UNIVERSITY OF LJUBLJANA
SCHOOL OF ECONOMICS AND BUSINESS

MASTER'S THESIS

INCREASING THE SMART CITY RANK OF LJUBLJANA THROUGH DEVELOPMENT OF ITS SMART MOBILITY

Ljubljana, October 2025 MARIIA ZHURAVLEVA

AUTHORSHIP STATEMENT

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LIST OF ABBREVIATIONS

sl. - Slovene; eng. - English

AI - artificial intelligence

AVL - automatic vehicle location

CIMI - Cities In Motion Index

E-bike/-scooter - electric bicycle/scooter

EV - electric vehicle

GHG - greenhouse gas

GPS - global positioning system

HDI - human development index

ICT - information and communications technology

IMD - International Institute for Management Development

IoD - internet of data

IoT - internet of things

IoV - internet of vehicles

ITL - intelligent traffic light

ITS - intelligent transportation system

JP LPT - (sl.) Javno podjetje Ljubljanska parkirišča in tržnice; (eng.) Public company Ljubljana Parking Lots and Markets

LPP - (sl.) Ljubljanski potniški promet; (eng.) Ljubljana public transport company

LUR - Ljubljana urban region

MaaS - mobility as a service

ML - machine learning

MOL - (sl.) Mestna občina Ljubljana; (eng.) Urban Municipality of Ljubljana

NFC - near field communication

P+R - park-and-ride

RDP LUR - Regional Development Programme of the Ljubljana Urban Region

RIS LUR - Regional Innovation Strategy of the Ljubljana Urban Region

RRA LUR - (sl.) Regionalna razvojna agencija Ljubljanske urbane regije; (eng.) Regional Development Agency of the Ljubljana Urban Region

SCI - Smart City Index

SUMP LUR - Sustainable Urban Mobility Plan of the Ljubljana Urban Region

TSP - transport signal priority

VANET - vehicular ad hoc network

VTL - virtual traffic light

WeGO - World Smart Sustainable Cities Organization

1 INTRODUCTION

In times of increasing urbanization, concerns about the negative impact of growing cities have gained considerable attention. Without a doubt, urbanization significantly contributes to economic growth, increased productivity, and disruptive innovation. However, the speed and scale of urbanization bring certain challenges for public safety, health, and transportation. Urbanization's evident impact on energy consumption and CO2 emissions also requires great consideration in the future development of urban regions (Churkina, 2015). Given these factors, the concept of smart cities was introduced to address various problems in urban areas and promote economic growth.

Over time, various smart city ranking systems were introduced to indicate how cities cope with the challenges urbanization brings and as a measure of the citizens' well-being. The ranking also encourages cities to adopt better solutions, foster competition, and guide policymakers in planning smarter urban development. In 2024, the capital city of Slovenia, Ljubljana, was ranked 32nd in the Smart City Index Report prepared by the International Institute for Management Development (IMD), which indicates a relatively good position in smart city development. Nevertheless, the report highlights various areas that require improvement. Mobility appeared to be one of the most problematic areas in Ljubljana, with an emphasis on road congestion, public transport, and air pollution problems (IMD, 2024).

The smart city is a comprehensive notion that includes various aspects of city development. One of these aspects is smart mobility, which implies the integration of modern technologies, data, and innovative solutions to create a more sustainable and efficient transportation system (Brzeziński, 2024). Smart mobility plays a significant role in the development of modern society. It can reduce overall traffic, commute time, environmental pollution, and even the number of road accidents. Successful implementation of smart mobility strongly relies not only on the integration of advanced technologies, but also on the shared efforts of numerous stakeholders such as public administration, private companies, and citizens themselves, as user knowledge and engagement play a crucial role in the acceptance and utilization of smart mobility solutions (Biyik et al., 2021). Commitment to smart mobility development in Ljubljana is evident, as many past and ongoing projects and initiatives have been implemented in this regard. Nonetheless, various statistical analyses and literature suggest that Ljubljana encounters notable issues with regular traffic congestion, declining public transport use, high dependence on private cars, and increasing CO2 emissions. Improvements in the field of mobility will help the city overcome the issues and strengthen Ljubljana's position as a smart city.

The first initiatives towards sustainable mobility in Ljubljana dated back to the late 1990s and early 2000s, with a key milestone being the adoption of the "Vision of Ljubljana 2025" in 2007. The vision implies a strategic plan for sustainable city development, aiming to improve the quality of life in the city and its overall image. Among other areas, the Ljubljana Vision 2025 focuses on improvements in the field of mobility, setting long-term goals for its

development (Koželj, n.d.). Since 2007, Ljubljana has organized and participated in multiple projects related to mobility improvement, conducted at the municipality, state, and even European Union levels. Many initiatives and solutions implemented within the framework of these projects are associated with smart mobility. Ljubljana began focusing on sustainable and smart mobility quite early on, positioning itself as one of the cities to catch the initial wave of the trend. Even though there is no specific period to which the emergence of smart mobility as a concept could be dated, it can be correlated with the advancements in digital technologies in the late 2000s. Leviakangas and Ahonen (2021) state that intelligent mobility systems made their first grand entry in 2005-2010, largely driven by the automotive industry and enabled by different market-ready technologies. Although Ljubljana's early adoption of sustainable and smart mobility initiatives could have secured a privileged position in this field, other cities have since achieved a higher level of advancement.

As the smart city notion is gaining popularity and the number of cities worldwide achieving notable results in this regard rises, it is important for Ljubljana to keep up with the increasing competition in this field. The purpose of this master's thesis is to explore how Ljubljana can leverage smart mobility solutions to enhance its position as a smart city, with a goal of becoming a more modern, sustainable, and attractive place to live in and visit. The thesis's main objective is to define and propose an action plan to enhance the state of smart mobility in Ljubljana, which in turn should improve its smart city rank. Suggested measures that the plan derives are designed to benefit the city dwellers and visitors, and can be used by the local authorities as a guideline for improvements. The thesis contains three main parts: a theoretical part, an overview of Ljubljana as a smart city, and the primary research. Each part contributes to a comprehensive analysis of smart mobility in Ljubljana, which plays an important role in the city's journey toward becoming a more livable and attractive destination. The thesis structure represents a logical progression from theoretical foundations to practical applications and research findings.

The first part is dedicated to an extensive literature review of the smart city and smart mobility concepts. The theoretical framework lays the ground for further analysis and discussion, showing the correlation between the concepts and their main components. The thesis starts with an overview of various smart city definitions, highlighting the broadness of the notion. Then, the six core components of smart cities proposed by Rudolf Giffinger are discussed. One of the components is smart mobility, which is the focus of this master's thesis. Hereby, the link between smart city and smart mobility is shown, and the further progression to the smart mobility concept description is more coherent. Thus, the smart mobility definition and main objectives are discussed next, followed by key technologies and practices that enable smart mobility.

The second part of the thesis contains an analysis of Ljubljana as a smart city with a focus on its smart mobility state. This part is mainly based on official documents and sources such as the municipality website, project plans, company reports, etc. However, personal observations and experience were also considered while assessing mobility in Ljubljana. The

chapter begins with an overview of the city's population and transport statistics, setting a baseline for the analysis. After that, the position of Ljubljana among other smart cities is presented, using the results of a few smart city and smart mobility ranks, in which the city's performance was evaluated. Subsequently, a review of the most relevant smart mobility projects and initiatives was done to understand the city's current mobility landscape and set a foundation for formulating the problems and further suggestions. The chapter concludes with an analysis of the main issues related to mobility in Ljubljana.

The primary research part presents the findings from an online survey conducted among citizens and visitors of Ljubljana, along with a defined action plan for smart mobility enhancement. The chapter starts with a description of the research methodology, followed by a descriptive analysis of the questionnaire results. It then presents a list of suggestions formulated based on the issues identified in the previous chapter and the survey findings, incorporating good practices from around the EU. The online survey was designed to address the following research questions:

- RQ1: What are the current trends in mobility for Ljubljana citizens and visitors?
- RQ2: What are the main mobility challenges for the different modes of transport in Ljubljana?
- RQ3: What enhancements to Ljubljana's current smart mobility solutions would attract more users and improve the overall user experience?

The results of the survey help identify the main pain points in the current state of mobility in Ljubljana, better understand the traveling habits of Ljubljana citizens and visitors, and define the ways to improve the existing smart mobility solutions. All these inputs are crucial for the development of the action plan on Ljubljana's smart mobility state improvement.

The thesis is finalized with a summary of contributions and practical implications of the study, followed by a discussion on the study's limitations and direction for possible future research. In the conclusion, the final reflection on the study and the topic is presented, as well as the summary of the key insights.

2 SMART CITY

In this chapter, the smart city concept is described. This includes an overview of existing smart city definitions, various elements, and aspects of such cities. The content of this chapter is mainly based on scientific literature, including different economic and business articles, journals, and papers.

2.1 Definition of Smart City

The concept of a smart city is relatively new, as it primarily appeared in the early 1990s. However, it was not until 2008 that it was defined within a certain framework. This occurred

primarily due to IBM Corporation launching a series of projects that year, including the Smarter Planet project, which focused on guiding businesses and society as a whole to build a more sustainable future and foster development (Yin et al., 2015). The concept gained considerable attention in the following years as the concerns regarding climate change became more apparent, especially after the Sustainable Development Goals were adopted by the United Nations in 2015. Although many projects are striving to increase the number of smart cities worldwide, the notion of smart city remains quite vague.

In the last decades, the concept of smart cities has also started gaining considerable attention in scientific literature. According to numerous studies on smart cities, the understanding of a smart city's definition and its core components is continuously expanding. In particular, research usually touches on four areas: the technological aspect, including the technological infrastructure and support network for building smart cities, the sociocultural aspect, or citizen engagement, the political-institutional aspect, such as government support and policies, and the economic-business aspect, namely business models and profitability (Zhao et al., 2021).

The technological aspect of smart cities is often considered the core element in describing the term. Various definitions emphasize the use of data, Information and Communications Technologies (hereafter ICT), Internet of Things (hereafter IoT), smart energy devices, logistical applications, et cetera within smart cities. Indeed, smart cities' dependence on technology is evident, and it is inevitable. Technologies help achieve the main purposes of smart cities, which are focused on improving citizens' quality of life, economic welfare, and overall sustainability. Nevertheless, many scientists criticize the excessive focus on technology and extreme dependency on it. For instance, Kunzmann, in his paper "Smart Cities: A New Paradigm of Urban Development" (2014), writes that sooner or later society will not manage to live without ICT-based services, which are central to smart city development, and that the concentration processes, which characterize the global market of smart technologies, are threatening.

As the concept of smart city evolves, scholars increasingly emphasize the integration of social and economic dimensions alongside technology when defining the term. It is important to emphasize that smart cities are not only about technological development, but rather about improvement and overcoming social, environmental, and economic obstacles. Piro et al. (2014) define a smart city as an urban environment that, supported by pervasive ICT systems, can offer advanced and innovative services to citizens to improve the overall quality of their lives. Similarly, Lim et al. (2023) argue that smart cities are cities that can provide considerable benefits, such as high quality of life, social inclusion, economic prosperity, and environmental sustainability through advanced technologies and intelligent infrastructure.

Frequently, smart cities are also described just from the perspective of life standards and sustainability they are associated with, not touching on the technological aspect. In this

regard, a smart city can be defined as a community that systematically promotes the overall well-being of all of its members, and is flexible enough to proactively and sustainably become an increasingly better place to live, work, and play (Lara et. al., 2016). In a similar fashion, Zhao (2011) describes smart cities as cities that improve the quality of life, including ecological, cultural, political, institutional, social, and economic components without leaving a burden on future generations.

Finally, some scientists touch more on the governmental side and the political-institutional aspect when describing smart cities. In this way, a smart city can be defined as a public administration or authority that delivers or aims to deliver a set of new-generation services and infrastructure, based on information and communication technologies (González & Rossi, 2011). Similarly, it can be described as a local community, one where city governments, enterprises, and residents use ICT to reinvent and reinforce the community's role in the new service economy, create jobs locally, and improve the quality of community life (Eger, 2009). Such definitions often refer to the early years of spreading the concept. More recent definitions usually highlight and focus on technology, sustainability, and well-being, which tells us about the shift in perspective through the years when talking about smart cities.

As it is evident from all the examples above, the smart city definition is multidimensional, but it has certain aspects that are often repeated and mixed with each other. It is also fair to say that more recent concept definitions use and blend more features than older definitions, which helps to better characterize smart cities from different points of view. There is still no unique and defined term for this buzzword as the concept continues to evolve. For this thesis, I opted for a broad yet concise and clear definition that highlights the key features distinguishing smart cities, in my opinion. Therefore, I chose the following definition: “A smart city can be defined as an urban area where technology and data collection help improve the quality of life as well as the sustainability and efficiency of city operations” (Jonker & Gomstyn, 2023).

2.2 Components of Smart City

Similar to the wide diversity of definitions, there are numerous ways to describe the smart city components. Many years of research have resulted in a variety of concepts and models existing nowadays. However, the model proposed by R. Giffinger in 2007 is still considered the benchmark and most widely used by both academics and practitioners. Griffinger defines six main smart city components, also referred to as dimensions: Smart Environment, Smart Economy, Smart Governance, Smart People, Smart Living, and Smart Mobility (Giffinger et. al., 2007). The popularity of this model is attributed to the study being more comprehensive than others and the fact that the model covers all the dimensions described by other researchers, combining often overlapping dimensions and elements (Attaran et al., 2022).

2.2.1 Smart Economy

A smart economy implies the strengthening of a city's economy by improving the business environment and its attractiveness for investors and talents to use ICT to grow the economy innovatively (Attaran et al., 2022). A sustainable and smart region offers an ideal environment for innovation and innovative business models. These new models enhance sustainable economic competitiveness while creating links between local and global economic systems. Thus, concepts like sustainable entrepreneurship and the circular economy, for example, perfectly embody this vision and are common in smart environments (Uliège, 2021).

Other factors that contribute to a smart economy are e-commerce and smart selling. E-commerce has seen significant growth worldwide after the outbreak of COVID-19 in 2020. Many companies were forced to shift their business model to sell online, which caused some of them to go bankrupt; however, at the same time, it moved many economies toward being smarter. Smart selling is also very important for a smart economy; it mostly refers to marketing and supply chain organization. For smart selling, data is a crucial component as data analytics help to identify trends and desires of customers, and data-driven decisions help to increase overall sales (Attaran et al., 2022).

In addition, smart tourism and smart agriculture can highly contribute to the smart economy. Smart tourism implies using smartphone-based applications to provide tourism services and easy access to tourist and religious sights, as well as access to smart health facilities for tourists (Nitti et al., 2017). Smart agriculture, in its turn, includes the active use of IoT systems, which help with reducing energy consumption as well as costs associated with the use of manpower (Attaran et al., 2022).

2.2.2 Smart Environment

In general, a smart environment focuses on improving citizens' well-being by addressing the challenges mainly related to climate change, pollution, and resource management. Technologies such as the Internet of Data (IoD) and the Internet of Things (IoT) play a crucial role in developing applications related to the smart environment. For example, IoT sensors are used for optimizing garbage collection, sorting, and recycling. Smart sensors are put in garbage cans, tracks, and recycling plants so that real-time data on urban waste in each area can be shared. Such an approach may not only streamline decision-making in logistics and urban strategy but can also improve citizens' recycling behavior (Perera et al., 2013).

The energy sector is also affected by smart environment solutions. In this regard, smart energy grids are the most prevalent solution. With the help of IoT devices and sensors, they help to optimize the utilization of renewable energy sources based on real-time usage statistics. Smart grids also improve the quality of service and are capable of self-healing (to some extent) in case of severe weather conditions (Appio et al., 2019). While a traditional

grid merely distributes electrical power, a smart grid can generate, communicate, and store its decisions, enhancing the existing grid and enabling cooperative, responsive, and organic functions (Powell et al., 2024).

In agriculture, the use of sensors, drones, and Artificial Intelligence (AI) helps to optimize crop yields and reduce the use of pesticides and fertilizers (Gracias et al., 2023). Pollution levels can also be controlled by IoT applications. Sensors can detect and prevent wildfires, automatically alert about air pollution levels, and improve the prediction, visualization, and simulation of urban pollution (Appio et al., 2019).

Lastly, the development of smart homes and smart buildings, along with connected facility management initiatives, helps to create a better infrastructure in a city (Al-Hader and Rodzi, 2009). Data collected by sensors and meters in smart homes and buildings can be analyzed by AI, which learns about the habits of home dwellers and can, for example, optimize the heating level through connected thermostats; connected cameras improve security; advanced facility management applications monitor and improve electricity, water, sewer, gas systems, and so on. All of this helps to increase the productivity of facility management and reduce accompanying costs (Appio et al., 2019).

2.2.3 Smart Governance

Smart city applications in governance have the potential to evolve city operations, enhancing transparency, accountability, and citizen participation (Gracias et al., 2023). Nilssen (2019) emphasizes that governance is the fundamental building block in fostering effective interactions among all actors involved in smart cities. Smart governance uses technologies that help to process large volumes of data swiftly, thereby improving decision-making processes and delivering better services. Technologies also help to establish a better connection with the citizens and promote democratic engagement (Kaiser, 2024).

E-government is an important component of smart governance. It implies leveraging ICT applications to provide various government services with improved quality and efficiency (Malodia et al., 2021). It changes the traditional administrative management approach and breaks the physical limitations that such management holds. For instance, online platforms for tax management allow users to check and pay off tax debt or submit a tax return form without having to go to the tax office, which means cost and time savings for both parties involved.

2.2.4 Smart People

Technologies and infrastructure play an important role in forming smart cities, but they would be ineffective and unbeneficial without the presence of smart citizens. For stable development and smartening of cities, it is necessary to have educated, proactive, and

creative inhabitants. The concept of smart people entails a requirement for cities to provide good education to equip their residents with sufficient knowledge and skills (Nam & Pardo, 2011). Higher education institutions, such as universities, play a crucial role in developing human capital, which is necessary for creating a social infrastructure of smart cities. These institutions act as knowledge intermediaries, keepers, and providers of activities that help people become smarter (Sharif & Pokharel, 2022).

In the smart city framework, the important characteristic of smart people is a high level of engagement. As per Tonar and Talton (2019), the success of cities greatly depends on the ability of individuals, groups of citizens, and corporate actors to intelligently engage with each other and their environment. Engaged citizens contribute to the decision-making process, providing valuable input and feedback that helps shape policies and initiatives for the prosperity of a city and the improvement of living standards. According to Gupta et. al. (2017), smart people also require high ethical standards, an open mind, and a habit of engaging in public affairs. Open-minded and tolerant communities attract a diverse pool of creative workers, forming the foundation for developing social capital in innovation ecosystems (Appio et al., 2019). Smart people not only adapt to changes and adopt new technologies more easily but also possess the knowledge to create innovative smart solutions, which makes them a valuable human resource in the context of smart cities (Attaran et al., 2022).

2.2.5 Smart Mobility

Smart applications in transportation focus on enhancing mobility, safety, and efficiency on the road. In many cities, traffic congestion is a big problem, which causes delays, road accidents, and increased CO2 emissions. Part of smart mobility solutions is aimed at dealing with this problem. Smart transportation with the approach of urban traffic reduction uses the smart traffic guidance system, which includes software, signs, and human guidance to provide information about street traffic conditions (Soomro et al., 2018).

One of the main goals of smart mobility is to reduce air pollution and the carbon footprint caused by private vehicles and public transport. Traffic control systems and practices already contribute to emissions reduction; however, smart mobility also implies a reduction of the reliance on fossil fuels and a decrease in personal transport use, which positively affects the level of pollution as well. It implies technologies and solutions such as electric vehicles and ridesharing, and additionally, encourages the use of public transportation, cycling, and walking through enhanced infrastructure and services. This diminishes the number of individual car trips, which cuts down greenhouse gas emissions (Attaran et al., 2022). The main technologies, practices, and benefits of smart mobility are further discussed in more detail within the framework of this thesis in a separate chapter.

2.2.6 Smart Living

Smart living highlights one of the main objectives of a smart city, which is the overall improvement of citizens' quality of life. This final dimension analyzes how smart economy, environment, governance, people, and mobility may lead to smart living in modern cities (Appio et al., 2019). It comprises such aspects as healthcare, public safety, the attractiveness of tourism, and all other areas that influence people's well-being.

The smart living dimension represents the culmination of all the preceding components of the smart city. Therefore, it blends together many solutions from different areas. Real-time data coupled with sophisticated algorithms can improve the energy infrastructure, monitor environmental threats, and help public transport (referring to Smart Environment and Mobility); it can also help create value through better collaboration and innovation tools for learning and working (Smart People and Economy) and all of these efforts can be coordinated through centralized Smart Governance tools (Appio et al., 2019). Altogether, it leads to prosperity and improvement of the living standards in smart cities.

3 SMART MOBILITY

In this part of the thesis, the concept of smart mobility is described in more detail. The definition of the term and the key objectives are presented first, followed by the main technologies and practices that are common in this field.

3.1 Definition of Smart Mobility and Its Main Objectives

The number of vehicles as well as residents in cities is rapidly increasing, which puts a lot of pressure on cities' transportation infrastructure. The problem of increasing air pollution is also evident. Both can be addressed by implementing smart mobility solutions, which have become a significant area of research in urban planning (Yigitcanlar & Kamruzzaman, 2020). Similar to the smart city concept, there is no universally accepted definition of smart mobility, as the notion is still relatively new. As per Tomaszewska and Florea's definition (2018), smart mobility implies developing logistic and transport activities using digital smart technologies, the mandatory existence of online databases, and traffic optimization; it aims to reduce the negative effects of mobility, especially pollution, and optimize resource consumption.

Like any extensive concept, smart mobility has several key objectives it primarily strives to achieve. According to Ramos (2021), the main smart mobility objectives are:

- Improving traffic management systems
- Ensuring economic and environmental sustainability
- Enhancing road safety
- Increasing efficiency in communications and travel time
- Offering citizens a new community perspective

These objectives collectively aim to create a transportation ecosystem that is more sustainable, efficient, and user-friendly. Technologies play a crucial role in enhancing smart mobility and helping to achieve these goals. Besides that, the engagement of the citizens, governmental bodies, and other stakeholders is also important to implement new technologies and infrastructure and shift the behavior of users to utilize more modern and sustainable mobility practices (Lampkin et al., 2023).

