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USE OF INTELLIGENT TRANSPORTATION SOLUTIONS BY CITY RESIDENTS. THE CASE OF LODZ

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Purpose: The purpose of the paper is to examine the opinions of the residents of the city of Lodz on the innovativeness of the city's transportation system and to assess the extent to which residents use intelligent transportation solutions. The paper analyzes 3 groups of solutions: (1) digital solutions that facilitate individual car trip planning; (2) digital solutions that facilitate public transportation planning and use; (3) shared mobility applications.
Design/methodology/approach: The article presents the results of a survey conducted in 2022 on a sample of 250 residents of Lodz.
Findings: Survey participants perceive the city's transportation system and available transportation services as relatively innovative. The adoption of modern digital transportation solutions varies by type. Residents are predominantly inclined to utilize applications that facilitate the planning and execution of individual car trips, with shared mobility systems being employed to a lesser extent. Among the solutions supporting public transportation trip planning, electronic passenger information displays at bus stops have gained more popularity than mobile apps. Ticket machines are also more frequently utilized than mobile apps for ticket payments. The frequency of using these solutions is influenced by respondents' gender and car ownership.
Practical implications: The results obtained can be used to determine the directions of intervention in the field of urban transport policy, as well as strategies for popularizing intelligent transport solutions among residents.
Originality/value: This study seeks to contribute to the current body of literature on the adoption of three categories of digital transportation solutions among urban residents. The article targets researchers and practitioners in the field of smart city development, particularly those engaged in the implementation and promotion of digital solutions within urban transportation systems.

Keywords: smart mobility and transportation, smart transportation solution, Intelligent Transport System, transportation mobile application, smart city.

Category of the paper: research paper.

1. Introduction

Contemporary cities play a crucial role in the digital twin transformation towards sustainability. Specifically, significant efforts are currently focused on reducing the carbon dependence and enhancing energy efficiency of urban transportation. These endeavors rely on the implementation of innovative technological solutions as part of the broader framework for developing sustainable smart cities (Bokolo, 2023; Müller-Eie, Kosmidis, 2023; Wolniak et al., 2023). A smart city (SC) can be characterized as a city that collaborates with its residents, leveraging modern technologies to provide innovative solutions across various domains, including mobility, economy, administration, environment, and quality of life (Dzupka, Horvath, 2021; Toli, Murtagh, 2020; Eremia et al., 2017). Notably relevant to the article's focus, smart mobility is defined as a cohesive set of activities aimed at enhancing the efficiency, effectiveness, and environmental sustainability of cities. A key aspect of smart mobility is connectivity, which, in conjunction with extensive datasets, enables real-time transmission of traffic information for users, while local government officials can concurrently engage in dynamic traffic management (Paiva et al., 2021; Pinna et al., 2017; Tomaszewska, Florea, 2018).

In recent years, intelligent transportation solutions have also gained popularity among urban residents. These innovative technologies aim to improve transportation efficiency and reduce traffic congestion. Intelligent Transportation Systems (ITS) refer to the integration of advanced technologies into transportation systems to increase their efficiency (Anedda et al., 2023; Boukerche, Wang, 2020). These technologies include real-time traffic management, smart parking, public transportation applications, ticketing solutions, smart traffic lights and ride-sharing platforms, among others (Tasgaonkar et al., 2024; Din, Rehman, 2019). These are supported by in-vehicle transportation systems that offer a communication framework for vehicles, road infrastructure and pedestrians (Hernández-Jiménez et al., 2019).

By leveraging data and connectivity, Intelligent Transportation Systems (ITS) contribute to optimizing transportation networks and enhancing the commuting experience for urban residents (Waqar et al., 2023; Angelidou et al., 2022; Šurdonja, 2019). This is particularly significant in the context of urban quality of life and residents' well-being, as research indicates that prolonged commute times have adverse effects on mental health, job satisfaction, and leisure time contentment (Lampkin et al., 2023). Smart solutions play a pivotal role in addressing this issue by reducing travel time through the provision of real-time traffic updates and suggesting alternative routes. These solutions are designed to offer citizens more sustainable, efficient, and convenient transportation options, thereby minimizing environmental impact through the promotion of electric vehicles and ride-sharing. Furthermore, ITS contributes to enhanced safety by facilitating improved traffic management and a reduction in accidents. Through the effective utilization of these solutions, city managers can strategically plan transportation systems, alleviate congestion, enhance public transportation operations, and offer convenient and sustainable mobility choices for both residents and visitors.

Technological solutions in urban transportation, are effective only when they find acceptance among users. In other words, technologies are considered useful and intelligent only when they are used intensively by people and when people do not experience inconvenience while using them (Popova, Zagulova, 2022). Studies of the degree of use of modern transportation solutions by users are basically not conducted. Contemporary research focuses primarily on analyzing the feasibility of implementing digital solutions in cities' transportation systems and related management systems. Our article fills the research gap in this area.

The aim of this article is to discern the perceptions of Lodz residents regarding the innovativeness of the city's transportation system and to evaluate the extent of their utilization of intelligent transportation solutions. The study scrutinizes three categories of solutions: (1) digital tools facilitating individual car trip planning; (2) digital solutions supporting public transportation planning and usage; (3) shared mobility applications. In the subsequent section, we conduct a literature review on these groups of intelligent transportation solutions and their functionalities. The next section outlines the availability of these solutions in Lodz and delineates the survey's assumptions regarding their adoption by city residents. The presentation of survey results incorporates sociodemographic characteristics such as gender and car ownership.

