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ORIGINAL SCIENTIFIC PAPER

Smart Mobility in Smart Cities

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Abstract: Contemporary urbanization trends today are defined in accordance with the principles of sustainable development, aiming to create a balance between the need for increased mobility, economic progress, and environmental protection in cities. The increase in the world's population therefore requires a new way of optimizing human movement and the transportation of goods. The concept of smart mobility emerged alongside smart cities. Smart cities represent urban environments where information and communication technologies are applied to increase the efficiency of the urban system, leading to constant exchange of information with the population to improve the level of services available in the city and enhance the quality of people's lives. The concept of smart mobility represents a system that collects and processes data in real-time using various information and communication technologies to optimize travel, ultimately leading to reduced traffic congestion, emissions of harmful gases, increased traffic safety, and improved efficiency and effectiveness of the transportation system. This paper will define the concepts of smart cities and smart mobility, and through examples of good practices, implemented solutions of the smart mobility concept in European cities will be presented. Furthermore, the paper will also address the challenges of implementing smart mobility systems that may arise due to the complexity of transportation systems in cities.

Keywords: smart mobility, ITS, ICT, sustainability, city

INTRODUCTION

The global population is characterized by a trend of continuous growth, and according to the United Nations (UN), it was estimated to have reached 8 billion in November 2022. The latest projections suggest that the global population could grow to around 8.5 billion in 2030, 9.7 billion in 2050, and 10.4 billion in 2100 (United Nations, 2022). Such rapid growth without adapting the management of human and goods transport poses a significant challenge for the further development of cities and countries. The increase in the world's population itself represents one of the main demands for creating a new perspective on optimizing people mobility and freight transport.

The concept of urbanization includes the spatial expansion of existing cities, the emergence of new urban centres, and the increase in the proportion of the population living in cities. The urbanization process itself has a significant impact on the transportation system. As an increasing number of people migrate to cities for better living conditions and economic opportunities, the demands for transportation and better management of the existing transportation system become more pronounced. This phenomenon necessitates a change in the current system regarding infrastructure, traffic demand and supply management, introduction of new transportation modes, etc. Understanding the impacts of rapid and increasing urbanization is crucial for achieving sustainable development and creating a sustainable transportation system.

The process of urbanization can be described through the following phenomena (Rodrigue, 2024):

Increasing traffic congestion: If not managed properly, urbanization leads to a significant increase in the number of motor vehicles on the road network, ultimately resulting in traffic congestion and parking issues. This leads to decreased productivity from an economic standpoint, as well as increased environmental pollution. For these reasons, it is essential to address the problem of traffic congestion through the introduction of smart mobility, utilizing intelligent transportation systems (ITS), alternative modes of transportation, etc.

Increasing pressure on public transport: The rapid process of urbanization can also overwhelm existing public transport systems. This issue manifests in an excessive number of passengers in systems designed to operate at a required level of service with a smaller number of passengers. Due to increased traffic congestion, vehicles often experience delays. All these problems lead to a decrease in the level of service provided. With the increase in the number of passengers using public urban transport, it is necessary to adapt the system to the new needs of the population. Some possible implementations include the introduction of Bus Rapid Transit (BRT) sys-

tems, Light Rail Transit (LRT) systems, or metro systems.

Infrastructure challenges: The urbanization process itself leads to increasing demands for investments directed towards transportation infrastructure to keep up with both the heightened economic growth and the population growth of the urban area. The construction and maintenance of existing infrastructure become more difficult during the urbanization process. To ensure that infrastructure development meets user needs, it is desirable to introduce various ITS and Information and Communication Technologies (ICT) to increase the efficiency of transportation infrastructure while also enhancing traffic safety to a high level.

Changes in travel patterns: Increased concentration of people in urban areas directly affects the alteration of their travel planning and behaviour from origin to destination. Traffic management in this case aims to encourage travel using sustainable modes of transportation, whether it be walking, cycling, scooters, or the increasing use of public transport. Indirectly, by providing alternative modes of transportation, the need for car ownership is reduced.