3.2 Key Technologies and Practices

3.2.1 Big Data and Analytics

Big Data and its analysis are substantial aspects of designing applications and services related to smart mobility infrastructure. Big Data provides the insights and tools needed for smart mobility components to work, which is why it is at the core of most technologies used in this field. However, Big Data makes an impact only when information processing techniques are applied to it so that predictive information and pattern analysis can help in making decisions. The sources that feed data into the large datasets include smartphones, data from social networks, vehicle sensors, GPS and location applications, traffic light sensors, and other road locations, public agencies, connected cars, and camera feeds (Paiva et al., 2021).

Combining Big Data with Artificial Intelligence or Machine Learning tools makes a truly powerful input in creating smart mobility solutions. Such technologies as AI and ML allow automated data analysis, which otherwise can be very complex and time-consuming, reduce the human error factor, and help to make real-time predictions. By collecting and analyzing large datasets on urban mobility, transportation patterns can be detected and studied, which helps, for instance, forecast the demand for transportation and identify peak traffic hours. In its turn, it helps authorities plan public transport roads and schedules and provides the necessary information for various mobile apps, future infrastructure planning, and other intelligent tools used within the framework of smart mobility (Tao et al., 2023).

3.2.2 Smart Sensors and the Internet of Things

Other important technologies related to smart mobility are smart sensors and the IoT. Smart sensors are crucial for collecting real-time data on mobility. Nowadays, a wide variety of smart sensors exists which are used for improving urban mobility, supporting the design and development of many applications primarily for traffic control and safety. Sensors that are located inside the vehicles perform various functions such as diagnostic, safety, traffic monitoring, assistance, environment monitoring, and user monitoring. The number of in-vehicle sensors grows as vehicles become “smarter” and can reach as many as 200 sensors per vehicle (Guerrero-Ibáñez et al., 2018).

The other group of sensors is in-road sensors located either intrusively or non-intrusively on or near the roads. These sensors collect real-time environmental data, which is then analyzed to improve transportation networks and make them resilient. They also help to build new services for drivers, such as smart parking, for instance, showing currently available parking slots. Traffic sensors like Inductive Loop Detectors, radar and infrared sensors, video cameras, ultrasonic sensors, etc., play a very important part in traffic management. The main advantage of road sensors is their technology maturity and accuracy in measurements; however, such sensors usually imply high installation and maintenance costs (Guerrero-Ibáñez et al., 2018).

Smart sensors represent hardware essential for data collection, but they are not as effective without the Internet of Things. IoT connects sensors to a network, allowing data sharing and its complex analysis. The interaction of IoT elements (traffic lights, cameras, etc.) can lead to intelligent management and optimized operations in the transportation system, effectively solving problems such as inefficient transportation, traffic jams, and car accidents, among others; it also enables quicker response to emergencies (Guerrero-Ibáñez et al., 2015). The idea of IoT evolved into the Internet of Vehicles (IoV) concept, which implies a large-scale distributed system for wireless communication and information exchange between vehicles following agreed communication protocols and data interaction standards (Paul et al., 2017).

3.2.3 Electric Vehicles and Renewable Energy Integration

According to recent estimates, the transportation sector accounted for 20.7% of CO2 emissions worldwide in 2022 (Ties, 2024). One of the goals of smart cities and smart mobility in particular is to reduce emissions and promote sustainability. Most of the energy used in the transportation industry is derived from products that are based on fossil fuels, the use of which leads to air pollution and can cause environmental damage when fuels are extracted and transported. Moreover, fossil fuels are finite resources, which rapidly decrease every year. To address these issues, numerous automotive companies are taking measures to produce electric vehicles (EVs), striving to achieve global carbon neutrality and shift to better energy sources (Barman et al., 2023). In 2023, nearly 14 million new electric cars were registered worldwide, bringing their total number on the roads to 40 million (International Energy Agency, 2024). Electric vehicles operate on the fundamental principle of utilizing a battery system to power an electric motor, and after batteries deplete, EVs recharge at special charging stations. Electric vehicles can significantly reduce global warming emissions when charged by a clean electricity grid powered by environmentally sensitive sources. Therefore, to fully realize the benefits of EVs, the energy used for electricity generation must come from renewable sources (Aydogan, 2024).

Renewable energy sources are derived from resources that can be replenished naturally on a human timeline; wind, solar, water, and biomass are all examples of renewable sources that can be used for energy production (Manousakis et al., 2023). Public charging stations based

on renewable energy sources for electric vehicles have begun to emerge worldwide, which helps to enhance the overall efficiency of energy use and reduce energy waste (Aydogan, 2024). Despite the existence of numerous renewable energy sources, the current EV charging technology adopts only solar, wind, and hydropower, but future research on the topic might examine the utilization of other potential sources, such as geothermal, oceanic, or tidal energy. To further optimize the charging process, EV owners can use smart charges, which represent an ecosystem where an EV and a charging device share a standard network alongside a charging operator. Smart charging devices are connected to the cloud, which allows owners to manage, monitor, and restrict the devices' usage to optimize energy distribution (Barman et al., 2023).

3.2.4 Intelligent Transportation Systems

By leveraging technologies such as smart sensors, data analytics, communication networks, and real-time information systems, cities can implement so-called Intelligent Transportation Systems (ITSs), which aim to improve the efficiency, safety, and sustainability of transportation networks. As urbanization accelerates and the demand for efficient transportation grows, ITSs play a crucial role in shaping the future of urban mobility. ITSs are vital for the development of smart cities, as they reduce vehicle idle time, prioritize emergency vehicles, shorten emergency response time, enhance traffic efficiency, prevent unexpected collisions, and lower carbon emissions (Elassy et al., 2024).

Vehicular Ad-hoc Networks (VANETs), Intelligent Traffic Lights (ITLs), Virtual Traffic Lights (VTLs), and Mobility Prediction are key components within the broader framework of ITS. VANETs provide a wireless communication network infrastructure designed to connect devices contained within vehicles to create services that are particularly relevant to a vehicular environment (Lee & Atkison, 2021). The primary goal of VANETs is to improve road safety, traffic management, and driving efficiency by collecting and sharing core information about cars, roads, and surrounding infrastructure (Elassy et al., 2024).

Intelligent Traffic Lights (ITLs) manage traffic movements and increase road safety by using real-time traffic data and efficient traffic scheduling algorithms. ITLs can adjust the timing of traffic lights to ease congestion in heavy traffic. They can also identify bicycles and pedestrians and organize secure road-crossing periods for them. Additionally, ITLs can control traffic in a way that enables emergency vehicles to pass without delays (Elassy et al., 2024). Virtual Traffic Lights (VTLs) represent a different paradigm in traffic management, shifting from traffic signals as road-based infrastructures to traffic signals as in-vehicle virtual signs. While having the same functions as ITLs, VTLs represent a more modern approach and are more adaptive to various traffic situations as they can work without physical infrastructures in place (Ferreira & d'Orey, 2012). Both systems aim to improve traffic management and can potentially complement each other in a comprehensive smart transportation network.

Mobility prediction involves the prediction of vehicle movement patterns inside a transportation network by using various data sources and analytical algorithms. This prediction is supported by historical data, the current flow of traffic, and real-time sensor data from vehicles and the roadside. Mobility prediction can help to reduce traffic congestion, enhance safety on the road, and support the decision-making process for mobility infrastructure and planning. Accurate predictions of mobility patterns are also crucial for optimizing resource allocation (Elassy et al., 2024).

3.2.5 Mobility as a Service and Shared Mobility

In recent years, the concept of Mobility as a Service (MaaS) has gained popularity in cities promoting smart mobility. This is an emerging framework that represents a multimodal, user-focused mobility management system where an integrator combines various travel alternatives through a single digital platform that offers trip planning, booking, ticketing, and payment (Kamargianni et al., 2018). MaaS can change travelers' perceptions of mobility services, influence personal vehicle ownership and usage, and affect daily transportation activity, mode, and route choices (Cisterna et al., 2023). The service introduction aims to reduce private car use and its negative consequences, like traffic congestion and emissions, as well as improve public transport ridership (Ho & Tirachini, 2024).

MaaS not only contributes to a shift from individual car rides to the use of public transport but also promotes shared mobility, another important and recently very popular practice related to smart mobility. MaaS platforms incorporate shared mobility services like carsharing, bike sharing, ridesharing, and scooter sharing. This makes it easier for users to incorporate shared mobility in their daily lives as MaaS streamlines the process of finding, booking, and paying for services. Shared mobility services can enable cost savings, provide convenience for users, and reduce overall vehicle ownership (Narayanan & Antoniou, 2023).

4 LJUBLJANA AS A SMART CITY

This part of the Master's thesis provides an in-depth analysis of Ljubljana as a smart city, focusing on its achievements and initiatives in the field of smart mobility. It begins with an overview of the city's population and transport statistics to better understand the scale and set the ground for the following examination of Ljubljana's position among other smart cities. Then, the analysis of the smart mobility state in Ljubljana is presented with further discussion of past and ongoing projects and solutions in the field. Finally, the chapter addresses the main challenges related to mobility in the city, derived from the secondary sources analysis.

4.1 Ljubljana's Population and Transport Statistics

Ljubljana, the capital and the biggest city of Slovenia, is located in the central part of the country, surrounded by the northern Alpine region, the Dinaric region in the south, and the Adriatic coast to the west. Geographically, the city occupies a strategically important position, serving as a natural crossroads between Central Europe, the Mediterranean, the Balkan Peninsula, and the Pannonian Plain. It also serves as a central hub within the county, connecting regions around it. This makes the city an important transit and destination point for both locals and foreigners, acting as a natural center for business and tourism (ICLEI Europe, n.d.; Data.si; n.d.).

According to the Statistical Office of Slovenia, the City Municipality of Ljubljana (also known as MOL) has 297,575 inhabitants as of the beginning of 2024. Ljubljana is not only part of the municipality but, on a bigger scale, also belongs to the Ljubljana Urban Region (LUR), which encompasses 26 municipalities with a total population of over 500,000 and generates one-third of the Slovenian gross domestic product (Mestna Občina Ljubljana, 2024). The LUR, with the city of Ljubljana as its center, is the most important destination for daily commuting in Slovenia, attracting people from the region and surrounding areas to commute to work and school. The MOL provides over 222,000 jobs, which is more than a quarter of all jobs in the country. Of this, over 120,000 people (55%) commute daily to the MOL from other areas, with around 25% coming from other municipalities within the LUR and 30% from the rest of Slovenia (RRA LUR et al., 2019).

Within the last Representative Survey of Travel Habits in the MOL and the LUR held in 2014, the data on journeys to and within the MOL was evaluated. The study showed that the majority of journeys to the MOL (84.3%) are made by car and only 14.6% by public transport. Within the city, the selection of transport mode is the following: 38.2% of the MOL residents choose cars for their journeys, 37.5% prefer to walk, 13.3% use public transport, and 11% commute by cycling. Short distance allows people to use different modes of commute; however, there is still a high percentage of people who prefer cars for their daily trips, and the percentage of public transport users is quite low. Another survey that was carried out in preparation for the Sustainable Urban Mobility Plan of the LUR in 2018 showed that there is a strong need for the reorganization of public transport in the region and that the capacity of public transport is minimal. The capacity of public rail transport in the morning rush hours (until 9:00) from the outside of the MOL into the MOL was estimated to be around 7,000 passengers, while the capacity of public bus transport in the same period was estimated at 11,000. Even if the capacity were fully utilized, it could only take over a small percentage of daily commuters coming to the MOL by car (RRA LUR et al., 2019).

Buses are the main type of public transport in the city of Ljubljana. The bus network is managed by the public company LPP (Ljubljanski potniški promet), which provides city and intercity bus transport in Ljubljana and its surroundings. According to the company's last available annual report, as of 2024, LPP had a fleet of 281 buses, comprising 214 in city

service and 67 in intercity scheduled traffic. At the end of 2024, the average age of the vehicle fleet increased compared to the end of 2023. There were 38 buses aged over 20 years operating in the fleet in 2024, compared to 23 buses in 2023. The urban scheduled transport was provided on 29 regular lines with a total length of 415.3 km. The intercity scheduled transport was provided on 35 lines with a total length of 760.1 km. In urban regular traffic, the punctuality of departures from initial stops was 88.0%, and from intermediate stops, 73.6%. The punctuality of departures from final and intermediate stops has decreased compared to 2023. For the intercity buses, the accuracy of departures from the initial stops was 78.7%, and has increased compared to 2023. The percentage of punctual departures from intermediate stops was 63.9% which is also higher than in 2023. In 2024, the average fuel consumption in urban transport was 53.84 l/100 km, which is a bit higher compared to the previous year. The average gas consumption was 49.18 kg/100 km, also slightly higher than in 2023. The average fuel consumption in intercity transport was 34.72 l/100 km, showing the same trend (LPP, 2024; LPP, 2025).

Traffic jams are one of the biggest mobility problems in Ljubljana. In 2024, the extra hours travelers spent in the car during rush hours in Ljubljana accounted for about 50 hours over the year. The average speed for the morning rush hour in the city center was 32.1 km/h, and for the evening rush hour, 25.6 km/h. For the larger metropolitan area, the average speed was 43.8 km/h and 37.9 km/h, respectively. Out of all the days of the week, Fridays have the worst rush hour, between 3 and 4 pm. Driving 10 km during this hour would take on average 26 min 1 sec in the city center, with a congestion level of 87%, and 16 min 54 sec in the rest of the city, with a 70% congestion level (TomTom, 2025).

4.2 Position of Ljubljana Among Other Smart Cities

Ljubljana began implementing smart city initiatives in the early 2000s, focusing on sustainable development, urban innovations, and improvement of the environmental state. Today, Ljubljana is well-recognized in the smart city landscape and has multiple awards for its sustainability, green innovation, digitalization, and urban planning achievements. In order to understand Ljubljana's specific position among other smart cities, different ranking systems for smart cities can be examined.

As the concept of smart city has gained popularity and global attention, many organizations and research institutions have developed ranking systems for assessing cities' performance in this regard across multiple dimensions. One of the most widely recognized and influential smart city rankings is the Smart City Index (SCI) developed by the Institute for Management Development (IMD) in partnership with the World Smart Sustainable Cities Organization (WeGO). The popularity of this index can be attributed to the fact that it ranks cities on a global scale and has a human-centric approach.

The IMD started conducting a comprehensive and balanced analysis of smart cities in 2019 when it published its first index report. In 2023, the scope and methodology of the report

significantly improved when WeGO became a partner of IMD for the report preparation. As a result, the number of analyzed cities grew from 118 to 141. Ljubljana was one of the newly included cities in the ranking and appeared in the report for the first time. The SCI is based on citizens' perceptions of issues related to structures and technology applications available to them in their cities. Survey responses are collected from 120 residents in each city, and the final score is calculated using the perceptions of the last three years. There are two pillars for which perceptions are solicited: the Structures pillar, relating to the existing infrastructure of a city, and the Technology pillar, referring to the technological provisions and services available to the inhabitants. For each pillar, there are five key dimensions for evaluation: health and safety, mobility, activities, opportunities, and governance. The SCI also uses the Human Development Index (HDI) score by which cities are distributed into four groups. Within each group, cities are assigned a rating scale (from AAA to D) based on the perception score of a city relative to the scores of all other cities in the same group. Rankings are then presented in two formats: an overall ranking among all the cities and a rating for each pillar (IMD, 2023).

In the 2024 edition of the report, 142 cities were evaluated. Ljubljana was ranked 32nd this year, which shows a significant improvement compared to the previous year, when Ljubljana was ranked 47th. Overall, Ljubljana has a good relative position in terms of smart city development. Nonetheless, the report clearly illustrates that there are a lot of priority areas that require attention and have potential for further improvement. Out of the 15 indicators, these were chosen as the priority ones by the higher number of respondents: affordable housing (65.4% of respondents chose this area as a priority), health services (55.4%), road congestion (49.7%), corruption/transparency (42.1%), air pollution (36.1%), public transport (35.3%). The list of prioritized areas has changed a bit compared to the 2023 report, where the first three areas were the same, followed by public transport, corruption, and basic amenities. Air pollution was put in 8th place in the 2023 report, with 26.9% of survey respondents selecting it as a priority area, which signals a negative shift for this indicator (moved up by three positions in one year). On the other hand, the public transport area moved down by two positions, as 5.9% fewer people mentioned it as a priority. Nevertheless, three main areas stay the same, one of which (road congestion) is related to mobility and gained even more priority over the year in terms of selected percentage (IMD, 2024).

Furthermore, only 21% of respondents agreed with the statement that traffic congestion is not a problem in Ljubljana, which is notably lower than the mean for the assigned group. Also, only 53.2% of surveyed residents agreed that public transport in the city is satisfactory, which is also below the group mean. These results indicate certain problems in the mobility sector for Ljubljana, which affect its overall smart city rating. For the Structures pillar, other low results were in the Governance and the Health & Safety sectors (IMD, 2024).

In the Technologies pillar, the lowest indicators of agreement are for the Government dimension: 35.4% agreed that online public access to city finances has reduced corruption, and 39.4% agreed that online voting has increased participation. For the Mobility dimension,

the Technologies pillar has much better results, with most of the indicators being higher than the mean for the group. The only indicator that is below the group mean in this category is agreement with the statement «The city provides information on traffic congestion through mobile phones»: 52.7% of respondents did not agree with it. Relatively the same picture was present for both pillars in the previous report, with a few percent differences in the level of agreement (IMD, 2024).

Within the SCI, Ljubljana is assigned to the 1st group of cities based on its HDI score, which places it among most of the top-tier cities in the rank. Competing with the highest-rated cities is challenging, but it also means that the group's average indicators are comparable to those of the top cities, making it easier to benchmark Ljubljana against best practices. It is noteworthy that Ljubljana was one of the few cities with the largest change of rank over the year, moving 15 places up. This significant rise in the rank could be attributed to various factors such as improvements in smart city initiatives, better citizen perception scores, relative changes in the performance of other cities, or the combination of these factors.

In terms of factor ratings, Ljubljana received a BBB rating for the Structures pillar and an A rating for Technologies in 2024, indicating that the city needs certain improvements in its physical infrastructure and governance systems. Most of the top cities in the rank have AA or AAA ratings for the Structures pillar, while having the same rating for Technologies as Ljubljana, which highlights the importance of the first pillar for smart city development.

Another well-known ranking for evaluating city development is the IESE Business School Cities in Motion Index (CIMI), published yearly by the business school of the University of Navarra. The authors position IESE Cities in Motion as a research platform to promote changes at the local level and develop valuable ideas and innovative tools to make cities smarter and more sustainable (Berrone & Ricart, 2024). The CIMI evaluates the performance of 183 cities based on the analysis of successful cases and a series of interviews with authorities, entrepreneurs, and urban growth specialists. The evaluation is based on nine key dimensions: economy, human capital, international profile, urban planning, environment, technology, governance, social cohesion, and mobility and transportation.

In the overall ranking of the cities, Ljubljana was positioned in 102nd place in the 2024 edition of the CIMI. Its performance was evaluated as medium, although the city was placed closer to the end of the medium group list. Ljubljana's ranking in the CIMI is relatively low, considering that most European capitals, including neighboring ones, have a higher rank. In the ranking by dimension, Ljubljana has low positions for the following dimensions, signaling the presence of certain challenges in those areas: governance (124th place), technology (120th), mobility and transportation (118th), and international profile (116th). For the following dimensions, Ljubljana has an intermediate position: human capital (103rd), urban planning (98th), and economy (93rd). Social cohesion and environment are dimensions where the city occupies a relatively good position in the dimensional ranking (63rd and 52nd, respectively) (Berrone & Ricart, 2024). The correlation with the IMD Smart City Index can

be seen here, as both ranking systems identify governance and transportation as one of the main challenging areas for Ljubljana.

The CIMI also provides rankings by region and by population size of the cities. In the regional ranking, compared to other Eastern European cities, Ljubljana takes the middle position, being ranked 11th out of 24 cities in the region. It is rather surprising that Ljubljana did not secure a place among the top ten cities of the region. This signals that good practices and role models for city development can be found not only to the west of Slovenia but also in the countries to the east of it, which are often more similar in terms of culture, state budget, and other important conditions. By population size, Ljubljana belongs to the group of the smallest cities (under 600,000 inhabitants), which includes only nine cities in the 2024 edition of the report. Unfortunately, the CIMI report does not show the full ranking by population size and lists only the top five cities. Ljubljana was not included in the top five in its category, where the leading positions were occupied by Reykjavik, Basel, Bern, Canberra, and Wellington (Berrone & Ricart, 2024). Most of these cities have lower numbers of residents than Ljubljana, but still have much higher positions in the overall rating, showing that a high state of development can be achieved even in smaller cities.

The authors state that the results of the CIMI 2024 should not be directly compared with previous editions, as significant changes in the number and type of indicators, along with evaluation methods, were introduced in the newest version. The rank provides a specific dynamic analysis to evaluate the growth trend over the past three years and the overall potential of each city. It divides all the cities into four groups: high-potential (currently holding a mid-to-low position in the index but advancing very rapidly), challengers (rapidly improving their position and currently in a mid-to-high position in the ranking), consolidated (having a mid-to-high position but either not changing over the period or dropping one or more positions), and vulnerable (growing at a slower pace than other cities and holding mid-to-low positions in the ranking). Ljubljana was classified as the vulnerable group, which is the least favorable of the four. The results are not very satisfactory, and Ljubljana should find its way to enter the group of challenger cities in the future.