2. Literature review

Research conducted by Baldauf and Tomitsch (2020) leads to the conclusion that urban mobility apps provide residents with useful solutions in the areas of Intermodal Route Planning, Advanced Ticketing, and Real-time Information. Some of these apps are supported by local authorities and/or can be accessed through their official websites.

One of the key applications of intelligent transportation solutions in urban areas is trip planning. With advanced algorithms and real-time data, travel planning applications can offer personalized routes and transportation modes, taking into account factors such as road conditions, public transportation schedules and individual preferences. Through the analysis of diverse data sources, including GPS data from public transportation vehicles and historical traffic patterns, these apps have the capacity to suggest the most efficient and time-saving routes for commuters. This not only results in time savings and stress reduction for individuals but also contributes to the broader goal of mitigating traffic congestion.

Digital travel planners, including those for public transport travel, address users' needs for real-time access to information, saving pre-trip search time and travel time itself. The literature indicates that time savings through access to real-time information can range from 5 to 15%

(Bian et al., 2022; Li et al., 2021). Lopez-Carreiro et al. (2020) in their study showed that the areas of information most desired by travelers were specifically travel time, mode of transportation, itinerary, cost of travel and service incidents. Caulfield and O'Mahony (2007) conducted a study to collect data on public transportation passenger preferences and describe the methods of providing information that a passenger requires at each stage of the trip. The authors defined the stages before traveling to the destination, at the stop, on board and before traveling to the origin (return trip). A key finding was the importance of real-time information. The lack of certainty about passengers' arrival time at their destination emerged as a major factor causing frustration in public transportation use. Furthermore, passengers engaged in intermodal travel (involving multiple modes of transportation) were more likely to use public transportation information. Grotenhuis et al. (2007) further found that passengers were most concerned about timely arrival at interchanges. Real-time knowledge of estimated arrival times diminishes the uncertainty associated with waiting and increases user satisfaction due to its enhanced reliability (Bian et al., 2022).

Utilizing public transportation in cities is facilitated by various smart solutions beyond digital trip planners. These encompass functionalities like real-time tracking of buses and obtaining information about their arrival times at bus stops, digital ticket purchase via electronic ticketing systems, and automated fare collection. The Real-Time Monitoring and Tracking System for Vehicles enables travelers to monitor the location of public transportation vehicles through an app and access information about the anticipated arrival time at a specific stop from passenger information boards installed at bus stops. This functionality is enabled by GPS modules installed in public transportation vehicles, transmitting the vehicle's location in real time to receiver boards (Sharif et al., 2018). Electronic ticketing systems enable the purchase of digital tickets through various channels, including:1) Smartphone apps: users can buy digital tickets through dedicated applications on their smartphones. 2) In-vehicle and bus stop ticket machines: these machines, besides printing physical tickets, offer the option to store digital tickets on the traveler's payment card. This allows for greater flexibility in ticket management. 3) Traveler payment cards, smartphones with NFC, smart QR codes, or apps: these methods facilitate check-in and check-out on the vehicle, supporting the pay-as-you-go concept. Users can use payment cards, smartphones with Near Field Communication (NFC) capabilities, smart QR codes, or specific apps to record their journey and enable seamless payment based on actual usage (Ferreira et al., 2017; Joshi et al., 2023).

Public transportation trip planning apps that provide real-time information contribute to the attractiveness of public transportation. Some authors claim that more than 30% of public transportation app users increase bus use (Bian et al., 2022). Also Bielińska-Dusza et al. (2021) indicate that certain implemented smart solutions contribute to enhancing the appeal of public transportation. However, they highlight that measures such as prioritizing public transport vehicles at intersections or adjusting traffic signals based on traffic volume do not positively influence the perception of public transport among users as a reliable means of navigating the city.

Another prominent domain within smart transportation solutions in cities revolves around the concept of shared micromobility services (Reck, Axhausen, 2021). The development of the sharing economy (SE) contributes to the realization of sustainable development goals (Boar et al., 2020; Sadiq et al., 2023) in various areas, including transportation (Standing et al., 2019; Arias-Molinares et al., 2021). This is exemplified by diverse low-carbon urban initiatives encompassing bicycle programs, ride-sharing systems, scooters, and cars (Pereira, Silva, 2023; Shaheen et al., 2020; Oeschge et al., 2020). In general, mobility sharing entails innovative transportation services designed to optimize vehicle use and reduce the reliance on private cars. These services enable users to access transportation on a short-term, "as-needed" basis (Machado et al., 2018). Most of the shared services scrutinized in our article, particularly scooters and bicycles, fall under the category of shared micromobility. Micromobility aims to cover short distances, as well as the first or last miles (Hosseinzadeh et al., 2021). Vehicles used for micromobility are lightweight, small and do not reach speeds above 45 km/h. Both human-powered and electric-powered bicycles and scooters fall into this micromobility category (Krauss et al., 2022). On the other hand, carsharing, another mobility form analyzed in our study, allows for longer-distance travel and provides access to a variety of vehicles with different functionalities. Similar to shared micromobility services, carsharing operates on an access-based model rather than ownership, contributing to the development of sustainable urban transportation systems (Vanheusden et al., 2022). This solution is appealing to customers due to its flexibility, allowing them to choose the right car for each purpose, lower costs, and reduced maintenance efforts. A carsharing operator that ensures an adequate fleet size, equitable distribution of cars, and sufficient available parking spaces for its vehicles in response to urban parking space shortages presents an attractive option for residents navigating through urban spaces (Jian et al., 2020; Jochem et al., 2020).

