TRANSPORT PROBLEMS 2024 Volume 19 Issue 2
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2023.19.2.03

Keywords: smart and sustainable mobility; public and shared transport; cities; digital competencies

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SMART AND SUSTAINABLE URBAN MOBILITY – PUBLIC AND SHARED TRANSPORT USERS' BEHAVIOR IN GDYNIA CITY: A CASE STUDY

Summary. Novel technologies have resulted in the unprecedented and dynamic development of transport systems—one of the most important sectors of the economy. The implementation of smarter commuting solutions, in order to improve the processes of transportation, allows for cost and energy saving, better organization of time, and, as a result, an increase in quality of life. Also, this supports the operationalization of the sustainable development concept, enabling a compact and efficient urban transport system to be developed. The purpose of this paper is to analyze smart urban mobility development prerequisites and challenges, taking Gdynia city public and shared transport users' preferences and transport behavior as a case study. A research hypothesis has been formulated stating that most commuters have sufficient digital competencies and benefit from the available modern technological solutions contributing to smarter and more sustainable urban development. The obtained results prove the importance of the role the digital world plays these days and show how the impact of technology on the transportation sector has helped to develop new opportunities for urban mobility.

1. INTRODUCTION

In recent years, one can observe unprecedented rapid technological development. This is due to the ongoing Fourth Industrial Revolution, which focuses on combining the physical, digital, and biological environments, mainly with the use of artificial intelligence. Just like in the 18th century, when the changes introduced in production led to the first Industrial Revolution, as well as in the 20th century, which was initially marked by the Second and ended with the Third Industrial Revolution, the changes also affected the economy and, above all, society.

The idea of Industry 4.0 involves the development of smart factories, functioning through diverse information and communication technologies that enable the automation of processes along the advanced supply chain, leading to its optimization. This ultimately allows the development of innovative working methods, including in the transport, forwarding, and logistics sector. It is noteworthy that this ubiquitous digitization encompasses more and more aspects not only related to the efficient operation of factories or businesses but also to the daily lives of each of us. That is why it is so important to make the most of the potential that lies in the Fourth Industrial Revolution. Its emergence has seen the expanded application of digitalization as a universal and complex key facilitator for urban sustainable development [1].

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A smart city model entails taking advantage of the latest advances in order to create an eco-friendly, liveable, and sustainable space. Vehicular social networks could enable smart mobility. Sustainability, innovativeness, and safety of the transport system, information and communication technology infrastructure, and access to local transportation infrastructure are considered the primary drivers of success in smart mobility. According to Italian researchers, Smart Hubs' network based on electric micro-mobility has the potential to optimize urban mobility [2-5]. Also, there is a need to create a 15-minute neighbourhood network based on long-term strategies.

The development of smart mobility depends on transport supply, demand, and the size of the city. One should remember that security also poses a great challenge. Consequently, security and privacy play an important role in urban sustainability [6-8], such as anonymous threats [9]. According to some researchers, smart parking may be a game changer for smart and innovative mobility. Solutions such as electronic parking systems could furnish real-time parking prices while providing reservation and navigation amenities. Crowdsourced data may be crucial for reaching smart mobility objectives [10, 11]. Smartphones may be important mobility behavior sensors. As a matter of fact, they are currently a crucial information source for figuring out urban mobility preferences and behaviors [12-15].

It is also important that, in parallel with technological progress, public awareness of sustainable development is formed [16]. The increase in the quality of life caused by, among other things, the use of the latest technological solutions [17, 18], has also resulted in the dynamic development of transportation, one of the most important sectors of the economy. At the same time, it should be remembered that it is transport that is counted among the leading negative sources affecting the environment. So, the concept of sustainable mobility was created in order to reduce the effects of excessive exhaust emissions and noise [19].

Taking advantage of the effects of the Fourth Industrial Revolution, humans can more easily manage the available resources, meeting their needs, but at the same time not limiting the quality of life of future generations [20]. Such a concept is characteristic of the idea of Smart City, with the city of Gdynia as a perfect example thereof, being the first city in Poland to be certified under the ISO 37120 standard: "Sustainable cities and communities – Indicators for city services and quality of life" [21, 22]. In the near future, Gdynia could become an even more ecological, clean, and friendly city. Gdynia is already the Polish leader in zero-emission public transport thanks to a large fleet of trolleybuses and modern electric buses. In addition, it was the first Polish city to introduce subsidies for the purchase of an electric bike for residents, which means that awareness of sustainable and emission-free mobility is increasing, and living in a friendly city with clean air is slowly becoming a reality [23, 24].

