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Managing Public Transport Safety Using Digital Technologies

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Abstract

Public transport is an important component of the infrastructure of modern cities and other settlements, as it ensures the mobility of all segments of the population. In this regard, improving the level of public transport safety is an important task. In this article, the main causes of accidents in transport were studied, the experience of developing various transport safety systems was analyzed, and digital technologies and tools that would improve the level of safety were identified. As a result, a reference model for managing the public transport system based on digital technologies was developed.

Keywords: Transport Safety Management; Public Transport; Digital Technologies; Internet of Things; Architectural Approach.

1. Introduction

In the modern world, the level of population mobility is increasing from year to year, which means that the importance of transport systems is also growing. At the same time, despite the fact that the percentage of the population with personal transport is gradually increasing, the public transport system remains an important infrastructural component for any territorial unit and performs a number of important functions. For example, public transport ensures the territorial integrity of cities and districts, as well as the availability of various elements of the urban economy (educational and medical institutions, leisure organizations, places of work, etc.) to any category of the population. Thus, the high level of importance of the public transport system requires constant development and improvement of this system, especially with regard to the level of safety, since transport is considered one of the sources of increased danger, which poses a threat to property, the environment, as well as the life and health of people.

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The safety of public transport implies not only the internal ability of the transport complex to safely perform its functions, but also the ability to provide reliable protection of passengers and personnel from external influences (Stoop et al., 1997). Accidents cause colossal damage to both individual citizens and the state as a whole. This is due to the trauma and death of the population, as well as significant material losses from damage to vehicles and infrastructure facilities. In this regard, ensuring a high level of public transport safety is one of the most important and urgent tasks.

Today, various measures are taken to improve the safety of public transport in the world. In general, all these measures have several main directions. Firstly, in most countries, a carrier must have a special license to carry out passenger transportation. Such a license guarantees that regular and pre-trip maintenance of vehicles is carried out, drivers undergo pre-trip medical examinations and periodic medical commissions, special means have been introduced that control the work and rest regime of drivers, and so on. Thus, licensing is intended to improve the quality of the fleet of vehicles that carry out passenger transportation, as well as to prevent drivers who are unsuitable for health reasons from carrying out transportation. Another measure is the permanent improvement of the transport infrastructure. Violation of the integrity of the roadway, old badly read traffic signs, worn out road markings can cause accidents. In this regard, in any country in the world, periodic repairs are carried out to restore and improve the road and transport infrastructure. In addition, with the development of technology, additional measures have begun to appear to improve safety. For example, tachographs have begun to be installed in public transport. These are devices designed to register the speed, work schedule, rest of drivers and crew members (Azarov et al., 2016).

All these measures will certainly contribute to improving the overall level of public transport safety. However, they do not consider many other factors that may affect the transport safety of a particular vehicle. To ensure the safety of each specific vehicle, it is proposed to use modern digital technologies.

Since each vehicle must be as safe as possible for passengers, a so-called “personalized” approach to safety activities is required. It is digital technologies and tools that provide a personalized approach in many areas of activity, since it involves the collection of processing a huge amount of data. An example of an industry where a personalized approach is implemented using digital technologies is medicine (Ilin et al., 2019). For example, with the help of Internet of Things technology, patient health data can be continuously recorded anywhere. This data is then processed, and the doctor can propose a personalized treatment path that will be most effective for a particular patient (Ilin et al, 2020). It is assumed that a similar mechanism will significantly improve the overall level of public transport safety due to the fact that each specific vehicle will become safer.

Thus, taking into account the current trends of widespread digitalization, it is assumed that it is digital technologies that will qualitatively improve the situation with transport safety. In this regard, the purpose of this article is to study modern digital technologies and tools that will improve the level of public transport safety, and to create a reference architecture for a public transport safety management system using these digital technologies.

2. Materials and Methods

Despite the fact that public transport is considered safer than other modes of transport, various types of accidents still occur. At the same time, according to statistics from different countries, buses are most often involved in accidents. Also, bus accidents kill significantly more people than other types of public transport. In this regard, it seems appropriate to consider some of the serious bus accidents that have occurred in recent years in various regions of the world in order to study the main causes of their occurrence.