Social aspect: With the increase in urbanization, there arise problems related to a certain segment of the population who, for various reasons, are unable to own a vehicle or drive one. This refers to the fact that all people have a need for mobility, and their needs must be met. This issue is addressed through the construction of a transportation system with a high degree of accessibility.

When all characteristics of the urbanization process are considered, it is evident that the process significantly affects the transportation system as a whole, particularly the people mobility. It is essential for the transportation system to be shaped in a way that it can keep up with the increasingly rapid process of urbanization and to adapt the mobility of the population in a timely manner through the implementation of new solutions aimed at achieving smart mobility.

THE ROLE OF SMART MOBILITY IN SMART CITIES

Smart cities represent urban environments where ITS and ICT are applied to increase the efficiency of urban systems. In this process, there is a continuous exchange of information with the population aimed at improving the level of services available in the city and enhancing people's quality of life. Smart mobility is one of the most important systems in a smart city. The concept of smart mobility involves a system that collects and processes real-time data using various ICT to optimize travel, ultimately leading to reduced traffic congestion, emissions of harmful gases, increased traffic safety, and improved efficiency and effectiveness of the transportation system (Brčić et al, 2018; CEPT, 2024).

Smart mobility is based on the following principles:

- Flexibility, which means offering multiple travel options to passengers so they can choose what works best in a given situation;
- Efficiency, ensuring travel to the destination with minimal delays and in the shortest time possible;
- Integration, planning routes from door to door regardless of the mode of transportation used and
- Clean technology, transitioning from polluting vehicles to those with zero emissions.

Two more aspects of smart mobility are accessibility and social benefit, meaning it should be accessible to

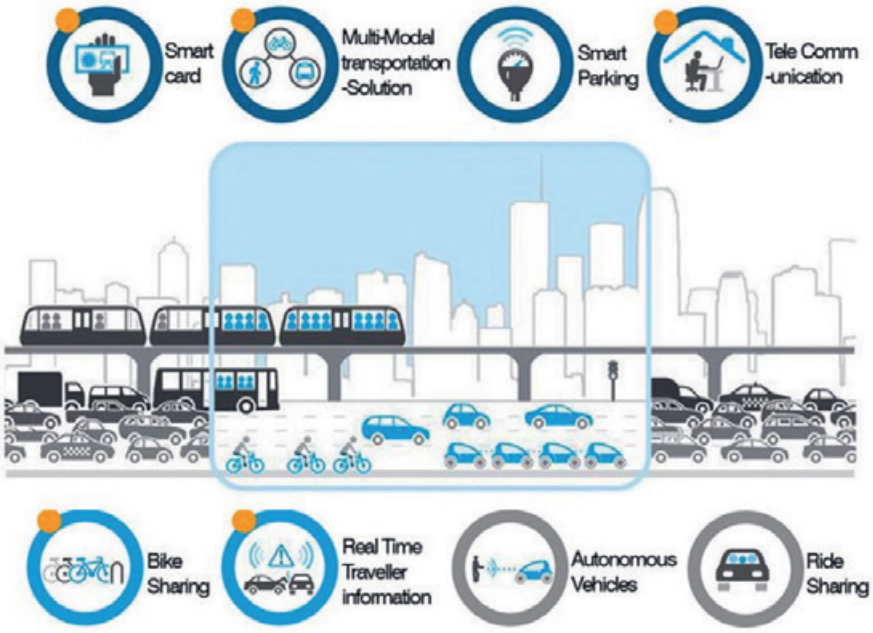

Figure 1. The smart mobility concept (CEPT, 2024)

everyone and provide a better quality of life (Gabelica, 2019).

Smart mobility encompasses the integration of a variety of different technologies, whose interconnectedness into one system enables data collection for the purpose of innovation and improvement of the transportation system as a whole. Some key aspects of smart mobility are (Butler et al., 2020):

Intelligent infrastructure: Smart mobility relies on infrastructure equipped with modern sensors, cameras, and communication technologies for data collection and real-time traffic management. This includes smart transportation systems that involve adaptive traffic signals, as well as travel route planning based on existing traffic conditions in real-time to reduce traffic congestion and travel times.

Autonomous vehicles: They are equipped with modern sensors, artificial intelligence (AI) and ICT. This type of vehicle eliminates the human factor in traffic.

