



Information and Communication Architecture of the Passenger Information System on the Railway Network of the Republic of Croatia

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Abstract. HŽ Infrastructure Ltd is a company in charge of management, maintenance, and building of railway infrastructure which is obliged to provide the user with all relevant information on the departure and arrival of trains and possible delays. There are currently 545 official places (stops and stations) on the Republic of Croatia's railway network. To implementing modern communication solutions in the function of informing passengers, it is essential to make a systematic analysis of the technical-technological ecosystem to connect all the elements and deliver information to passengers. In this paper, an analysis of the current state of telecommunication infrastructure and equipment of all official places on the Republic of Croatia's railway network is made. Based on the analyzed data, the central system's functions, the passenger information system's conceptual architecture, and the way the system communicates with the vehicle are defined. The technical-technological requirements that end users must obtain accurate and real-time information can be implemented according to the phased introduction and upgrade of the system, which is visible in the passenger information system's proposed conceptual architecture in this paper.

Keywords: Informing passengers · Telecommunication infrastructure · Internet of Things · Sensor networks

1 Introduction

List of railways lines in the Republic of Croatia is an integral part of the *Odluke Vlade Republike Hrvatske o razvrstavanju željezničkih pruga* (OG no. 03/14) [1]. According to this, the length of railway network in Republic of Croatia is 2,617 km and the lines are classified into: lines for international transport, lines for regional transport and lines for local transport.

The infrastructure manager in the Republic of Croatia is HŽ Infrastruktura Ltd (HŽI). According to the *Zakonu o sigurnosti i interoperabilnosti željezničkog sustava*, telematics applications for passenger traffic are a functional subsystem of the railway infrastructure, therefore they must ensure the minimum quality of service to passengers [2, 3]. Following the *Commission Regulation (EU) on the technical specification for interoperability* (No 454/2011, 1273/2013), the station manager is obliged to provide the user with train departure data at railway stations [4, 5]. In Croatia infrastructure manager acts as station manager, therefore it is the infrastructure manager responsibility to provide mentioned data.

Passenger information systems implemented on the EU railway network are based on modern information and communication (IC) solutions. The passenger information system's architecture is possible to perceive through the elements located at the station, stop or platform, and in the vehicle. The architecture is presented through four levels:

- application center,
- digital solution at the station,
- communication between train and track equipment and
- digital on-board solution.

The application center consists of applications and tools in the dispatch center, control center, ticket sales system, and information center. The digital solution at the station consists of a core network that is the network infrastructure's backbone. At that level, there is a passenger information system and other displayed elements (dispatch station, video surveillance station, ticket sales system, customer service center, and other communication equipment). Communication between the train and the track equipment consists of connection technologies (railway and distribution network) to the train by the track equipment (infrastructure). The train's digital solution consists of communication technologies for connection (LAN and Wi-Fi) of the train to the distribution network and in-vehicle technology (video surveillance and monitoring, passenger counting via sensor technology, Internet access, and other IC services).

Current research in this field represents solutions based on modern IC technologies in a smart city environment [6]. This research aims to design a system based on the concept of the Internet of Things (IoT) to provide real-time and accurate information to the system's user. Mobile applications are increasingly used in the field of providing information to system users [7]. The analysis of mobile applications' use in this study provided data on user expectations according to finding information in the user information system and the functions of the passenger information system. In the field of high-speed rail, system services bring more significant customer satisfaction and help create a socio-economic and balanced society as a whole. The development and application of newer communication networks such as 4G and 5G in the railway system enable networks with higher data and information capacities, leading to the system's more reliable operation [8].

The development and application of the LTE-R network and its introduction into railway systems in the world are shown in Fig. 1. Analysis of the application of different communication networks such as mobile communication system - railway (GSM-R), LTE-R, fifth-generation (5G), IEEE 802.11, and wireless sensor networks (WSN) have

shown their capability in the operation of the Industrial IoT network [9]. In the environment of stations and stops, there is increasing use of WSN networks that can be used in object identification and applications in the environment of artificial intelligence, machine learning, and more [10]. The context of data modeling is essential from the point of view of creating and delivering real-time data to users. Forms of providing information to users are through web and mobile application services that have been increasingly used recently. In this context, it is possible to apply semantic web solutions and ontology [11].