Smart parking is emerging as another crucial aspect of smart urban mobility, gaining popularity as cities strive to become more intelligent and sustainable. With the increasing number of vehicles, smart parking is becoming a strategic concern for urban development (Al-Turjman, Malekloo, 2019). It is estimated that in urban areas, up to 30% of traffic is attributed to vehicles searching for available parking spaces. This often involves slow-moving vehicles, negatively impacting overall efficiency and contributing to increased transport pollution (Yang, Lam, 2019; Zhang, Li, 2018). Furthermore, driver distraction caused by the search for parking spaces is a contributing factor to collisions in parking lots. Individuals are often too preoccupied to pay attention to traffic or pedestrians (Kumar et al., 2023). Intelligent parking guidance systems that rapidly provide drivers with accurate information about parking availability can significantly reduce the time spent searching for parking spaces and alleviate traffic congestion (Xiao et al., 2023). Parking Guidance and Information Systems (PGI) play a key role in providing drivers with information about the nearest parking lots and the number of available spaces. Vision-based solutions are increasingly being deployed in cities as a cost-effective alternative to traditional PGI systems relying on hardware sensors installed on each parking space. Vision-based systems utilize cameras to capture images of the parking lot, providing information about space occupancy (Grbić, Koch, 2023).

Smart transportation solutions are consistently recognized by residents as one of the most crucial components of people-centered smart cities (Del-Real et al., 2023; Ji et al., 2021; Wei et al., 2023). Thompson (2016), on the other hand, points out, that among city-related mobile applications, by far the most popular are those related to travel (car, bus, bicycle, parking, etc.) in cities. Since the concept of smart mobility is relatively new, there are limited studies on the use of specific technologies and user behavior (Wang et al., 2021).

Most research in this area focuses on factors influencing the acceptance of digital solutions in urban transportation (Ferreira et al., 2017; Wang et al., 2021). The adoption of digital transportation services depends on factors such as digital competence, attitude (Ahmed et al., 2020), intention to use, accessibility to and operation of shared mobility systems (Turoń, 2022), trust, income, gender (Lenz, 2020; Singh, 2020), or age (Battarra et al., 2018; Docherty et al., 2018; Sourbati, Behrendt, 2021). Groth (2019) notes that access to smart mobility services is constrained for certain demographics, including the elderly, unemployed, and individuals with lower incomes.

3. Methods

3.1. Characteristics of digital transport solutions to support travel in Lodz

The study investigates 3 groups of digital transportation solutions dedicated to individual users of the city of Lodz:

1. digital tools to facilitate individual car trips planning - navigation apps that offer route planning and real-time traffic information, variable message signs, parking space available signs, parking meters and apps for parking payments,
2. digital tools to facilitate planning and use of public transport - dynamic passenger information displays at bus stops, apps for navigating public transport offering information on public transportation routes, schedules, and real-time updates, ticketing system (applications, Open Payment System and ticket machines),
3. shared mobility applications – car-sharing, e-moped sharing, scooter sharing, bikesharing.

Solutions in each of these groups can be classified in terms of the required user interaction as well as the type of provider (Table 1).

Table 1.
Smart transportation solutions in Lodz by type of provider and required user interaction

Item		Smart transportation solutions		
		Digital tools to facilitate individual car trips planning	**Digital tools to facilitate planning and use of public transport**	**Shared mobility applications**
Required user interaction	yes	- navigation apps - parking meters and apps for parking payments	- apps for navigating public transport - apps for ticket payments - ticket machines - digital ticket purchase system assigned to a payment card (Open Payment System)	- apps for renting a car by the minute - apps for renting a e-moped by the minute - an app for renting a scooter by the minute - an app for renting a bicycle by the minute
	not	- variable message signs - parking space available signs	- dynamic passenger information displays at bus stops	-
Supplier type	public	- parking meters - variable message signs - parking space available signs - apps for parking payments	- dynamic passenger information displays at bus stops - apps for navigating public transport - apps for ticket payments - ticket machines - digital ticket purchase system assigned to a payment card (Open Payment System)	- an app for renting a bicycle by the minute
	private	- navigation apps - parking space available signs - apps for parking payments	- apps for navigating public transport - apps for ticket payments	- apps for renting a car by the minute - apps for renting a e-moped by the minute - an app for renting a scooter by the minute

Source: own elaboration.

Solutions supporting individual travel planning by car in Łódź encompass various types of digital tools, both requiring interaction from travelers and not necessitating such activity. Providers of these solutions include both the municipal government and private operators. Travel planning in Łódź is aided by navigation applications provided by the private sector, which drivers can access via smartphones (e.g., maps.google) or, using appropriate devices, within vehicle navigation systems. These solutions involve user interaction. Support for travel planning also includes variable message signs (9 VMS boards), constituting the driver information subsystem—a component of the city's intelligent transportation systems (Sprint, 2023). The boards provide information on road incidents, repairs and detours. They are positioned on major streets throughout the city and do not require user interaction. Digital transportation solutions also apply to the city's parking system. Using the municipal parking system in Łódź requires payment for parking, which can be done through applications (currently 8 apps: AnyPark, CityParkApp, ePARK, FlowbirdParking, Karta Łodzianina, moBILET, MobiParking, mPay) or parking meters located in the paid parking zone, equipped with touchscreen displays (Urząd Miasta Łodzi, 2023). Additionally, a municipal parking space information system based on 30 signs was implemented in 2014. In addition to the city's system, a parking information system is implemented at one of the central locations in Łódź, the Manufaktura shopping center. This system includes sensors installed at each parking space, determining the current occupancy status. The processed information is then collectively displayed on boards at the entrances to the parking lots surrounding Manufaktura. Consequently, drivers receive information about the number of available and occupied spaces before entering the parking lot. If all parking spaces are occupied, the information enables the driver to bypass a specific parking lot and proceed to another one with less congestion (Barwiński, Kotas, 2015).