In order to evaluate Ljubljana's position in terms of smart mobility, specific ranks for this smart city pillar can be examined. The final report of the Pan-European City Rating and Ranking on Urban Mobility, published in 2022 by Ricardo-AEA Ltd, evaluates the performance of 36 European cities in terms of urban mobility solutions that help create liveable, zero-emission cities. The ranking system includes Ljubljana, making it possible to benchmark its performance against other cities and highlight the areas in mobility that can be improved. The system uses five categories for evaluating the cities' performance, with most of the categories having a few indicators for evaluation. The Space for People category assesses the amount of public space allocated to people and sustainable mobility as compared to the amount of public space allocated to motorized vehicles. The Safe Roads category evaluates citizens' safety as they utilize active modes of transport. Access to Climate-Friendly Mobility assesses the adequacy of the city's infrastructure and services in

facilitating access to public transport and zero-emission mobility. To evaluate whether low or zero-emission zones are already implemented or planned, whether there are national commitments to exclusively permit the sale of zero-emission vehicles, and the extent to which MaaS solutions are available, the category Polluting Cars Out, Shared Mobility In is used. Finally, the Clean Air For Everyone category assesses the air quality within the cities, based on current pollution levels and their recent trends (Virdo et al., 2022).

In the Space for People category, Ljubljana shows different results by all three indicators. By opportunity for walking, Ljubljana is placed in the 27th position in the ranking with 24.7% of the road network designed for pedestrians, which is quite an undesirable result. By opportunity for cycling, Ljubljana is in 13th place with 9.5% of the roads equipped for cyclists. This result shows achievements in the organizing infrastructure for cycling in the city, but also indicates room for further improvements. The best score in this category is for the congestion level in the city; Ljubljana takes 8th place in this indicator. Nevertheless, road congestion remains one of the main mobility problems in the city. In the Safety Roads category, Ljubljana holds a middle position for pedestrian safety and quite a low (28th) position for cyclist safety. In terms of access to climate-friendly mobility, the city's score fluctuates again: low 28th place for public transport affordability, the lowest possible 36th place for access to public transport, however, a very high position for access to electrical vehicle charging – 7th place in the rank. In the Polluting Cars Out, Shared Mobility In category, Ljubljana shares the last place with three other cities, having an overall score of 6.5 out of 20, which is a very bad result. This category is directly related to smart mobility initiatives, which shows that Ljubljana has not yet achieved great results in this field compared to other European cities. The city also received a relatively low rating for air quality: 31st place for the current state and 21st for the quality trend (Virdo et al., 2022). Overall, Ljubljana’s results are hard to call satisfactory. They demonstrate significant weaknesses in pedestrian infrastructure, public transport, and some other areas. The city's poor score in the fourth category highlights the need for stronger smart mobility initiatives and improvements in sustainable transportation.

4.3 Smart Mobility Projects and Initiatives in Ljubljana

A detailed examination of various mobility projects and initiatives is essential for understanding Ljubljana’s progress and effectiveness in the field of smart mobility. In this subchapter, the main past and recent smart mobility projects, solutions, and initiatives that became important milestones for the city’s journey toward smarter mobility are analyzed. The analysis not only sheds light on how well Ljubljana is incorporating advanced technologies and sustainable practices into its mobility infrastructure but also provides valuable insights for potential future developments in this area.

4.3.1 Vision of Ljubljana 2025

The Vision of Ljubljana 2025 is one of the first comprehensive initiatives toward making Ljubljana a more sustainable and developed city. This project plan, released in 2007 by the city municipality, is focused on multiple key areas aiming to improve the quality of life in the city (Koželj, n.d.). In addition to development guidelines, the Vision also introduced 93 projects focused on different areas of urban development. Although it does not focus solely on mobility improvement, the Vision includes initiatives aimed at promoting smart mobility in the city.

The details of the project plan were not disclosed to the public, and only the general ideas, along with a set of potential architectural projects, were presented. The goals stated in the textual part of the vision are rather vague and do not specify the quantitative improvements, the time frame for the initiatives, or their priority. The Urban Planning Council for Ljubljana commented on the Vision 2025 goals as follows (translated from Slovene): "They [goals] are set without prior analysis of the situation, they are mostly very general, so they say almost everything, but also almost nothing. The goals are also not hierarchically arranged (or at least valued), so it is not possible to judge which are more important and which are less. Among the general goals, very concrete ideas about spatial design (e.g., six-lane entrances) are collected and randomly mixed without clear criteria, which have not been professionally studied enough nor verified from the point of view of the interests of various public " (Mestni svet Mestne občine Ljubljana, 2007, p. 30). Such a limited plan disclosure makes it challenging to provide a detailed examination of the goals and their achievement.

Although the specific initiatives on transportation and mobility under the Ljubljana Vision 2025 are ambiguous, several goals and promises in this regard were outlined in the textual part of the vision. As the time frame for the plan is nearly over, it is now an opportunity to assess the achievements in this area and how efficiently the vision was realized in practice. Among the main goals of the vision was the reduction of traffic in the city, resulting in saving energy and reducing emissions, along with the overall improvement of mobility in Ljubljana. Whilst it is hard to compare the state of traffic over 15 years due to the lack of comparable data and the fact that the city has changed and grown, it is evident that excessive traffic and road congestion remain one of the biggest problems in the city. The change in greenhouse gas emission levels over these years can be tracked only at the country level, giving an approximate understanding of the change in Ljubljana. The available statistics from the Slovenian Environment Agency show an overall decrease in total greenhouse gas (GHG) emissions from 20,954 kt CO_2 eq in 2007 to 15,615 kt CO_2 eq in 2022. It is noteworthy, however, that the proportion of emissions attributed to the transport sector increased from 25.01% to 37.11% over the same period (Majaron, 2024). This shows that while some improvements in decreasing GHG emissions were made, the emissions from road traffic (which dominate the transport sector emissions) became the main challenge in this field for the country and Ljubljana, as the most populated city, in particular.

An important plan for traffic reduction included in the Ljubljana 2025 Vision was a closure of the old city center to motor vehicles in combination with a new, more efficient delivery system for goods. The implementation of the plan started in the same year the vision was released. The renovation of Wolfova Street and the main Prešernov Trg Square in 2007 began the gradual closure of the city center for all motor vehicles, with only delivery vehicles having permits allowed to enter between 6 am and 10 am. The former parking spaces in the city center were also closed to vehicles and redesigned into event and social areas. Nowadays, more than 18 hectares of surface in the city center are dedicated to pedestrians and cyclists only. In 2015, a part of Slovenska Street was also permanently closed for personal motor vehicles, resulting in a reduction of black carbon concentrations by 70% and noise pollution by around 6dB in this area (Mestna občina Ljubljana, n.d.*f*). The project can be called a success as it formed a pedestrian-focused and environmentally sustainable area in the middle of the capital city.

Another aim of the 2025 Vision was an increase in the bike lanes and paths network threefold and pedestrian areas by 70%. Since the project description lacks the initial 2007 statistics or the exact target for 2025, it is challenging to assess whether these goals were in fact met. According to the EU Urban Mobility Observatory article on the pedestrianization of Ljubljana city center (2020), the closure of the historical center to motorized traffic increased the pedestrian zone by 620% since 2007. This percentage refers solely to the city center area and therefore cannot reflect changes across the entire city. However, the increase is significant enough to suggest that the target of a 70% increase citywide was likely achieved. The change in the infrastructure for cyclists is shown in the Cycling Yearbook of Ljubljana. Its last published version contains a comparison between the decree on the categorization of municipal roads from 2005 (amended in 2008) and the draft decree for 2022. According to the provided statistics, the total length of organized bicycle paths increased by over 150,000 meters for this period, signaling a doubling of the 2005/2008 indicators (Koželj et al., 2022). Although the data is from 2022, it is improbable that Ljubljana will succeed in tripling its bicycle lanes and paths network by 2025 compared to 2007.

The plan also mentioned the establishment of an integrated public transport system, which will be connected to the park-and-ride terminals, and the introduction of a single ticket for transport. By introducing regional zones and harmonizing the payment system, the integration of intercity bus lines from the suburban municipalities of Škofljica, Brezovica, Dobrova-Polhov Gradec, Medvode, Grosuplje, Ig, and Vodice with the Ljubljana city lines was established, which significantly increased the number of transported passengers in these areas (Mestna občina Ljubljana, n.d.*b*). Also, the establishment and renovation of park-and-ride (P+R) facilities in the outskirts of Ljubljana and nearby towns has begun. Thanks to P+R terminals, passengers who travel to the city center from outside of Ljubljana can leave their vehicles at the parking lot and easily transfer to a city bus to continue the journey. An important improvement was also made by introducing the Urbana Smart City Card in 2009. It is a multifunctional card that was first introduced for fare payment on Ljubljana public

buses, allowing free transfer within a 90-minute period. Later on, the functionality extended to the payment for integrated buses, rental bicycles, parking in the city, Ljubljana City Library services, and even some Ljubljana Castle events (Mestna občina Ljubljana, n.d.*b*).

The 2025 Vision also highlighted the introduction of hydrogen-powered buses in the fleet of LPP. The first test of a hydrogen bus happened in Ljubljana in September 2022. The test was successful and received positive feedback from citizens. However, it emphasized the need for additional infrastructure, which is required for the efficient introduction of the new buses (Murovec, 2022). In May 2024, the contract was signed under which the company Autocommerce will supply the Municipality of Ljubljana with eight articulated low-floor hydrogen buses. The delivery of the buses must be realized no later than October 25th, 2025 (Pušnik, 2024). Hydrogen technologies are increasingly appearing as one of the possible solutions for the decarbonization of transport, making this agreement an important step for Ljubljana. However, the pace at which the plan for introducing hydrogen-powered buses is progressing remains suboptimal. There is also uncertainty regarding whether the required infrastructure has been established and whether the city will be able to utilize the buses immediately upon their delivery.

The Vision of Ljubljana 2025 also outlines several ambitious goals related to the city's railway transportation. First of all, according to the strategic plan, the railway should gain importance as a form of public transport in the metropolitan region. This goal is again very vague and is not supported by any statistics. Hence, it is quite challenging to evaluate the progress in this regard. The survey conducted in preparation for the Sustainable Urban Mobility Plan for the Ljubljana Urban Region shows that the car is still a prevailing means of transport in the MOL and that traveling by train is not a widespread practice even for people living outside the municipality (RRA LUR et al., 2019). There is significant potential for further development to strengthen the role of railway transportation in the Ljubljana region. Multiple issues, such as frequent train delays, should be addressed first, as well as the railway infrastructure improvement, plans for which were also included in the 2025 Vision.

A plan for the modernization of the main city's railway and bus stations by creating a new Ljubljana Travel Center was also introduced. This project is one of the crucial ones for enhancing mobility in Ljubljana, particularly for railway transportation. The travel center is set to streamline rail connections, improve integration with other modes of transport, and provide a more efficient, accessible, and, what is also important, attractive hub for both local and international travelers. Despite the importance of the project, the timing of its implementation can be described as exceptionally lengthy. The first plans for the building of the new travel center were introduced in the early 2000s. However, the construction only began in 2024 and is planned to be finished by the end of 2025 (Mestna občina Ljubljana, n.d.*e*). The extended timeline for the Ljubljana Travel Center project highlights inefficiencies in urban planning and execution, bureaucratic problems, and funding

challenges. Such prolonged delays have hindered the city's ability to modernize its transport infrastructure and meet a growing mobility demand.

4.3.2 Sustainable Urban Mobility Plan of the Ljubljana Urban Region

In October 2018, the regional council adopted the Sustainable Urban Mobility Plan of the Ljubljana Urban Region (SUMP LUR), which has become the main transport-related strategic input for the Regional Development Programme of Ljubljana Urban Region for the programming period of 2021-2027 (Chinellato & Morfoulaki, 2019). The plan provides concrete measures for sustainable mobility regulation and an innovative approach to solving transport challenges in the region. It also serves as a crucial professional foundation for the regional spatial plan and a basis for finding resources for implementing development projects in the field. The key objective of the SUMP LUR is the establishment of a sustainable mobility system to ensure the accessibility of jobs and services for everyone, improve road safety, reduce greenhouse gas emissions and energy consumption, increase the efficiency of public transport, lower the cost of passenger and freight transport, and improve the environmental state. The key emphasis is on friendliness towards pedestrians and cyclists, the development of public transport, and ways of changing the travel habits of the region's population (RRA LUR et al., 2019).

The strategic objectives of the plan are divided into five pillars of sustainable mobility: walking and cycling, public transport, motorized transport, freight transport and logistics, and sustainable mobility planning. For each pillar, the current status, achievements, and objectives are stated. For the walking and cycling pillar, the three main objectives were defined. Firstly, good connections with the network of cycling routes should be established. This objective is related to the improvement and enlargement of the existing cycling infrastructure. Attention is also being paid to the growing number of electric bicycles on the roads, stating that the infrastructure should be adapted to this trend. Another objective related to this pillar is increasing the percentage of journeys made by bicycle. In order to achieve this, the authors suggest encouraging the use of electric bicycles and promoting the integration of bicycles with train travel. In addition, secure bicycle parking should be provided at the destinations. Finally, the improvement of intermodal points for pedestrians and cyclists is the last objective in this field. This will ensure seamless and safe transitions between different transport modes, enhancing sustainable mobility and inclusivity for all users (RRA LUR et al., 2019).

Public transport has the largest potential for the development of sustainable mobility in the Ljubljana urban region; however, without reducing the number of cars, significant progress cannot be achieved. The first objective concerning public transport is upgrading the related infrastructure. The introduction of separate lines for public buses should continue, as well as the construction of the P+R network and bicycle parking areas in the vicinity of stations and stops to achieve better connectivity between different modes of transport. The authors also

state that it is necessary to introduce good practices in the regulation of intersections and signalization automation, which gives priority to public transport vehicles (RRA LUR et al., 2019). In addition, great importance is attached to improving the railway infrastructure, including the renovation of the Ljubljana railway hub. The second objective is related to the modernization of the public transport fleet. The railway has already started to update its rolling stock, having 52 new trains and a plan to acquire 20 new modern passenger carriages and four multi-system locomotives, delivery of which is expected in 2026 (Delo, 2023). The third objective of the plan is to improve the management of the public transport system. Adjusting timetables and frequencies of public transport to the actual needs of the passengers is the key initiative in this regard (RRA LUR et al., 2019).

The first objective regarding motorized transport is the optimization of car traffic. The authors of the plan take into account the experience of other European cities, stating that expanding infrastructure only temporarily reduces congestion, ultimately leading to increased vehicle use and a reduction in public transport reliance. Therefore, actions aimed at optimizing car traffic should be focused on sustainable solutions. The second objective is a comprehensive regulation of stationary traffic. Municipalities in the LUR will balance parking demand and supply through smart planning, management, and informatization. The last objective is related to ensuring more safety and less pollution of towns with emissions and noise. The region and municipalities will ensure safe infrastructure, promoting zero road fatalities and severe injuries. The speed in towns will be reduced, thereby achieving lower levels of noise and emissions; in addition, the promotion of the use of electric and gas vehicles will be continued (RRA LUR et al., 2019).

Freight transport in the LUR has increased in recent years, negatively impacting the local safety and environment. At the same time, it significantly contributes to economic growth when the origin of goods is in the home country or region. The key is in the effective organization of freight transport. Certain limitations for freight transport, particularly the transit one, are planned to be implemented, such as restrictions during rush hours, the reduction of speed limits, limiting long-term parking, or even a total ban in some cases. It is also highlighted that the redirection of freight from the road to the rail is important; however, it is necessary to first modernize the rail infrastructure and transport policy measures at the national level. Other measures regarding freight transport proposed in the SUMP LUR focus on sustainable urban logistics and promoting modern, environmentally-friendly logistics centers (RRA LUR et al., 2019).

The last pillar is related to sustainable mobility planning. Firstly, a more coherent and focused management at both vertical and horizontal levels is to be established, involving concentration on joint projects and work, which may imply the establishment of a joint regional working body. Secondly, sustainable mobility planning should be coordinated between various areas such as transport, spatial, economic, and others. A separate objective is dedicated to education, raising awareness, and public participation. Last but not least, the authors emphasize the importance of improving financing conditions and the rational use of

resources. The available funds for the construction of infrastructure should be significantly increased, and programs related to sustainable mobility should be expanded, supported by national and international sources. Soft measures for enhancing sustainable mobility, like subsidies for employers or users of public transport, should also be implemented (RRA LUR et al., 2019). The plan is finalized by introducing 49 sets of measures for sustainable mobility, specifying the actors, time, and financial frames.

4.3.3 Regional Innovation Strategy of the Ljubljana Urban Region

The Regional Innovation Strategy of the Ljubljana Urban Region (RIS LUR) highlights key societal and economic challenges of the region and provides guidelines for addressing these challenges in line with the region's and municipalities' competencies in promoting innovation. The RIS LUR identifies activities that can be realized at the regional and local levels and are based, above all, on non-technological innovations. The strategy is prepared with a focus on people and their needs, with the final objective of improving the well-being of the inhabitants of the LUR. The RIS LUR was released in October 2022 and covers the period of 2022-2030. It derives from the Regional Development Programme of the Ljubljana Urban Region (RDP LUR) and functions as its innovative part (RRA LUR, 2022b). In the framework of the regional innovation strategy, the key development projects were also defined, which were categorized by the six smart city components. In this subchapter, only the smart mobility projects related to the city of Ljubljana are reviewed.

One of the smart mobility projects presented in the RIS LUR is related to developing a model of an e-bike sharing scheme. This project has a short-term timeframe, implying one to two years for its implementation. It is part of the bigger project included in the RDP LUR, which is aimed at establishing a standardized e-bike rental scheme in the region by connecting existing schemes, developing uniform infrastructure, setting up cross-municipal rental and charging services, implementing a unified information and payment system, and ensuring connectivity to other regional mobility systems (RRA LUR, 2022a). This initiative should positively affect the adoption of e-bikes among locals and visitors. The sharing basis also makes e-bikes available for economically vulnerable people, like students or the elderly. E-bikes serve as an environmentally friendly means of mobility while also being much more time-efficient than traditional cycling or walking, a factor that can be crucial for some users.

Another important smart mobility project within the RIS LUR framework refers to the establishment of the Regional Mobility Centre LUR. The establishment of such centres was carried out according to the model developed by the ReMOBIL project, which ran between May 1st, 2022, and April 30th, 2024. In total, six regional mobility centres were opened in different parts of Slovenia. The main goals of the ReMOBIL project were the reduction of the negative environmental impact of traffic and the improvement of sustainable mobility management. The six regional mobility centres serve as practical hubs for implementing and testing the regional mobility management model. Their primary purpose is to enhance the

planning, coordination, and promotion of sustainable mobility at the regional level. They also facilitate the cooperation of the regional and national levels responsible for transport, spatial planning, and digitalization of MaaS (RRA LUR, n.d.). Opening the Regional Mobility Centre LUR positively affects mobility management and the adoption of sustainable mobility practices in the region, spreads awareness among dwellers, and promotes harmonization of related legislation.

The last project to be discussed is related to the expansion of the volunteer driver model to assist the mobility of elderly citizens. Slovenia has a great nationwide program called Prostofer, which is volunteer-based and aimed at connecting older people who need transportation and cannot use public or paid transportation with older active drivers who, on the other hand, are willing to help (Prostofer, n.d.). Within the RIS LUR project, the program will be extended, and the integration of the service across the region will be implemented (RRA LUR, 2022b). Services like Prostofer reduce the social isolation of the elderly, enhancing their independence and quality of life. They are also aligned with smart mobility principles by leveraging shared resources and innovative transport models to create sustainable and user-centric mobility solutions.

The RIS LUR presents important smart mobility projects that will enhance the management and sustainability of mobility in the region. In total, six projects related to mobility were presented. It is important to mention that most of them (five out of the six) are short-term projects, and only one project is medium-term (3-5 years for implementation). The strategy lacks more extensive long-term initiatives for mobility, highlighting a missed opportunity to address future regional challenges and implement forward-thinking in the development of sustainable transport solutions.

4.3.4 SmartMOVE

The project SmartMOVE (Smart Solutions for Sustainable Mobility) was held between May 1st, 2022 and April 30th, 2024. It addressed sustainable mobility management in high-traffic locations in Ljubljana and aimed at limiting the negative environmental impacts resulting from unsustainable forms of mobility. The main objective of the project was to introduce and promote sustainable mobility at the company level (Republic of Slovenia, Ministry of Cohesion and Regional Development, n.d.). The SmartMOVE can be called one of the most comprehensive smart mobility projects held in Ljubljana in recent times, and the fact that the project has been concluded allows for a proper overview of its achievements.

The main focus and achievement of the SmartMOVE project is the development of mobility plans for four companies – major traffic generators (the University Medical Centre Ljubljana, BTC, IKEA Slovenia, Studio Moderna) and the Ljubljansko Barje Landscape Park area. The mobility plans introduced a comprehensive set of measures that influence changing the travel habits of users, along with a set of soft measures such as information dissemination, education, and organizing activities to promote sustainable mobility. The

measures increase arrivals at the location by walking, cycling, or using public transportation and also benefit the wider area by reducing traffic on surrounding roads and significantly improving traffic safety and accessibility in the area. The developed plans already got the first results, for example, a new secured bike storage facility was installed in front of the Ljubljana Medical Center as a result of the survey held among the employees, showing that many of them would travel to work by bike if they had safe parking guaranteed at the destination. IKEA Slovenia, in its turn, assigned the role of mobility coordinator to a selected employee, who will ensure the successful progression of the company's sustainable mobility efforts (RRA LUR, 2024).

As part of the project, the dynamic group transport to work was also tested. For three months, 131 selected employees from the University Medical Centre Ljubljana and BTC were using the transfer organized by the project's partner, GoOpti. The provided vans picked up and dropped off the employees at the agreed-upon time according to their preferences. The pilot test not only got positive feedback from the users (a survey showed that three-quarters of the users would choose this mode of travel to work in the future) but also showed promising results in affecting the pollution levels: as found by the Jožef Stefan Institute (the project's partner), the transition to a dynamic commuting leads to a significant reduction in harmful CO2, NOx, and particulate emissions. The problem of funding was also revealed: the participants would be willing to pay around 70 euros per month for such transportation, which is slightly less than half of the estimated cost per person for this mode of transport (RRA LUR, 2024). Therefore, the long-term existence of dynamic transportation to work is a feasible idea, but it is only possible with additional sources of funds provided by companies, public transport providers, or the government.

The project also introduced a specialized certificate that can be obtained by organizations actively involved in managing mobility. The certificate not only shows that a company is environmentally responsible but also serves as a tool for improving the state of sustainable mobility by identifying the greatest potential for influencing employees' travel habits. Before applying for the certificate, any organization can take a short questionnaire available on the official project's website to test whether the organization is entitled to the SmartMOVE certificate. The questionnaire also provides recommendations on specific actions needed in order for the company to get certified (RRA LUR, 2024).