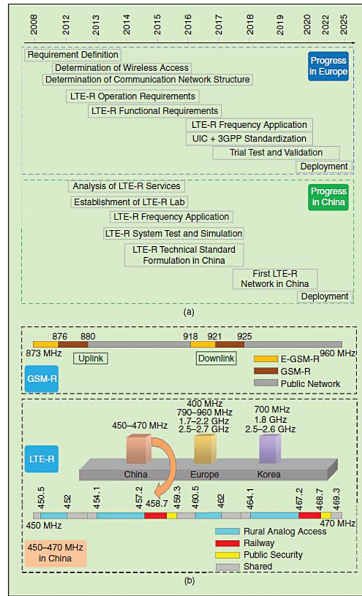


Fig. 1. Communication networks and their application in the railway system [8]

2 Analysis of the Current State of Telecommunication Infrastructure on the Railway Network in the Republic of Croatia

According to official data, there are 545 passenger stations for reception and departure of passengers on the Republic of Croatia’s railway network. Each official place also contains specific technical characteristics: area for reception and departure of passengers, station/stop buildings with or without waiting rooms, the lighting of official places, number and type of tracks, the purpose of tracks, type of safety and signaling system at the railway stations, and communication infrastructure. Type of safety and signaling system are shown in Fig. 2. The figure’s markings are RC – remote control, AB - Automatic block, TWT - two-way traffic, and SI - station interdependence. The communication infrastructure consists of the following elements:

- telecommunications and electronic devices,
- telephone devices and method of registration,
- radio devices,
- teleprinter and fax machines,
- types and manner of use of telecommunication lines
- receipt and dispatch of telegrams
- intercom and public address devices,
- IT devices,
- railway automatic telephone switching office and ways of intermediation, and
- telecommunication and information devices and lines.

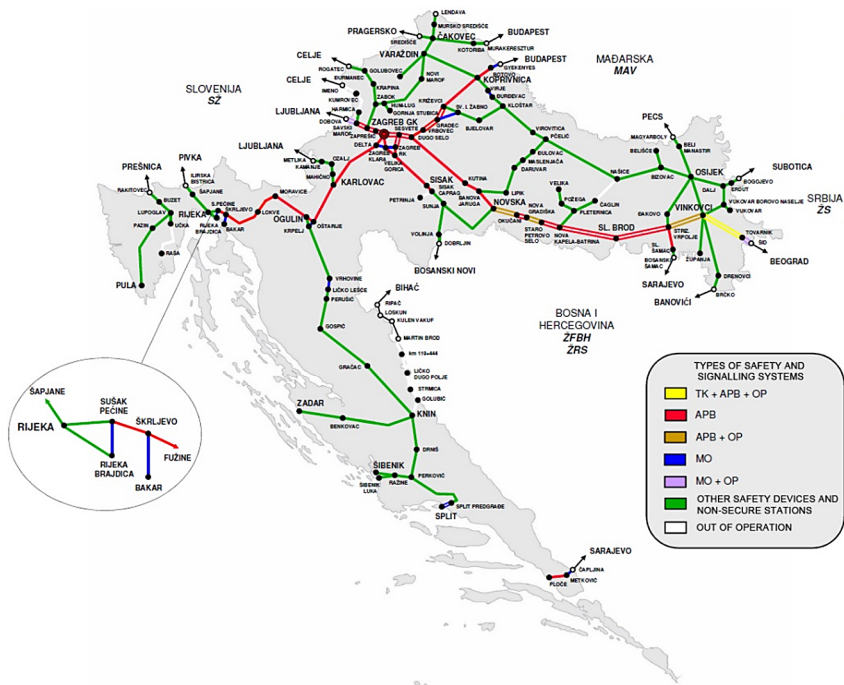


Fig. 2. Types of insurance on the railway network

The research analyzes the state of communication infrastructure for each official place: type of telephone use, type of radio, fax, teleprinter, type and method of using telecommunication lines, method of receiving and sending telegrams, intercom and public address devices, telecommunications devices, IT devices. Part of the analysis is shown in Table 1.