Carpooling and carsharing systems: These two systems are just examples of possible solutions. These systems reduce the need for private car ownership while providing flexible and affordable transportation options.

Electric vehicles: They represent just one of the alternatives to vehicles with internal combustion engines. The increasing use of electric vehicles significantly contributes to reducing the negative impacts of traffic in terms of emissions of harmful exhaust gases.

Mobility as a Service (MaaS): This concept integrates a variety of transportation solutions into one system (e.g., public passenger transport, bike, scooter, and car rental). These systems typically operate through one or more digital platforms. MaaS offers a wide range of solutions for trip planning, facilitates payment for transportation fares, and increases the level of service of the transportation system, its affordability, and sustainability.

The role of smart mobility lies in enabling significantly easier and more efficient use of all aspects of the transportation system by users, while also facilitating traffic demand management in urban environments. To achieve this, it is necessary to change the perspective on people mobility because what is crucial for smart mobility is that there are certain advantages for both traffic participants and the administrative part of traffic management (Figure 2).

With adequate planning, urban areas can become more efficient, functional, and sustainable from a transportation perspective. Introducing smart mobility into the existing transportation system leads to improvements in its efficiency, resulting in benefits that can be observed from an economic standpoint as well. The development of smart mobility creates space for the existence of simple, accessible, and sustainable modes of transportation (Bıyık et al., 2021).

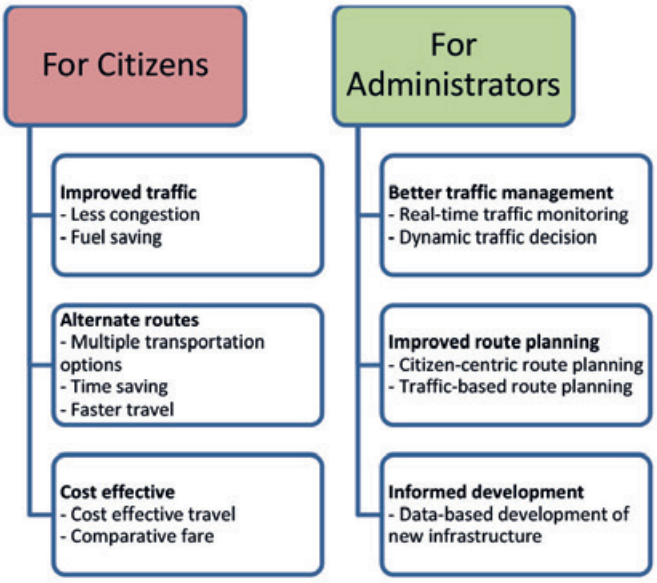

Figure 2. Need and importance of smart mobility (Paiva et al, 2021)

EXAMPLES OF SMART URBAN MOBILITY SOLUTIONS

The using of modern technologies significantly transforms traffic systems in cities that have started implementing smart mobility in recent years. In this chapter, it will be described examples of good practices in implementing smart mobility solutions. These solutions aim to improve the quality of life for citizens, reduce negative environmental impact, and enhance the planning and efficiency of public transportation, decrease traffic congestion, as well as citizen dissatisfaction. The entire concept of smart mobility aims for a transportation system that is highly flexible and practical based on intelligent management.

Helsinki (Finland): For a while now, the city of Helsinki has been investing significant resources in developing sustainable transportation, with a strong focus on public transport and other alternative modes. In terms of modal split, passenger cars account for 36% of trips, public transport for 25%, and walking and cycling for 39%. One of the tasks and goals of implementing the Whim application is precisely to reduce the share of passenger cars and increase the use of public transport and alternative modes of transportation in modal share. The application was launched in 2017, and by the end of 2018, the number of users had exceeded 70,000. The aim of implementing this application is to connect different modes of transportation through one platform. The application itself enables easy trip planning by providing access to public transport schedules, taxi booking, and even car and bicycle rental services. Depending on the type of monthly subscription, the application offers various service options, as certain categories include the costs of using taxi services and renting cars or bicycles.

