Application of Internet of Things in urban mobility

Dunja Srpak, Josip Srpak
University North
Department of Electrical Engineering
104. brigade 3, Varaždin, Croatia
dsrpak@unin.hr; jsrpak@unin.hr

Miljenko Mustapić
University North
Department of Logistics and Sustainable Mobility
Trg dr. Žarka Dolinara 1, Koprivnica, Croatia
mmustapic@unin.hr

***Abstract**. This paper presents the results of research on the integration of Internet of Things (IoT) technologies within smart city initiatives, focusing on mobility solutions in Croatia and selected European urban areas. Through comparative analysis, the study investigates how IoT-based innovations enhance service availability, streamline urban movement, and support the development of sustainable city environments. The findings underscore the value of real-time data, accessible digital platforms, and citizen engagement in developing smarter, more resilient communities.*

Keywords. Internet of Things (IoT), public transport innovation, smart cities, urban mobility

1 Introduction

Smart management of urban entities, popularly called "smart cities," is gaining importance with the accelerating trend of urbanization. At the centre of this transformation is often the Internet of Things (IoT) technology, which enables the connection of different urban systems through a network of devices and sensors. Through the implementation of IoT in sectors such as transport, energy, security, and communal services, energy consumption, the use of public resources, and compliance with Environmental, Social, and Governance (ESG) standards are optimized. This contributes to a more sustainable, efficient, and dynamic urban future, moving towards smarter, greener cities.

The Internet of Things (IoT) is a network of interconnected devices that communicate and exchange data in real time (Srpak et al., 2024). In the context of smart cities, IoT is a key set of technologies that enable the connection and collection of data from a network of sensors and data processing, for intelligent decision-making and efficient city management. In addition, the comfort of living in an urban environment, both for local residents and tourists/visitors, depends on the accessibility of city services. Public transport services come first, followed by information on the availability of sports and cultural content at the current location, in real time.

The application of IoT in urban mobility and traffic management has been widely examined, with particular attention to its benefits, challenges, environmental impact, and improvements in user experience (Vaidian et al., 2019). However, a gap persists in models that would lead to an increase in the use of public transport within urban areas. Therefore, the focus of this paper is on the impact of technological innovation as a tool for sustainable urban mobility and reducing dependence on private cars, through the following research questions:

RQ1: What are the main barriers to implementing IoT-based models for increasing public transport use in urban areas?

RQ2: How can the implementation of IoT technologies affect the motivation of residents to use public transport instead of private cars in urban areas?

The article is organized as follows: after the introduction, the background section provides an overview of the relevant literature, followed by a description of the research methodology. The following section presents a comparative analysis of the application of modern technologies in public transport in several cities in Croatia and Europe. After a discussion of the findings, the corresponding conclusions are drawn at the end.

2 Background

In the future, the majority of the world's population (85% by 2050) is expected to live in cities. This demographic shift will require urban areas to enhance their services and resource management. The rapid advancement of IoT technologies is driving innovation in smart cities, improving system efficiency and quality of life, while also raising important questions about sustainability and environmental impact. Research by Nižetić et al. (2020) highlights both the opportunities and challenges of integrating IoT into urban environments, emphasizing the need for careful assessment to maximize benefits and minimize potential risks.

A study by Rajapaksha et al. (2017) proposed improving urban mobility through the introduction of an integrated iTrip (intelligent travel) framework, which addresses urban sustainability issues by utilizing data generated in cities - such as traffic flow, people mobility, goods distribution, and environmental data collected from various sensors. Smart cities employ monitoring and communication technologies to optimize operations and increase sustainability, with sensors having an essential role. Given the diverse applications of these sensors, a review by Moreno et al. (2021) categorizes their use into six main groups: energy, health, mobility, security, water, and waste management, with a particular emphasis on efforts to create smart cities. A review study by Allwinkle and Cruickshank (2011) first explores what it means for cities to be “smart”, and then offers an alternative path to smarter cities based on a critical and more realistic assessment. Additionally, the book by Coletta et al. (2019) draws on a series of international case studies and proposes social, policy, and practical interventions that recognize the benefits of smart city initiatives while also minimizing some of their potential drawbacks.