Train traffic, which includes signaling, regulation, reception, and dispatch of trains, and communication related to train traffic on the railway network, is managed by signal-safety devices and telecommunication devices. An overview of the types of telecommunication devices on railways network is shown in Fig. 3.

Table 1. The state of the communication infrastructure [12]

Stations	Telephone devices	Radio devices	Tele. ^a device	Types and method of use telecommunication lines	Receipt of telegram	Interphone and spiker device	IT devices	Telecommunication and information devices
Andrijevci	TT, T, R	RDV	Yes	Business line (PV) - 40-200, 41-200 Guideline - ČV 1, ČV 2 EV, SV, NEV, CDU and disp. line	e-mail	Yes	IST terminal	ŽAT-35961, ŽAT-35960, ŽAT-35969, ŽAT-35965, ŽAT-35966 (035)277-100 do 277-999
Bakar	T, R	UHF	No	PV-vod 40212 ČV-vod SV-vod	Telephone	No	IST terminal	ŽAT-54 470-478

(continued)

Table 1. (continued)

Stations	Telephone devices	Radio devices	Tele. ^a device	Types and method of use telecommunication lines	Receipt of telegram	Interphone and spiker device	IT devices	Telecommunication and information devices
Banova jaruga	T, inductor	Motorola Radio GP 300	No	DV - Zagreb - Novska 300-200 PV - Novska - Zagreb, 40-200,41-200,42-200 PV - Banova Jaruga - Virovitica 40-270 APB vod Lipovljani - Banova Jaruga - Kutina 60-200 SV Lipovljani - Banova Jaruga-Kutina 90-200 SV Banova Jaruga - Lipik 90-270 KV line	e-mail	Yes	IST terminal	Inductor 30-200, 40-200, 41-200, 42-200, 40-270, 60-200, 90-200, 90-270 Inductor (second) 40-200, 41-200, 42-200, 40-270 and 90-270 Inductor (signal) 90-200 Automatic ŽAT tel. 44611 Automatic HT tel. 044892 611 Automatic ŽAT tel. 44601 Loudspeaker PC HP Compaq Pro 6305, monitor AOC LED E 2360P PC HP Compaq Pro 6305, monitor AOC LED E 2260P

Tele. ^a device – Teleprinter and telefax devices, TT - Telecommunication table, T – Telephone, R - Registrophe

The radio dispatching (RD) system represents a radio dispatching system, while some of the stations use the UHF - radio network. On lines where station staff have visual control of the condition of station spatial sections, permits (approvals) and deregistrations are given to signaling and safety devices operated by station staff. In contrast, on lines without visual control of station spatial sections' condition, station staff give permits and deregistrations by telecommunications devices (usually by telephone) in a proven manner. There is currently no automatic train protection system on the railway network. Auto-stop device (AS) - INDUSI (I60) is in use. The AS device is used to control the movement of trains on the track. According to the way it works, it belongs to the group of devices for controlling the movement of trains at one point, the so-called punctual system. The purpose of the AS device is to increase safety in railway traffic when the driver does not notice or does not take appropriate measures to reduce speed in front of the signal sign "Limited speed" or stop the train in front of the signal sign "Stop".