This paper examines smart urban mobility development prerequisites and challenges in view of public and shared transport users' preferences and behavior in Gdynia city in Poland. Pilot survey research was meticulously conducted to discern the nuanced preferences and transport patterns within the Gdynia (Poland), with an acute awareness to identify uncharted territories within existing research such as specific digital competencies possessed by commuters, their receptiveness to emerging technological solutions, and the extent to which these factors contribute to fostering smarter and more sustainable urban development in the city. Additionally, the survey aimed to shed light on any latent preferences or behaviors among commuters, thereby enriching our understanding of the complexities inherent in urban mobility dynamics within the city. Consequently, a research hypothesis has been formulated stating that most of Gdynia public and shared transport systems' commuters have sufficient digital competencies and benefit from the available modern technological solutions contributing therefore to smarter and more sustainable urban development.

2. MATERIALS AND METHODS

A diagnostic survey method was used and a questionnaire survey, which is one of the most common techniques used to study the behavior and reactions to actions taken, was conducted in order to reach as many people as possible who could provide information on selected elements of Gdynia's transportation system. The research tool used in this study was a survey questionnaire previously created using the Google Forms online form builder. The questionnaire comprised 30 closed-ended questions in both

single-choice and multiple-choice formats, along with two open-ended inquiries, which allowed verification of the hypothesis.

The survey was conducted last year on a sample of 222 randomly selected people from a diverse pool of individuals who declared that they move around Gdynia, ensuring a broad representation of the population's characteristics and behaviors. Additionally, the sample accurately reflects the demographic makeup and distribution of attitudes and behaviors within the population and can provide reliable insights despite its relatively small size. Given the small number of participants in the survey, the sample conducted is sample-based—that is, it covers only a small part of the population [25]. Participation in the survey was voluntary and anonymous, and data such as gender, age, education, professional status, place of residence, and monthly net income were collected from the respondents in order to characterize the study group from the socio-demographic perspective.

The sample was non-random and unrepresentative, but it may be the basis for further research and is an added value for the topic under discussion. This study uses exploratory factor analysis in order to explore the data set and find complex relationships between items and group items that are parts of integrated concepts. Factor analysis does not distinguish between independent and dependent variables because of its exploratory nature. Factor analysis merely employs the data correlation matrix to group related variables into one component to discover underlying variables. The statements in this study were subjected to factor analysis with principal component extraction to determine whether they represented distinguishable elements connected to visitor satisfaction. The statistical procedure known as principal component analysis is used to highlight the variance for which major data components are produced and highlight prominent patterns in the dataset.

Finding the fewest number of factors necessary to accurately capture the relationships between the collection of variables is referred to as factor extraction. There are numerous methods for identifying the underlying issues. Principal component analysis and common factor analysis can both be used to find factor solutions. Principal component analysis was utilized in this study since one of its goals was to determine the bare minimum number of components needed to adequately describe the provided data set. The number of factors needed to be extracted was established using Kaiser's criterion and a scree test, which are two methods utilized in this study to aid in the choice of how many factors to keep. The number of initial unrotated components to be extracted can be determined using the scree test and Kaiser's criterion (eigenvalue criterion). The ratio of the common variance to the specific variance explained by an extracted specific factor is the eigenvalue. The portion of the total variance explained by a factor is indicated by its eigenvalue. The notable factors in a factor analysis with an eigenvalue larger than one are kept. The reasoning behind this rule makes sense. An eigenvalue larger than 1 is regarded as significant and denotes that the factor accounts for more common variance than unique variance.

Due to strong cross-loadings, where a large number of factors are correlated with a large number of variables, factors obtained in the initial extraction phase are frequently challenging to interpret. Factor solutions that are orthogonal (uncorrelated) or oblique (correlated) are the two main methods for factor rotation. Because the answers produced via orthogonal factor rotation are simpler to understand and report, they are employed in this study. There are three methods for orthogonal rotation: varimax, quartimax, and equimax. Moreover, Kaiser's varimax approach (1958) is used to reduce the number of variables that have heavy loadings on each element. On a factor, varimax frequently aims to maximize the differences between the squared pattern structure coefficients (i.e., focuses on a column perspective). Loads that are high after extraction get greater after rotation, while loadings that are low become lower, maximizing the spread in loadings. It is advised to perform the factor analysis to obtain an item loaded in only one component by eliminating all cross-loaded variables if the rotated component matrix exhibits numerous significant cross-loading values.