One of the most obvious causes of accidents is vehicle malfunctions. Failure of the most important systems in the vehicle leads to problems or complete impossibility of control, as a result of which emergency situations arise. For example, on January 9, 2020 in Iran, a bus turned over and fell into a ravine as a result of a brake failure. The accident killed 19 people, another 24 people were injured (BBC, 2020). A malfunction of the brake system also caused an accident on August 29, 2019 in Azerbaijan, in which 1 person died, another 24 people were injured (APA, 2019). In 2014, in Thailand, a bus’s brakes failed while it was descending a mountain, resulting in the bus crashing into a truck with a trailer that was driving in front of them. There were teachers and schoolchildren on the bus who were heading for an excursion to one of the resort towns. The accident killed 15 people (13 of them were children) and about 40 were injured (Bonnici, 2014). Another accident due to a technical malfunction of the vehicle occurred

on August 17, 2019 in the Russian city of Perm. The bus hit the wall of the building, as a result of which one person died on the spot, 34 people were injured. An auto technical examination determined that the bus had a steering malfunction (TASS, 2019).

Also, quite often accidents involving public transport occur due to adverse weather conditions. For example, it was unfavorable weather conditions that were recognized as the cause of the accident with a passenger bus in Turkey on August 21, 2017. The bus overturned while exiting the tunnel, as a result of which 20 people were injured (Novinite, 2017). Severe icing caused the accident on January 8, 2017 in the south of France. The bus driver lost control on a slippery road and the vehicle pulled over and overturned. In this accident, 4 people died, more than 20 were injured of varying severity (AFP, 2017). A major accident involving a bus, 66 cars and four trucks occurred in Slovenia on January 31, 2016. The police admitted thick fog as the cause of the accident. The scale of this accident is explained primarily by poor visibility due to fog: drivers could not assess the road situation at a safe distance and did not have time to take measures to avoid collisions (BBC, 2016).

In addition to these reasons, a large percentage of accidents with public transport are caused by drivers. As a rule, such accidents occur because drivers cannot objectively assess the traffic situation and make decisions that entail serious consequences, such as accidents; or they simply do not follow traffic rules or ignore warning signs. Poor health or other problems with the physical state of the driver can also cause a traffic accident. For example, significant speeding by the driver caused the bus to fall into the abyss. The incident occurred in Peru on January 3, 2018, on a dangerous stretch of a mountain serpentine. The bus collided with a freight wagon, and due to the fact that both vehicles were moving at an overspeed, the driver lost control and the bus fell down from a height of one hundred meters. According to the police, 48 people died in the accident (Independent, 2018). In 2013, fourteen people were killed and more than 25 injured in a bus crash in Bolivia. According to witness statements, the bus driver fell asleep while driving, causing the bus to crash into an excavator. From the impact, the bus was thrown off the road into a cliff about 50 meters deep (Latin American Herald Tribune, 2013). On October 29, 2020, a tourist bus collided with a truck in a suburb of Shanghai. 4 passengers were injured, and the driver lost his leg. According to the police, the accident occurred due to the fact that the driver was distracted by a mobile phone (Chen, 2020).

Thus, the analysis of the presented cases allows us to conclude that the main causes of accidents involving public transport are technical malfunctions of the vehicle, adverse weather conditions, as well as improper behavior or poor physical condition of the driver. It should be noted, however, that public transport may be involved in an accident due to the fault of other road users. For example, at the end of December 2019, a bus and a truck collided in Brazil. The accident occurred due to the fault of the truck driver, who drove into the oncoming lane in poor visibility conditions. At least six people were killed and 26 injured (Trend, 2019).

The development of a transport security system requires taking into account all of the above reasons in order to achieve a high level of passenger and driver safety.

To improve the level of transport security, various methods are used, including digital technologies, which is due to the widespread digital transformation of all spheres of life. Digital and information technologies are gradually being introduced into various transport systems in different countries. It seems advisable to study several cases where digital technologies were applied to improve the safety of the public transport system.

San Diego partnered with Cisco, Davra Networks, and Intel on an innovative solution that brings new levels of connected intelligence to the transit system. The solution, called the Metropolitan Transit System (MTS) and based on IoT technologies, GPS navigation and analytics systems, provides an edge for the exchange of information in real time between various participants in the transport system. For example, MTS provides passengers with the most up-to-date information about the time of arrival at a particular station, about delays on the way and about cancellations of flights due to unexpected situations through dynamic displays and a mobile application. In addition, MTS plays a significant role in transport security. This solution provides a safe environment for passengers and personnel through enhanced environmental monitoring for potential security threats. In addition, the alert system and real-time data transmission allow you to quickly respond to possible threats and disruptions in the transport network and inform other system participants about this, which can potentially prevent some emergency situations (Cisco, 2017).