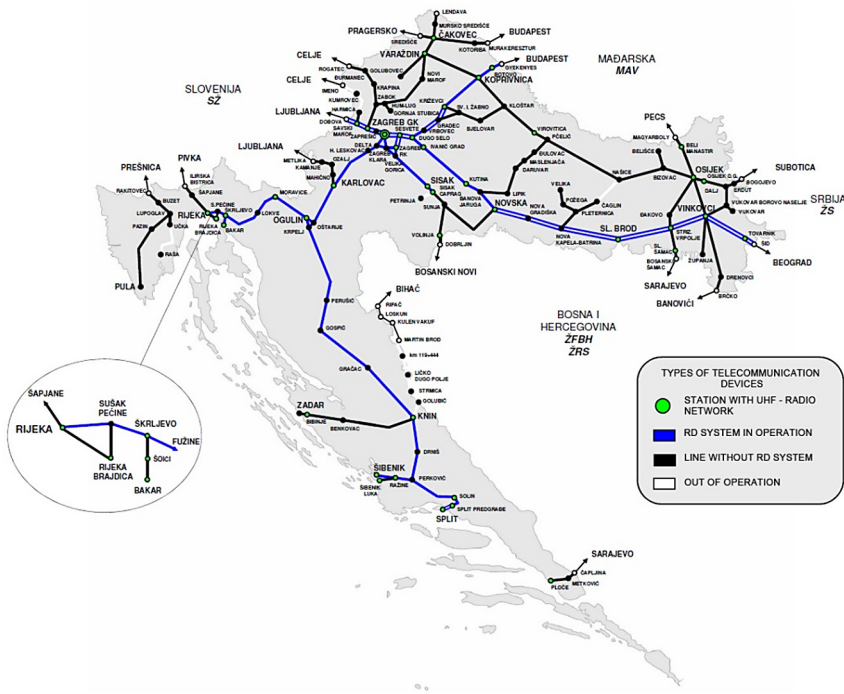


Fig. 3. Types of the telecommunication devices on railways network

According to official data, 124 stations and 132 stops are equipped with systems to provide visual information to users. Dynamic passenger information is provided via a screen at six stations. The current systems for providing information to passengers on the railway network managed by HŽI are EXOR and EK GIP-1.

IC infrastructure equipment analysis for each official position was made according to the assessment of the condition and existence of:

- passenger information systems with info boards, loudspeakers, clocks, and the manufacturer,
- cable sewers,
- concentration and connection of the official place with the railway cable,
- on-site electricity connection,
- possible components of the passenger information system.

Part of the conducted analysis is shown in Table 2. The analysis was made for all official positions (545 of them).

Table 2. Analysis of the current state of telecommunication infrastructure [12]

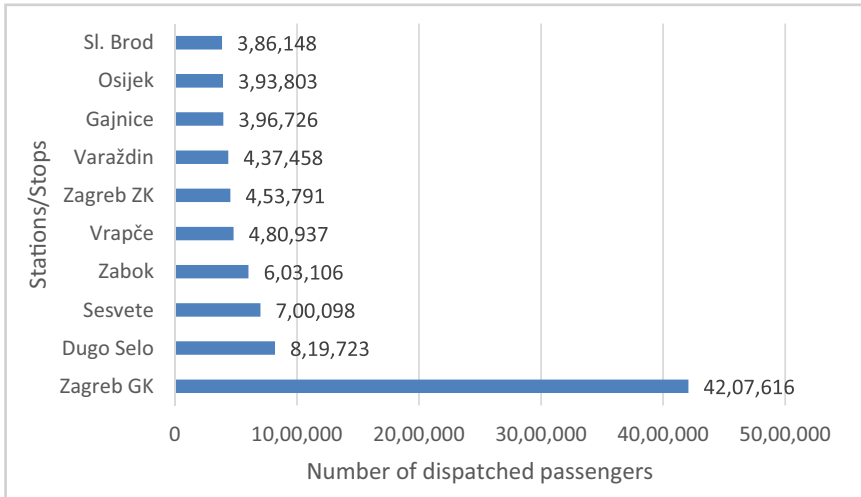
OP	Official place name	Status	Main stations	KM	Existing PIS	Cable canalization	Connection with official places (railway cable)	Rail cable available	Electro energetic cable
M101	DG- Savski Marof - Zagreb GK								
	Savski Marof	Main. station		446+116	no	no	yes/ STKA	1971/ good/ 5	yes
	Brdovec	Station	Savski Marof	443+800	no	no	no	nd	yes
	Zaprešić-Savska	Station	Zaprešić	441+500	no	no	no	nd	yes
	Zaprešić	Main. station		439+549	no	no	yes/ STKA	1971/ good/ 5	yes
	Podsused Stajalište	Station	Zaprešić	435+800	no	no	yes/ STKA	1971 /bed/ 1	yes
	Podsused Tvornica	Main. station		433+021	no	no	yes/ STKA	1971/ good/ 5	yes
	Gajnice	Station	Zagreb Zap.Kol	432+879	no	no	no	nd	yes
	Vrapče	Station	Zagreb Zap.Kol	431+061	no	no	yes/ STKA	1971/ bad/ 1	yes
	Kustošija	Station	Zagreb Zap.Kol	428+840	no	no	no	nd	yes
	Zagreb Zapadni Kol.	Main. station		427+584	no	yes	yes/ STKA	1971/ good/ 5	yes
	Zagreb Glavni Kol.	Main. station		424+500	EXOR/ 2002	yes	yes/ STKA	1971/ good/ 5	yes