3. RESULTS

3.1. Destinations and transportation behavior of respondents

Discovering residents' transportation preferences and behaviors is one of the elements that allows the development of an efficient transportation system for the city. Consequently, this makes it possible to meet the transportation needs of modern society and increase their quality of life. Therefore, during the survey, information was collected from respondents on their most common ways of moving around the city, destinations and directions of travel, and the use of applications that help them do so.

By analyzing the two most common ways of traveling around the city indicated by the survey and taking their socio-professional category as a reference (Fig. 1.), we can see that the vast majority of car users are the working people (74.8%). Additionally, a minor degree, university students (18.9%). A marginal role in this mix is played by high school students (3.9%), the unemployed (1.6%), and retirees (0.8%). In contrast, the percentage of working people using public transportation is only 50.8%, with university students and high school students accounting for more than 40%. But, importantly, other users of public transportation represent a high percentage, considering all the people of a given category participating in the survey. Overall, 100% of schoolchildren, 80% of university students, and 78% of retirees declared that they travel around the city, especially by public transportation.

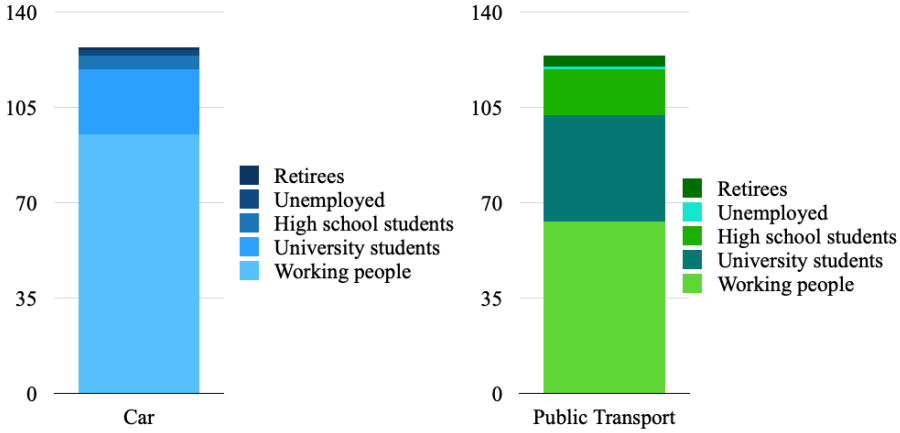

Fig. 1. Comparison of car and public transport users in Gdynia city

Another facet explored in this research was to determine the travel destinations of the survey participants. According to the data presented in Fig. 2, it can be observed that the most common reasons for the respondents' moving around refer to work (146 people), shopping (111 people), running errands in the city (85 people), and school or university (64 people). Taking into account the four most frequent destinations of the survey participants in relation to their age group and comparing the obtained values with the percentage of the surveyed people, it can be concluded that the most active age groups that move around the Gdynia city are those between 18 and 45 years old.

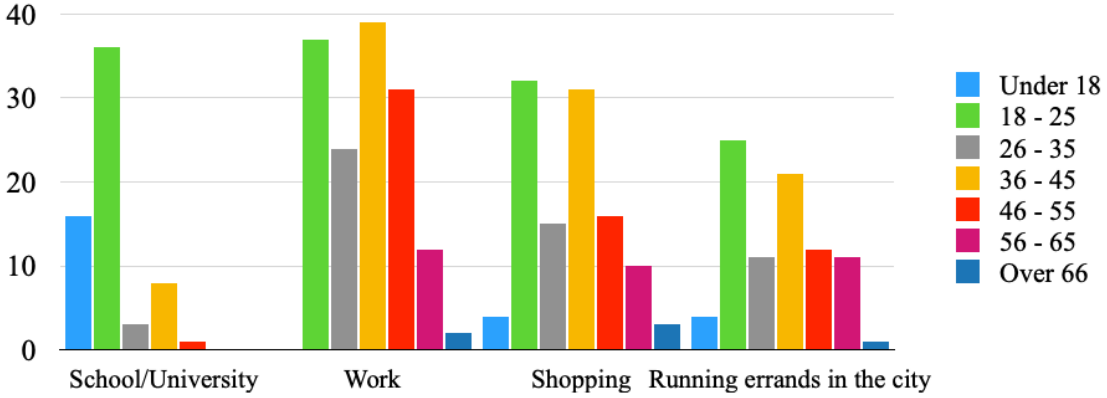

Fig. 2. Comparison of most popular destinations by age group

Tab. 1 presents examples of applications supporting the Gdynia transportation system and divides them into groups [26, 27].