Research on the travel characteristics of Helsinki residents has shown that users of the Whim application tend to use public transport and taxi services more frequently and use passenger cars less compared to residents who do not use the application. Although the average daily mobility does not differ significantly between the two categories of residents, the conclusion is that besides significant changes in travel redistribution, the significance of the application lies in easier trip planning and realization (Maas Alliance, 2024).

Milton Keynes (England): Research has shown that Milton Keynes, a city with around 280,000 inhabitants, has a very low usage rate of public transport (6%) and cycling (3%) for commuting purposes. The reasons for this situation include poor cycling infrastructure and low-quality public transport services. To increase the number of trips taken using public transport, it is necessary to modernize the system with services that provide users with real-time information and to simplify the payment system. The high level of motorization and neglect of the development of other modes of transport have led to the dominance of cars in the transportation system (Milton Keynes Council, 2018).

Predictions indicate an increase in traffic demand in the future, hence the need for radical changes in traffic management and the introduction of modern systems to achieve smart mobility. One idea to increase the share of passenger trips using public transport is to improve the level of service with the help of the MotionApp application, launched in 2017. The idea revolves around designing an application that provides users with real-time information about the system in a simple way, enables payment, and simultaneously offers easier use and information about parking systems alongside public transport. Specifically, the application collects data on the occupancy status of parking garages and, through an interactive system, facilitates easy finding of available parking spaces (Valdez et al., 2018).

The MotionApp application collects data through a system of sensors, as well as through feedback from users of the application. The data it gathers include public transport vehicle schedules, their exact real-time locations, traffic congestion information, and parking lot occupancy data. The goal of collecting this information is to provide participants in traffic with useful information to facilitate trip planning and increase the efficiency of all modes of transportation. Bus performance has shown a significant improvement, with journey numbers increasing by 6%, and the proportion of customers satisfied with the overall service increasing. Bus punctuality has also improved, with up to 90% of non-frequent buses now running on time. Additionally, the average minimum travel times by public transport to key services for Milton Keynes residents have dropped by 15% (Milton Keynes Council, 2018). The application is just one part of a broader program called MK:Smart, which aims to make the city one of the leading smart cities in the United Kingdom (UK). The initiative oversees the development of the 'MK Data Hub', which enables and manages data related to energy and water consumption, transport data, social media, specialized apps, and other data sources.

Barcelona (Spain): Over the past decade, Barcelona has invested significant funds in reducing traffic congestion and developing and implementing a sustainable transportation system. One measure to achieve smart mobility is the implementation of a bike-sharing system called Bicing. The implementation of this system, along with investment in cycling infrastructure, has enabled a large portion of daily trips to be made by bicycle. Currently, there are 428 bike rental stations in the city, with 105,545 active Bicing system users (Wolnjak, 2023). Due to the observed imbalance in the number of bicycles available for rental in different zones depending on the altitude, the system has been expanded to include electric bike rental services, which can more easily handle the terrain variations in the city. In line with the trend of smart mobility development, an application has been developed for system users to reserve bicycles, make payments, and easily find the nearest available bike (Castells, 2020). With the development of micro mobility, the system also offers electric scooter rentals as part of its services.

The public transport system in Barcelona is a complex system consisting of several subsystems (bus, metro, and tram). To facilitate the use of these systems, they have been integrated into a single fare system, meaning that one type of ticket can be used for any of the mentioned systems or their combination. Additionally, to simplify trip planning, a real-time passenger information system has been implemented. This system provides passengers with necessary information through an application, inside vehicles, as well as at public transport stops.

In addition to the mentioned initiatives, there are several other projects in Barcelona aimed at achieving smart mobility, such as incentives for using electric vehicles (purchase subsidies, free parking, electric vehicle charging station construction, etc.). Barcelona has implemented a smart parking system where sensors collect information to help users find available parking spaces more easily and direct drivers to the nearest available spot. Additionally, shared mobility systems such as Carsharing and Carpooling have been successfully operating in the city for some time, reducing the reliance on owning private vehicles. When it comes to sustainable smart mobility, Barcelona is perhaps best known for its urban neighbourhoods called "Superblocks." These residential areas contain a network of streets reserved exclusively for pedestrians and cyclists, with only a small portion designated for motor vehicles.