PIS – passenger information systems, nd – No data available

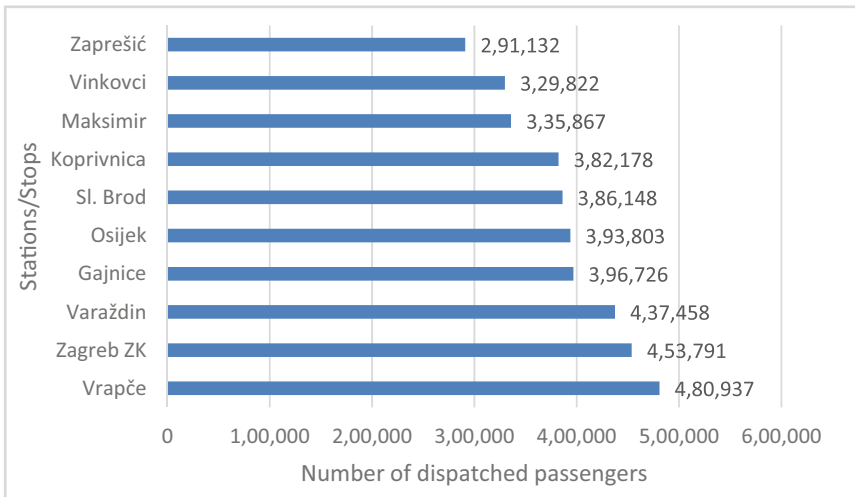
3 Analysis of Transport Demand on the Railway Network of the Republic of Croatia

The analysis of transport demand on the Republic of Croatia’s railway network includes passengers dispatched by long-distance, local and suburban trains based on available data (2019). An analysis of dispatched passengers by train traffic routes was made, separately for long-distance trains and local and suburban trains. The analysis showed that passengers from 498 stations and stops were dispatched in long-distance, local and

suburban trains. The total number of dispatched passengers in these types of trains is 19,799,362 passengers during the 2018/2019 timetable period (TP). In the Republic of Croatia, most passengers depart from Zagreb GK station, which is expected given that most passenger trains start or end their journey at Zagreb GK station. Apart from Zagreb GK, among the first ten stations with the largest number of dispatched passengers are the stations and stops that are part of the Zagreb city-suburban traffic shown in Graph 1.



Graph 1. Stations with the highest number of dispatched passengers during 2018/2019 TP [12]



Graph 2. Top 10 stations with between 100,000 and 500,000 dispatched passengers [12]

On the Republic of Croatia's railway network, 355 passenger station dispatched between 1,000 and 100,000 passengers (Graph 2), while 66 official places dispatched less than 1,000 passengers during the 2018/2019 TP.

It is a devastating fact that 41 official places did not dispatch a single passenger based on the conducted analysis. Twenty-nine official places dispatched between 50,000 and 100,000 passengers, meaning 326 stations and stops dispatched between 1,000 and 50,000 passengers. 404 official places dispatched 4.2 million passengers, approximately equal to the number of dispatched passengers from Zagreb GK station in 2019.

A total of 1,813,083 passengers were dispatched in long-distance transport during 2018/2019 TP (Table 3).