The paper by Bellini et al. (2022) provides an overview of the latest literature on IoT-based smart cities, highlighting the main trends and challenges in applying these technologies to develop sustainable and efficient cities. It also analyses the implementation of innovative services and advanced applications for various city stakeholders. In the paper Hurem and Kadrić (2023), present an overview of research on the application of IoT in urban areas, focusing on smart traffic systems, energy management, waste management, air quality monitoring, citizen safety, and related fields. Mobile applications that citizens can use to access information about city services, especially in problematic situations (natural disasters, traffic accidents, public protests...) were also analysed in particular. The study by Apata et al. (2024) highlights how IoT solutions in smart transportation infrastructure and fleet management enable more efficient, safer, and more sustainable transport systems through real-time monitoring and data-driven management. The authors emphasize the importance of integrating IoT into existing transportation systems, addressing data security and privacy issues, and fostering innovation, while recommending that future research analyse the long-term effects of IoT on preventive maintenance and real-time data processing.

Several articles, such as Hancke et al. (2013), address the challenges of increasing traffic congestion, pollution, and traffic accidents that accompany the rising number of vehicles in urban areas, and propose intelligent solutions for mobility and traffic control. Other studies focus on efforts to enhance pedestrian safety as a crucial aspect of improving urban mobility (Hussein et al., 2016). The IoT significantly improves transportation by automating processes and increasing both safety and efficiency; however, it is essential to address security and integration challenges with existing infrastructure. Application examples such as smart traffic lights, autonomous vehicles, and cargo monitoring systems demonstrate the considerable potential of this technology, as highlighted by Ziuziun and Parasiuk (2024).

From the other side, research by Belli et al. (2020) points out that discussions about smart cities often concentrate too heavily on technological and technical aspects, while the needs of citizens are sometimes overlooked. The IoT paradigm includes multiple scenarios and contexts, through a series of connected devices that collaborate to adapt the physical world to a changing environment.

Scientific research regarding the concept of smart cities, i.e. various technological and social innovations to improve urban life, predominantly focuses on urban mobility as a key subset, particularly regarding traffic and movement within cities. In these discussions, public transportation consistently emerges as a primary topic. Public transport users in all cities report varying levels of satisfaction with factors such as station accessibility, service frequency, and transfer options. Additionally, the availability of digital services for obtaining information or purchasing tickets has become an important factor influencing the overall user experience in public transport systems.

The primary motivation for this research was the identified lack of an effective model to encourage greater use of public transport among citizens. Given the interdisciplinary nature of the topic, the research team included experts in electrical engineering as well as logistics and transport sciences. This approach is essential for a comprehensive analysis of the challenges and potential solutions related to public transport usage. The paper presents initial comparisons of personal experiences within smaller groups, using examples of good practice from several EU cities. These findings can serve as a valuable foundation for future research on a larger scale, such as more systematic studies involving detailed surveys in multiple cities, carried out in partnership with city authorities and public transport providers.

3 Methodology

Relevant insight into the research area, (specifically, the connection between modern technologies and smart cities, particularly in the context of urban mobility) was obtained by searching the Web of Science platform and the Scopus database. At the same time, gaps were identified in the field of research, especially regarding the application of IoT to user experiences in public city transportation, as outlined in the introduction.

To encourage the wider implementation of IoT technology in the future, it is necessary to analyze the current situation and practices in different Croatian cities (both smaller and larger ones) and compare them with advanced systems in more developed European countries. Due to the impact of disruptions (such as traffic accidents, weather conditions, protest marches, the passage of extraordinary cargo, VIP movements, etc.), changes to timetables should be updated in real time and communicated to users.

Through a case study conducted in several Croatian and European cities, different methods of organizing public transport systems were compared, with an emphasis on possible ways for users to access up-to-date information. Finally, the summary identifies the factors that influence the dynamics of implementing modern technologies and the actions worth taking to encourage the use of public transport over private cars in city centres.

4 Application of modern technologies in public transport

This section presents a comparative analysis of the application of modern technologies in public transport in Croatia and Europe. Among Croatian cities, the public transport systems in the author's hometowns (Varaždin and Koprivnica) and Zagreb, the largest city and capital of Croatia, are compared in more detail. The analysis of the public transport situation in several European cities is also summarized based on the experience of the authors and the people close to them (rather than on a public survey).