Copenhagen (Denmark)

Copenhagen stands as one of the global leaders in the realm of smart mobility solutions. Renowned for its dedication to sustainable transportation, the city has introduced a variety of pioneering initiatives to encourage cycling, walking, and the use of public transport. Among these initiatives, the development of cycling infrastructure emerges as a key smart mobility solution. Additionally, Copenhagen has successfully integrated its public transport systems, boasting an extensive network of buses, trains, and metro lines that operate under a unified ticketing system. This integration ensures seamless and convenient access to public transport for both residents and visitors alike. Furthermore, Copenhagen has installed real-time information displays at bus and train stops, enabling passengers to access up-to-date arrival times for their next bus or train. Additionally, the city has embraced various smart traffic management solutions aimed at alleviating congestion and enhancing traffic efficiency. Copenhagen's intelligent traffic management system continuously monitors traffic patterns and dynamically adjusts traffic signals to optimize flow and minimize congestion. Moreover, the implementation of a smart parking system equipped with sensors has revolutionized parking in the city. By detecting available parking spaces and guiding drivers to the nearest spot, this system reduces the time spent searching for parking and effectively mitigates congestion. Moreover, Copenhagen has implemented various smart mobility solutions aimed at enhancing safety and accessibility. These include pedestrian and cyclist detection systems installed at key intersections, as well as the introduction of low-floor buses and tactile paving. By prioritizing sustainable transportation modes and optimizing transportation efficiency, Copenhagen's smart mobility initiatives not only improve the quality of life for residents but also position the city as a global leader in reducing greenhouse gas emissions and addressing climate change (Wolnjak, 2023).

Glasgow (Scotland)

The role of ITS is indeed crucial in the transformation of cities into smart digital societies. Cities can address traffic challenges effectively, thereby improving traffic efficiency. ITS provides users with valuable information such as real-time traffic updates, local amenities, public transport schedules, and seat availability, enabling commuters to plan their journeys more efficiently. This not only reduces travel time but also enhances safety and comfort for passengers. The application of ITS has gained widespread acceptance and usage across many countries worldwide. ITS is not only utilized for managing traffic congestion and providing real-time information but also plays a crucial role in enhancing road safety and optimizing infrastructure utilization. A notable example of effective ITS implementation is observed in the city of Glasgow (Choudhary, 2019).

In Glasgow, ITS provides regular updates to daily commuters regarding public bus schedules, timings, seat availability, the current location of buses, estimated time of arrival at specific destinations, next bus stop locations, and the passenger density inside buses. The entire application of ITS relies on data collection, analysis, and utilizing the insights from the analysis in traffic management operations, control, and research. Location data plays a crucial role in these processes. In the application of ITS systems, sensors, information processors, communication systems, roadside messages, GPS updates, and automated traffic prioritization signals play crucial roles. The Traffic Management Centre (TMC) serves as a vital component of ITS, operated by the transportation authority. It functions as a technical system where data is collected and analysed for real-time operations and traffic control management, as well as providing information about local vehicles.

The entire process consist of data collection, transmission, analysis and travel information.

Data collection: It relies on various hardware devices that form the foundation for ITS functions. These devices primarily record data such as traffic volume, surveillance footage, vehicle speed and travel duration, location information, vehicle weight, delays, etc. These hardware devices are linked to servers typically located at data collection centres, which store vast amounts of data for subsequent analysis.

Data Transmission: This part of process involves transmitting collected data from the field to the TMC, and subsequently relaying analysed information from the TMC back to travellers. Traffic-related notifications are communicated to travellers via the internet, SMS, or on board vehicle units.

Data Analysis: The data collected and received at the TMC undergoes several processing steps. These include error rectification, data cleaning, data synthesis, and adaptive logical analysis. This refined collective data is further analysed to predict traffic scenarios, providing appropriate information to users.

Traveller Information: Travel Advisory Systems (TAS) are utilized to provide transportation updates to travellers. These systems deliver real-time information such as travel time, travel speed, delays, road accidents, route changes, diversions, and work zone conditions. This information is disseminated through various electronic devices including variable message signs, highway advisory radio, internet platforms, SMS, and automated cell notifications.