Table 3. Passengers dispatched in long-distance transport [12]

Traffic relation	Trains per day		Number of passengers per year
Zagreb – Koprivnica GR	2		56,127
Tovarnik – Zagreb GK	4		169,290
Rijeka – Šapjane	4		31,466
Split – Zagreb GK	8		125,185
Osijek – Zagreb	4		298,569
Rijeka – Zagreb	1		4,130
Osijek – Rijeka	2		216,356
Vinkovci – Zagreb	10		696,109
Požega – Zagreb	2		8,561
Zagreb – Varaždin	2		131,778
Virovitica – Zagreb	1		37,790
Križevci – Virovitica	1		9,219
Zagreb – Bjelovar	1		24,993
Pula – Rakitovec	4		3,510
		Total:	1,813,083

The smallest number of trains was sent between Pula and Rakitovac, where trains do not run all year round. The average occupancy of long-distance trains for TP 2018/2019 is 52%, depending on the time of the year.

4 Proposal of the Conceptual Architecture of the Passenger Information System

For the passenger information system's reliable and efficient operation, the following subsystems are needed: automatic train control (ATC), automatic resolution of incident situations, timetable monitoring, ticket sales, and maintenance. According to the current

Network Status Report 2021, it can be seen that there is no ATC system [13]. The passenger information system needs to be integrated as a subsystem or module of the future operational management and traffic control center, which is a prerequisite for developing a system that will enable fully automatic traffic management.

The operational management center’s goal is to achieve organization and greater efficiency of executive staff, regular traffic, reduction of train delays, more straightforward elimination of traffic disruptions, and providing information to system users. The operations center scheme is shown in Fig. 4, and the possible interaction with the passenger information system.

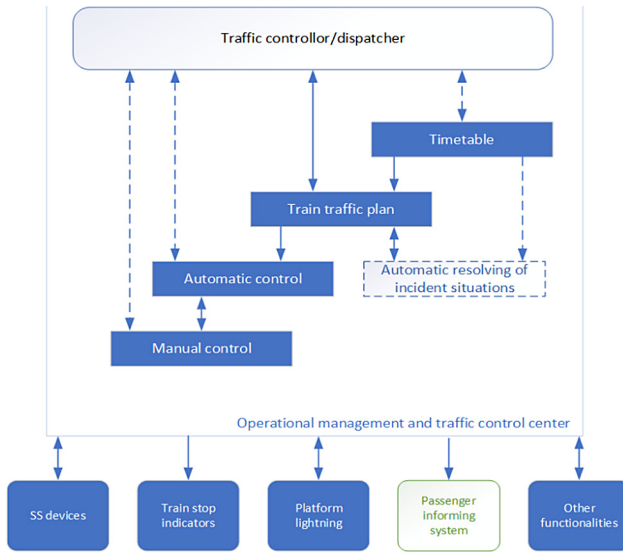


Fig. 4. Scheme of the operational management and traffic control center

Operational management and traffic control center consist of:

- system server (communication server, web server) and
- computer programs and applications to inform users.

According to the above, this includes and implies hardware equipment and devices (servers, personal computers, active and passive network equipment, etc.) and software components necessary for the passenger information system’s operation. The system’s operation’s primary platforms include the most common operating systems such as Microsoft Windows, Linux, and operating systems for mobile devices Android, iOS, and Internet browsers for web-based applications (Google Chrome, Mozilla Firefox, etc.).

Modern solutions in this area are based on IoT technologies and sensor networks. The current state of the communication infrastructure on the railway network in the Republic of Croatia can lead to high initial costs of implementation and the complexity

of integrating new systems. The advantages and opportunities that technologies, such as Cloud Computing and IoT, and modern communication and sensor networks can provide in the environment of railway infrastructure management are shown in Fig. 5. Such an approach creates a smart infrastructure within the railway system.