Table 1

Apps to help people travel around Gdynia

International Applications	Nationwide Applications	Local Applications
Google Maps	jakdojade	ZKM Gdynia
Apple Maps	Skycash	SKM KomPas
Uber	yanosik.pl	Morabus
Bolt	KOLEO	

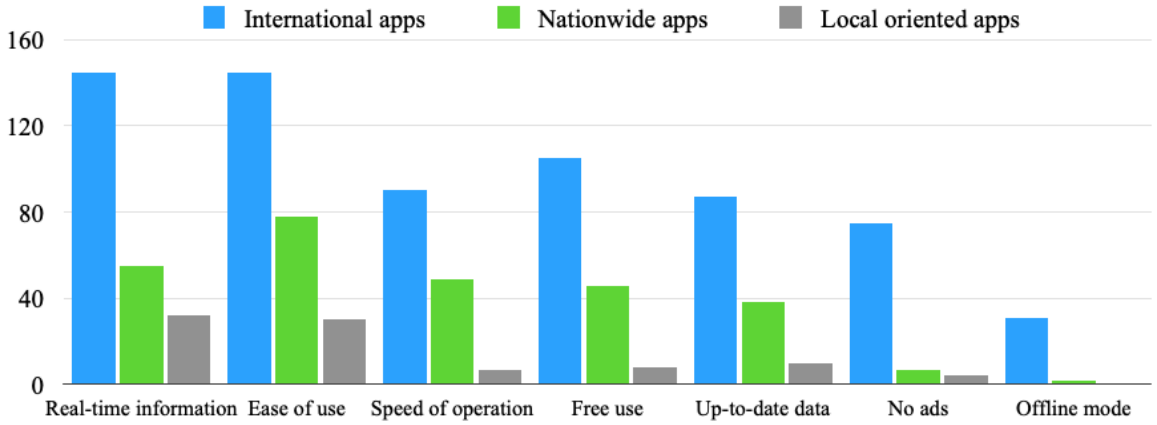

Fig. 3. Comparison of the most popular applications that support traveling in relation to the functions they offer, taking into account their origin

Applications have been divided into parts of subgroups: international, nationwide, and local. Here, it can be seen how progressing globalization affects the users of Gdynia's transport system. International applications, such as Google Maps, are chosen much more often than domestic or city products. In every aspect examined—real-time information, ease of use, speed, the possibility of free use, up-to-date data, no ads, and the possibility of using offline—users indicated the advantage of international applications without hesitation.

3.2. Public and shared transport system in Gdynia

The analysis of the results of the previous part of the survey made it possible to find the preferences and transportation behaviors of people traveling around Gdynia. It is clear that there are two dominant forms of transportation—the personal car and public transportation—and that the movement mostly takes place in the area of Gdynia's central districts. Therefore, it made sense for the next part of the survey to focus on the operation of public and shared transportation in Gdynia, which can consequently help organize these services within the city, so that, in accordance with the principle of sustainable mobility, the flow of private cars in the center is reduced [28]. Moreover, according to the introduced Electromobility Development Strategy for the Municipality of the City of Gdynia by 2035, the city is expected to reduce the emission of harmful substances generated by car traffic in the near future. Therefore, it is reasonable to create favorable conditions for the promotion and use of electric vehicles—not only cars or small electric vehicles such as bicycles or scooters—and, above all, to focus on the increase of the importance of low- and zero-emission means of public transport.

According to the data presented in Fig. 4, respondents selected bus—158 people (75% of all people using public transportation)—and SKM rail—102 people (48%)—as the most common type of public transportation used. Further positions were occupied by trolleybus, indicated by 41% of respondents, Regio trains (10%), and PKM (8%). Meanwhile, from comparing the age structure of the survey

participants with the type of public transportation they most often choose, it can be seen that their main passengers are those in the 18–25 age group, as they account for 30% of all bus users, 40% of SKM passengers, 25% of trolleybus travelers, 45% of Regio travelers, and 37.5% of those declaring to use PKM. Only in the case of trolleybus users did respondents in the 36–45 age category play the largest role, accounting for 27% of all travelers by this mode of transportation.