ITS represents a win-win situation for both citizens and city administrators. It ensures safety and comfort for citizens by providing real-time information and efficient transportation services. At the same time, it offers city administrators easier maintenance and surveillance of transportation systems, enabling them to make data-driven decisions for optimizing traffic flow and enhancing overall urban mobility.

CHALLENGES IN THE TRANSITION TO SMART MOBILITY

Considering the complexity of existing transportation systems, the implementation of smart mobility faces the following challenges (Pavia et al., 2021):

Infrastructure issues: During the implementation of smart mobility, certain challenges arise regarding infrastructure, mainly concerning how to adapt the existing transportation infrastructure to new needs. With the increasing popularity of autonomous vehicles and electric vehicles, there is a need to build infrastructure tailored to these vehicles. This includes constructing charging stations, implementing advanced communication and information technologies, etc.

Last Mile Connectivity: This problem primarily pertains to public transport systems, specifically how to facilitate door-to-door travel. To overcome this issue, it is necessary to reorganize the public transport system according to passengers' needs and integrate it with other modes of transportation.

Security and Privacy: The demand for interconnected devices and the swift accumulation of extensive personal data raise significant privacy issues concerning data exchange between devices and users. Additionally, the interconnected nature of devices renders the entire network susceptible to external attacks and breaches.

Governance: The expansion of smart mobility has broadened the reach of traditional transportation systems to encompass additional stakeholders, including technology companies and service providers. The involvement of these new participants requires revised policies and regulations governing smart mobility. It is essential to integrate existing traffic laws seamlessly to address the requirements of smart mobility solutions.

Initial Adoption: A significant challenge in smart transportation is raising awareness among potential users to encourage adoption. Many solutions are still in early stages of development, lacking substantial evidence of their precise objectives and benefits.

Dynamic Routing and Transportation Mobility: Efficient solutions require dynamic routing systems capable of estimating users' travel demands and optimizing available resources to deliver solutions. This process relies on sophisticated software and technological advancements.

Network Management and Monitoring: Smart mobility systems consist of a multitude of smaller elements and subsystems that need to be organized and integrated into a cohesive system. The primary challenge often encountered in this context is the cost associated with implementing and maintaining these systems.

Data Acquisition and Integration: Collecting data from diverse sources with varying security and privacy protocols presents a challenge. Managing the vast volumes of real-time data generated by connected devices is a complex task.

Legal Challenges: The engagement of various stakeholders such as payment companies, governments, city administrations, public-private transportation entities, users, and others underscores the need for a clearly defined legal framework and supportive policies to facilitate smart mobility initiatives.

This chapter highlights just some of the potential challenges that may arise during the implementation of smart mobility systems. To ensure that the implemented system operates at a high level and thereby meets the needs of traffic participants and the goals for which these solutions were implemented, close collaboration is required between city administrations, traffic participants, and potential investors.

CONCLUSION

This paper presents the key elements and characteristics of smart mobility, as well as the challenges encountered during the implementation of smart mobility systems in cities. It also highlights examples of best practices in the application of smart mobility across Europe to achieve a sustainable transportation system. From intelligent infrastructure and autonomous vehicles to mobility as a service, the smart mobility system encompasses a wide range of interconnected elements into one system to optimize the transportation system and improve levels of service for its users.

The benefits offered by smart mobility are undeniable, as evidenced by the reduction of traffic congestion, decreased environmental pollution, and improved safety for traffic participants, increased accessibility, and easier travel planning. Smart mobility enables the creation of a healthier and safer living environment for both city residents and tourists.

With advancements in autonomous vehicles, electric vehicles, MaaS systems, ITS and ICT, there is even greater potential for innovation and progress in transportation. While there are certain challenges associated with the implementation of smart mobility systems, there is also significant scope for the development of modern transportation systems aimed at meeting all societal needs and enhancing the quality of life for future generations.

Two key concepts that will influence the development of smart mobility in the near future are freight transportation and a significant shift towards MaaS service for passenger transport. In both cases, the Internet of Things (IoT) and Artificial Intelligence (AI) will play an increasingly important role in the future development of smart mobility concepts in cities.

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