The use of public transportation in Łódź is supported by interactive and non-interactive digital solutions provided by both the public and private sectors. One implemented solution is the Real-Time Information Display System at Bus Stops, comprising 130 boards installed at 65 stops managed by the Bus Stop Information Subsystem. The system provides arrival times and information about the bus or tram, including whether it is low-floor and wheelchair-accessible. The Mobile Information Subsystem allows passengers to access vehicle routes, departure times, and plan their journeys through the website www.rozklady.lodz.pl. The system is supported by 88 CCTV cameras installed at 82 intersections (Borowska-Stefańska et al., 2021). Additionally, the city has implemented a Public Transport Management Subsystem and a well-equipped Traffic Control Center. The software implemented was the Sydney Coordinated Adaptive Traffic System (SCATS), which manages traffic lights phases. The ITS system is complemented by the Sensor and Video Device Subsystem, automatically registering vehicle characteristics using ANPR (Automatic Number Plate Recognition) and collecting data on vehicle types and license plates at measurement points. The visual monitoring system consists of high-speed HD cameras at major intersections (Sprint, 2023). Despite the introduction of these ITS solutions, Łódź still remains the most congested city in Poland (Podgórniak-Krzykacz et al., 2022).

For accessing passenger information related to public transportation, mobile applications such as Jakdojade, myBus, and WatchLine Lodz are available. The myBus application allows users to check departures from a specific bus stop, the current location of the vehicle on its route, and whether the bus or tram is equipped with air conditioning, a ticket vending machine, or space for bicycles. Interchanges on the map are marked, displaying departures from all stops within the intersection in chronological order.

Passengers can purchase tickets at 24-hour ticket machines, located in most districts of Łódź. There are approximately 50 of these machines, and they are also installed in all vehicles. Digital tickets for local public transportation in Łódź can be obtained through mobile applications such as banking apps, Karta Łodzianina, zbiletem, moBilet, SkyCash, Jakdojade, mintmobile, or mPay (MPK-Łódź Spółka z o.o., 2023). In selected public transportation vehicles, the "Entry-Exit" fare in the Open Payment System (OPS) can be utilized, enabling payment for the traveled route. Modern ticket terminals are installed at all doors of trams, where passengers need to tap their payment card upon entering the vehicle and again when disembarking, ensuring payment is only collected for the traveled route. (Kowalska, 2020).

The available shared mobility systems in the city include (Podgórniak-Krzykacz et al., 2022; Podgórniak-Krzykacz, Przywojska, 2022):

- Bikesharing: the Łódzki Rower Publiczny system is organized by the city, with Homeport as the current operator. It currently provides 1,500 bicycles, and bike rentals are possible through both applications and terminals at bike stations;
- Scooter sharing: currently offered by two operators - Bolt and Lime;
- E-moped sharing: until 2022, the service was provided by the operator Blinkee.city;
- Car sharing: currently provided by three operators - Easyshare, Traficar, and Panek - these services collectively offer around 600 cars for rent in the city.

These systems utilize mobile applications for accessing vehicle rental services, location services, and payment for the ride.

In 2023, a mobile point was launched in one of the Łódź neighborhoods called Zenit. Echo Share, a neighborhood mobility point, offers residents the opportunity to rent electric vehicles such as scooters, bicycles, or cars. This point also serves as an eco-friendly charging station, obtaining energy from photovoltaic panels located within the neighborhood (ECHO Residential by Archicom, 2023).

3.2. Method and research sample

The study focuses on the perception of the innovativeness of Łódź's urban transportation system by city residents and the extent to which they use intelligent transportation solutions. Additionally, the study aimed to determine whether the availability of digital solutions in public transportation influences its usage. Analyses took into account control variables such as respondents' gender and car ownership. The online survey was conducted in 2022 with a sample of 250 respondents who are users of the city's transportation system. The characteristics of the sample are included in Table 2.

Table 2.
Sample structure

Category		**Respondents**	
		n	**%**
Total		250	100.0
Gender	Woman	132	52.8
	Man	118	47.2
Car ownership	Yes	157	62.8
	No	93	37.2

Source: own elaboration.

3.3. Measurement

Assessment of the modernity of the city and its transportation system was measured using the variables in Table 3. Respondents used a 7-point Likert scale: from "strongly disagree" to "strongly agree”.

Table 3
Measuring the modernity of the city and its transportation system

Question	Items	Scale
Assessing the innovation of the city and its transport system	1. Łódź is a modern city 2. Łódź has modern transport infrastructure and systems 3. Modern transportation services are available in Lodz	strongly disagree, disagree, somewhat disagree, undecided, somewhat agree, agree, strongly agree

Source: own elaboration.

The use of intelligent transportation solutions assigned to 3 groups (1) digital tools to facilitate individual car trips planning (2) digital tools to facilitate planning and use of public transport (3) shared mobility applications was measured in terms of frequency. The variables are presented in Table 4. Respondents used a 7-point scale: from "never" to "always".