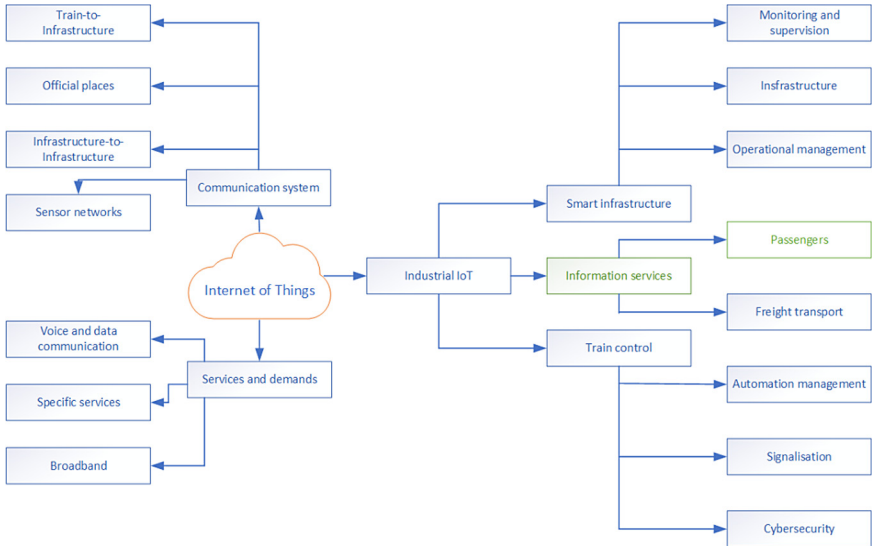


Fig. 5. Possibilities of IoT technology in the process of railway infrastructure management

The application of communication systems in railways can be divided into three functional groups: safety, management and user-oriented networks. The most common communication technologies [14]:

- train to infrastructure - GSM-R ili IEEE 802.11, LTE-R,
- Trans European Trunked Radio (TETRA),
- Dedicated Short-Range Communications (DSRC),
- Ultra-wideband (UWB) - IEEE 802.15.4a,
- IEEE 802.11p,
- Machine-to-Machine (M2M),
- Human-Machine Interface (HMI),
- WSN,
- Ultra-High Frequency (UHF) RFID,
- Visible Light Communication (VLC),
- 3G, LTE, 5G,
- GPS.

The passenger information system is an integral part of the operational management and traffic control center. All data necessary for users' real-time information and the possibility of pre-trip information must be part of a central database. Based on the collected

and analyzed all relevant data needed to define the central passenger information system's functions and elements, the conceptual architecture of the system was proposed. The conceptual architecture of the system is based on the concept of Cloud Computing and IoT sensor technology. It is an integral part of the system's central units (servers) in the operational management and traffic control center (Fig. 6).

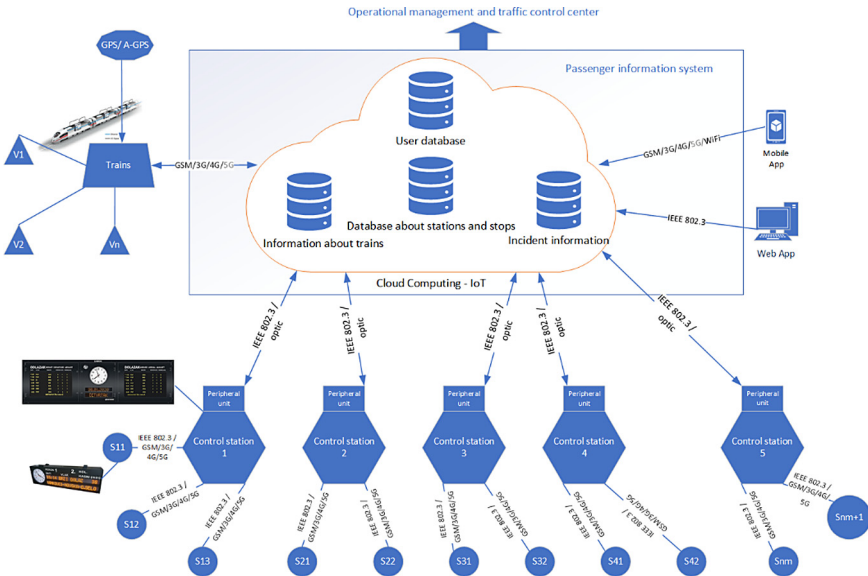


Fig. 6. Proposed conceptual architecture of passenger information system

All the data needed to inform users is in the Cloud Computing environment. Services provided via screens on official sites, web and mobile solutions can be tailored to user requirements. This option applies to people with disabilities who require adaptation of the content depending on the degree and type of damage.