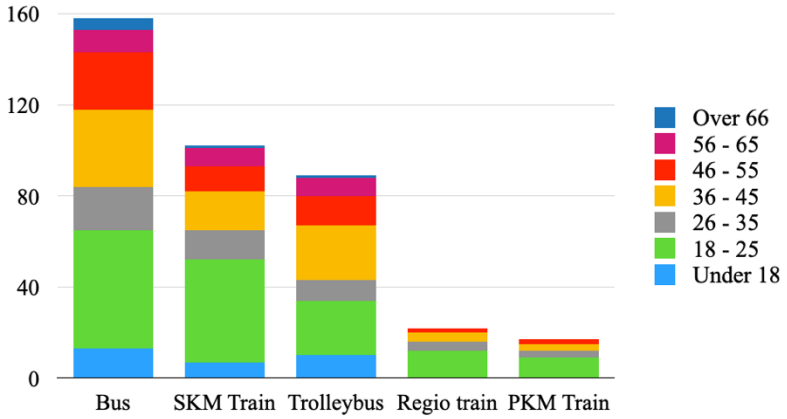

Fig. 4. The most popular modes of public transport chosen by survey participants from each age group

In the next section of the survey, participants were prompted to grade the functioning of public transportation in Gdynia (Fig. 5.). The received opinions on nine aspects of key importance to the organization of public transportation made it possible to provide an overall assessment of the functioning of Gdynia's public transportation system. The areas surveyed included punctuality, travel comfort, regularity, accessibility, frequency of connections, directness of connections, speed, low cost of travel, and access to information. According to the collected responses, the highest-rated element is accessibility, and the lowest is the low cost of travel. However, by averaging all the results, it can be concluded that among the participants, Gdynia's public transportation, on a five-point scale, is rated good (4). This was the answer given by 97 respondents. Meanwhile, 62 respondents rated it medium (3), while 41 rated it very good (5). Only 22 people spoke critically about it (16 - badly (2), 6 - very badly (1)). Therefore, it can be concluded that in the near future, Gdynia's public transportation system may become more competitive with private car transportation, or at least it has good grounds for doing so.

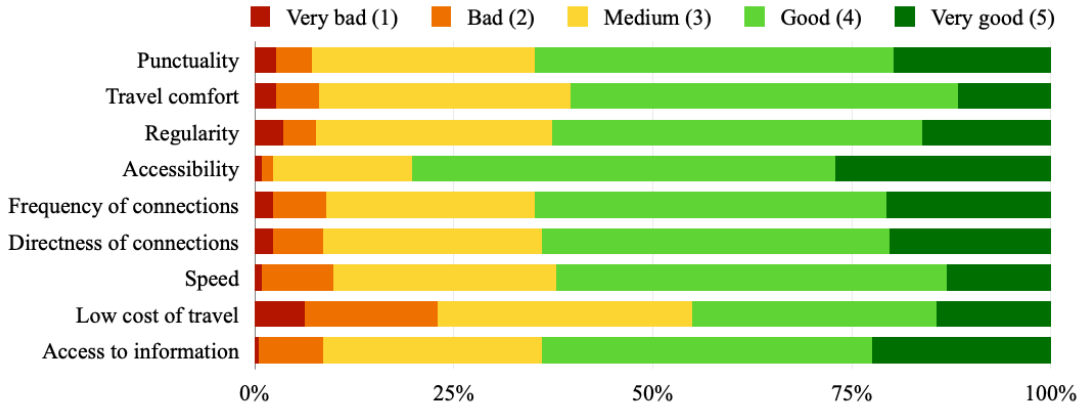

Fig. 5. Opinions about the functioning of public transport in Gdynia

Since it is ticket prices that were rated lowest in the earlier part of this survey and because they are the main factor discouraging survey participants from using public transportation on a regular basis, the next section of the manuscript was dedicated to this factor. The data presented in Fig. 6. show the types of tickets used by respondents. According to the responses, single-pass electronic tickets are the most popular among survey participants, as they are selected by 50% of all users of Gdynia's public

transportation, while traditional paper single-pass tickets are also commonly used (25%), as are monthly tickets stored on a city card (25%). Furthermore, 15% of respondents said they use electronic timed tickets, while paper timed tickets (6%), paper monthly tickets (6%), and timed tickets on a city card (1%) played a minor role in the mix. As for the functioning of Gdynia's public transportation, we cannot disregard passengers taking advantage of the opportunity for free travel. In the case of this survey, all 12 people who selected this answer were in the under-18 age group.