Training sessions for employees and employers are also part of SmartMOVE's achievements. Various topics on sustainable mobility were discussed during five sessions, free of charge. A set of recommendations for policymakers at the national, regional, and local levels was also prepared within the project. Overall, more than 50 recommendations were formulated, and they were classified according to the difficulty of implementation, priority, and their impact on the reduction of greenhouse gas emissions. In order to prepare the recommendations, international policies and guidelines of European legislation were examined, and an analysis of the mobility situation in Slovenia was conducted (RRA LUR, 2024).

The project has not only contributed to the development of sustainable mobility but also introduced innovative solutions to one of the main mobility problems of Ljubljana – traffic congestion. It is also noteworthy that the project developers have formulated a set of suggestions for authorities; in this way, the changes that the project brought do not just stop with the project's duration, but they can further transform into more comprehensive policies adopted on multiple levels. The responsibility now lies in the hands of the policymakers who need to decide whether to consider and implement the proposed recommendations. The pilot test of dynamic group transport to work demonstrates that significant changes in urban mobility are achievable only with the active involvement and support of authorities.

4.3.5 Shared Mobility

Ljubljana has achieved notable success when it comes to shared mobility, having a variety of shared transportation modes available. The first and most noticeable transport-sharing option present in Ljubljana is the bicycle rental system called BicikeLJ. The system was introduced in May 2011, and the popularity of BicikeLJ has grown steadily since the launch; therefore, the network of stops and bikes continues to grow yearly. At the system launch, 30 stops were installed, incorporating 600 bicycle stands and 300 bicycles. Ten years later, in 2021, the BicikeLJ system included 80 stops, with 1,602 bicycle stands and 820 bicycles in total. On average, each bike in the system was borrowed eight times per day that year, and a total of 1,047,069 bicycle rentals were made. The number of active users of BicikeLJ reached 63,823 at the end of 2021 (Koželj et al., 2022).

The popularity of the system can be attributed to multiple factors. First of all, cycling is one of the best modes of transport for a city like Ljubljana. The city has a flat terrain and is compact enough to make it easy to travel around by bike. Moreover, cycling helps to avoid traffic congestion, which remains a challenge for Ljubljana. Secondly, a rental service is a convenient option for many people, as there is no need to purchase, store, and maintain a bike and worry about it being stolen one day. The pricing model of BicikeLJ also contributes to its success. The first hour of the ride is free, which is usually enough time to get to a destination within Ljubljana. The additional hour of rent costs 1 EUR, the second extra hour costs 2 EUR, and all subsequent hours cost 4 EUR each. Users also have the option to park the bike at the BicikeLJ station at the end of the first hour, wait for five minutes, then rent a bike again, and continue the journey; in this case, the ride would be free of charge. The service also includes an obligatory subscription – 1 EUR for a weekly and 3 EUR for a yearly one, which is more of a symbolic value and is affordable to anyone (Bicikelj, n.d.). The system works based on the mobile application, enhancing its accessibility and usability, which makes it appeal to a wide range of users. Additionally, BicikeLJ allows users to engage in physical activity while traveling to work, school, or sightseeing, coupled with the opportunity to choose an environmentally friendly mode of transport. Last but not least, BicikeLJ has established a wide network of stations, strategically located throughout the

city. This encourages frequent use of the service and enables users to combine cycling with other modes of transportation.

Along with BicikeLJ, new systems for bicycle rental started to appear in Ljubljana. For example, one of the growing bike rental systems is Nomago Bikes. Their competitive advantage is the availability of e-bikes to rent. Moreover, their bikes can be rented without a subscription. Another distinctive feature of Nomago Bikes is the possibility of reserving a bike at a particular station ten minutes before arrival and the ability to return a bike at a station even if it is full. The system works on a mobile application basis, but users can also rent a bike using terminals available at the bike stations. Nomago offers different payment plans, providing its users with more options than BicikeLJ; however, the cost of a subscription is also much higher: 8 EUR for a weekly plan and 45 EUR for an annual plan (as per the price list available in December 2024). The service operates on 30-minute cycles. For users with a subscription, the first 30 minutes are free, and every other half hour costs 1.30 EUR. Users without a subscription pay starting from the first minute of rent; the cost in this case stays at 1.30 EUR per 30 minutes, regardless of the actual time of use (users are charged per half hour even if the ride was less than 30 minutes) (Nomago, n.d.). The emergence of new bike rental systems provides users with more alternatives and also boosts competition in the market, which can lead to improved service quality, the introduction of innovative features, and potentially lower costs for the service.

Another popular mode of shared mobility is an e-scooter. A few rental systems for e-scooters are available in Ljubljana, the most widespread of which is Bolt. The service is similar to bike rental and is based on the mobile app. Renting is charged by the minute, and the only payment option is a credit card. At the introduction of the service, the e-scooter rental system implied the «free-float» principle, meaning that a user could park and lock the scooter where it is convenient. If users could not find an available scooter on the street, they could locate one using a special map in the app. This approach was very user-friendly, but it led to many scooters being parked at inappropriate places, such as in the middle of a sidewalk or lawn. Scooters were also often left lying on the road, blocking the way for pedestrians and spoiling the overall appearance of the streets (Atelšek, 2022). This raised discontent among the citizens, and certain regulations for e-scooter riders were implemented. Ljubljana city municipality started building special parking spots for e-scooters, and inappropriate parking is now punished with a fine of 40 EUR (Kamenarič, 2023). Additionally, Bolt introduced a requirement to take a picture of a parked e-scooter at the end of each ride to prove that the parking was done correctly. The service has a team dedicated to monitoring the parking situation and relocating wrongly parked e-scooters (Fašalek, 2022).

Finally, the city also has various carsharing systems. Remarkably, many of them rent out only electric cars. One of the pioneering and most popular electric carsharing platforms in Ljubljana is Avant2GO. The system was introduced in 2016 as part of the European Green Capital program. The entire service, from car reservation to final payment, is carried out via the Avant2Go mobile application. With every kilometer traveled using Avant2Go cars, users

save 100 grams of CO2 emissions, reduce mobility costs by renting over owning, and contribute to noise reduction (Mestna občina Ljubljana, 2022b). The cost of renting differs depending on the vehicle model, the time of the day, and the duration of the use. The minimum cost of renting varies from 4.50 EUR to 39 EUR, and the maximum daily cost from 29 EUR to 79 EUR. Additionally, the users must pay a one-time registration fee of 19 EUR. There are also different packages available for deductible franchises in case of damage caused by a renter, from 38 EUR to 600 EUR per year (Avant Car, 2024). Carsharing is a very popular and increasingly recognizable mode of mobility in Ljubljana, and the joint use of cars is also constantly promoted by the authorities. In 2020, Ljubljana won second place in the international competition for the Carshare City Award in the category of up to 750,000 residents, which proves the presence of achievements in this field (Mestna občina Ljubljana, 2020a).

4.3.6 Parking Management

Ljubljana provides numerous private car parks and parking garages around the city. In addition to that, Javno podjetje Ljubljanska parkirišča in tržnice (JP LPT) manages short-term parking areas. The city is divided into three parking zones based on proximity to the center. Parking in these zones requires the purchase of a ticket in the parking machines that do not provide change in case the fee is paid in cash, which makes drivers insert the exact amount needed or lose money. Alternatively, the payment can be made with the Urbana card or through the Urbana SMS Parking service (JP LPT, n.d.). These were the only payment options until the payment through the mobile applications EasyPark and Urbana was implemented.

The hourly parking fee varies in each zone. Parking Zone 1 is located in the city center and has the highest fee of 1.30 EUR per hour. It applies from 7 am to 7 pm every day of the week except Sunday. Parking in Zone 2 costs 0.50 EUR, while the hourly cost in Zone 3 is 0.80 EUR. The closer the area is to the center, the higher the parking fee. Parking is chargeable from Monday to Friday for both Zone 2 and Zone 3 (Ljubljana Tourism, n.d.*b*). However, on the 16th of December 2024, Ljubljana city councilors adopted an amendment that introduced the payment of parking fees in Zone 1 on Sundays and Zone 2 on Saturdays, effective from January 1st, 2025. The new amendment aims to reduce the number of motor vehicles in the city center, change travel habits, and promote more sustainable forms of mobility (STA, 2024). In addition to that, the parking period is limited in time for these zones. All the limitations created an important incentive that can help with reducing the use of private vehicles since parking is limited in duration, the payment is obligatory, and the rates are relatively high compared to the alternatives in shared mobility or public transport.

On March 1st, 2022, the City of Ljubljana enabled the payment of daily parking fees in short-term parking zones with the EasyPark mobile application. EasyPark charges a commission for its services in the amount of 15 percent of the parking fee value, with a minimum

commission of 0.10 EUR, including VAT. Alternatively, there is an option of a monthly subscription that removes the commission for all parking payments, and it costs 2.99 EUR per month (Mestna občina Ljubljana, 2022a). The app provides higher flexibility in payments and the highly anticipated digitalization of the whole payment process. At the same time, it may cause certain security concerns as the application requires information on the user's location and credit card details attached to the account. Interestingly enough, the payment details cannot be removed once added. It can only be deleted with the removal of the whole account. It may cause certain inconveniences and additional concerns in terms of security and flexibility, as users should be able to manage their sensitive data more freely.

In the meantime, since 2012, JP LPT has started installing smart parking systems equipped with sensors on some of its parking lots. All the parking systems are automated and use registers that are connected via a fiber-optic link to a control center where operators can monitor all the activities. Also, a smart system detects the occupancy. An overview of the available spots is demonstrated near the entrance to such parking lots in real time (Q-free Traffic design, 2012).

In a similar way, many private parking garages and city malls, such as BTC City Ljubljana, use smart parking systems for time efficiency and greater ease of parking on their premises. In particular, the system provides live data on available spots based on sensors and has a specific classification of them by color. The red light implies that the spot is occupied, while green means that it is available. Also, the spots for disabled people are marked with a distinctive blue color above, which makes finding them much easier. What is more, systems with number plate recognition technology are becoming more widespread in Ljubljana. They allow automated access control by identifying and matching the plate number with information in the user database. The parking facility at the Ljubljana School of Economics and Business is a great example of such a system in practice (Quercus Technologies, 2022).

Ljubljana also has multiple P+R (park-and-ride) facilities located on the outskirts of the city, where people can leave their vehicles and switch to a city bus to continue their journey. The purchase of a parking ticket in such facilities also provides two bus tickets valid for the day of the ticket purchase. This approach has great potential to reduce traffic congestion in the city and can stimulate the use of public transport. The price of 24-hour parking at the P+R point is 1.30 EUR. The same amount is charged for just an hour of parking in the city center (Ljubljana Tourism, n.d.*b*).

4.3.7 The Urbana Mobile Application

In 2014, it was announced that a new Urbana mobile application for smartphones would be released. The application was based on Near Field Communication (NFC) technology, which enables the app to have the same functionality as the Urbana card. In other words, with the application installed and the NFC connection turned on, users could place their mobile phone on the validator in the same way as the physical Urbana card. The application

was tailored to support payment for tickets on Ljubljana public transport and the castle funicular, parking fees in Ljubljana at parking machines or with the SMS Parking service, and use of the BicikeLJ bike system (Cvjetović, 2016).

Before the release of the Urbana app, only the Moneta service was available. Moneta is a cashless mobile payment system of Nova KBM and Mobitel. Payment for a ride on the LPP bus was possible by calling "1899" and bringing the mobile phone close to the payment terminal or to the validator installed at the bus entrance. After successful payment, the user received a confirmation via SMS. In this process, the user received a virtual token as a one-time ticket, without the possibility of further transfers that were possible with the physical Urbana card. Additionally, it was not possible to buy tickets for several people at the same time using Moneta (Pritržnik, 2009).

The Urbana mobile app did not have such limitations. Moreover, the application could display how long the ticket was still valid. If the validity period expired during the journey on a bus in which the passenger had previously validated their transfer, the user could still use this bus to finish the journey to the desired stop. However, the application had its own limitations. For example, the app was only available for smartphones running on the Android operating system with version 4.4 or higher. Other operating systems were not supported. It significantly limited the availability of the Urbana app. Also, the balance could be topped up the same way as regular Urbana cards: at Urbanomat machines and authorized sales points or through the Moneta payment service. There was no option to add credit card details and manage the account's balance in the app (Cvjetović, 2016).

Existing limitations had a significant impact on the application usage. In particular, a survey conducted by LLP among its customers in 2019 clearly illustrates that only 19.1% knew and used the Urbana virtual value card for mobile phones, more than half of the respondents knew about the app but did not use it, and one-fifth of them did not even know that it existed (LPP, 2020). Since then, the app has been updated with the new functionality. In particular, the long-awaited support for the IOS system - the second most popular mobile operating system - was finally introduced in 2020. Also, the parking fee payment was improved with the new Upark service in the Urbana app. The latest built-in feature significantly simplified the parking payment process (Mestna občina Ljubljana, 2020c).

Just recently, the older version of the app was replaced when LPP successfully implemented the concept of Mobility as a Service into the new Urbana application. It was in development for a couple of years and was released in July 2023. The new application allows travelers to choose between different means of transport and routes based on price benefits, travel time, and comfort, taking into account current traffic conditions and minimizing the transfer time. All these features are supported by modernized hardware and software that now enable connectivity with other products and applications (LPP, 2024). These changes transformed the Urbana app into a focal point for access to all city mobility services. Indeed, the app provides access to information on all forms of urban mobility and could assist in route

planning via a multimodal interface. It also provides valuable analytics that display the history of driving, parking, and topping up. This allows users to make informed decisions on the mode of traveling and fully incorporate the benefits of the MaaS in daily life.

Overall, there are many positive changes in the features of the new app compared to the old one. In particular, contactless validation is now conducted via Bluetooth technology rather than NFC, as in the previous app. More importantly, the option to connect the debit card and top up the balance finally became available in the app. It significantly simplified the way Ubana's balance could be managed and refilled on demand with a straightforward and modern payment system. Also, the new application addressed many limitations of its predecessor. For example, the purchase of time-based tickets, intercity buses, and bus rides for more persons without contacting the driver became available. In addition to that, the new application became considerably advanced in the automation of certain processes that used to require manual intervention. For instance, the app can automatically open gates upon entry to closed car parks and parking garages. It also enables contactless use of P+R parking services and payment directly in the app. Moreover, the new Urbana app has a feature dedicated to passengers with disabilities. This feature enables them to notify a driver directly in the app that assistance will be required at the specific bus stop (Mestna občina Ljubljana, 2023a). The feature simplifies and speeds up the process and makes trips by bus more convenient for people with disabilities.

4.3.8 Electric Vehicles

Current trends clearly illustrate the rapid growth in the number of electric and hybrid vehicles in Slovenia. Out of all first-time registered new passenger cars in Slovenia in 2023, 23% were hybrid cars and 9% were electric ones. In one year, the number of first registrations of new hybrid passenger cars went up by 24% and of electric cars by 88% (Gostiša, 2024). Although the vast majority of all registered cars in Slovenia still use diesel and petrol fuel, the increasing demand for hybrid and electric cars clearly illustrates the gradual switch to eco-friendly alternatives on a national level.

One of the main incentives to switch to electric and hybrid cars is the purchase subsidies available for both physical and legal entities. For private individuals, legal incentives are applicable for both new and used electric vehicles, with a maximum amount of subsidies of 6,500 EUR. The legal entities are eligible for subsidies only for new electric vehicles, with the highest eligible vehicle value capped at 65,000 EUR. Similarly, there is registration tax and VAT deductions, along with other financial benefits in place to increase the uptake of alternative fuel vehicles (European Alternative Fuels Observatory, 2024).

Another important thing to consider is the infrastructure readiness in terms of charging points. The adjustment of the city infrastructure started taking place back in 2013, when the Electromobility Strategy in the City of Ljubljana was adopted to improve the existing strategies and further promote e-mobility. As a result, Ljubljana featured approximately 100

charging stations for electric vehicles by the end of 2017 (Mestna občina Ljubljana, n.d.*a*). Only three years later, there were more than 150 charging stations available in the city. Ljubljana was recognized as the most e-mobile city in Slovenia based on the overall mark given by the expert jury and the votes cast in an online survey conducted in 2020 (Mestna občina Ljubljana, 2020b). Similarly, in 2023, Ljubljana was ranked 9th on the availability of public electric vehicle charging stations among the analyzed European cities. The score indicated the availability of charges per 1,000 inhabitants (Carlier, 2023). Over the last decade, the infrastructure of Ljubljana has significantly improved to make the city more suitable and friendly for electric vehicles.

Ljubljana is also continually integrating electric vehicles into the infrastructure and operations of public companies. For instance, the first fully electric vehicle, Urban, was introduced for sightseeing in 2016 and further upgraded in 2018 with greater capacity and extended service (Mestna občina Ljubljana, 2016; Mestna občina Ljubljana, 2018). In December 2023, a second Urban vehicle was introduced as part of the EU's "100 climate-neutral and smart cities by 2030" mission (Mestna občina Ljubljana, 2023b). Additionally, the electric vehicles called Kavalir support mobility for the elderly and people with disabilities. They drive through the old city center of Ljubljana, which is closed to traffic. Also, a special Kavalir Clinic runs in the area of the University Hospital Ljubljana and the Ljubljana Oncology Institute. Kavalir rides are provided by the public company Ljubljana Passenger Transport in cooperation with the City Municipality of Ljubljana and Ljubljana Tourism (Ljubljana Tourism, n.d.*a*).

Similarly, two new LPP electric buses were introduced for a trial in Ljubljana in 2024. They run on bus lines number 1, 22, and 25 and are available for passengers as any other standard city bus. The new electric buses have an impressive battery capacity of up to 420 km on a single charge, which makes them suitable for public service (Mestna občina Ljubljana, 2024). In addition to that, Slovenske Železnice started renewing its rolling stock with electric trains. Moreover, 100% of the electricity for all electric trains in passenger and freight traffic was purchased from renewable sources in 2024, and it is planned to use only renewable energy in the future. This implies a significant reduction of the carbon footprint in railway transportation, which can minimize environmental risks (Slovenske Železnice, 2024).

4.3.9 Passenger Information Systems for Public Transport

Ljubljana introduced and actively uses various systems that provide information for public transport users. Although trains and railway stations are also equipped with such systems, the widest variety of solutions is present for city buses. Since 2017, all city buses have been fitted with the updated tracking system and automatic vehicle location technology (AVL). In addition to bus tracking and announcing bus arrivals, this also allows monitoring of fuel consumption for individual vehicles, automatic transfer of data on vehicles and drivers to the default LPP systems, and transfer of traffic information to other systems like PROMinfo

or Google Transit (Mestna občina Ljubljana, n.d.*b*). Currently, passengers can obtain information on bus arrivals in several ways. They can use the LED displays available at more than 120 stops around Ljubljana. These displays provide real-time information on bus arrivals. Printed bus schedules are also available at most bus stops, along with so-called "e-paper" schedules installed at stops on Slovenska Street in the city center (Mestna občina Ljubljana, 2019). Additionally, real-time information on public transport is available in various mobile applications like Urbana or Google Maps. The official website of LPP also provides access to the current schedules for all city buses.

The city buses themselves are also equipped with systems for informing the passengers. Several screens are installed in each vehicle, not only providing information on the next stop (the name, remaining time to arrival, transfer options) but also displaying content like information on road constructions, changes on the bus lines, weather conditions, the latest news, promotion of various upcoming events, and so on. The city buses also have an audio announcement system. As the bus approaches a stop, the system makes an audio announcement about the upcoming stop. Simultaneously, a small screen, usually located at the front of the bus, projects the name of the stop. Both systems not only make the ride on the bus more convenient for regular passengers but are also crucial for assisting passengers with visual or hearing impairments.

Overall, the public transport in Ljubljana is well-equipped with passenger information systems. However, from personal experience, it can be fairly said that these systems are not always performing well. The "real-time" information on the LED displays or "e-paper" schedules is often incorrect. Not infrequently, the information on certain bus arrivals just "freezes" and does not change until the bus arrives at the stop. Moreover, not every bus stop in Ljubljana and its surroundings where LPP buses run is equipped with such a display. Audio announcements or in-bus information screens are sometimes also faulty or switched off. Therefore, certain improvements can still be made in this field.

4.4 Analysis of Existing Issues in Mobility

Analyzing the state of mobility in Ljubljana helps to identify the main challenges in the field and lays the groundwork for recommendations on future improvements. The following are the key mobility issues that the city currently faces, determined based on the analysis of the secondary resources provided in the previous chapters and personal experience. They can be addressed or mitigated by introducing certain smart mobility initiatives.

Issue 1: Excessive use of private cars among commuters

As mentioned in the previous chapters, the majority of journeys to the MOL are made by car. A similar pattern applies to the journeys conducted exclusively within the MOL. However, the use of other modes of transport significantly differs between these two types of journeys. In particular, the share of journeys made by public transport conducted outside the LUR to the MOL area is significantly lower compared to public transport journeys made

within the MOL (RRA LUR et al., 2019). This trend represents a significant issue regarding traffic congestion and CO2 emissions in Ljubljana, as the majority of commuters are still traveling to MOL from other parts of Slovenia on a daily basis, while the existing infrastructure and current capacity of public transport could accommodate only a small percentage of passengers who daily commute to Ljubljana by car. Therefore, the development of regional infrastructure is crucial as the current capacity of public transport is not sufficient. More importantly, the accessibility of public transport in other areas of Slovenia has a direct impact on the traffic in Ljubljana. This creates a fast-growing issue of increased car usage within the MOL.

Issue 2: Inefficiency of public transport

Public transport presents great potential for the development of sustainable mobility in the city, yet the number of its users is stagnating (RRA LUR, 2022b). This can be attributed to numerous issues related to public transport. Based on personal experience and multiple papers on mobility in Ljubljana, the problem of inefficient public transport schedules is evident. For instance, the need for timetable adjustments and schedule alignment between different transport modes is discussed within the frameworks of SUMP LUR, RIS LUR, and RDP LUR (RRA LUR, 2019, 2022b, 2022a). During weekends, most city buses run at big intervals or do not run at all; the examples can be found in the timetables for buses number 8, 3, 11, 22, 24, 27, and others (LPP, n.d.). This poses inconveniences and might discourage some people from using public transport on weekends. Intercity public transport timetables also remain unoptimal, showing that journey times on these routes are too long, and that buses and trains are too infrequent (RRA LUR, 2022a).