4.1 Public transport in Varaždin

Varaždin is connected to other places and cities in Croatia and Europe by trains or buses, although passengers use buses more often than trains, mainly due to better timetables and shorter travel times. However, attempts to organize a functional public bus transport within the city of Varaždin have been failing for a number of years, especially in an economically sustainable way. Without majority public funding of municipal passenger transport, it is not possible to maintain lines on which buses run almost empty. Varaždin currently has five bus lines that complete a circuit through part of the city and suburban. They meet only in the city centre, and some lines touch or intersect at some other stations, as shown in Fig. 1 (Gradski-buseki, n.d.-a).

Although the bus routes are arranged to circulate through several streets, some residents of Varaždin still have a long way to get to the nearest station. On the other hand, this makes some parts of the route faster to cover on foot (by taking a shortcut) than by bus, which circulates in this way. In addition, the lines are not frequent enough to be suitable for going to school or work, so pensioners who have enough time and free tickets mainly use them. For example, (Fig. 2) to get to work in the center of Varaždin at 7:30 am, from suburbs like Zbelava or Kučan Marof, you need to leave a little after 6 am (6:08 - 6:15), line 5 arrives in the center at 6:32 where transfers to other lines are possible (towards the University, hospital, high schools, bus or train station, etc.). The next departure from Kučan Marof is at 7:18 and arrives in the centre at 7:38, which is too late. The distance is about 4 km, which can be reached by car (even during the morning rush hour) in about ten minutes, and on foot in less than an hour. The same situation exists on the other side of the city, line 1 (Hrašćica). Therefore, private cars are still the most common means of transportation in the city, possibly bicycles or scooters, when the weather is nice or on weekends (during free time).

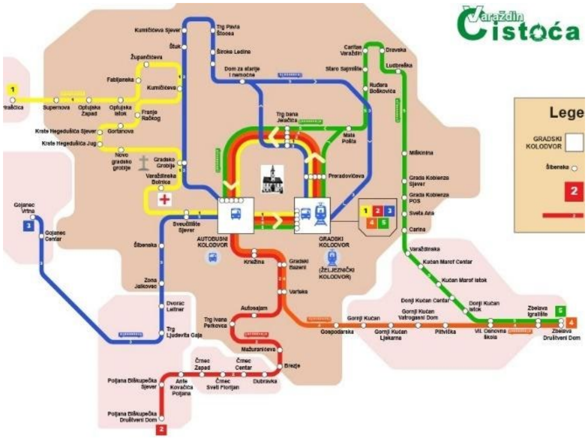

Figure 1. Public transport network in Varaždin

LINE 5 — Zbelava - Donji Kučan - Kućan Marof - Banfca - Bus Station - City Station