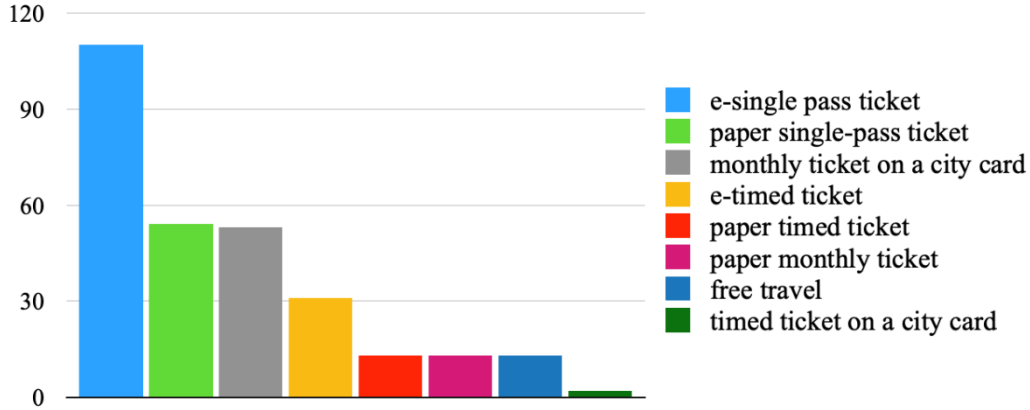

Fig. 6. Most popular types of tickets chosen by survey participants

Apps also play a significant role in the constantly emerging popularity of shared mobility. However, among the survey participants, only 80 people (36%) answered positively when asked if they use shared transportation (Fig. 7.). Among them, it is also an action that is not their travel pattern, but only an option they support occasionally/if necessary—62 people (77.5% of those using shared transportation) declared doing so. Fourteen people (17.5% of those using shared transportation) stated that they traveled around the city by shared transportation several times a month, while regular use was declared by four people. Three respondents use shared mobility from three to four times a week, while one survey participant does so daily.

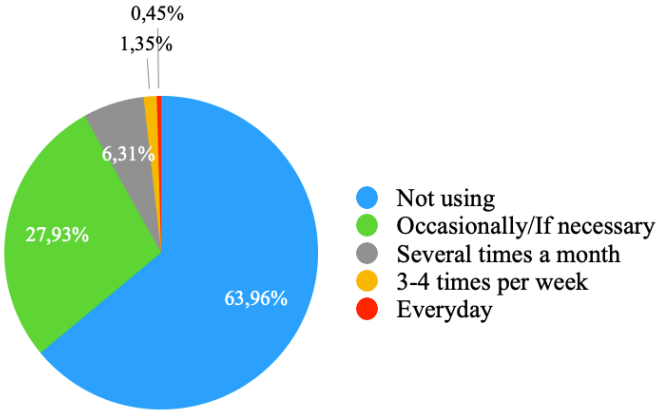

Fig. 7. Frequency of shared transportation use

In the following question, respondents were tasked with choosing which types of shared transportation they use most often (Fig. 8.). Among this list, the respondents' most common choices were carsharing (indicated by 56% of those surveyed who use shared transportation), and electric scooters (53%). It is also noteworthy that shared mobility is more often chosen by men than women. Indeed, they account for 71% of all carsharing users and 53% of those moving around the city using electric scooters.

The survey participants also pointed out the reasons why they chose this modern form of transportation around the city. The answers were grouped and presented in Tab. 2.

Thanks to such openness to interacting with the digital world, it was possible to extend urban transportation services to include shared mobility [29]. In Gdynia, apart from the carsharing system, there is a very large fleet of electric scooters from various companies at the disposal of residents. ITS solutions launched in the city are constantly improving the comfort of travel, regardless of the means of transport.

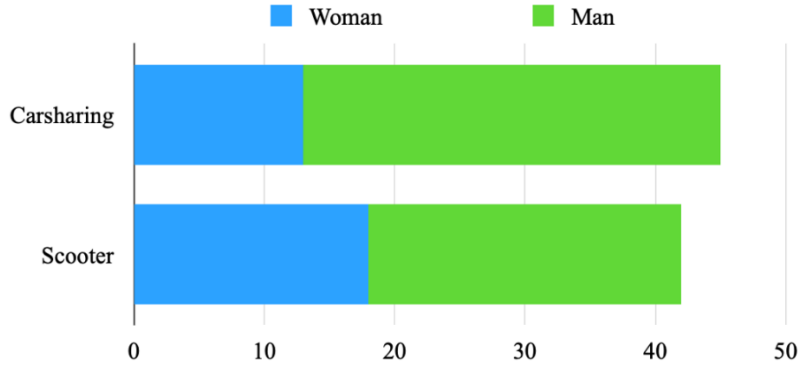

Fig. 8. Most popular forms of shared mobility by survey participants

Table 2

Reasons why respondents choose shared mobility

Reason	Number of respondents
Use in emergency situations	50
The possibility of deciding to use it at any time	45
Easier to travel around the city	40
Faster than modes of public transport	25
No need to use a single mode of transportation	19
Too long waiting time for public transport	17
Not having your own vehicle	13

4. DISCUSSION

The results of the factor analysis applied to the questions indicating the assessment of the respondent regarding the functioning of the public transport show that there is only one factor with an eigenvalue above 1.0 (with 56% of initial variability retained). This is further confirmed by the reliability analysis performed indicating that this is, in fact, a reliable, one-dimensional scale with all Cronbach's alphas above 0.88. This shows that all of the aspects of public transport display the same variability in the eyes of the customers—they do not seem to differentiate between different aspects, the pattern is the same for all of them, and if the customer positively assesses the cleanliness, he's just as likely to positively assess comfort, punctuality, and cost. This is indicative of somewhat of a tunnel vision from the customer's perspective.