Delays in public transport, which are described in LPP annual reports and regularly experienced firsthand, also pose an issue. This can be attributed to various reasons, including traffic congestion, inefficient urban planning, vehicle malfunction, etc. Frequent bus and train delays inconvenience public transport users, especially those who must transit. This may also encourage people to change their mode of transport to a more convenient and predictable one, such as a personal car. Technologies like the LED displays placed at bus stops serve to inform people about delays, allowing them to correct the route accordingly if needed. However, as already mentioned, they do not always display accurate information and are not present at every city bus stop.

Although the LPP fleet is constantly replenished with new buses, there are still numerous old vehicles in operation (LPP, 2025). The adoption of eco-friendly fuelled and electric-powered buses is also happening at a rather slow pace. In addition, some lines with a large number of passengers have smaller rigid buses running around instead of articulated buses. An example can be line number 27, which connects the two largest shopping areas in Ljubljana - the one in the Rudnik district and BTC City. The popularity of the destinations leads to high demand on this line, resulting in overcrowded buses, which is supported by personal observations.

People in wheelchairs still face limitations when using public transport. Buses and trains are not equipped with automatic ramps. Therefore, people with disabilities must ask for assistance from bus drivers or railway staff on the spot to organize the folding ramps. Slovenske Železnice recommends people with reduced mobility to announce their journey 24 hours before the train departure (Slovenske Železnice, n.d.*a*). For bus rides, the Urbana app now has an option to notify the driver of the assistance needed in advance. However, the process is still highly inefficient and may cause inconveniences and delays in public transport departures.

Issue 3: MaaS limitations

The new Urbana app has brought significant advancements to traveling optimization in Ljubljana. However, the app has its own drawbacks and limitations. Based on the user feedback, there are certain technical issues related to online payments that require 3D Secure authentication - an international security standard supported by Mastercard and Visa used for verifying the identity of cardholders when making online payments. Similarly, many customers were facing difficulties in the migration of their Urbana cards to the new app (App Store, 2023). This experience might be a significant barrier to switching to the app for LPP customers who are used to a physical Urbana card. Also, certain customer responses indicate that bus delays are not timely reflected in the app (App Store, 2023). The app provides live data on the arrivals, but the changes do not always represent an objective estimation and therefore threaten its reliability. This could potentially reduce the usage of the app.

In addition to that, the application does not allow you to pick the destination directly on the city map interface unless it is a BicikeLJ station, bus stop, parking lot, or some other predefined location such as a museum or landmark. The list of predefined locations is rather limited. Hence, the precise address must be checked and manually typed in the search box to build the route to it. For example, the app does not include information on the School of Economics and Business or any other faculty of Ljubljana University. Based on this, it can be concluded that there is an evident lack of map interactivity and ease of building the route in the app.

What is more, the Urbana app does not include railways in its suggestions. Therefore, if a user travels from or to another city, the application might not provide the most cost-efficient and time-saving solution. It poses a significant challenge for users who conduct intercity trips on a regular basis. There is a separate app called “Grem z vlakom” developed by Slovenske Železnice, which allows users to purchase train tickets directly in the app and provides information on train cancellations and delays (Slovenske Železnice, n.d.*b*). However, the application does not provide any additional information. Train routes, the location of railway stations, and other details cannot be viewed in the app. Hence, the railway system in Slovenia does not yet have a digitalized MaaS solution available.

The Urbana app also cannot estimate the travel time for cycling. The suggested route and the estimated travel time will not be precise for users traveling by bicycle. As mentioned before, the app can provide the route to the selected BicikeLJ station, and it even provides information on available bikes and stands. Nonetheless, rental setup and payment management are conducted in a separate BicikeLJ app. The Urbana app allows redirection to the BicikeLJ app in one click; however, it still creates additional complications in MaaS integration, as users need to have two apps downloaded and switch between them for using different modes of travel. This should not be the case for a harmonized and unified implementation of MaaS.

Issue 4: Traffic congestion

As previously mentioned, Ljubljana faces the problem of traffic congestion, especially during peak hours. Traffic jams and extended travel times on the road network are especially pronounced during the morning rush hour, which lasts for approximately two hours. At the end of the working day, Ljubljana also faces a high level of traffic congestion on its main roads. Heavy traffic during peak hours is mainly the result of daily commuting. In the event of such a travel pattern, constructing new infrastructure and expanding existing major roads is not an effective approach to resolving the issue. It would serve as a temporary solution, shifting the congestion problem to areas where expansion is impossible due to spatial limitations or other reasons (RRA LUR et al., 2019). Moreover, it further encourages people to use cars; hence, the problem repeats on a greater scale. More advanced solutions should be established to address the issue.

5 IMPROVING SMART MOBILITY IN LJUBLJANA

This chapter focuses on primary research conducted in the form of a survey that analyses the mobility habits of Ljubljana's citizens and visitors, along with the main challenges related to different modes of transport and the city's main smart mobility solutions. Based on the survey findings and the overview of the smart mobility initiatives, the action plan for improving the smart mobility state of Ljubljana is presented. The action plan is determined to address the mobility issues identified in the scope of this thesis, as well as the problems identified through the survey. At the end, the study's contributions and practical implications, along with limitations and directions for future research, are discussed.

5.1 Methodology

The survey was conducted online using the 1ka portal, with the option to choose between English and Slovene. Providing the survey in both languages allowed a wider range of respondents and made it more inclusive. The survey consisted of 21 questions, most of which were conditional. Therefore, the actual number of questions and the completion time varied among the respondents, the median duration being 3 min 20 sec. The questionnaire was fully anonymous, and respondents were notified about this before the start.

The survey was distributed using a snowball sampling method. Initially, the questionnaire was shared with 27 acquaintances (friends, relatives, and coworkers) primarily through online channels such as Facebook, Teams, and other messaging platforms. They were encouraged to distribute the survey further, which resulted in obtaining the vast majority of respondents. Overall, 143 people participated in the survey, of which 10 people only partially completed it. The results of the partially finished survey were also included in the analysis.

The snowball sampling method was used for several reasons. First of all, the target population is vast and non-defined, as there is no list or database containing all of Ljubljana's urban mobility users with a classification on car users, public transport users, cyclists, and shared mobility users. Snowball sampling allows for reaching this diverse population through social networks and personal connections. Secondly, this sampling technique is characterized by both cost-effectiveness and time-efficiency due to reliance on initial respondents to refer others, reducing the time and effort required for data collection (Cohen & Arieli, 2011). Last but not least, snowball sampling provides a higher response rate by utilizing referrals from trusted contacts (Ting et al., 2025). Snowball sampling is used in many modern studies; for instance, this sampling technique was chosen by A. Sheykhfar et al. (2025) in their study "Gender roles in sustainable mobility: exploring e-scooter adoption intentions in a developing country through an integrated TPB-UTAUT framework" and by S. R. Leat et al. (2022) in the study "Exploring the feasibility of shared mobility services for reducing transportation disadvantage among survivors of intimate partner violence".

Despite the advantages of the chosen sampling method, it also has its limitations. A significant drawback of snowball sampling is the limited representativeness of the broader population (Sadler et al., 2010). Given the non-probability nature of the sampling, statistical testing against the population is not possible, which limits the generalizability of the research findings. Nevertheless, the obtained results provide us with relevant insights into the experiences and opinions of a segment of the city’s urban mobility users, and they can be used to draw further recommendations for improvements.

The survey questions can be divided into three subcategories: demographic-related, questions related to the modes of transport the respondents use, and questions on the usage and satisfaction with some of the current smart mobility solutions in Ljubljana. A combination of multiple-choice, single-answer questions and Likert scales was used when designing the questionnaire. Some of the questions also had an open-answer option. The first question («What is your primary role in Ljubljana?») was designed so that people who are not related to Ljubljana and do not travel to the city can finish the survey immediately by choosing the option «I do not visit or live in Ljubljana». This enabled the filtering of respondents to include only the relevant population with valid responses based on their experience, and provided the option to exit the survey for individuals who were not part of the target population.

Analysis of the results was done using descriptive statistics. All answers were transferred to Microsoft Excel, where they were analyzed, and corresponding charts were created to present the survey results visually. For most of the questions, bar or column charts were used to better present the trend, making the leading answers more prominent. The column charts were used to show the usage of the smart mobility solutions (P+R parking, Urbana mobile application, and shared mobility modes). The bar charts were used to present certain transportation challenges, desired improvements, the importance of certain parameters when choosing the modes of transport, and the reasoning behind the non-usage of some smart mobility solutions. As these questions had multiple answer options, I chose a bar chart for the presentation as it allows better readability and easier comparison of the results. Additionally, I also used pie charts to present the distribution of different transport modes for traveling to and within Ljubljana. With such charts, it is easier to check the distribution between the modes and see which one is the most widely used.

5.2 Survey results

The first three questions of the survey aimed to assess the demographic characteristics of the sample population. In total, 143 participants answered the question on their primary role in Ljubljana. Since one of the answer options implied the end of the survey, fewer people answered the other two questions. Additionally, we can see that there were two survey dropouts after the first question. Overall, 136 participants shared their age group and main occupation. In the table below, the results of the demographic-related questions are presented with both the number of responses (f) and their relative proportion in percentage (f%).

Table 1: Demographic structure of the respondents

		f	f %
Primary role in Ljubljana	Resident	62	43,3%
	Commuter (travel to work or study)	42	29,4%
	Occasional visitor	34	23,8%
	None of the above (I do not visit or live in Ljubljana)	5	3,5%
Age group	Under 18 years old	0	0,0%
	18 - 34 years old	62	45,6%
	35- 54 years old	52	38,2%
	Over 54 years old	22	16,2%
Main occupation	Student	17	12,5%
	Employed	107	78,7%
	Unemployed	9	6,6%
	Retired	3	2,2%

Source: Own work

As evident from the results table (Table 1), the residents of Ljubljana formed the biggest group of respondents. Commuters (regular visitors) form the second-biggest group, followed by occasional visitors. Altogether, the number of visitors (regular and occasional) slightly exceeds the number of residents who participated in the survey, but the two groups are fairly balanced (53,2% against 43,3%). There is less balance in the age group distribution. There were no respondents under 18 years old, and few respondents over 54 years old. The other two groups are close to each other, with a slight prevalence of 18-34-year-olds. The highest inequality is in terms of respondents' occupation. The leading position is occupied by employed people (78,7%), which is not surprising considering the main active population. Also, the question was about the main occupation; thus, people who work and study, for instance, might consider working their main activity.

Based on the primary role of respondents, they were given a different set of questions regarding their main mode of transportation. While residents were only asked about the main modes of transport they use in Ljubljana, commuters and occasional visitors were also asked to share their main mode of transportation to the city. As people often combine different modes of transport when traveling around the city, this question was multiple-choice. Both questions aimed to understand transportation preferences among the population and the popularity of sustainable transport modes like public transport, cycling, or walking. These questions were inspired by the survey results provided in the SUMP LUR mentioned earlier, which reveals similar statistics for the year 2014. Hence, the results can be compared. Figure 1 shows the distribution of transport modes for traveling to Ljubljana and within the city.

Figure 1: Distribution of transport modes when traveling to and within Ljubljana

Source: Own work

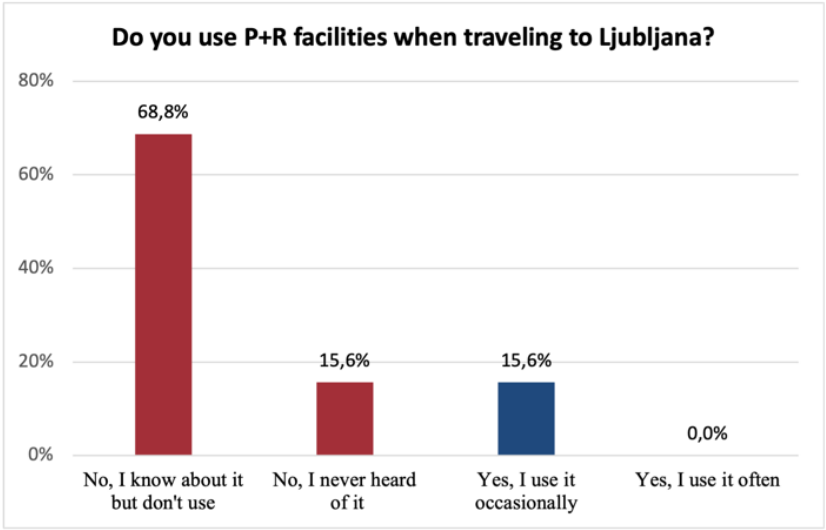
When traveling to Ljubljana, most people prefer to use cars, which also correlates with the survey results provided in the Sustainable Urban Mobility Plan of LUR. Only 12,3% of respondents use public transport when visiting Ljubljana, a bus being a more popular mode than a train. These results show a clear trend of overwhelming reliance on private vehicles, signaling the low attractiveness of public transport options for people traveling from outside the city. The need for improvements in public transport is evident. The low level of railway usage in both cases (4,1% and 2,7%) also highlights the failure to meet one of the Ljubljana

2025 Vision points on increasing the importance of railways as public transport in the metropolitan area.

The relative percentages of the selected options were used to analyze the distribution of transport modes within Ljubljana. The statistics show that cars are also the prevailing transport mode for traveling around the city, similar to the SUMP LUR survey results. High car usage in both cases contributes to regular traffic congestion, air pollution, and carbon emissions, lowering the quality of life in Ljubljana. The popularity of public transport for inside-the-city travel is slightly higher (cumulative of 19,8%). However, the figure is still unsatisfactory, being more than half lower than the leading result. The same percentage is allocated for walking. Due to the scale and landscape of the city, this transportation option is quite popular and takes up the second position in the chart. Cycling is also relatively widespread, second only couple of percent to buses. E-scootering is a fairly new mode of transport, but it has already outperformed trains in usage. Two respondents chose the option "Other", and both stated skateboarding as their transportation option.

Further on, commuters and occasional visitors who chose a car as their main mode of transport were asked whether they use P+R parking when traveling to Ljubljana. As P+R parking facilities are promoted to encourage people to use public transport in the city more, it is important to assess the percentage of people who, in fact, use them. The results are presented in Figure 2 below.

Figure 2: Usage of P+R facilities

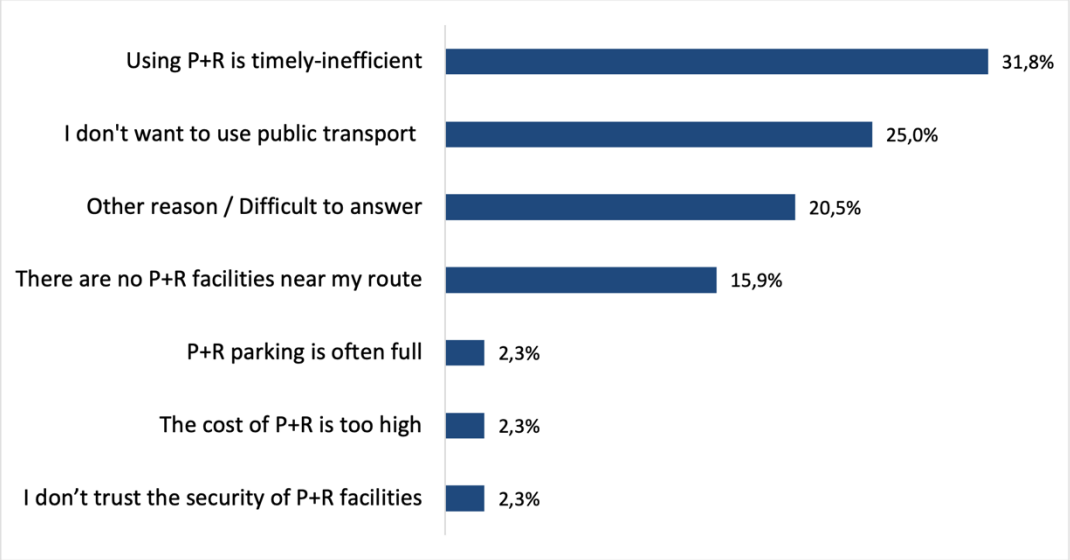


Source: Own work

The results show that most respondents are aware of P+R facilities but do not use them (68,8%). The percentage of people who have never heard of P+R is the same as that of those who use the parking occasionally (15.6%). What is important, none of the respondents use P+R facilities often. The resulting distribution suggests that the P+R solution is not very popular among Ljubljana visitors and that the concept is not working as anticipated. To

understand the leading causes of non-usage, people who replied: “No, I know about it but do not use”, were asked to provide the main reason why they do not use the facilities.

Figure 3: Main reasons for non-usage of P+R facilities

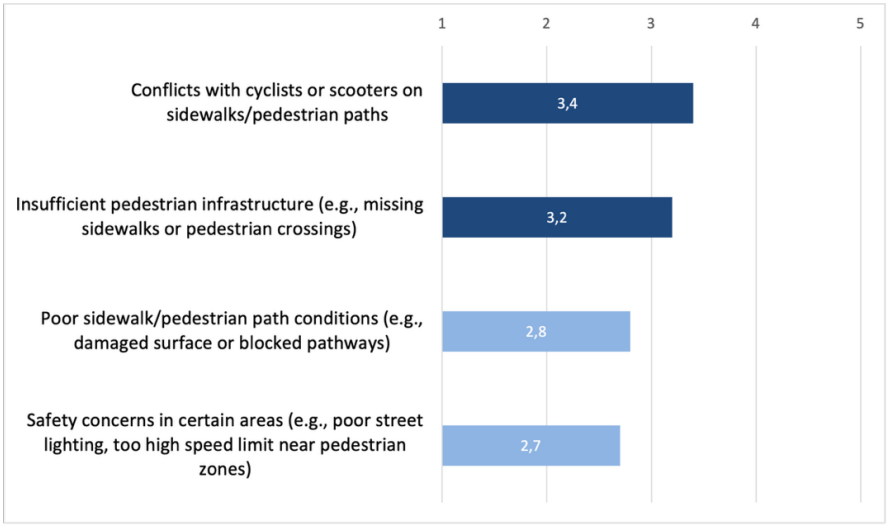


Source: Own work

As Figure 3 shows, the leading reason is time inefficiency (chosen by roughly a third of the respondents). This could also be related to the second most popular reason - an unwillingness to use public transport when traveling from or to P+R parking, as time inefficiency can be attributed to long waiting times for public transport, inefficient road connections, or bus schedules. Another reason that stands out is the absence of P+R facilities near some routes. The P+R network is constantly growing, but the results suggest that there are still not enough facilities to cover the demand effectively. Some respondents had other reasons or struggled to answer the question, and only a small proportion of respondents chose the rest of the reasons.

Based on the responses about the main modes of transport in Ljubljana, survey participants were then asked follow-up questions on the challenges associated with the chosen modes. A Likert scale was used to assess the relevance of each challenge for Ljubljana. The scales allowed assessment from 1 to 5, where 1 means the challenge is not relevant at all, 3 means the challenge is somewhat relevant, and 5 implies it is extremely relevant. For presenting and analyzing the results, the average scores were used. Challenges receiving an average score of 3 or more are considered to be relevant for Ljubljana, meaning these issues should be addressed. Challenges with an average score of less than 3 are considered to be not problematic for the city.

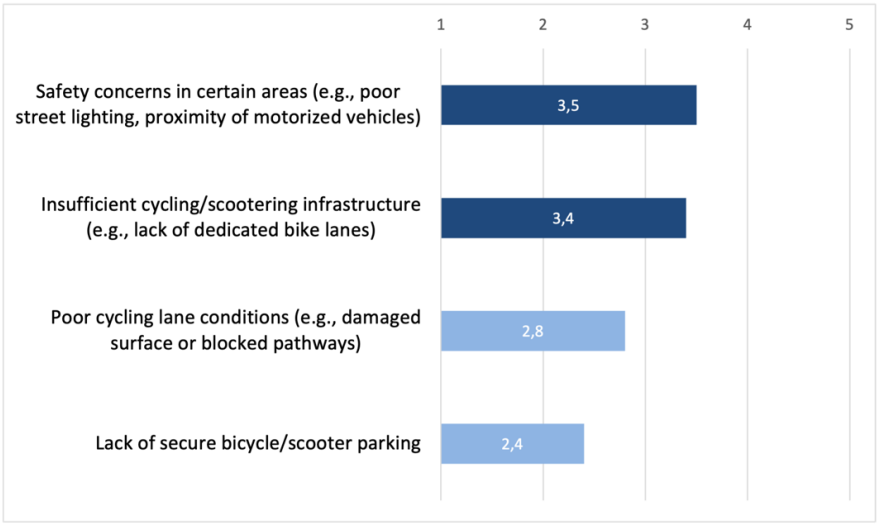
Figure 4: Challenges for walking in Ljubljana



Source: Own work

Respondents highlighted two main challenges related to walking in Ljubljana.“Conflicts with cyclists or scooters on sidewalks/pedestrian paths” is the leading one, having on average a score of 3,4. It is followed by the problem of insufficient pedestrian infrastructure, having an average score of 3,2. While neither of the scores is that critical, they indicate that certain improvements could make walking in Ljubljana more pleasant. The first issue suggests that there are either not enough bike lanes in the city, or the cycling/scootering on the sidewalks and pedestrian paths is not well-regulated. This is not only disturbing for pedestrians but can also be dangerous. The second issue suggests that the pedestrian infrastructure should be expanded. Respondents, on average, did not find the other two challenges relevant for Ljubljana (poor sidewalk/pedestrian path conditions and safety concerns in certain areas).