In the United States, digital technology is actively used to ensure safety on school buses. For example, more and more 360-degree cameras are being used, which allow drivers to assess the situation outside the bus. This measure is due to the unpredictability of the behavior of children on the road, as well as their lower visibility compared to adults. In addition, GPS tracking and GPS telematics technologies are popular. They are used to track the route of

the bus, its speed, the driver's behavior while driving, etc. Also, pedestrian detection technology is currently being developed using a combination of video cameras, high-sensitivity radars, artificial intelligence and deep learning. This technology will allow at any time and in any weather conditions to detect pedestrians and other obstacles in dangerous blind spots (A&S Adria, 2019).

In 2018, SAP, together with the Ministry of Transport of Azerbaijan and a number of partners, developed a solution to monitor the safe conditions of passenger traffic on intercity bus routes to Baku. The need to implement such a decision was explained by the fact that the safety of movement by public transport was one of the most pressing problems of the Republic of Azerbaijan. It was found that the main reason for frequent accidents involving shuttle buses was the carelessness and inattention of drivers. To solve this problem, a solution was proposed which allows dispatchers to monitor, manage and analyze bus routes in real time. IoT technologies allow real-time monitoring of such parameters as the technical condition and conditions in the vehicle interior, as well as biometric indicators of the driver. Machine vision and machine learning technologies provide real-time information on passenger traffic and driver fatigue (Bakutel, 2018).

Another example of the use of digital technologies to ensure the safety of a public transport system is the Skytracking Transport Security (STTS) system developed in Russia. This system is designed to continuously monitor the driver's concentration, identify dangerous situations on the road and respond to them in real time. Skytracking Transport Security is based on IoT technology, neurotechnology, machine learning, video analytics and geolocation. With the help of these technologies, STTS allows real-time implementation of a full cycle of collection, analysis, storage, visualization of information about the location of the vehicle, the physical and psycho-emotional state of the driver, the technical condition of the vehicle (Tadviser, 2019).

The considered cases allow us to conclude about the importance of transport security, in connection with which it seems appropriate to develop a system for its management.

The creation of a public transport safety management model will be based on the architectural approach. The architectural approach, due to its consistency, enables researchers to create a holistic view of the activity in question, to take into account all the relationships and interactions of elements (Ilin et al., 2021). Thus, the constructed architectural model will reflect the integration of information technologies and digital tools into transport processes, which will make it possible to effectively manage this system in the future.

There are several basic standards and methods for building an enterprise architecture, however, in this study, the TOGAF framework was applied. TOGAF (The Open Group Architecture Framework) is the most widespread and recognized framework in the world. To describe a holistic architecture, TOGAF assumes its division into several layers: business architecture, application architecture and technology architecture (Levina et al., 2019). This framework is flexible and can be adapted for various modeling purposes. The architecture visualization was performed using the open and independent enterprise architecture modeling language ArchiMate.

3. Results

Despite the fact that public transport is considered safer than other modes of transport, various types of accidents still occur. At the same time, according to statistics from different countries, buses are most often involved in accidents. Also, bus accidents kill significantly more people than other types of public transport. In this regard, it seems appropriate to consider some of the serious bus accidents that have occurred in recent years in various regions of the world in order to study the main causes of their occurrence.

Before embarking on the formation of the architecture of a public transport safety management system, it is necessary to determine which factors mainly affect the level of transport safety.

Based on the analysis of cases on the causes of accidents with public transport, the main factors affecting transport safety were identified. They can be divided into four groups:

- the psychological and emotional state of the driver (drowsiness, exposure to alcohol or drugs, a state of anger);
- behavior and attitude towards driving (non-compliance with the speed limit, driving at a red light, ignoring traffic signs, refusing to use a seat belt, using a mobile phone);
- the condition of the equipment in the vehicle (condition of the braking and anti-lock braking system, engine, passive safety equipment (seat belt, airbag));

- the surrounding situation (weather conditions (snow, fog, heavy rain), the state of the road infrastructure, the situation on the road, the conditions in the vehicle (noise, vibration, temperature, CO_2 level)).