No.	St Name / Address of Stop	DEPARTURE TIMES												Possibility of transfer to the line
		M-F	M-S	M-S	M-S	M-S	M-S	M-S	M-F	M-F	M-F	M-F		
1	Zbelava * / Varaždinska ulica 119	5:03	6:08	7:13	8:23	10:28	11:43	12:58	14:43	15:48	16:58	19:48	20:58	
2	Zbelava ** / Varaždinska ulica 65	5:04	6:09	7:14	8:24	10:29	11:44	12:59	14:44	15:49	16:59	19:49	20:59	
3	VII. Osnovna škola / Varaždinska ulica 131	5:05	6:10	7:15	8:25	10:30	11:45	13:00	14:45	15:50	17:00	19:50	21:00	
4	Donji Kučan Istok / Varaždinska ulica 111	5:06	6:11	7:16	8:26	10:31	11:46	13:01	14:46	15:51	17:01	19:51	21:01	
5	Donji Kučan Centar / Varaždinska ulica 73	5:07	6:12	7:17	8:27	10:32	11:47	13:02	14:47	15:52	17:02	19:52	21:02	
6	Kućan Marof Istok / Varaždinska ulica 161	5:08	6:13	7:18	8:28	10:33	11:48	13:03	14:48	15:53	17:03	19:53	21:03	
7	Kućan Marof Centar / Varaždinska ulica 93	5:09	6:14	7:19	8:29	10:34	11:49	13:04	14:49	15:54	17:04	19:54	21:04	
8	Varaždinska / Varaždinska ulica 27	5:10	6:15	7:20	8:30	10:35	11:50	13:05	14:50	15:55	17:05	19:55	21:05	
9	Customs / Ulica Braće Krajanski 18	5:11	6:16	7:21	8:31	10:36	11:51	13:06	14:51	15:56	17:06	19:56	21:06	
10	Sveta Ana *** / Ulica Vilka Novaka 30/A	5:13	6:18	7:23	8:33	10:38	11:53	13:08	14:53	15:58	17:08	19:58	21:08	
11	Grada Koblenza POS / Ul. Grada Koblenza 4	5:14	6:19	7:24	8:34	10:39	11:54	13:09	14:54	15:59	17:09	19:59	21:09	
12	Grada Koblenza **** / Ul. Grada Koblenza 22	5:15	6:20	7:25	8:35	10:40	11:55	13:10	14:55	16:00	17:10	20:00	21:10	
13	Miškinina / Ulica M.P. Miškine 64	5:16	6:21	7:26	8:36	10:41	11:56	13:11	14:56	16:01	17:11	20:01	21:11	
14	Ludbreška / Ispred (Vukovarska 2A)	5:20	6:25	7:30	8:40	10:45	12:00	13:15	15:00	16:05	17:15	20:05	21:15	
15	Dravska / Dravska ulica 30	5:21	6:26	7:31	8:41	10:46	12:01	13:16	15:01	16:06	17:16	20:06	21:16	
16	Caritas Varaždin / Bombelesova cesta 15	5:22	6:27	7:32	8:42	10:47	12:02	13:17	15:02	16:07	17:17	20:07	21:17	
17	Staro Sajmište / Trg Matije Gupca 54	5:23	6:28	7:33	8:43	10:48	12:03	13:18	15:03	16:08	17:18	20:08	21:18	
18	Ruđera Boškovića / Ul. Ruđera Boškovića 21	5:25	6:30	7:35	8:45	10:50	12:05	13:20	15:05	16:10	17:20	20:10	21:20	
19	***** Ulica Ivana Kukuljevića Sakcinskog 35	5:26	6:31	7:36	8:46	10:51	12:06	13:21	15:06	16:11	17:21	20:11	21:21	
20	Trg Bana Jelačića / Trg bana Josipa Jelačića 9	5:27	6:32	7:37	8:47	10:52	12:07	13:22	15:07	16:12	17:22	20:12	21:22	1,2,3,4
21	Bus Station / Kapucinski trg 6	5:31	6:36	7:41	8:51	10:56	12:11	13:26	15:11	16:16	17:26	20:16	21:26	1,2,3,4
22	City Station / Trg kralja Petra Svačića 3	5:35	6:40	7:45	8:55	11:00	12:15	13:30	15:15	16:20	17:30	20:20	21:30	1,2,3,4
1	City Station / Trg kralja Petra Svačića 3	5:40	6:45	7:50	10:00	11:05	12:20	14:15	15:20	16:25	19:00	20:25	22:15	1,2,3,4
2	Preradovićeva / Ulica Petra Preradovića 15	5:43	6:48	7:53	10:03	11:08	12:23	14:18	15:23	16:28	19:03	20:28	22:18	1,2,3,4
3	Mala Pošta / Međimurska ulica 2	5:44	6:49	7:54	10:04	11:09	12:24	14:19	15:24	16:29	19:04	20:29	22:19	
4	Ruđera Boškovića / Ul. Ruđera Boškovića 14a	5:45	6:50	7:55	10:05	11:10	12:25	14:20	15:25	16:30	19:05	20:30	22:20	
5	Staro sajmište / Trg Matije Gupca 54	5:47	6:52	7:57	10:07	11:12	12:27	14:22	15:27	16:32	19:07	20:32	22:22	
6	Caritas Varaždin / Bombelesova cesta 15	5:48	6:53	7:58	10:08	11:13	12:28	14:23	15:28	16:33	19:08	20:33	22:23	
7	Dravska / Dravska ulica 15	5:49	6:54	7:59	10:09	11:14	12:29	14:24	15:29	16:34	19:09	20:34	22:24	
8	Ludbreška / Ludbreška ulica 70	5:50	6:55	8:00	10:10	11:15	12:30	14:25	15:30	16:35	19:10	20:35	22:25	
9	Miškinina / Ulica M.P. Miškine 47	5:54	6:59	8:04	10:14	11:19	12:34	14:29	15:34	16:39	19:14	20:39	22:29	
10	Grada Koblenza **** / Ul. Grada Koblenza 37	5:55	7:00	8:05	10:15	11:20	12:35	14:30	15:35	16:40	19:15	20:40	22:30	
11	Grada Koblenza POS / Ul. Grada Koblenza 1	5:56	7:01	8:06	10:16	11:21	12:36	14:31	15:36	16:41	19:16	20:41	22:31	
12	Sveta Ana *** / Ulica Vilka Novaka 32	5:57	7:02	8:07	10:17	11:22	12:37	14:32	15:37	16:42	19:17	20:42	22:32	
13	Customs / Ulica Braće Krajanski 18	5:59	7:04	8:09	10:19	11:24	12:39	14:34	15:39	16:44	19:19	20:44	22:34	
14	Varaždinska / Varaždinska ulica 30	6:00	7:05	8:10	10:20	11:25	12:40	14:35	15:40	16:45	19:20	20:45	22:35	
15	Kućan Marof Centar / Marofska ulica 1	6:01	7:06	8:11	10:21	11:26	12:41	14:36	15:41	16:46	19:21	20:46	22:36	
16	Kućan Marof Istok / Varaždinska ulica 148	6:02	7:07	8:12	10:22	11:27	12:42	14:37	15:42	16:47	19:22	20:47	22:37	
17	Donji Kučan Centar / Varaždinska ulica 66	6:03	7:08	8:13	10:23	11:28	12:43	14:38	15:43	16:48	19:23	20:48	22:38	
18	Donji Kučan Istok / Varaždinska ulica 106	6:04	7:09	8:14	10:24	11:29	12:44	14:39	15:44	16:49	19:24	20:49	22:39	
19	VII. Osnovna škola / Varaždinska ulica 132	6:05	7:10	8:15	10:25	11:30	12:45	14:40	15:45	16:50	19:25	20:50	22:40	
20	Zbelava ** / Varaždinska ulica 67	6:06	7:11	8:16	10:26	11:31	12:46	14:41	15:46	16:51	19:26	20:51	22:41	
21	Zbelava * / Varaždinska ulica 119	6:07	7:12	8:17	10:27	11:32	12:47	14:42	15:47	16:52	19:27	20:52	22:42	