The scores obtained via the above factor analysis have been saved and treated as the dependent variables in a series of applications of analysis of variance (ANOVA). ANOVA is a statistical technique utilized to examine variations among two or more means. ANOVA is utilized when comparing more than two means, whereas the t-test is typically employed for comparing two means.

ANOVA is used to compare the variance between data samples to the variance within each sample. High between-group variance and low within-group variance suggest considerable differences in group averages. Specifically, the apparent aggregate variability within a data collection is explained by separating systematic components from random causes using this statistical analysis technique. The systematic factors statistically impact the supplied data set, while random factors do not. Consequently, age and place of residence were tested to look for their impact on the score. The results indicate that there are no significant differences in either age (except the group of people 46 + mentioned in Fig. 9.)

or the place of residence of the respondents (Fig. 10.). While there are certain minor differences in the variability patterns presented by different age groups and different citizen groups—the perspective of the public transport as represented by factor 1 is the most positive for the age group of 46+ when it comes to age strata and the least positive for citizens of peripheral districts for the residence strata—these differences cannot be said to be statistically significant at an alpha level of 0.05. All of the formal assumptions of the ANOVA have been verified. Specifically, the homogeneity of variances has been verified by the means of Levene's test as well as Cochran, Hartley, and Bartlett tests, and the normality of residuals has been verified using a graph of means vs. standard deviations. Finally, the size of none of the groups exceeds triple the size of any of the other groups, satisfying the commonly accepted threshold for group equality.

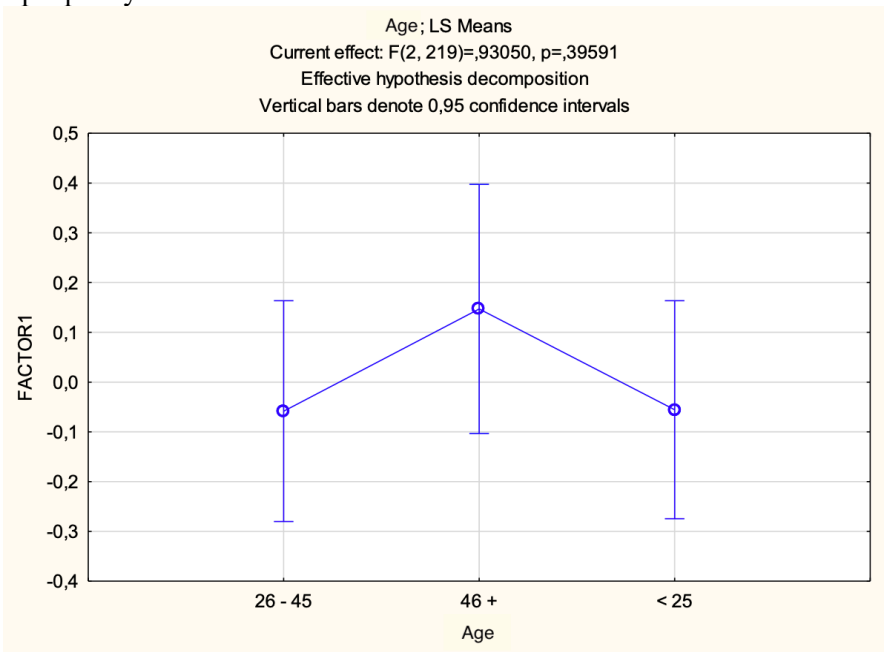

Fig. 9. Assessment of the respondents regarding public transport depending on their age