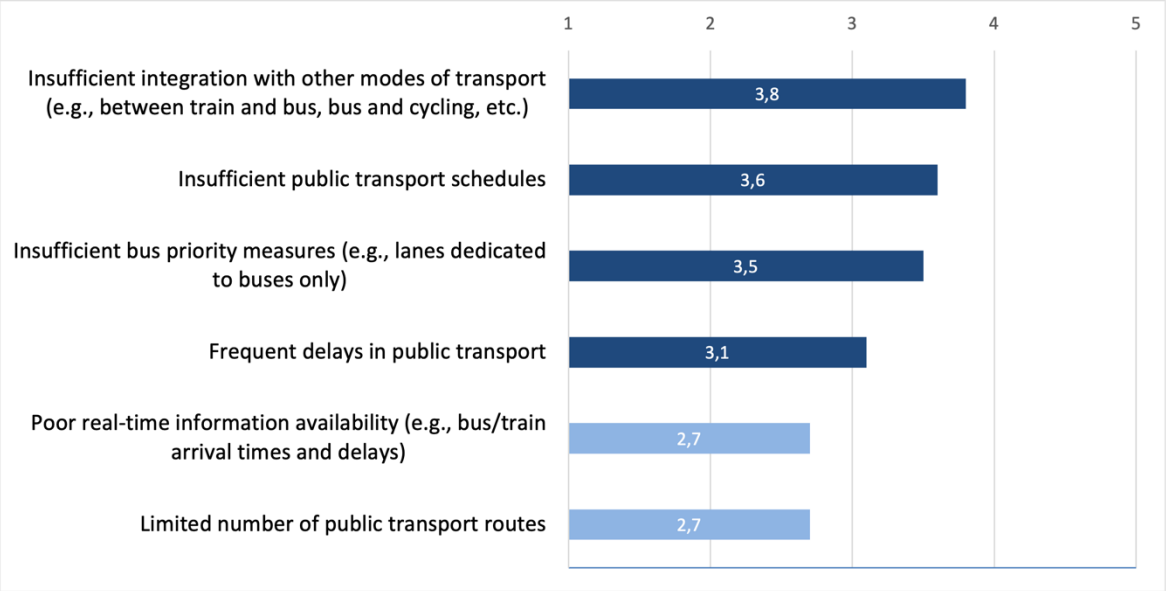
Figure 5: Challenges for cycling and scootering in Ljubljana



Source: Own work

Figure 5 shows that insufficient cycling/scootering infrastructure in Ljubljana, implying the scarcity of bike lanes, is one of the challenges highlighted by riders, which correlates with the main challenge chosen by pedestrians (conflict with cyclists and scooters). The challenge that was ranked even slightly higher is the safety concerns in certain areas. Most likely, the respondents were guided by the examples given in brackets when evaluating this option. As street lighting was not a concern for pedestrians, it is unlikely this is a concern for riders either. The proximity of motorized vehicles when cycling/scootering might be a bigger problem, which is again related to the lack of separate bike lanes. When there are no sidewalks, cyclists often use the main road, which raises the risk of accidents and disturbs all road users. Initiations on expanding cycling infrastructure in Ljubljana should continue so that cycling and scootering in the city become easier and safer. This could also potentially increase the number of users for these transport modes. As the results show, there are no major problems with cycling lane conditions and secured parking for bikes and scooters.

Figure 6: Challenges related to public transport in Ljubljana

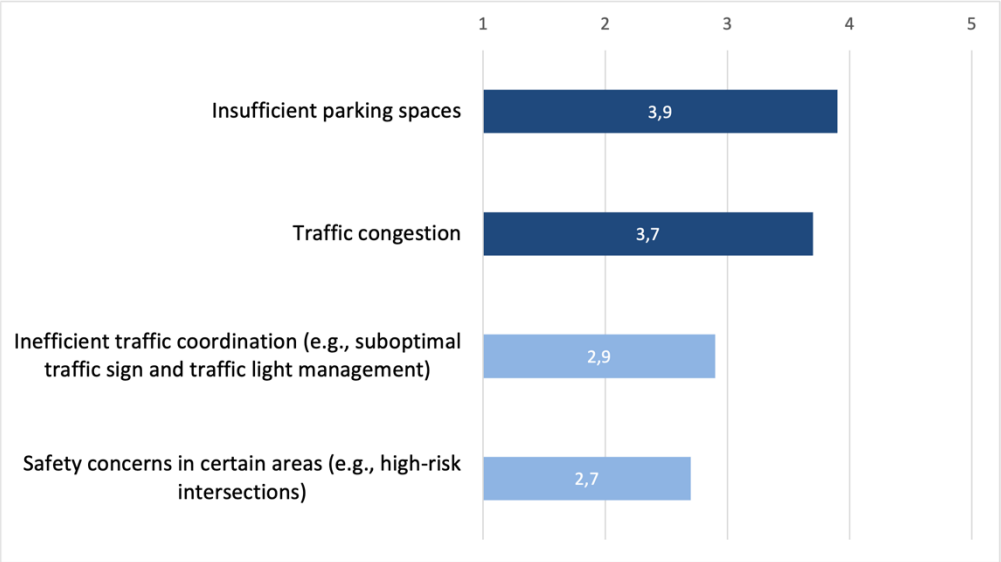


Source: Own work

More potential challenges can be associated with public transport; therefore, more options were allocated to the corresponding survey question. As shown in Figure 6, the public transport users in Ljubljana highlighted four relevant challenges. “Insufficient integration with other modes of transport” appeared to be in the leading position with a 3,8 average score for relevance. This suggests that better infrastructure and planning are needed to enhance the seamless transition between the transport modes in Ljubljana. Another issue with a high score was “Insufficient public transport schedules” (with a score of 3,6 on average). This signals the need for improvements in the frequency, reliability, and flexibility of public transport schedules. This challenge partially relates to the previous one, as insufficient schedules may disrupt transfer journeys. Also, it might be connected to another

highlighted challenge – "Frequent delays in public transport". Insufficient bus priority measures were also considered relevant for Ljubljana by the respondents, indicating that more dedicated bus lanes, for instance, can be introduced to improve the user experience. Additionally, it will also positively affect the problem of delays for buses. Finally, the collected data shows that the real-time information availability is sufficient and that the number of public transport routes is not an issue.

Figure 7: Challenges for car users in Ljubljana

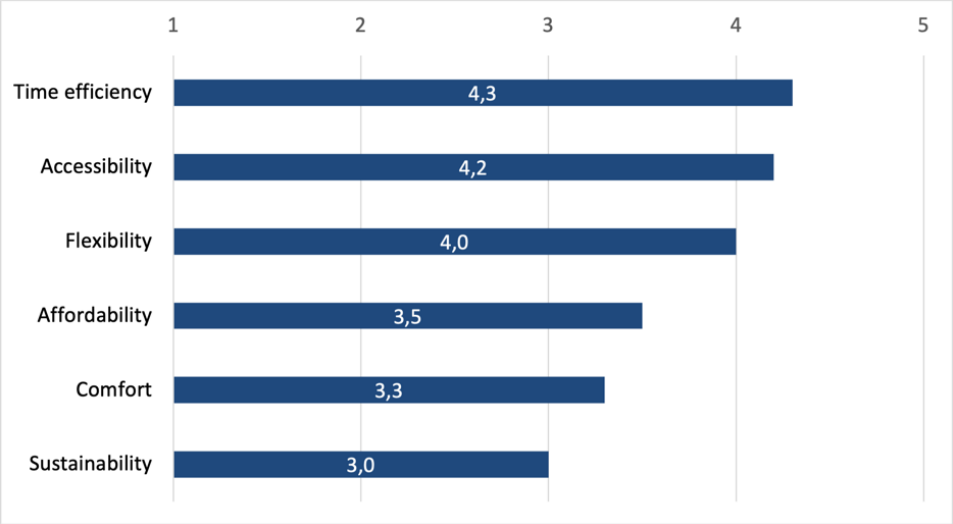


Source: Own work

As shown in Figure 7, car users chose "Insufficient parking spaces" and "Traffic congestion" as the most relevant challenges for Ljubljana. The results signal that the city struggles to meet the high car demand. This might be an opportunity to encourage people who find these challenges relevant to reduce their dependence on private vehicles, but this needs to be done together with increasing the attractiveness of alternative transport modes. Inefficient traffic coordination got a bit less than a score of 3 on average, staying on the "irrelevant" side, but it could still be a problem in some areas of the city. Safety concerns, in their turn, were not considered a significant challenge for Ljubljana by most car users surveyed.

Further on, all the survey participants were asked to rate the importance of different parameters when it comes to choosing the mode of transport in Ljubljana. For this question, a 1-5 Likert scale was used as well, where 1 stands for "Not important at all", 3 for "Somewhat important", and 5 for "Extremely important".

Figure 8: Importance of parameters for choosing a transport mode in Ljubljana

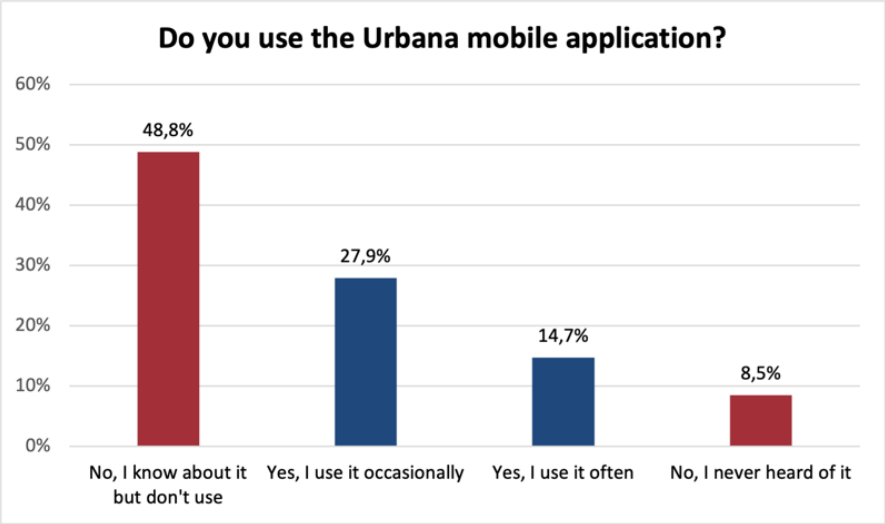


Source: Own work

As seen in Figure 8, all the parameters received an average score of 3 or higher. However, we can still see that some of them are considered more important than others. Time efficiency got the highest average score of 4,3. When people choose a means of transportation, it is important for them to go from point A to point B as fast as possible. This indicator is crucial to consider for improving public transport in the city; it implies that insufficient schedules and frequent delays could be a big barrier for many people to use public transport daily. Accessibility was ranked the second most important parameter, having an average score of 4,2. This parameter can be understood differently, but generally, it refers to the accessibility of certain infrastructure. For example, if people do not have a bus station within walking distance of their house, it is unlikely that they will use buses as their main mode of transport. This leads to a high dependency on personal vehicles. Flexibility is the next important parameter, having a 4,0 score on average. Usually, driving a car gives people the highest flexibility as they are not tight to schedules and routes. This highlights the need for other modes of transport to become more flexible as well. It is related to better integration between different transport modes and improving the public transport schedules, which would increase flexibility and, hence, the attractiveness of more sustainable transport means. Interestingly, affordability, comfort, and sustainability received noticeably lower scores than the first three parameters. Sustainability as a factor affecting the choice of transport mode got the lowest score of all. This is remarkable, considering many past and current smart mobility projects related to Ljubljana focused on sustainable mobility.

The next block of questions for the participants was about the use of the Urbana mobile app. First, they were asked whether they use the app and, if so, how often. Then, based on the provided answer, they were asked about the improvements they would like to see in the app or about the main reason behind non-usage.

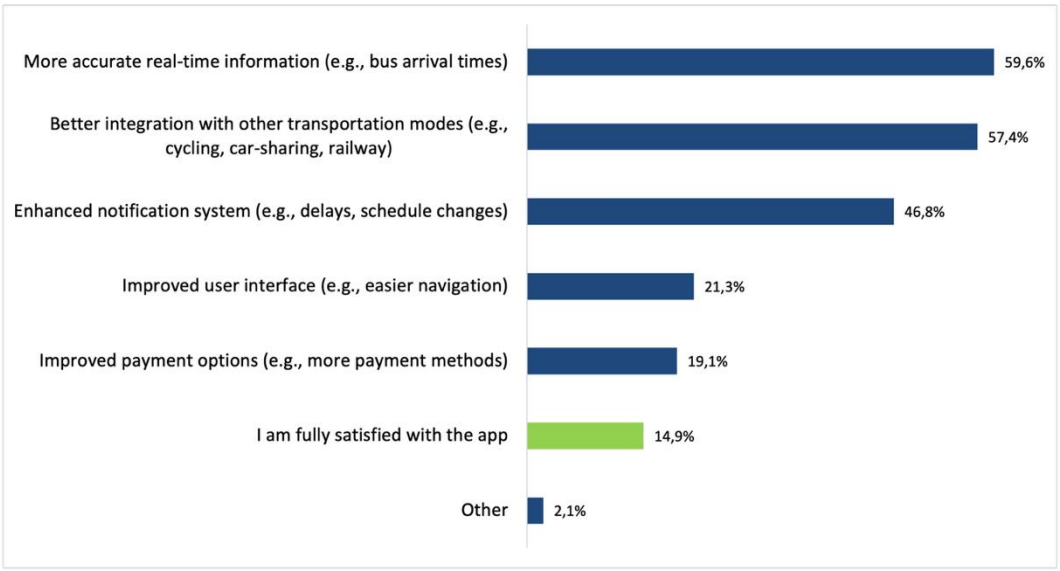
Figure 9: Usage of the Urbana mobile app



Source: Own work

Figure 9 shows that nearly half of the respondents know about the app but do not use it (48,8%), which slightly surpasses the cumulative share of those using it occasionally or often. Based on this, we can conclude that awareness of the potential users does not necessarily translate into actual use. This suggests that some people might not see the value in the app, or there are certain barriers to its usage. 27,9% of respondents use the app occasionally, and only 14,7% use it often. We can see that there is a big potential for increasing the number of regular users. It is a good sign that only 8,5% of respondents have never heard about the Urbana app, which means that efforts to raise awareness about it work.

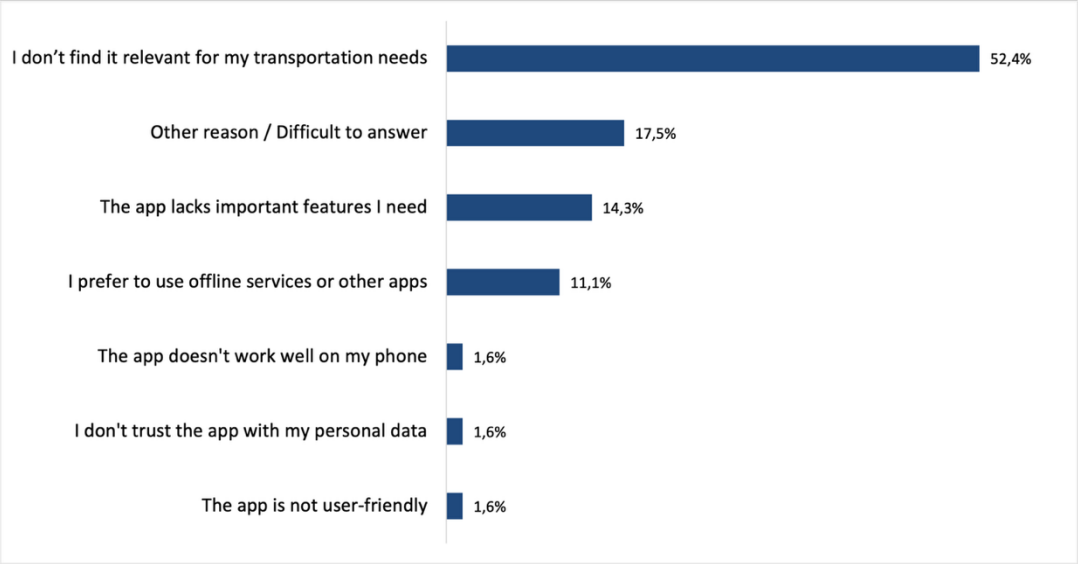
Figure 10: Improvements for the Urbana mobile app



Source: Own work

The question about improvements for the Urbana app was multiple choice. People who chose the option "I am fully satisfied with the app" could not select any improvements they would like to see. For the analysis of the results, I decided to show the actual percentages of the respondents choosing each option. The leading improvement respondents would like to see, selected by 59,6%, is related to more accurate real-time information provided. Here, we can see that reviews from the Apple App Store mentioned earlier are supported by statistics, highlighting the inaccuracy of real-time data as a big drawback for the app. The second most desirable improvement is better integration with other transportation modes, chosen by 57,4% of respondents. Urbana would benefit from introducing new features and expanding its functionality to cover more modes of transport within one app. This would also strengthen its position as a MaaS platform and contribute to an increase in its number of users. The enhanced notification system of the app is the third choice by popularity, 46,8% of respondents chose this option as a desirable improvement. Timely and effective notifications that improve user experience can be considered an important area for further app development. The other two options ("Improved user interface" and "Improved payment options") were selected much less than the first three, suggesting that the problems in these areas are not that crucial but can still be considered. Only 14,9% of respondents are fully satisfied with the Urbana app, which is a relatively low level of user satisfaction. There was one response under "Other", which stated "Clear instructions on getting a monthly subscription" as a desirable improvement

Figure 11: Reasons for non-usage of the Urbana app



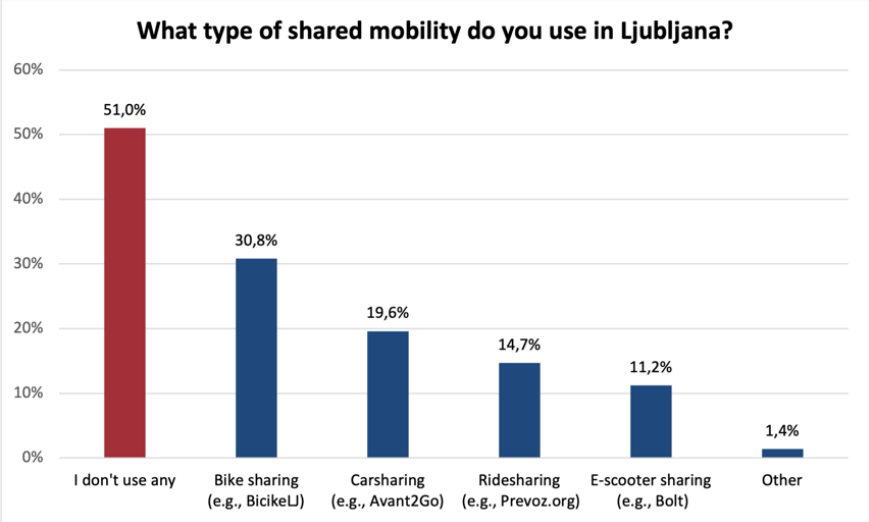
Source: Own work

The results displayed in Figure 11 show that more than half of the respondents do not use the Urbana app because they do not find it relevant for their transportation needs. This reason stands out as the percentage of respondents selecting this option significantly exceeds that of the next popular choice. This again signals the need to expand the functionality of the app.

However, it might also mean that some people are unaware of the existing functionalities of the Urbana app and that it can also be used by car drivers and BicikeLJ users, for instance. Therefore, special emphasis should be placed on the multiple functionalities when promoting the app. The "Other reason / Difficult to answer" option was the second most popular, chosen by 17,5% of respondents, followed by "The app lacks important features I need" with 14,3% selection, and "I prefer to use offline services or other apps" with 11,1% choosing this option. The other three options received the same number of selections (each was chosen once). Such a low level of selection suggests that these reasons are not common and should not be considered critical.

The last block of questions in the survey was dedicated to shared mobility. Respondents were asked whether they use any types of shared mobility in Ljubljana and, if they do, which ones. The question was multiple-choice without the possibility of simultaneously choosing any solution, and the option "I do not use any". Then, respondents who stated they do not use any type of shared mobility in the city were asked to provide the main reason for this. The rest were asked to identify challenges they encountered when using their chosen shared mobility modes, if any.

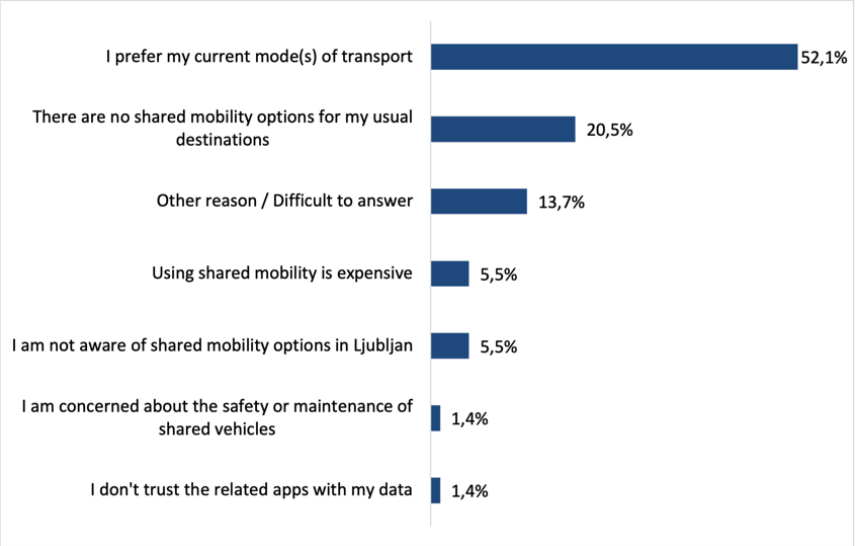
Figure 12: Usage of shared mobility in Ljubljana



Source: Own work

Slightly more than half (51,0%) of the respondents do not use shared mobility options in Ljubljana (Figure 12). The most popular type of shared mobility in Ljubljana is bike sharing, used to a varying degree by 30,8% of respondents. Carsharing takes the next place by popularity, with 19,6% of respondents choosing this option. Ridesharing is used slightly less; 14,7% of respondents stated that they use this type of shared mobility. Finally, e-scooter sharing is the least popular, with 11,2% of selection. Replies in the category "Other" are not valid in this case, as they stated "Car" and "Nomago električni kolesa"; both refer to categories that already exist separately as options (carsharing and bike sharing).