* Community Center / ** Playground / *** Konzum / **** North / ***** Little Post Office - Bakery Žito / M-F (Monday-Friday) / M-S (Monday-Saturday)

Figure 2. Timetable of public transport line 5 in Varaždin

Regarding the application of modern technologies, the timetable is available on the web and also delivered by mail with the garbage collection bill (since the same company provides both household waste collection and public city transport services). In timetables the arrival time and the addresses of the stops for each line (e.g. at house number 27 or 161) are indicated, while most bus stops have no signs at the location, not even a metal plate with a bus sign, let alone a screen with the arrival time of the next line(s). The timetables for Line 5 is shown as an example in Fig. 2 (Gradski-buseki, n.d.-b). The last column shows at which stops it is possible to transfer to other lines. In addition, the official website of the public transport provider contains a table with a list of stops, geolocation and a link to the location of the stop in Google Maps.

4.2 Public transport in Koprivnica

Koprivnica's connectivity with surrounding towns is similar to that of Varaždin (Hrvatske ceste, 2022.; Feletar, 2016), and lines within the city itself face the same problems. Free public transport by electric buses (BusKo, Fig. 3) was introduced as part of the CIVITAS DYN@MO project (2012-2015), which is largely financed by the European Union's programme for scientific research and development in the context of competitiveness. It aimed to develop the most effective transport sustainability measures based on electromobility and sustainable urban transport planning, and was implemented in four cities: Aachen, Palma de Mallorca, Gdynia and Koprivnica. Line 1 has five stops and the interval between two arrivals (the frequency of arrivals) is more than an hour. as in Varaždin, while line 2 has more stops, but runs only twice a day, from Monday to Saturday.

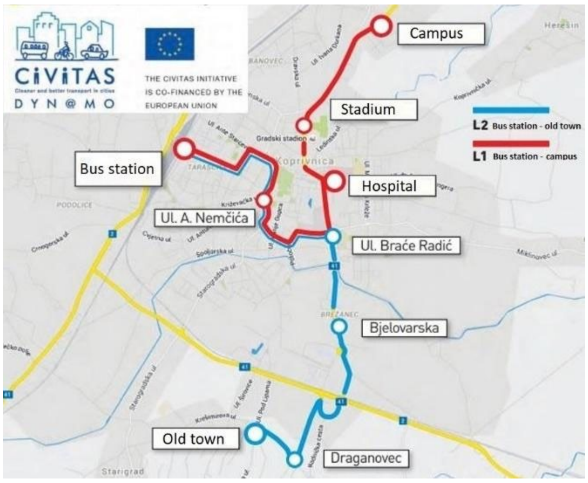

Figure 3. Public transport lines in Koprivnica

These buses can carry 12 passengers, their maximum speed is limited to 90 kilometers per hour, and they have been in operation since 2018. The city of Koprivnica did not have an established public transport system before that, but it is arguable whether the number of daily passengers justifies the predicted vision of this project.