Accordingly, in order to ensure safety in public transport, it is necessary to control these factors, and in order to carry out control, first of all, the collection of data about the driver, the state of the vehicle, as well as the state and conditions of the environment must be established. The analysis of the presented cases showed that in such projects, technologies and tools of the Internet of Things are used to implement data collection (Levina et al., 2018). Based on this experience, we also suggest using these technologies.

To collect data on the driver's condition, it is proposed to use smart wearable devices (smart clothes, smart watches, fitness bracelets, etc.) that will give the ability to control the driver's pulse, respiratory rate, temperature, pressure, body position and other biometric indicators. However, it should be noted that at the moment there is no proven methodology for analyzing a person's biometric indicators, on the basis of which one could confidently conclude that he is in one or another state. Therefore, the technology for collecting biometric indicators is advisable to be used in conjunction with video analysis technologies. To do this, it is proposed to install a high-resolution camera with infrared illumination in front of the driver, which will record video clips and transmit them to a special system for analysis. The obtained biometric and video data will allow determining:

- dangerous conditions of the driver, such as fatigue, drowsiness, distraction of attention;
- changes in the emotional and mental state;
- dangerous position of the driver's body while driving (turning the head back, tilting the head and trunk).

Collecting vehicle data involves collecting several types of data, and therefore several different devices must be used. First of all, sensors for monitoring the main technical systems of the vehicle are needed, which will allow monitoring their serviceability. A number of sensors are also required to monitor the conditions in the cabin, for example: temperature and humidity sensor, CO_2 sensor, noise sensor, vibration sensor. It is also important to track the vehicle's location and speed, which can be done using GPS sensors. Among other things, it is always necessary to keep an eye on the traffic situation in which the vehicle is located. In this regard, it is proposed to use CCTV cameras to track the situation on the road, as well as sensors for fixing a dangerous approach. The data received from all the listed devices will allow:

- track the location of the vehicle, as well as compliance with the route and schedule;
- register dangerous driving style (speeding, sudden braking, sharp acceleration, sharp turns);
- monitor compliance with a safe distance and warn of a possible forward collision;
- monitor the interior of the vehicle (temperature, humidity, CO_2 level, vibration and noise).

Sensors that record data on the state of the environment are necessary in order to record weather conditions (air temperature, air humidity, precipitation) and road situations (traffic and emergency situations). This data will allow drivers to adjust some of the ride parameters (route, speed limit, etc.) for a safer ride. It should be noted that some of the environmental data may come from external sources rather than being collected by our own sensors (for example, weather data may come from the local meteorological office).

It is also recommended to collect data on passenger traffic. This does not directly ensure safety, but the data obtained can be useful in case of a dangerous situation: for example, in the event of an accident, the dispatcher, based on the data on the number of passengers, will send the required number of rescuers and doctors to the scene. It is proposed to use video cameras to collect information about passenger traffic. To reduce the amount of data to be recorded, it is recommended to configure so that recording is made only when the vehicle doors are open.

The data received from IoT devices should be centrally transmitted for analysis and processing to the corresponding modules of a single information platform. Video data requires preliminary processing in a special intelligent video analysis system, which, using machine vision and machine learning technologies, will analyze the received video materials and convert them into a data format that is available for other information modules.

To achieve full information support of the public transport security system, it is proposed to use several information modules: transportation management module, worker safety module and predictive maintenance and

service module. The functionality of these modules will be integrated into a single interface, using which the dispatcher will be able to manage various aspects of the public transport security system.

The entire public transport security system can be roughly divided into several main functional subsystems:

- security management and monitoring;
- analytical activities;
- master data management.

All subsystems have a certain set of functions, respectively, all these functions must have information support. A set of basic requirements for information support of functions of the public transport safety system is presented in Table 1.

Table 1. Requirements for information support of functions of the public transport security system.