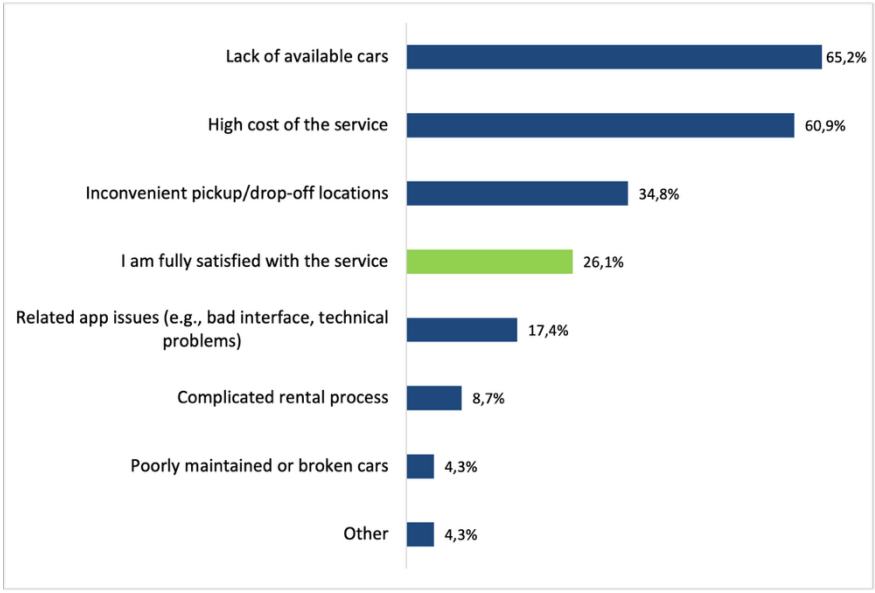
Figure 13: Reasons for non-usage of shared mobility in Ljubljana



Source: Own work

The most popular reason why respondents do not use shared mobility in Ljubljana is, expectedly, the fact that they are satisfied with their current modes of transport. 52,1% of respondents stated this as the main reason. The next reason received fewer than half the responses as the previous one. It refers to the fact that there are no shared mobility options for the usual destinations of people choosing this option. This indicates that shared mobility infrastructure should grow to be accessible to more potential users. The "Other reason / Difficult to answer" option was next by popularity, with 13,7% of respondents choosing it. The rest of the reasons were not selected often.

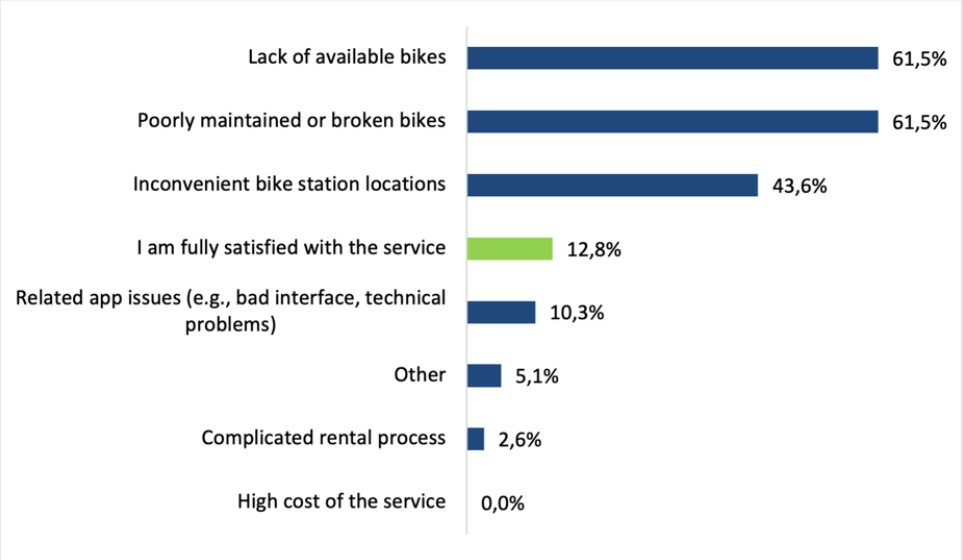
Figure 14: Challenges related to carsharing in Ljubljana



Source: Own work

Figure 14 presents the results of the question: “What challenges have you experienced when using carsharing in Ljubljana?”. Participants could choose more than one answer. Two challenges are particularly prominent, selected by more than 60% of respondents: “Lack of available cars” and “High costs of the service”. The next challenge in the list is “Inconvenient pickup/drop-off locations”, faced by 34,8% of respondents. This percentage is already much lower, but still significant enough to consider it an issue. The percentage of answerers fully satisfied with carsharing in Ljubljana is 26,1%, presenting the highest satisfaction rate among all shared mobility types analyzed in the survey. “Related app issues” was chosen as a challenge by 17,4% of those who answered the question. The rest of the options got an insignificant percentage of 8,7% for “Complicated rental process” and 4,3% for “Poorly maintained or broken cars”, meaning these challenges are not that common and are more likely isolated cases. One respondent who chose “Other” wrote in the description: "No charging cable in the car" as an encountered challenge.

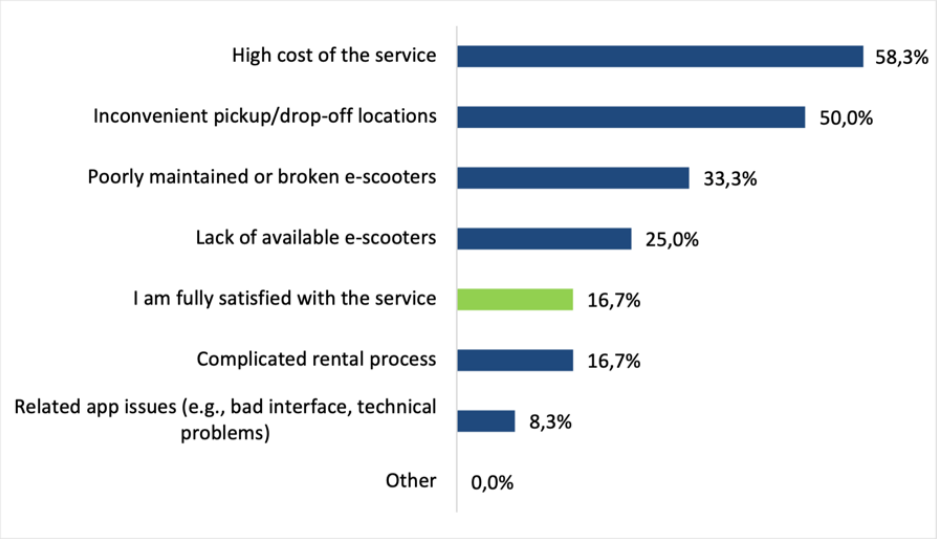
Figure 15: Challenges related to bike sharing in Ljubljana



Source: Own work

In Figure 15, we see that the two leading challenges related to bike sharing in Ljubljana were highlighted by the same percentage of respondents (61,5%) – “Lack of available bikes” and “Poorly maintained or broken bikes”. “Inconvenient bike station locations” was selected as a challenge by 43,6% of answerers. These three issues were selected most often, by a wide margin from the other options, suggesting they are the most critical ones. The satisfaction rate with this service is already much lower than for carsharing – 12,8%. “Related app issues” and “Complicated rental process” options were not selected by a high percentage of respondents, meaning that these issues were likely individual instances. Two respondents chose the option “Other”, both stating that the lack of parking spots for bikes at the end of the rental process is a challenge. We can see that there are no complaints about the cost of bike sharing being high, as this option was not selected by any service users surveyed.

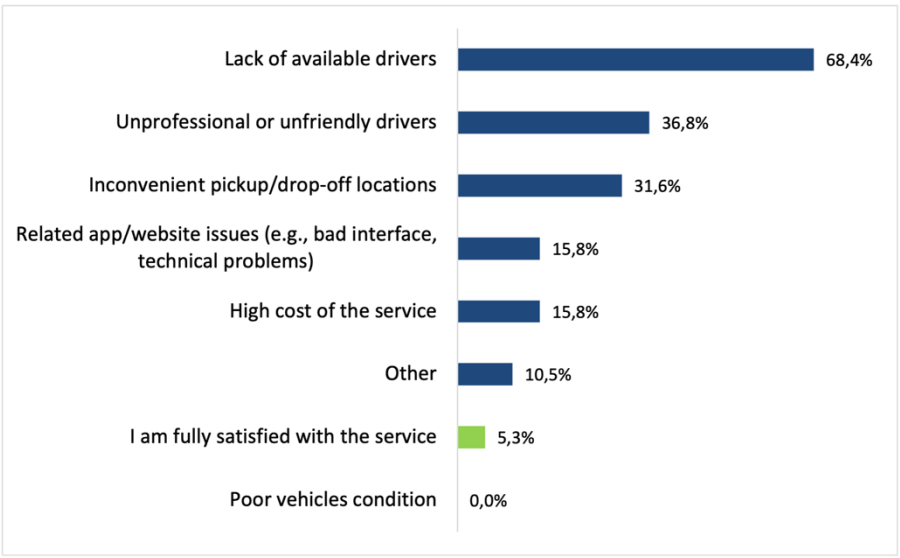
Figure 16: Challenges related to e-scooter sharing in Ljubljana



Source: Own work

The results highlight that the biggest challenge for e-scooter sharing in Ljubljana is the high cost of the service (Figure 16), selected by 58,3% of respondents. "Inconvenient pickup/drop-off locations" were chosen as a challenge by half of the respondents. One-third of them encountered poorly maintained or broken e-scooters when using the service. 25% had a problem with a lack of available e-scooters. The satisfaction rate for e-scooter sharing is slightly higher than for bike sharing, but is still quite low (16,7%). The complicated rental process was pointed out by the same percentage of respondents as those who were fully satisfied with this type of shared mobility. Finally, the related app issues got the lowest number of respondents selecting it (8,3%). There were no responses for the "Other" option.

Figure 17: Challenges related to ridesharing in Ljubljana



Source: Own work

Figure 17 summarizes the challenges related to ridesharing in Ljubljana. The biggest challenge, selected by nearly 70% of people who received this question, is the “Lack of available drivers”. Around a third of respondents chose “Unprofessional or unfriendly drivers” (36,8%) and “Inconvenient pickup/drop-off locations” (31,6%) as challenges. Both “Related app/website issues” and “High cost of the service” were selected by 15,8% of ridesharing users. One of the respondents choosing the “Other” option stated: “I do not use cars yet”, which is not a valid response in this case, and another respondent mentioned: “You need to pay if you publish too many rides on prevzi.org” as a challenge they faced. The percentage of users fully satisfied with the service is the lowest among all shared mobility types observed (5,3%). None of the respondents encountered problems with poor vehicle conditions when using ridesharing in Ljubljana.

5.3 Action plan for smart mobility enhancement in Ljubljana

In this subchapter, a detailed action plan for improving the smart mobility state of Ljubljana is presented. The part of the smart city concept - smart mobility has a big impact on city ranking because it can influence the other four pillars: smart people, smart economy, smart environment, and smart living (Pop & Proștean, 2019). Therefore, improving smart mobility in the city implies a subsequent increase in Ljubljana's smart city rank, given that there are no negative changes in other pillars. To improve the smart mobility state in Ljubljana, the initiatives should tackle the main mobility challenges it faces. After the analysis of the secondary sources and the survey results, the following areas are determined to be problematic and are addressed by the action plan:

1. Excessive use of private cars
2. Inefficiency of public transport
3. MaaS limitations
4. Traffic congestion
5. Insufficient capacity of the parking system
6. Limitations of walking and cycling infrastructure
7. Shared mobility usage
8. P+R facilities usage

For the plan preparation, smart mobility solutions that are best suited for the current challenges were examined and proposed. Some of them are backed with examples of the solutions implemented in real life, which illustrate their practical application and the direction the city should take. For contextual relevance, examples of European cities are used due to similarities in policies, funding, scale, and residents' behavior. The detailed table with the action plan summary is presented in Appendix 2.

- Increasing the attractiveness of public transport

Most of the mobility issues listed above are interrelated, meaning that some solutions can address several problems at once, and that improvements in one area may imply enhancements in another. Increasing the attractiveness of public transport is a perfect

example of such a solution. This is one of the focus areas of the action plan, as the corresponding solutions directly address the 1st, 2nd, and 4th problems simultaneously, and others circumstantially. Improvements in public transport can not only increase the satisfaction rate of the current passengers but also encourage some people to switch from using personal cars to buses and trains. Moreover, public transportation has been widely accepted as one of the most effective solutions to mitigate traffic congestion (Cheng et al., 2024).

The observed issue with inefficient public transport schedules can be tackled by introducing big data analytics and AI-based scheduling. Collecting and analyzing real-time data from GPS, automated vehicle location systems, and passenger counting systems provides insights into actual vehicle performance and passenger behavior. AI systems, particularly those using machine learning, can analyze a large amount of historical and real-time data, identifying patterns and predicting demand fluctuations. By understanding these patterns, public transport agencies can design more efficient schedules, taking into account passengers' needs and the load on different public transport routes (Lukic Vujadinovic et al., 2024). This would help to increase public transport reliability while simultaneously better resource allocation. Additionally, the same solution can be used for aligning schedules of different public transport modes (city buses, intercity buses, and trains), which will positively affect the integration between the transport modes. Examples of AI-driven optimization of public transport can be found in Vienna and Lisbon, where machine learning models for bus and tram schedule optimization were introduced. This resulted in reduced wait times and improved adherence to timetables, enhancing overall service reliability and efficiency (Lukic Vujadinovic et al., 2024).

To further enhance the attractiveness of public transport, the fleet of city and intercity buses should continue to be renewed. The focus should be on acquiring more modern vehicles with sustainable energy sources. The size of the buses is also important. Assessing the demand would also help to identify which routes require articulated buses and for which routes rigid buses would be more suitable. Moreover, public transport should become more inclusive and provide better solutions for people with limited mobility. Thus, the public transport fleet should introduce vehicles equipped with automatic ramps for wheelchairs. This will drastically increase accessibility for disabled or injured people, along with a more efficient and speedier boarding process. For instance, automatic ramps in public buses were introduced in Denmark in 2023. The installed electrical ramps allow users to activate the ramp themselves, providing more autonomy. Alternatively, the bus driver can push a button from their seat. Since introducing the new ramps showed positive results, the number of electrical ramps in Danish public buses continues to grow (European Commission, n.d).

Public transport in Ljubljana and its surroundings would also benefit from implementing an integrated ticketing system. Introducing a single ticket for bus and train rides would enable seamless travel across different transport modes. An example of integrated ticketing can be found in the Netherlands, where the OV-chipkaart system is present. Passengers can use the

OV-chipkaart to travel on every mode of public transport in the Netherlands. For the owners of the card, different payment options and packages are available, including discounts (Dutch Railways, n.d.). Introducing various discounts and special deals can also boost the usage of public transport. For instance, a discount for group or family travel, or a daily ticket with the possibility to use a train and a bus without additional payment, might attract more passengers.

As the survey results show, many public transport users in Ljubljana find the current bus priority measures insufficient. Dynamic bus lanes can be introduced to address this issue. Currently, the city has shared bus lanes, which are also accessible to taxis; they are often present only on certain sections of the streets. As an alternative, dynamic bus lanes provide more flexibility and are a better solution for limited space capacity, reserving the lane for public transport based on traffic conditions or demand (Olstam et al., 2025). Implementing dynamic bus lanes can be combined with another solution – transit signal priority (TSP) systems for buses. Public transport priority in traffic signals can reduce travel time and improve bus regularity with a relatively low cost for other traffic participants (Wahlstedt, 2011). As part of the city's Integrated Urban Transport Project, TSP systems were implemented at 32 intersections in the Bulgarian city of Burgas back in 2015. The technology was fitted to 77 public transport buses in the city, which ensures that when any of them approaches one of the 32 equipped intersections, the system sends a request from the bus to the traffic light controller, which gives it a priority signal at the traffic intersection (ITS International, 2016).

- Upgrading the Urbana app

The new Urbana app laid the ground for the development of a MaaS platform, an important element of smart mobility. However, it currently lacks certain functionalities necessary to fully realize its potential as a competitive MaaS solution. Therefore, a further upgrade of the app is needed to address the 3rd problem identified earlier.

First of all, the Urbana app should incorporate additional modes of transport such as railway, taxis, car-sharing, e-scooter sharing, and potentially ride-sharing. The current integration of bike-sharing should also be improved so that it is possible to use the service within the same app with extended functionalities, like estimation of travel time for cycling. This would make Urbana a more comprehensive MaaS platform, enabling seamless multimodal travel and greater flexibility for its users. Additionally, it would promote the use of shared mobility in the city. As a guideline, an example of a Finnish MaaS platform, Whim, can be used, which was introduced for the Helsinki Metropolitan Area in 2017. Initially, three mobility solutions were proposed to Whim customers besides the proposition to walk from origin to destination. Users of the Whim app could decide to either use public transport, rent a car, or realize their trip by taxi. Later on, bike sharing and e-scooter sharing were also introduced as options. All of this was possible due to collaboration between the involved party actors (Audouin & Finger, 2018).

Another step in upgrading the Urbana app would be incorporating gamification into its functionality. Gamification implies the use of game design elements in non-game contexts with elements like points, badges, levels, and leaderboards (Deterding et al., 2011). These elements can be implemented in Urbana to encourage users to use sustainable modes of transport and increase their engagement with the app. For instance, a system of points earned for choosing public transport, cycling, or other sustainable transport means can be introduced. Further on, these points could be exchanged for Urbana credit, discounts at local businesses, or free museum entrance. The advanced app personalization can also be achieved, for example, by introducing personal carbon emission tracking. In 2014, within the STREETLIFE EU project, an experiment on implementing gamification to promote sustainable urban mobility was held in the Italian city of Rovereto. The experiment resulted in increased participants' reliance on ICT mobility services and their willingness to adopt sustainable transport options, and led to a significant shift in travel behavior (Kazhamiakin et al., 2015).

The need for an enhanced notification system in the Urbana app was also highlighted by its users. Incorporating notifications about public transport arrivals and delays, as well as schedule changes, would improve user experience and potentially increase the attractiveness of the app. For instance, bus schedules usually change for the school holidays, and it would be easier for people who are not aware of the holiday dates to follow these changes if the app notifies them.

Last but not least, some technical improvements would benefit the current app. The attention should be drawn to improving the accuracy of the real-time information provided, as many users find it a current flaw. Furthermore, previously mentioned issues with online payment and the migration of physical Urbana cards to the app should be addressed. The ability to type any location in the search bar or pick a destination on the map should also be introduced, as it would significantly ease the use of the app and extend its functionality.

- Intelligent Traffic Lights

Besides the increase in public transport attractiveness, there are other potential solutions for mitigating traffic congestion in the city. One of them is the implementation of intelligent traffic lights, also known as smart traffic lights. Such traffic lights were introduced in the Finnish city of Kuopio in 2021. The adaptive traffic light system was introduced at the highest traffic volume intersections in the city to reduce delays. According to a study conducted afterward, the introduction of the system reduced delays by 15% compared to traditional traffic light control. The system does not imply fixed, pre-planned programs; it adjusts the operation of the traffic lights automatically. The system’s modeling recognizes traffic disruptions and long-term changes in traffic and can change the control without separate reprogramming of traffic lights (City of Kuopio, n.d.). Ljubljana could adopt a similar intelligent traffic light system to regulate traffic in areas that frequently experience congestion.

There are also smart traffic lights for pedestrians and cyclists. For example, smart traffic lights for pedestrians were introduced in Vienna back in 2018. They use a small camera to detect when a pedestrian is approaching and then observe their direction and behavior to predict whether the person wants to cross the road or is just walking past the traffic light. The new generation of smart traffic lights, recently developed by a team from Graz University of Technology, can also recognize people with mobility impairments or strollers due to improved camera resolution, higher computing power, and an appropriately trained, deep learning-based model. Additionally, it can monitor and control several crossings simultaneously (Jarke, 2024). Introducing such a system in Ljubljana would improve conditions for pedestrians and cyclists, making travel around the city more convenient and enjoyable.

- More dedicated routes for pedestrians, cyclists, and e-scooter riders

The results of the survey suggest that there is a need for an enlarged infrastructure for pedestrians and bike/e-scooter riders in Ljubljana. To further promote these sustainable transport modes and make walking and riding a bike/e-scooter in the city safer, investments in creating more dedicated cycling lanes and walking routes should be made. Connected routes should be created across the city so it is possible to seamlessly travel from any part of Ljubljana to another by bike/e-scooter. Pedestrians should also be able to travel without obstacles, especially in the areas near bus and train stations. Every roadway in the city should be accompanied by a safe and spacious sidewalk to ensure accessibility and safety for pedestrians.

- Find parking function

The reduction in car use should positively affect the problem of limited parking spaces in Ljubljana. However, to make finding available parking spots easier and faster, a dedicated functionality can be introduced to the existing parking-related app, EasyPark. Besides online payment for parking, in other countries, the app also has a function called Find, which allows users to find a parking spot based on the probability of its availability. This function has not been introduced in Ljubljana yet, but it is available in numerous European cities like Madrid, Oslo, Berlin, Barcelona, and many others (EasyPark, n.d.). Introducing the Find function would provide car users with useful insights into the available parking spots in the city and make the process of finding parking more efficient.

- Supporting shared mobility

Along with integration into the Urbana mobile app, the increase in shared mobility use can be achieved with governmental support. The collaboration between public and private entities in the field of shared mobility should continue to establish new projects and enhance the development of the existing ones, such as BicikeLJ. Furthermore, the municipality of Ljubljana should consider introducing direct municipal subsidies and/or offering tax breaks to shared mobility providers. This will help the related businesses to grow and expand their

infrastructure, attracting more users. This could also positively affect service quality and make some shared mobility means more affordable for the end-user. Currently, such practices are not widespread in Europe and are usually heavily targeted (e.g., subsidies for electric cars, cargo bikes, or electric charging stations etc.). Often, government support for shared mobility is provided through public funding and is typically managed at the federal level. The German "Clean Air 2017-2020" action programme can be considered as an example. Within its framework, the Federal Ministry of Transport and Digital Infrastructure (BMVI) provided around 20 million euros in funding to support municipal vehicle fleets, public transport, and commercial entities. In particular, the programme provided funding for the procurement of electric vehicles in the taxi industry and carsharing companies (NOW GmbH, 2018).