Table 4
Measuring the use of smart transportation solutions and services by Lodz residents

Area	Items	Scale
Digital tools to facilitate individual car trips planning	(1) Frequency of using websites/apps for route planning including information about possible traffic jams, collisions, and road congestion (2) Frequency of using variable message signs informing about traffic intensity and road difficulties (3) Frequency of using apps/boards/systems informing about available parking spaces	never, very rarely, rarely, moderately, often, very often, always
Digital tools to facilitate planning and use of public transport	(1) Frequency of using electronic dynamic passenger information displays for public transportation (2) Frequency of using apps for navigating/planning public transportation trips, e.g., jakdojade (3) Frequency of using ticket machines at stops (4) Frequency of using ticket machines in vehicles (5) Frequency of using digital tickets in apps (6) Frequency of using digital tickets assigned to a payment card	never, very rarely, rarely, moderately, often, very often, always
Shared mobility	(10) Frequency of using of shared city bikes (11) Frequency of using of shared scooters (12) Frequency of using of shared e-mopeds (13) Frequency of using shared cars	never, very rarely, rarely, moderately, often, very often, always

Source: own elaboration.

The variables used to measure the impact of the availability of digital solutions in public transportation on its usage are presented in Table 5. Respondents utilized a 7-point Likert scale, ranging from "definitely not" to "definitely yes".

Table 5.
Measuring the impact of accessibility to digital public transport solutions on public transport use

Question	Items	Scale
Impact of availability of digital solutions in public transport on more frequent use of public transport	(1) Impact of the availability of digital ticket assigned to a payment card (2) Impact of ticket availability in the app (3) Impact of ticket machine availability (4) Impact of public transportation navigating app availability (5) Impact of electronic dynamic passenger information displays availability	Definitely not, rather not, I have no opinion, rather yes, definitely yes

Source: own elaboration.

4. Results and discussion

4.1. Assessment of the city's transport system in terms of modernity

The evaluation of the city and its transportation system in terms of modernity, based on respondents' opinions, appears quite favorable (Table 6). The availability of modern transportation services received the highest rating. Slightly over 65% of respondents agreed or strongly agreed with this opinion. In the second place was the statement that Łódź is a modern city, with just over 63% of respondents fully or partially agreeing with it. The lowest ratings were given to the presence of modern transportation infrastructure and systems. Just under 60% of respondents held this opinion. Women and respondents without a car were more likely to agree with opinions about the city's modernity, infrastructure, and transportation services. Car owners and men were more critical. The obtained results align with the findings of other authors' research. For example, research by Borowska-Stefańska and others (2020) on the quality of public transportation services in Łódź paints a positive picture—the current policy regarding fleet and transport organization is heading in the right direction. However, a clear recommendation is the popularization of ITS systems displaying information about the arrival time of the next vehicle. According to other researchers (Fajczak-Kowalska et al., 2017) the introduction of the new transportation system in Łódź slightly improved the quality of public transportation services. Visible improvement occurred primarily in the information sphere, including dynamic content boards providing information about the vehicle's location, upcoming stops, transfer possibilities, as well as voice announcements in buses, information at stops, and on the Internet.

Table 6.
Respondents' opinions of Lodz and its transportation systems in terms of modernity by gender and car ownership (N = 250) (%)

Agreeing with the statement		strongly disagree	disagree	somewhat disagree	undecided	somewhat agree	agree	strongly agree	Total
		Łódź is a modern city							
Gender	Woman	7.6	3.0	18.2	2.3	49.2	12.9	6.8	100.0
	Male	3.4	11.0	26.3	1.7	39.8	14.4	3.4	100.0
Owning a car	Not	5.4	4.3	19.4	2.2	48.4	18.3	2.2	100.0
	Yes	5.7	8.3	23.6	1.9	42.7	10.8	7.0	100.0
Total		5.6	6.8	22.0	2.0	44.8	13.6	5.2	100.0
		Łódź has modern transport infrastructure and systems							
Gender	Woman	6.8	4.5	22.0	2.3	42.4	14.4	7.6	100.0
	Male	0.8	14.4	28.8	4.2	33.1	16.9	1.7	100.0
Owning a car	Not	4.3	7.5	21.5	2.2	46.2	18.3	0.0	100.0
	Yes	3.8	10.2	27.4	3.8	33.1	14.0	7.6	100.0
Total		4.0	9.2	25.2	3.2	38.0	15.6	4.8	100.0
		Modern transportation services are available in Lodz							
Gender	Woman	6.1	4.5	15.2	6.1	42.4	18.2	7.6	100.0
	Male	0.8	4.2	22.9	6.8	39.8	22.0	3.4	100.0
Owning a car	Not	3.2	3.2	20.4	5.4	45.2	20.4	2.2	100.0
	Yes	3.8	5.1	17.8	7.0	38.9	19.7	7.6	100.0
Total		3.6	4.4	18.8	6.4	41.2	20.0	5.6	100.0

Source: own elaboration.