In addition to electric buses, this project also introduced a public bicycle transport system - BicKo, which can be used seven days a week from 6:00 to 22:00 during the season (April - October). Information about available bicycles and stands is available to users at each pylon and on the system's website.

The BicKo system has 70 bicycles (60 regular and 10 electric) available at eight stations throughout the city. Data shows it is a successful project and that the most popular pick up and drop off stations are at the train station and the city market, which means both locals and visitors, have embraced this modern way of getting around. Usage varies throughout the year: in 2022, there were 2,950 rentals, while in 2021 there were 4,380, though that year saw a drop due to construction work at Zrinski Square, which made one terminal harder to reach. Since the system started, there have been over 89,000 rentals, and in 2022, there were 112 active users. Bearing in mind there is a significant increase in new users of 10% each year, this project will continue its success. Currently, more than 1,400 people are registered, and the system is increasingly used by tourists. Figure 4 shows one of the BicKo system stations in Koprivnica, (Podravina, n.d.).

Figure 4. BicKo system station in Koprivnica

When the system was introduced, to start using the bikes, it was first necessary to sign a rental agreement with the BicKo system operator. The user was then issued an Radio Frequency Identification (RFID) card or a one-time bike rental code, which allowed them to unlock an available bike at any BicKo terminal. After a maximum of 120 minutes, the bike had to be returned to the next available terminal. Today, the bike stations are clearly marked and located at key spots in the city, such as the train station, city market, and university campus. At each station, users can check bike availability and station status via the Go2bike website and mobile app, which provide real-time updates on available bikes and free docking spots. This makes it easier to plan trips and ensures a smooth rental experience. The app lets users register, scan a QR code on the bike, and start riding - no paperwork needed.

4.3 Public transport in Zagreb

The company Zagreb Electric Tram (ZET - Zagrebački električni tramvaj) manages public transport in Zagreb. The tram network covers public transport in the city centre of Zagreb, while buses run to the outskirts of the city. An overview of the tram network and stations in the inner city is shown in Fig. 5, (ZET n.d.). Zagreb is a much larger city and significantly more people use public transport than in small towns, such as Varaždin and Koprivnica.

Two mobile applications are available to passengers: "ZET info" and "moj ZET" (my ZET). ZET info contains information on the current status, changes and warnings about the movement of trams and buses, and in the event of works or events (races, protests, accidents, track works). The website also provides a fixed timetable, which is often not relevant due to congestion or road conditions. The ZET info application provides the current status, i.e. the location of all vehicles, detected by their built-in GPRS, with an overview by lines or stations. Also, a fixed timetable is posted at each station, but it is often outdated or worn/faded due to the passage of time and non-renewal. In addition, at certain stations (about 50%, mainly at larger stations) there is a screen with a live display of upcoming trams, which is very reliable, like the ZET info application.

The my ZET application is newer (May 2023), and can be used to purchase tickets for all city zones, including the funicular. Funds need to be transferred into the application in advance, which are deducted from the account when purchasing a ticket (prepaid). When boarding a tram or bus, it is necessary to scan the QR code or Near Field Communication (NFC) tag built into each door using the application (with a mobile phone), which activates the ticket.

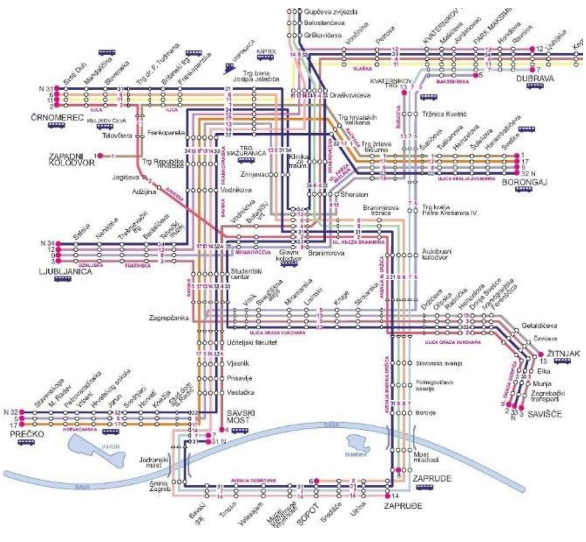

Figure 5. Tramlines overview in Zagreb

Waiting times for trams during the day are usually 10-15 minutes, and for buses are up to 20-30 minutes. For everyday use (going to school or work), it is convenient to use public transport within the city centre of Zagreb. However, for longer distances, if the route has multiple transfers, the journey can be quite long, especially with delays on some lines.