Databases that are an integral part of the architecture contain data on trains, official places, and incident information. All relevant data are processed and included in appropriate applications depending on the purpose for:

- trip computers,
- information screens,
- computer applications for traffic monitoring and management,
- various web interfaces and mobile applications as well
- web servers.

Communication modes can be performed in several ways:

- as continuous real-time communication between trains and central system units (servers) during which information on the train's current status (position, status, occupancy, etc.) or other peripheral units of the system is continuously exchanged,
- as a continuous communication between information screens at stops/stations and central units of the system which exchanges all necessary data that will be displayed on information screens at stops (time until the arrival of an individual vehicle at the stop, deviations, etc.), but also the status of the information screen itself at the stop (automatic fault reporting, etc.),
- as occasional communication between the central units of the system, and trains and information screens at stations, which send various textual and/or voice notices and information on the traffic situation, intended for traffic staff or passengers,
- as an occasional communication between the central and peripheral units of the system which sends all the necessary data for the operation of the peripheral units (timetable, etc.).

In this way, the following functionalities would be enabled:

- supplying trains with all the necessary information in the shortest possible time, regardless of their current location,
- timely sending of changes in the timetables of trains in traffic, i.e., changes in the mode of traffic on the routes of individual lines (shortening, rerouting, etc.) and
- timely informing passengers on trains and at railway stations and stops about the current traffic situation or other events necessary for railway services.

Communication servers serve as a mediator in exchanging data between central and peripheral units of the system in real-time, using different protocols. Data communication should be based on mobile 3G/4G/LTE and 5G technology and wireless and wired technology (IEEE 802.11 and 802.3) in the access segment of the communication network, depending on the capabilities and technical performance of the communication infrastructure.

Web servers allow users to access web-based applications on the local network. Access via the public Internet network is possible if the servers are located in a network segment (demilitarized zone, DMZ), protected by a firewall and appropriate methods of protecting the internal communication network, and connected to an adequate connection to the Internet network.

Traffic controllers' workstations are computers through which traffic controller in the operational management and traffic control center carry out supervision and management of overall traffic entities for which they are responsible. Workstations consist of computers, screens, and voice communication equipment and contain all the necessary computer applications to monitor and manage traffic.

The functions of the central passenger information system can be divided according to the presented architecture:

- user profile management
- activities and measures in case of incident situations
- management of train information and possible delays,
- information management of all official places.

A user database is used to manage user profiles, where all data about the user (passenger) are stored. It consists of information on special user requirements, the possibility of defining pre-trip information, reservation and purchase of tickets, and other facilities. Activities and measures in case of incident situations are related to the operational management and traffic control center. In an incident, the passenger is informed about the possible evacuation and emergency services, police, or fire brigade. The management of information on trains and possible delays of the function connected to the operational manager and traffic control center influences possible routes in traffic accidents or other forms of traffic jams.

It is also possible to integrate with other forms of passenger transport if it is integrated passenger transport. All official places' information comprises information on the monitoring station and all stations under its supervision and management. These places can also be adapted to people with disabilities, so this information needs to be stored. Information on additional facilities and the possibility of connecting with other forms of transport can also be part of this functionality.

5 Conclusion

The development and application of 4G and 5G communication networks in the railway system lead to more reliable system operation. In contrast, WSN networks can be used in object identification in the station and stops environment. There are 545 official places for the reception and departure of passengers on the Republic of Croatia's railway network, while out of that number, 124 stations and 132 stops are equipped with systems for providing visual information to users. Each official place also contains specific technical-technological characteristics, such as communication infrastructure or type of safety and signaling system at the station. The research also analyzed transport demand, which established the devastating fact that 41 official places did not dispatch a single passenger in the observed period.

The condition of the communication infrastructure on the railway network in the Republic of Croatia is not satisfactory. Thus, based on collected and analyzed all relevant data necessary for defining the functions of the elements of the central passenger information system, the conceptual architecture of the system was proposed. This system is an integral part of the operational management and traffic control center and is based on the concept of Cloud Computing and IoT sensor technology. In such a solution, end-users' requests to obtain real-time and accurate information would be considered. Future research will focus on the types of information needed for the transfer and information of passengers and the phases of the introduction of this system of passenger information in the Republic of Croatia.

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