4.2. Use of modern transportation solutions

The first group of digital solutions that facilitate individual car trip planning in Łódź, which we analyze, includes: (1) websites and route planning applications that consider information about traffic jams, accidents, and congestion on roads, (2) variable message signs providing information about traffic intensity and road disruptions in the city, (3) applications/boards/ systems providing information about available parking spaces. The frequency of using these tools by respondents when planning and driving in Łódź is presented in Table 7. Respondents used a 7-point scale, ranging from 'never' to 'always'. Among respondents, the most popular are applications enabling route planning, with over 60% of respondents often, very often, or always using them. Women tend to use them more frequently than men, and non-car owners more than car owners. Sociodemographic variables have been identified in many studies as factors influencing residents' transportation behaviors, including those related to the use of digital solutions (Prieto et al., 2017). The lower popularity of such tools among car owners may result from drivers having in-vehicle navigation systems at their disposal. Conversely, non-car owners who travel as passengers and use these applications can inform drivers about current congestion on the route. Additionally, the information provided by these applications is useful for individuals using other means of transportation, such as public transport.

Variable message signs are used significantly less frequently by respondents (approximately 35%). Every fourth respondent uses them with moderate frequency. Over 46% of individuals without a car rarely or never use them. Applications and systems providing information about available parking spaces in the city are the least popular solution.

Every fifth respondent has never used them. This solution is least popular among women and individuals without a car. It can be assumed that the low popularity is a result of the weak organization of the system in Łódź. The city has not implemented an intelligent parking system accessible through an application in the paid parking zone. Only parking space availability counters are available on selected streets in the city center. Counters also operate in some private parking lots located near large shopping centers. Furthermore, research by Borowska-Stefańska and Wiśniewski (2019) indicates that parking organization issues in Łódź are not limited to the city center alone (mainly the Śródmieście district). Areas along the main communication arteries of the city running parallelly (e.g., Piłsudskiego Avenue) or meridianally (e.g., Kościuszki Street, Zachodnia Street) deserve special attention.

Table 7.
Respondents' use of modern services to plan individual car trips by gender and car ownership (n = 250) (%)

Frequency of use		never	very occasionally	rarely	moderately	often	very often	always	Total
		Websites/apps for route planning including information about possible traffic jams, collisions, and road congestion							
Gender	Woman	6.1	5.3	12.1	12.9	27.3	22.7	13.6	100.0
	Male	6.8	5.9	11.0	16.9	30.5	22.9	5.9	100.0
Owning a car	Not	8.6	5.4	7.5	7.5	26.9	26.9	17.2	100.0
	Yes	5.1	5.7	14.0	19.1	29.9	20.4	5.7	100.0
Total		6.4	5.6	11.6	14.8	28.8	22.8	10.0	100.0
		Variable message signs informing about traffic intensity and road difficulties							
Gender	Woman	11.4	9.8	13.6	25.0	21.2	14.4	4.5	100.0
	Male	9.3	14.4	22.0	24.6	19.5	9.3	0.8	100.0
Owning a car	Not	7.5	14.0	21.5	25.8	14.0	10.8	6.5	100.0
	Yes	12.1	10.8	15.3	24.2	24.2	12.7	0.6	100.0
Total		10.4	12.0	17.6	24.8	20.4	12.0	2.8	100.0
		Apps/boards/systems that inform about free parking spaces							
Gender	Woman	22.0	9.1	10.6	22.7	20.5	12.9	2.3	100.0
	Male	18.6	9.3	15.3	23.7	20.3	8.5	4.2	100.0
Owning a car	Not	25.8	5.4	15.1	21.5	17.2	10.8	4.3	100.0
	Yes	17.2	11.5	11.5	24.2	22.3	10.8	2.5	100.0
Total		20.4	9.2	12.8	23.2	20.4	10.8	3.2	100.0

Source: own elaboration.

The second group of modern solutions, examined in terms of frequency of use by respondents, pertains to digital tools supporting public transportation and includes two types of functionalities: the ability to plan public transportation journeys (applications and electronic dynamic passenger information displays) and the ability to purchase tickets (four available modern options were considered: ticket vending machines on vehicles and at stops, ticket payment through applications, and assigning it to a payment card, including the Open Payment System). Among the solutions supporting public transportation journey planning, electronic passenger information displays at stops gained more popularity than applications with similar functionality (Table 8). Every fourth respondent has never used such applications, almost 40% are men, and nearly 30% own a car. These data may be related to the nature of the passenger's interaction with the tool. In the case of applications, installation on a smartphone is necessary, and providing data is also required, which may be a discouraging factor. On the other hand, electronic passenger information displays do not require additional activity from the user. This conclusion thus confirms the findings of other researchers regarding the significance of perceived ease of use in using solutions (Haldar, Goel, 2021). Women more frequently use both solutions compared to men. Additionally, both solutions are more popular among individuals without a car, which is likely linked to more frequent use of public transportation.

Among the modern ticket purchasing options, respondents most frequently choose ticket machines in public transport vehicles (used often or always by approximately 47% of respondents), followed by purchasing a digital ticket in a mobile app (42% of respondents often or always buy a digital ticket). In third place is the purchase of a ticket at a ticket machine at the bus stop (about 23% of respondents often or always buy tickets this way), and the least popular option is the Open Payment System or buying a digital ticket at a ticket machine and assigning it to a payment card (used often or always by only 13.5% of respondents). For the option of saving a digital ticket on a payment card, the highest percentage of individuals who never use this solution was recorded (almost 60%). Once again, women more frequently use every analyzed ticketing method compared to men. Ticket machines are more commonly used by individuals who own a car; on the other hand, non-car owners prefer digital tickets through the app, which may be attributed to the frequency of public transportation use. It can be assumed that car owners use it occasionally, opting not to install an app and instead using a ticket machine. For those who use public transportation more regularly, installing an app is more justified. Thus, our results support the findings of other researchers who argue that the perceived usefulness and benefits of a mobile ticketing service are perceived differently in different usage situations, and the usage situation significantly influences usage intention (Mallat et al., 2006).