4.4 Experiences with public transport systems from Europe

Many European cities have been using public transport for a long time and have developed many different variants of it, but what they all have in common is the constant improvements trough the integration of new technologies.

In Stuttgart, one of Germany's biggest cities, there is an intricate network of buses, street trams (U-Bahn) and light rail (S-Bahn) spanning tens of kilometres in every direction. Most stops are equipped with screens indicating live updates of arrival times, in addition to the printed schedule. Multiple apps (VVS, DB...) also provide live updates and travel schedule suggestions, which have certain minor limitations and assumptions that can affect the suggestions. For example, when switching between a bus and a light rail, the program assumes that a person takes 5 minutes to travel the distance between those stops. Therefore, a connection within 5 minutes of the bus arrival will not be shown, even though someone running may arrive in 2 minutes. Nevertheless, the apps are absolutely necessary to navigate the public transport system due to frequent construction works and cancellations. Despite occasional issues, the German public transport system is one of the most affordable in the world, thanks to the Deutschland Ticket initiative. That is a monthly ticket that enables unlimited travel on local and regional trains, buses, trams, and the underground across Germany for a set fee.

Figure 6. Screen at the bus stop in Stuttgart with arrival times updated live, recorded on May 26, 2025.

In Copenhagen, the official Danish public transport app DSB offers several options for purchasing a ticket.

It is possible to buy a ticket with a limited duration for a certain number of zones and not think about it any further. However, one can save money by enabling GPS, i.e. allowing access to personal data stored in other apps (such as health-related apps). Furthermore, a person needs to continuously map their journey in the app, marking the change of transport mode (bus, metro, light rail). Exchanging personal data for a discount may seem like a strange choice, but the data collected in this way are used to improve the service in the future. Therefore, the quality and punctuality of the public transport system there is unquestionable.

In Zürich, one can always rely on high punctuality and very detailed updates on any possible issues. Multiple apps (ZVV, SBB) allow passengers to navigate the transport smoothly. Zürich has no metro, and light rail mainly connects suburbs further away, but the buses and trams come frequently and cover the whole city. SBB also has a tracking method by which the app can track the location of the passenger and automatically charge accordingly.

In Stockholm, public transport is organized by bus, tram, and boat. The mobile app allows easy navigation through the different transport options, with a built-in map of the lines included. Using the same app, it is possible to buy a ticket (single, daily, monthly, etc.) to access any form of transport. The waiting time at the station until the next line arrives is comparable to that Zagreb, i.e., the gap between two arrivals of the same line is about ten minutes, during the day.

Cyprus, as an island country, is in the EU, but it is still a bit isolated. It has city buses and intercity buses, and a couple of apps that show a fixed timetable, but they can be confusing to navigate. The waiting time for the next bus is 30-60 minutes, depending on the line. Cyprus is relatively small, so a 30-minute wait for a bus that runs for 1 hour to the other end of the island is acceptable. Apart from these apps, there is no digitalization, and tickets are purchased with cash on the bus.

5 Discussion

By comparing examples of good practice for an efficient and accessible public transport system in some European cities, ideas applicable in Croatia can be obtained. An affordable monthly ticket for a larger area and different modes of transport significantly encourages greater use of public transport and facilitates the payment system, although it is not completely free. The idea is similar to the vignette payment system for motorways, unlimited travel for a fixed monthly amount as in many European countries (Slovenia, Hungary, Slovakia, Czech Republic, Austria), as applied to the Deutschland Ticket.

A prepaid system like the one in Zagreb via the "my ZET" application, if the app is activated when entering a bus or tram, would correspond to the current motorway payment system in Croatia via the Electronic Toll Collection (ENC) system. It is planned to replace the ENC payment system so that vehicles are tracked and charged for exactly the number of kilometers of motorway used in the near future. This requires the installation of stations with cameras that automatically read vehicle license plates at multiple locations, so the existing toll stations on motorways can be removed. Such a system can be applied to track public transport users (via mobile phone applications) and charge accordingly, as in Zurich. This is where the application of new technologies such as IoT comes to the fore.

