiveness of ITS in the case study is as follows:

If SR1ϵL1 ∧ SR2ϵL1 ∧ SP1ϵL2 ∧ SR1ϵL2 ∧ S3ϵL3 ∧ EV1ϵL3 ∧ EC1ϵL3 ∧ S2ϵL4 ∧ SP2ϵL4 ∧ Sp4ϵL5 then LE = 4.

Thanks to the comparison of the obtained values in the examined Polish city with the defined values of the reference indicators (Table 2) and on the basis of defined rules, the effectiveness of ITS was obtained at Level 4: very effective.

Moreover, thanks to the developed rules, the value for the smart city level was obtained at the Level SC: very effective, as follows:

SR2ϵL1 ∧ S3ϵL3 ∧ EC1ϵL3 ∧ S2ϵL4 then SC = 4

4. Discussion

The purpose of its data analysis was to provide different information and management measures on the basis of collected data from different sources. The use of ITS solutions can be considered as part of traffic management, which is responsible for ensuring road safety and for the transparent and sustainable future of cities. The use of ITS in the context of urban public transport in this case study offers the following advantages:

- Reduced travel times and power consumption by optimizing routes in its use, as well as controlling detour routes and battery levels. The implemented busman network management software takes into account the operation of electric buses, which is a convenience in designing routes, defining travel times and generating inter-stop distances. The map also speeds up the creation of detours through a special interface. You can also use it to display chronological departures from loops, as well as departures on individual communication lines.
- Improve travel comfort and traffic conditions for drivers and pedestrians by implementing customer amenities in the form of passenger satisfaction surveys, e-cards and a mobile app. When purchasing a ticket in the mobile application, it is enough to show the ticket on the screen of your smartphone during the ticket control. Mobile timetables in the mobile app make it easy to plan your trip, as they allow you to access timetables from any mobile device.
- Increase the availability of up-to-date information by installing information boards indicating actual data on bus departures and weather conditions, including the possibility of obtaining audible information (data update every 9 s).
- Improving the environment through the use of public transport of around 60,000 passengers per day and the implementation of e-cards that replace paper tickets.
- Increase capacity on the busiest lines by controlling the number of passengers on each line and modifying timetables in such a way as to eliminate the phenomenon of "herds" and, where possible, ensure an optimal supply of seats on the different transport lines. The driving timetable is built "from the inside" of the route, setting departure times from the starting stops so that at stops shared with other lines they form synchronized departures. After the departure times are assigned, the courses are combined into brigades, i.e., transport tasks. The transport task (brigade) is the transport work of one bus per day—assigning the bus to the courses in the schedule. Currently used specialized programs allow the efficient use of vehicles in the process of building a timetable and operating them even on several lines during the day.

Both the theoretical and empirical research results demonstrate the usefulness and potency of the proposed matrix to assess the effects of the ITS implementation in the cities in the context of the development of a smart city. The proposed approach makes it possible to assess the effectiveness of ITS implemented in other cities aimed at the integrated development of all socio-economic dimensions. Cities based on long-term solutions, building a comprehensive development strategy, including in the field of local transport, can use the solution presented to assess the effectiveness of their activities. The proposed approach makes it possible to really assess the achievement of smart mobility policy objectives, taking into account parameters such as improved safety, optimal price, public satisfaction, low emissions, reduced fuel consumption, increased economic competitiveness and the attractiveness of public transport. The criteria adopted and the indicators selected for them make it possible to compare data from different cities in a clear way.

The limitation for this approach is the type of public transport and the different range of services provided by ITS in each city, so that a comparison of the results may be imprecise.

In that way, the proposed approach may be a useful tool for measuring the effects of ITS implementation in cities.

The presented solutions implemented for public transport in a Polish city, which had the largest fleet of electric buses in Poland and implements ITS, reflect the character of the smart city concept, highlighting mainly the functions of its two pillars: smart mobility and smart economy. It should be emphasized, however, that the interdependence of the presented features and the concept of the smart city is difficult to decipher. Doubts arise, for example, because "it is not clear whether a city is smart because of its smart economy or smart city is the reason behind the workings of a smart economy" [28].

5. Conclusions

In recent years there have been dynamic changes in public transport. Some of the changes are visible to society as a whole: electric vehicles, new toll options, modern means of information and communication between passengers and operators. Modern travel planning differs significantly from that of a few years ago, and lengthy study of the city plan and writing down timetables are almost things the past.

The development of ITS in public transport is a challenge for local governments as, despite the development of many technology sectors, public transport will remain needed. An important aspect from the point of view of further development of ITS in cities is the assessment of the effectiveness of the implemented actions. The idea, as presented, is an innovative approach to measuring the effectiveness of intelligent systems in public transport that uses low-carbon energy. Thanks to the implementation of our matrix, it is possible to present a level of smart city development and to evaluate the effectiveness of the intelligent systems in public transport that uses low-carbon energy. The proposed matrix could be a good tool to support decision-making in the further development of the city towards becoming a smart city.

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