Table 8.
Respondents' use of modern public transportation solutions by gender and car ownership (n = 250) (%)

Frequency of use		never	very occasionally	rarely	moderately	often	very often	always	Total
		TRIP PLANNING, CONNECTION INFORMATION							
		Electronic dynamic passenger information displays for public transport							
Gender	Woman	11.4	8.3	9.8	26.5	19.7	17.4	6.8	100.0
	Male	9.3	15.3	12.7	28.0	22.9	7.6	4.2	100.0
Owning a car	Not	7.5	5.4	8.6	29.0	23.7	15.1	10.8	100.0
	Yes	12.1	15.3	12.7	26.1	19.7	11.5	2.5	100.0
Total		10.4	11.6	11.2	27.2	21.2	12.8	5.6	100.0

Cont. table 8.

		Public transportation navigating/trip planning apps (e.g. Jakdojade)							
Gender	*Woman*	13.6	10.6	12.9	15.9	15.9	13.6	17.4	100.0
	Male	38.1	7.6	12.7	16.9	10.2	7.6	6.8	100.0
Owning a car	*Not*	19.4	10.8	12.9	12.9	8.6	14.0	21.5	100.0
	Yes	28.7	8.3	12.7	18.5	15.9	8.9	7.0	100.0
Total		25.2	9.2	12.8	16.4	13.2	10.8	12.4	100.0
		MODERN TICKET PURCHASING OPTIONS							
		Ticket machines at bus stops							
Gender	Woman	22.7	25.8	20.5	9.8	11.4	8.3	1.5	100.0
	Male	32.2	18.6	13.6	8.5	18.6	6.8	1.7	100.0
Owning a car	Not	23.7	24.7	23.7	7.5	12.9	6.5	1.1	100.0
	Yes	29.3	21.0	13.4	10.2	15.9	8.3	1.9	100.0
Total		27.2	22.4	17.2	9.2	14.8	7.6	1.6	100.0
		Ticket machines in vehicles							
Gender	Woman	6.1	13.6	14.4	15.9	19.7	24.2	6.1	100.0
	Male	16.9	10.2	14.4	14.4	24.6	13.6	5.9	100.0
Owning a car	Not	8.6	15.1	14.0	17.2	20.4	17.2	7.5	100.0
	Yes	12.7	10.2	14.6	14.0	22.9	20.4	5.1	100.0
Total		11.2	12.0	14.4	15.2	22.0	19.2	6.0	100.0
		Digital tickets in the app							
Gender	Woman	23.5	10.6	11.4	9.1	18.2	15.9	11.4	100.0
	Male	32.2	7.6	11.9	10.2	16.9	10.2	11.0	100.0
Owning a car	Not	18.3	5.4	8.6	9.7	18.3	19.4	20.4	100.0
	Yes	33.1	11.5	13.4	9.6	17.2	9.6	5.7	100.0
Total		27.6	9.2	11.6	9.6	17.6	13.2	11.2	100.0
		Digital tickets assigned to a payment card							
Gender	Woman	50.0	15.2	8.3	6.8	7.6	7.6	4.5	100.0
	Male	57.6	12.7	11.0	11.9	3.4	3.4	0.0	100.0
Owning a car	Not	47.3	17.2	8.6	9.7	4.3	8.6	4.3	100.0
	Yes	57.3	12.1	10.2	8.9	6.4	3.8	1.3	100.0
Total		53.6	14.0	9.6	9.2	5.6	5.6	2.4	100.0

Source: own elaboration.

The survey results reveal that respondents are more inclined to use public transportation due to digital solutions (Figure 1). The most substantial positive impact is associated with ticket machines, as almost 70% of respondents believe that they are more likely or definitely more likely to choose public transportation because of this payment option. The purchase of tickets through the app also holds significant importance, with 62% of respondents indicating a positive correlation. In contrast, respondents consider the system of saving a digital ticket on a payment card to have the least influence on their attitudes. Our findings align with those of other researchers; for instance, a study by Shaheen et al. (2016) demonstrated that respondents using transportation multimodal apps were motivated by the goal of making less energy-intensive trips and relying on public transportation.

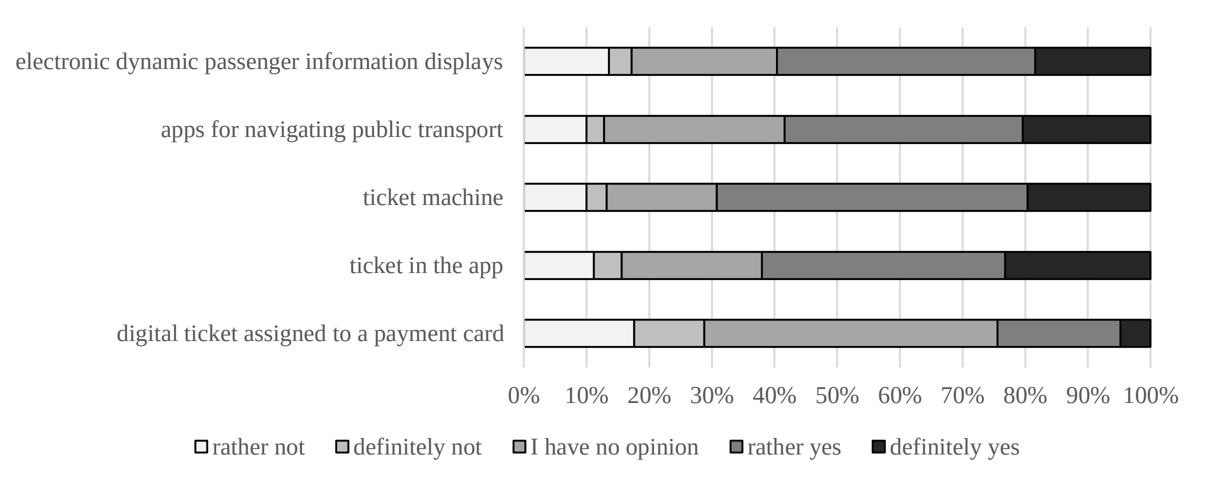

Figure 1. Respondents' opinions on the impact of innovations in Lodz public transport on their willingness to use it (n = 250) (%).