Functional subsystems of the public transport security system	Functions of the public transport security system	Requirements for information support
Security management and monitoring	Trip planning	Planning a trip for a specific date and time, taking into account the analysis of the weather forecast and the traffic situation on the route
	Trip management	Consolidation of information about all created trips, management of their statuses (start, end or cancel a trip)
	Trip monitoring	Presentation of the current (updatable) location of all vehicles making the trip; providing information about the condition of the driver, vehicle, passenger traffic, etc. when choosing a specific vehicle on the map
Analytical activities	Incident management	Presentation of incidents (for example, related to the state of the driver or vehicle, etc.); creating and managing an incident; providing an opportunity to contact the driver and view confirmation of the incident without going to another page
	Driver activity analysis	Formation of analytical data and reports on the activities of a particular driver in accordance with such parameters as driving style, deviations from the route, fatigue on routes, etc.
	Vehicle condition analysis	Formation of analytical data and reports on the condition and performance of a particular vehicle.
	Route analysis	Formation of analytical data and reports on such parameters as deviations from the route, compliance of the planned time of arrival of the vehicle at the checkpoint with the actual, high-emergency sections of the route.
	Passenger traffic analysis	Formation of analytical data and reports on the compliance of the plan for the number of passengers in the trip with the fact.
Master data management	Driver master data management	Management of master data about drivers, such as facts of road accidents, facts of traffic violations, results of medical examinations, results of trainings, etc.
	Vehicle master data management	Management of master data about the vehicle, such as model and capacity of the vehicle, data on the passage of maintenance, etc.
	Route master data management	Management of master data about the route

It should be noted that of all the listed functions, only incident management, driver activity analysis, vehicle condition analysis and route analysis are directly related to safety. Other factors, of course, also affect the level of safety, but indirectly.

Taking into account all the listed requirements, a model of architecture of a public transport safety management system based on digital technologies was formed. It is shown below in Figure 1.

Fig. 1. Public transport safety management architecture.

The presented architecture model is a reference and can be modified for the features of various transport systems. In addition, this architecture can be implemented separately or integrated into larger systems.

4. Discussion

The proposed architecture for managing the public transport security system, first of all, will allow preventing a significant part of emergency situations through preventive control measures. Assessing the physical condition of the driver will help to avoid human-related accidents. The analysis of the operability of the main systems of the vehicle will allow preventing their sudden failure due to timely diagnosis of problems and execution of service work for fixing any deviations. Analysis of the environment will allow transportation providers to adjust the parameters of the trip in such a way that the risks of accidents would be minimal. In addition, if an emergency does occur, it is possible to quickly respond to it. When one or another event is recorded, an incident is automatically created in the system and the dispatcher is notified. Furthermore, from the same interface, the dispatcher can react to the incident, for example, by contacting the driver or emergency services, or by creating an incident in the system for further analysis.

Implementation of such a public transport safety management system will not only prevent emergencies or significantly reduce the amount of damage incurred directly at the moment but will also allow to strategically develop and improve various aspects of transport security.

For example, the data collected about drivers will enable analysis of their driving habits for safer and more efficient task assignment. In addition, the analysis of data on the behavior of drivers in certain situations will make it

possible to develop more accurate recommendations for development of drivers' personal safety trainings, depending on their previous indicators.

Also, such system will significantly reduce amount of funds that are spent on maintenance, due to constant monitoring of the condition of key vehicle components such as braking system, ABS (anti-lock braking system), engine, lubrication system, etc. Cost savings also come from reduced vehicle downtime.

Thus, such a public transport safety management system has prospects for further development and improvement.

5. Conclusion

Public transport is one of the most important infrastructural elements of modern cities. In recent years, various states have been striving to redirect passenger traffic to public transport in order to unload traffic on the roads, and therefore this mode of transport is gaining more and more priority on the roads (for example, separate dedicated lanes), which means that it is becoming more comfortable and attractive for all categories of citizens. A significant increase in the number of passengers in public transport dictates the need to improve its safety level. In this regard, in this article, a reference model of the architecture for managing a public transport security system was proposed.

This architecture is based on digital technologies and tools that provide information support for all functions of the security system. All elements of the architecture were integrated with each other to ensure the correct functioning of the architecture.

The introduction of this system will reduce the number of accidents involving public transport, which means that the level of safety of drivers, passengers and other road users will significantly increase. In addition, continuous analysis of activities and emerging incidents will allow in the future to improve the level of service and make public transport more comfortable for passengers.

This architecture was formed on the basis of data obtained from the analysis of other projects for the implementation of public transport security systems in different countries, which guarantees its applicability in practice.

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