A good example is also the BicKo system in Koprivnica, created as a free, simple, and accessible way to get around the city, aiming to reduce CO2 emissions and promote sustainable mobility. While it is popular and increasingly used, especially by tourists, its usage still varies by season and there is room for further growth. Key improvements should include expanding the network to nearby municipalities, adding more e-bikes, and better integrating the system with other modes of public transport.

In the process of transitioning towards a smart city, it is essential to consider not only the opportunities and challenges related to smart urban infrastructure, but also how these new developments and the advancement of digitalization can enhance the overall quality of life for citizens. Smarter communities are characterized by active community engagement in adopting new technologies, which are shaped by local and regional social needs and values. In addition, the integration of artificial intelligence (AI) into traffic and resource management is becoming increasingly prevalent. As highlighted by Gheorghe and Soica (2025), AI is most commonly used for advanced data analysis and the prediction of traffic patterns.

To enable effective cooperation between cities, data openness and adherence to common standards are particularly important. However, the widespread adoption of digital technologies such as IoT in everyday life, especially when it involves broader sharing of personal data, introduces significant vulnerabilities, particularly in the areas of cybersecurity and privacy. The risk of cyberattacks and data breaches remains a major concern, as sensitive personal and institutional information may be exposed. It is therefore crucial to implement robust security protocols, raise public awareness, and ensure compliance with data protection regulations to safeguard both individuals and the community as a whole.

6 Conclusion

Based on the analysis of conditions in selected cities in Croatia and Europe, a review of the available literature, and the discussion presented, answers to the research questions have emerged.

RQ1: The main obstacles to implementing IoT-based models in urban public transport are the lack of digital infrastructure, especially in smaller cities, and the fragmentation between different transport providers, which hinders system integration. Additionally, concerns about data privacy and cybersecurity, as well as the need for data standardization, present significant challenges. Limited public awareness and the financial demands of building and maintaining IoT systems further complicate widespread adoption.

RQ2: The implementation of IoT technologies can motivate residents to use public transport instead of private cars by providing real-time information on arrivals, delays, and route changes, thereby increasing convenience and reliability. Integrated digital platforms and mobile apps also make ticketing and multimodal travel simpler and more accessible, enhancing the overall user experience. As public transport becomes more predictable, efficient, and user-friendly through IoT solutions, it becomes a more attractive alternative to private vehicles, helping to reduce congestion and emissions in urban areas.

To maximize the benefits of smart city initiatives, several improvements can be made to urban mobility and digital services:

- Integrated Transport Recommendations:

Link notifications from different transport modes (such as trains, trams, buses, ferries, catamarans, and funiculars), even if they are operated by different providers or fall under different national or local jurisdictions. This would enable seamless, multimodal travel planning and real-time updates for all users.

- Visitor Information Points:

Establish digital information points for visitors who are unfamiliar with the city. These points should provide suggestions for destinations that are accessible on foot or by available means of transport, including tourist attractions, cultural and sports facilities, universities, hospitals, police stations, and other key locations.

- Incentivizing Public Transport Use:

In smaller cities such as Varaždin, Koprivnica, and even Zagreb, motivating the population to use public transport more frequently can be achieved by making it free. This approach has been shown to increase ridership and reduce reliance on private vehicles, contributing to reduced traffic congestion and lower emissions.

- Expanding IoT Applications:

In addition to public transport, urban mobility should be supported by the broader application of the Internet of Things (IoT) across strategic and operational levels. This includes the deployment of intelligent waste containers, smart parking systems, and dynamic travel recommendation systems. Furthermore, cross-city applications targeting tourists and other visitors can be implemented to provide relevant tourist information and facilitate seamless navigation throughout the urban environment.

By addressing these opportunities and challenges, cities can foster smarter, more resilient communities that leverage digital innovation to improve the quality of life for all residents and visitors.

In future research, the goal is to collect, in a systematic manner, additional and varied data from a wider selection of cities, using surveys along with other relevant sources. By expanding the research team to include experts from the social sciences, as well as electrical and traffic engineering, the study will be better positioned to provide deeper analysis of emerging trends, explore innovative solutions, and develop original methodological approaches for improving urban mobility.

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