Source: own elaboration.

The third category of contemporary transportation solutions included in the survey comprises shared mobility services such as bikesharing, scooter sharing, e-moped sharing, and car-sharing. The frequency of utilization of these services by respondents is presented in Table 9. These services exhibit considerably lower popularity compared to all previously analyzed solutions. Approximately 60% of respondents have never utilized any of these vehicles, with the figure rising to almost 88% in the case of scooter sharing. A small percentage of respondents use these systems frequently, with car-sharing recording the highest frequency (more than 15.5% of respondents), followed by bikesharing (10%), scooter sharing (8%), and e-moped sharing, which is used less frequently. These results contradict the findings of other researchers regarding the increasing popularity of shared mobility systems (Bokolo, 2020). Men and non-car owners more frequently rent bicycles and scooters, while women and car owners prefer car sharing. Previous research suggests that these services are predominantly used by men (Singh, 2020), however our analysis indicates the need for further research to explain the higher acceptance of car sharing in Lodz among female respondents than among men.

Table 9.
Respondents' use of shared urban mobility by gender and car ownership (n = 250) (%)

Frequency of use		Never	Very rarely	Rarely	Moderate	Often	Very often	Always	Total
		Bike							
Gender	Woman	63.6	13.6	6.8	8.3	3.8	3.0	0.8	100.0
	Male	55.1	13.6	13.6	5.1	8.5	4.2	0.0	100.0
Owning a car	Not	60.2	16.1	6.5	6.5	7.5	2.2	1.1	100.0
	Yes	59.2	12.1	12.1	7.0	5.1	4.5	0.0	100.0
Total		59.6	13.6	10.0	6.8	6.0	3.6	0.4	100.0

Cont. table 9.

		Scooter							
Gender	Woman	65.9	7.6	7.6	13.6	1.5	1.5	2.3	100.0
	Male	54.2	16.1	16.1	2.5	7.6	3.4	0.0	100.0
Owning a car	Not	62.4	8.6	8.6	10.8	8.6	0.0	1.1	100.0
	Yes	59.2	13.4	13.4	7.0	1.9	3.8	1.3	100.0
Total		60.4	11.6	11.6	8.4	4.4	2.4	1.2	100.0
		E-moped							
Gender	Woman	88.6	5.3	3.8	2.3	0.0	0.0	0.0	100.0
	Male	86.4	5.9	2.5	3.4	1.7	0.0	0.0	100.0
Owning a car	Not	89.2	5.4	1.1	3.2	1.1	0.0	0.0	100.0
	Yes	86.6	5.7	4.5	2.5	0.6	0.0	0.0	100.0
Total		87.6	5.6	3.2	2.8	0.8	0.0	0.0	100.0
		Car-sharing							
Gender	Woman	62.1	12.1	3.0	4.5	6.1	8.3	3.8	100.0
	Male	62.7	11.0	9.3	4.2	4.2	6.8	1.7	100.0
Owning a car	Not	65.6	10.8	7.5	6.5	5.4	3.2	1.1	100.0
	Yes	60.5	12.1	5.1	3.2	5.1	10.2	3.8	100.0
Total		62.4	11.6	6.0	4.4	5.2	7.6	2.8	100.0

Source: own elaboration.

5. Summary

Smart transportation solutions have revolutionized travel planning in cities, providing real-time information about road conditions, alternative routes, public transportation schedules, and the integration of different transportation options. This empowers users to make informed decisions about travel routes and modes, ultimately reducing travel time and alleviating road congestion. Intelligent transportation solutions also contribute significantly to enhancing public transportation systems, making them more competitive and appealing compared to individual modes of transportation.

City residents are actively embracing smart transportation solutions to enhance the efficiency and effectiveness of urban travel. The increasing popularity of public transportation apps and ride-sharing platforms reflects their openness to innovative technologies. Our survey results reveal that residents utilize smart transportation solutions with varying frequencies, depending on the type of solution. The most commonly used solutions are those supporting trip planning and execution for individual transportation, followed by public transportation, and least frequently for shared mobility systems.

Among solutions supporting public transportation trip planning, electronic passenger information displays at bus stops enjoy greater popularity than mobile apps. Ticket machines are also more commonly used for ticket purchase compared to mobile apps. Moreover, differences in the usage of all analyzed solutions were observed between men and women, as well as car-owning and non-car-owning individuals. These findings underscore the necessity of promoting modern transportation solutions among city residents, particularly applications related to public transportation. This can be achieved through marketing campaigns, educational initiatives, and promotional efforts targeting diverse social groups and individuals of varying ages. Such endeavors are justified by the confirmed positive impact of these solutions on the inclination to choose public transportation for urban travel.

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