- Increasing the usage of P+R parking

As evident from the survey results, the main drawbacks of P+R parking are related to time inefficiency and unwillingness to use public transport. Therefore, the improvements for the public transport mentioned above, AI-based scheduling for public buses in particular, could also enhance the use of P+R. The other prominent obstacle to using the facilities is the absence of P+R parking near some routes. In order to meet the demand, the P+R network should grow steadily, with new facilities located strategically near heavy traffic routes that are not covered by other parking slots. Although there are plans in place for building new P+R facilities in the city, there is still room for improvement. The municipality should implement these plans in a more time-efficient manner, focusing on covering the neglected areas first.

5.4 Contributions and practical implications

The contributions of this master's thesis lie in both theoretical and practical fields. As a substantial part of the study is based on a detailed overview of secondary data, it contributes to a greater understanding of the smart city and smart mobility concepts. The study also provides a perspective on Ljubljana's position as a smart city and offers a comprehensive overview of its current state of smart mobility. It further presents a detailed examination of the main initiatives in the field of mobility introduced in the city over the last twenty years, which helped to analyze its smart mobility formation journey. The discussion on mobility initiatives also helped to formulate the main mobility issues Ljubljana currently faces, forming the basis for the primary research and main suggestions on improvements.

As part of the master's thesis, the primary research in the form of an online survey was also conducted. This gives valuable insights into the citizens' and city visitors' perspectives and their opinions on the mobility solutions present in Ljubljana. For instance, the main challenges related to the current smart mobility solutions and reasons for their non-usage were investigated. The survey results confirm some of the research findings from other studies and add new insights to existing knowledge. Both the primary and secondary research serve as the ground for formulating the action plan on smart mobility improvement

in Ljubljana, which is the main practical contribution of the study. The action plan was composed to address the main mobility challenges faced by Ljubljana and to improve the current smart mobility state of the city, which would positively affect its overall position as a smart city. Measures suggested within the framework of the plan strive to enhance sustainability and efficiency in the field of mobility, which would primarily benefit the end users.

The developed action plan can serve as a practical guideline for the local government authorities. They can use the insights to introduce new smart mobility measures or improve the current ones. The plan also suggests a prioritization level and a suitable timeframe for each measure, which could also help in creating a set of complex incentives. The identified mobility challenges and the survey results could also serve as orientations for future decision-making by urban planners, city officials, transport providers, and other stakeholders involved in the city's mobility.

Additionally, on an individual level, the study can benefit residents and city visitors by pointing out the benefits of smart mobility and promoting smart mobility solutions they might not have considered before (for instance, using the BicikeLJ service or the Urbana app). It can also spread awareness about the current mobility issues Ljubljana faces and potential solutions to mitigate them, which could help boost improvements faster. Finally, the study insights and statistical data gained through the survey may serve as a base for further research on the topic.

5.5 Study limitations and future research

The study limitations primarily come from the primary research conducted. As already discussed in the Methodology chapter, one of the main limitations in this regard refers to the snowball sampling method chosen for the online survey. As a non-probability sampling method, it limits the generalizability of the research findings due to the lack of proper representativeness of the broader population. By examining the demographic structure of the sample, we can see that the survey lacks respondents under 18 years old, meaning that the opinions of the younger generation were not considered during the study. This may limit the insights into the habits, needs, and challenges faced by students and minors using mobility means in Ljubljana. We can also see that the relative percentage of respondents over 54 years old is lower than for other age groups, which also contributes to limitations. The grouping by occupation shows a heavy predominance of one group - employed people, which may also bias the study results.

The secondary data availability and reliability are also part of the study limitations. The data used for the secondary research is often limited and, in some cases, may even be outdated. The lack of detailed and recent data on Ljubljana's mobility is a major obstacle to the analysis of its current state. Moreover, most of the sources used for the analysis describe

statistics, projects, and initiatives not solely at the level of Ljubljana city, but rather at the municipality or region level. This limits the assessment of the city-specific situation.

The future research can be conducted using a probability sampling method to ensure better representativeness of the general population. The scope of the study could also be enlarged, including a bigger sample for more reliable results. The future research could be focused on a more detailed analysis of smart mobility measures implemented in the city, exploring their impact on users' travel habits and their level of satisfaction, and the corresponding emissions produced. Thus, more suggestions for mobility improvements could be formulated. Additionally, future studies could address the improvement of Ljubljana's smart city rank through the enhancement of other smart city pillars rather than smart mobility.

6 CONCLUSION

Cities worldwide are increasingly adopting smart city strategies to address the growing number of modern urban challenges. Mobility plays a significant role in citizens' lives and is associated with certain problems that authorities strive to address within the smart city framework. Therefore, smart mobility has become an increasingly present theme in sustainability agendas, addressing the impacts of transportation systems in urban areas (Maldonado Silveira Alonso Munhoz et al., 2020). Ljubljana has emerged as a city committed to transforming and constantly improving its mobility landscape. The chapter dedicated to past and current smart mobility projects and initiatives demonstrates that Ljubljana has significantly evolved in this regard over the last two decades, introducing numerous smart mobility solutions. Although Ljubljana's early adoption of sustainable and smart mobility initiatives could have secured a privileged position in this field, other cities have since achieved a better level of advancement. As can be seen from the smart city ranks observation, Ljubljana currently holds a medium position in terms of smart city development, with mobility and transportation being one of the critical areas where improvements are needed.

The analysis of various secondary sources helped to determine the following issues in Ljubljana's mobility: excessive use of private cars by commuters, inefficiency of public transport, certain MaaS limitations, and frequent traffic congestion. This laid the ground for the action plan proposed in the framework of this master's thesis, showing the general directions for possible improvements. The primary research in the form of an online survey, conducted later, helped to further narrow the directions. The survey not only proved the relevance of the defined mobility issues but also gave further insights into usage and challenges related to the main smart mobility solutions existing in the city. The survey results showed that cars are indeed the transport mode of choice for most city visitors and residents when visiting Ljubljana and traveling around the city, significantly surpassing public transport in terms of usage. The survey participants also highlighted the most relevant challenges related to transportation modes they use in Ljubljana. The challenges defined for

walking in Ljubljana are conflicts with cyclists and scooters on sidewalks or pedestrian paths, and insufficient pedestrian infrastructure. The challenges for cycling and scootering are safety concerns in certain areas and insufficient related infrastructure. For public transport in Ljubljana, integration with other modes of transport, insufficient schedules, insufficient bus priority systems, and frequent delays were determined as relevant challenges. Finally, the lack of parking spaces and traffic congestion were defined as the main problems in Ljubljana for car users. The survey revealed relatively limited adoption of smart mobility solutions in Ljubljana. Only 15.6% of Ljubljana visitors participating in the survey occasionally use P+R parking, and none of them use the facilities regularly when visiting the city. The related time inefficiency was highlighted as the main reason for the non-usage of P+R. 42.6% of participants use the Urbana mobile app, most of them using it occasionally (27.9%). Among those who do not use the app, the majority indicated that they do not find it relevant for their transportation needs. The shared mobility usage in Ljubljana among the participants accounts for 49%, the leading cause for its non-usage being unwillingness to switch from the current modes of transport. The results also show that the leading challenges related to carsharing in Ljubljana are the lack of available cars and the high cost of the service. For bike sharing in Ljubljana, the main challenges are the lack of available bikes and poorly maintained or broken vehicles. For ridesharing, the high cost of the service and inconvenient pick-up and drop-off locations were chosen as the main problems in Ljubljana. Finally, for the main challenge related to ridesharing in Ljubljana, the survey participants indicated the lack of available drivers.

The insights gained from both primary and secondary research led to the proposal of a comprehensive action plan for enhancing smart mobility in Ljubljana. The suggested improvements primarily strive to maximize positive outcomes for the environment, decrease traffic congestion, and increase the usability and efficiency of public transport in the city. The action plan consists of 15 measures that tackle the main problems in the field of mobility determined in the course of secondary sources assessment and conducting the survey: 1. Excessive use of private cars, 2. Inefficiency of public transport, 3. MaaS limitations, 4. Traffic congestion, 5. Insufficient capacity of the parking system, 6. Limitations of walking and cycling infrastructure, 7. Shared mobility usage, 8. P+R mobility usage. For each measure, the number of the addressed problem(s) is stated, along with the estimated priority and timeframe for their implementation. The improvement of Ljubljana’s smart mobility state, the plan aims for, would consequently lead to a general enhancement of its smart city rank, making the city more attractive for living and visiting, at the same time ensuring the efficient use of resources and minimizing negative impact on the environment.

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APPENDICES

Appendix 1: Povzetek (Summary in Slovene language)

Magistrsko delo raziskuje, kako lahko Ljubljana z razvojem in uporabo rešitev pametne mobilnosti okrepi svoj položaj med pametnimi mesti ter se uveljavi kot sodobnejše, trajnostno in privlačno mesto za življenje in obisk. Analiza uvrstitve Ljubljane na lestvicah pametnih mest je pokazala, da se mesto uvršča v srednji razred razvoja, pri čemer je mobilnost eno ključnih področij, kjer so potrebne izboljšave. Pregled dosedanjih in obstoječih projektov ter pobud na področju pametne mobilnosti kaže, da je Ljubljana z uvajanjem tovrstnih rešitev pričela razmeroma zgodaj in da se je na tem področju postopno razvijala. Kljub zgodnjemu začetku pa so druga mesta na tem področju dosegla višjo stopnjo napredka.

Analiza sekundarnih virov je izpostavila več ključnih težav: prekomerno uporabo osebnih avtomobilov med dnevni potovalci, neučinkovitost javnega prevoza, omejitve sistema MaaS ter prometne zastoje. Rezultati izvedene spletne ankete med prebivalci in obiskovalci so te izzive dopolnili še z ugotovitvami o nezadostne kapacitete parkirišč, pomanjkljivi infrastrukturi za pešačenje in kolesarjenje ter nizki uporabi sistemov souporabe vozil in parkirišč P+R. Poleg tega je anketa ponudila vpogled v prednostne oblike prevoza za prihod v mesto in premikanje po njem, pomembne dejavnike pri izbiri prometnega sredstva v Ljubljani ter mnenja uporabnikov o želenih izboljšavah in izzivih, povezanih z obstoječimi rešitvami pametne mobilnosti. Identificirane težave so služile kot temelj za oblikovanje akcijskega načrta za izboljšanje pametne mobilnosti v Ljubljani.

Pri pripravi akcijskega načrta so bile analizirane in predlagane rešitve pametne mobilnosti, ki najbolje ustrezajo obstoječim izzivom. Predlagani ukrepi so zasnovani tako, da koristijo prebivalcem in obiskovalcem mesta, hkrati pa lahko služijo kot smernice lokalnim oblastem pri načrtovanju nadaljnih izboljšav. Skupaj je bilo predlaganih petnajst ukrepov, pri čemer vsak neposredno ali posredno naslavlja eno do štiri izpostavljene težave. Za večje udobje je bil povzetek akcijskega načrta predstavljen tudi v obliki tabele. Posameznim ukrepom je bila dodeljena stopnja prioritete (nizka, srednja ali visoka), ki odraža subjektivno oceno njihove pomembnosti ter nujnosti izvedbe. Poleg tega vsakemu ukrepu je bil predpisan časovni okvir (kratkoročen, srednjeročen, dolgoročen ali kontinuiran), ki kaže ocenjeni rok izvedbe glede na tehnično zahtevnost, finančne vire, institucionalne, pravne in druge dejavnike.

Izvedena raziskava ima določene omejitve, med katerimi je najpomembnejša povezana z metodo vzorčenja »snowball«, uporabljeno pri spletnem anketiranju. Ta metoda zmanjšuje reprezentativnost vzorca in omejuje možnost posploševanja ugotovitev na širšo populacijo. Prav tako je bila sekundarna analiza v nekaterih primerih opravljena na podlagi omejenih ali zastarelih podatkov, kar lahko vpliva na natančnost rezultatov. Prihodnje raziskave bi se morale osredotočiti na premagovanje teh omejitev, pri čemer bi se lahko bolj podrobno analizirali ukrepi pametne mobilnosti, že izvedeni v mestu. Dodatno bi bilo koristno raziskati tudi vpliv izboljšav na drugih stebrih pametnega mesta, ki bi lahko pripomogli k višji uvrstitvi Ljubljane med pametna mesta.

Appendix 2: Action plan for smart mobility improvement in Ljubljana

The layout of the action plan was prepared based on a plan presented in the framework of SUMP LUR (2019). Some parameters were changed to better correlate with the study inputs. Overall, the action plan is aimed at tackling the eight problems listed in chapter 5.3 (from 1. Excessive use of private cars to 8. P+R facilities usage). Under Addressed Problems, the corresponding number of a problem(s) that a measure addresses, directly or indirectly, is stated to illustrate its impact. The Priority column reflects a subjective assessment of the measures' importance. A given priority estimation correlates with how urgent a measure should be implemented and how big an impact it could generate. Timeframe implies the estimated realistic implementation horizon for each measure, considering the corresponding technical complexity, funding, institutional, legal, and other factors involved. It is grouped by short-term (up to 1 year), medium-term (1-3 years), long-term (3+ years), and continuous.

MEASURE	ADDRESSED PROBLEMS	PRIORITY	TIMEFRAME
Big data analytics and AI-based scheduling for public transport	1, 2, 4, 8	High	Medium/Long-term
Renewal of city and intercity bus fleet	1, 2	Medium	Continuous
Integrated ticketing system	1, 2	High	Medium-term
Discounts and special deals for Urbana card owners	1, 2	Medium	Short-term
Dynamic bus lanes	1, 2, 4	Medium	Short/Medium-term
TSP systems for buses	1, 2, 4	Medium	Medium-term
Incorporating new modes of transport into the Urbana app (railway and shared mobility)	3, 7	High	Medium-term

Gamification of the Urbana app	1, 3, 4, 7	Medium	Short-term
Enhanced notification sysytem in the Urbana app	3	Medium	Short-term
Technical improvements in the Urbana app	3	Low	Short-term
Intelligent traffic lights implementation	4, 6	High	Long-term
Enlarging of infrastructure for pedestrians and bike/e-scooter riders	1, 6, 7	High	Continuous
"Find" function in the EasyPark app	5	Low	Short-term
Subsidies/tax breaks for shared mobility providers	1, 7	Medium	Short/Medium-term
P+R network enlargement	1, 4, 5, 8	Medium	Medium/Long-term

Appendix 3: English version of the online survey questionnaire

Q1 - What is your primary role in Ljubljana?

- Resident
- Commuter (travel to work or study)
- Occasional visitor
- None of the above (I don't visit or live in Ljubljana)

IF (1) Q1!= [4] (None of the above)

Q2 - What is your age?

- Under 18 years old
- 18 - 34 years old
- 35- 54 years old
- Over 54 years old

IF (1) Q1!= [4] (None of the above)

Q3 - What is your main occupation?

- Student
- Employed
- Unemployed
- Retired

IF (2) Q1 = [3] or Q1 = [2]

Q4 - What is your main mode of transport when traveling TO Ljubljana?

- Car
- Bus
- Train
- Bicycle
- E-scooter
- Walking
- Other:

IF (3) Q4 = [1]

Q5 - Do you use P+R (park-and-ride) facilities when traveling to Ljubljana?

- No, I never heard of it
- No, I know about it, but don't use
- Yes, I use it occasionally
- Yes, I use it often

IF (4) Q5 = [2]

Q13 - What is the main reason why you don't use P+R facilities?

- There are no P+R facilities near my route
- Using P+R is time-inefficient
- I don't want to use public transport when traveling from/to P+R
- P+R parking is often full
- The cost of P+R is too high
- I don't trust the security of P+R facilities
- Other reason / Difficult to answer

IF (1) Q1!= [4] (None of the above)

Q6 - What is your main mode(s) of transport when traveling IN Ljubljana?

- Multiple answers are possible
- Car
- Bus
- Train
- Bicycle
- E-scooter
- Walking
- Other:

IF (5) Q6 = [Q6f]

Q7 - Rate the relevance of the following transportation challenges for WALKING in Ljubljana: (1 - Not relevant at all, 3 - Somehow relevant, 5 -Extremely relevant)

	1	2	3	4	5
Insufficient pedestrian infrastructure (e.g., missing sidewalks or pedestrian crossings)					
Conflicts with cyclists or scooters on sidewalks/pedestrian paths					
Safety concerns in certain areas (e.g., poor street lighting, too high speed limit near pedestrian zones)					
Poor sidewalk/pedestrian path conditions (e.g., damaged surface or blocked pathways)					

IF (6) Q6 = [Q6d] or Q6 = [Q6e]

Q14 - Rate the relevance of the following transportation challenges for CYCLING/SCOOTERING in Ljubljana: (1 - Not relevant at all, 3 - Somehow relevant, 5 -Extremely relevant)

	1	2	3	4	5
Insufficient cycling/scootering infrastructure (e.g., lack of dedicated bike lanes)					
Lack of secure bicycle/scooter parking					
Safety concerns in certain areas (e.g., poor street lighting, proximity of motorized vehicles)					
Poor cycling lane conditions (e.g., damaged surface or blocked pathways)					

IF (7) Q6 = [Q6b] or Q6 = [Q6c]

Q15 - Rate the relevance of the following transportation challenges for PUBLIC TRANSPORT in Ljubljana: (1 - Not relevant at all, 3 - Somehow relevant, 5 - Extremely relevant)

	1	2	3	4	5
Insufficient public transport schedules					
Limited number of public transport routes					
Insufficient integration with other modes of transport (e.g., between train and bus, bus and cycling, etc.)					
Poor real-time information availability (e.g., bus/train arrival times and delays)					
Frequent delays in public transport					

Insufficient bus priority measures (e.g., lanes dedicated to buses only)					

IF (8) Q6 = [Q6a]

Q16 - Rate the relevance of the following transportation challenges for CAR in Ljubljana: (1 - Not relevant at all, 3 - Somehow relevant, 5 -Extremely relevant)

	1	2	3	4	5
Insufficient parking spaces					
Traffic congestion					
Inefficient traffic coordination (e.g., suboptimal traffic sign and traffic light management)					
Safety concerns in certain areas (e.g., high-risk intersections)					

IF (1) Q1!= [4] (None of the above)

Q8 - Rate the importance of the following parameters when choosing the mode of transport in Ljubljana: (1 - Not important at all, 3 - Somehow important, 5 -Extremely important)

	1	2	3	4	5
Affordability					
Accessibility					
Time efficiency					
Comfort					
Flexibility					
Sustainability					

IF (1) Q1!= [4] (None of the above)

Q9 - Do you use the Urbana mobile application?

- o No, I never heard of it
- o No, I know about it but don't use
- o Yes, I use it occasionally
- o Yes, I use it often

IF (9) Q9 = [3] or Q9 = [4] (Urbana app users)

Q10 - What improvements would you like to see in the Urbana app?

- o Multiple answers are possible
- o Improved user interface (e.g., easier navigation)
- o Better integration with other transportation modes (e.g., cycling, car-sharing, railway)
- o Improved payment options (e.g., more payment methods)
- o Enhanced notification system (e.g., delays, schedule changes)
- o More accurate real-time information (e.g., bus arrival times)
- o Other:
- o I am fully satisfied with the app

IF (10) Q9 = [2]

Q17 - What is the main reason why you don't use the Urbana app?

- o I don't find it relevant for my transportation needs
- o The app is not user-friendly

- I don’t trust the app with my personal data
- The app lacks important features I need
- I prefer to use offline services or other apps
- The app doesn’t work well on my phone
- Other reason / Difficult to answer

IF (1) Q1!= [4] (None of the above)

Q11 - What type of shared mobility do you use in Ljubljana?

- Multiple answers are possible
- Car-sharing (e.g., Avant2Go)
- Bike-sharing (e.g., BicikeLJ)
- E-scooter-sharing (e.g., Bolt)
- Ride-sharing (e.g., Prevoz.org)
- Other:
- I don’t use any

IF (11) Q11 = [Q11a] (Challenges for car-sharing)

Q12 - What challenges have you experienced when using CAR-SHARING in Ljubljana?

- Multiple answers are possible
- Lack of available cars
- Inconvenient pickup/drop-off locations
- Poorly maintained or broken cars
- Related app issues (e.g., bad interface, technical problems)
- Complicated rental process
- High cost of the service
- Other:
- I am fully satisfied with the service

IF (12) Q11 = [Q11b] (Bike-sharing challenges)

Q18 - What challenges have you experienced when using BIKE-SHARING in Ljubljana?

- Multiple answers are possible
- Lack of available bikes
- Inconvenient bike station locations
- Poorly maintained or broken bikes
- Related app issues (e.g., bad interface, technical problems)
- Complicated rental process
- High cost of the service
- Other:
- I am fully satisfied with the service

IF (13) Q11 = [Q11c] (E-scooter-sharing challenges)

Q19 - What challenges have you experienced when using E-SCOOTER-SHARING in Ljubljana?

- Multiple answers are possible
- Lack of available e-scooters
- Inconvenient pickup/drop-off locations
- Poorly maintained or broken e-scooters
- Related app issues (e.g., bad interface, technical problems)
- Complicated rental process

- High cost of the service
- Other:
- I am fully satisfied with the service

IF (14) Q11 = [Q11d] (Ride-sharing challenges)

Q20 - What challenges have you experienced when using RIDE-SHARING in Ljubljana?

- Multiple answers are possible
- Lack of available drivers
- Inconvenient pickup/drop-off locations
- Poor vehicles' condition
- Unprofessional or unfriendly drivers
- Related app/website issues (e.g., bad interface, technical problems)
- High cost of the service
- Other:
- I am fully satisfied with the service

IF (15) Q11 = [Q11f]

Q21 - What is the main reason why you don't use shared mobility services in Ljubljana?

- I am not aware of shared mobility options in Ljubljana
- I prefer my current mode(s) of transport
- There are no shared mobility options for my usual destinations
- Using shared mobility is expensive
- I don't trust the related apps with my data
- I am concerned about the safety or maintenance of shared vehicles
- Other reason / Difficult to answer