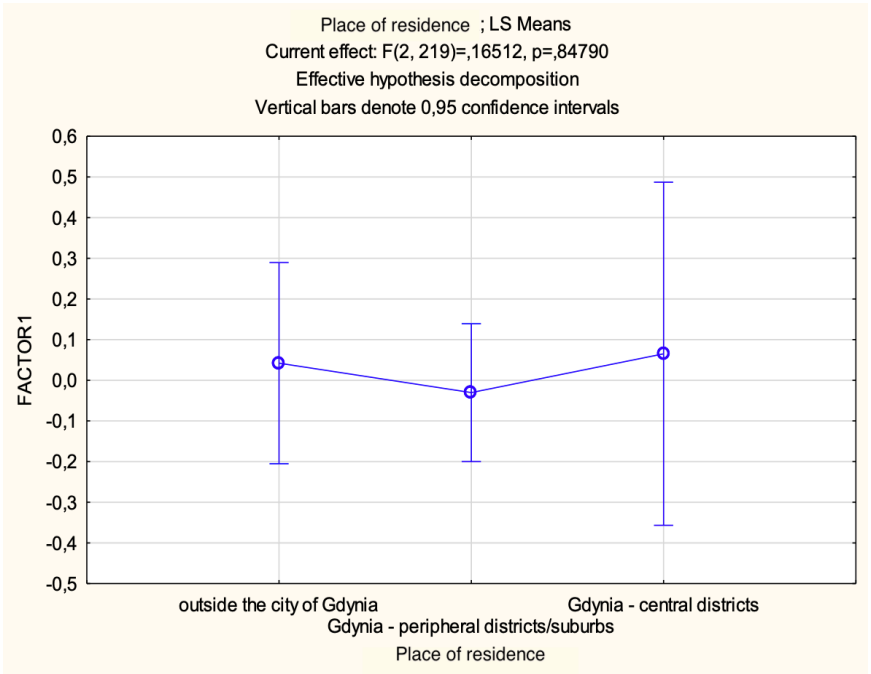

Fig. 10. Assessment of the respondents regarding the functioning of public transport depending on their place of residence

Interestingly, public transport is one of the most popular modes of transportation among the respondents, as it is in Poland [30]**.** The reasons why respondents are using public transportation are the inability to use a car, lower travel costs, avoiding congestion, and traveling to places with limited parking. Contrary to some Western European countries, taking care of the environment is not one of the reasons for choosing public transport as the main mode of transport, even though the city has a large fleet of low- and zero-emission vehicles [31-33]**.**

Digital technologies nowadays make it much easier to travel by public transport. The purchase of tickets from the application level and the possibility of locating the nearest public transport vehicle to optimize travel time is an effective way to form a positive perception of this type of transport [34]. An interesting factor that recently influenced the perception of public transport was the global COVID-19 pandemic, described by local researchers from the Tricity agglomeration and scientists presenting the phenomenon in China, where these effects appeared the earliest and were the most severe. On the one hand, it significantly accelerated technological progress, causing its users to use electronic tickets and timetables more often. On the other hand, restrictions related to maintaining social distance discouraged some users of public transport from using this method of travel [35, 36]. However, the presented research shows that people are slowly starting to return to normality and to use public transport to a similar, but slightly lower extent than before the pandemic [37, 38].

On the other hand, the concept of shared mobility in the city of Gdynia is just developing. Only 17.5% of respondents using shared transportation in Gdynia are regular users. The availability of only carsharing and electric scooter-sharing in Gdynia imposes notable restrictions on the expansion of this mode of transportation and might be one of the reasons that there is such little interest in it. Moreover, the lack of a city bike system means that the number of active trips is much lower than in other European cities of a similar size [39, 40]**.** This also has negative consequences in terms of air pollution and high noise levels, especially in the city center**.**

Shared transport is not seen as an alternative to the car or as a complement to public transport but as a service that is used in exceptional situations. Appropriate education in the field of multimodality of transport would create a basis for creating a transport system in Gdynia based on sustainable means of transport. The limited adoption of shared mobility in Gdynia not only hinders the city's efforts towards sustainable transport but also affects its overall urban functioning. According to research from other cities around the world and in Poland, the lack of various shared mobility options may contribute to a shortage of parking spaces and inefficient land use, which further deepens urban sprawl and environmental degradation. Using shared mobility as a viable alternative to private car ownership can alleviate these challenges, promoting the more efficient use of urban infrastructure and reducing a city's carbon footprint over time.

5. CONCLUSIONS

The obtained results prove the importance of the role the digital world plays these days and confirm how the impact of technology on the transportation sector has helped to develop new opportunities for urban mobility. The research hypothesis has been supported. Most of Gdynia’s public and shared transport systems’ users benefit from the available modern technological solutions contributing therefore to smarter and more sustainable urban development: 96% of all survey participants declared that they were users of various types of applications and that these applications helped them with urban traveling, while 77% of them regularly bought electronic tickets for available modes of public transport in the city.

Gdynia is a young, permanently growing city, and its citizens enjoy the benefits of living in a modern agglomeration located in the northern part of Poland along the Baltic Sea. Technological progress plays a special role in its modernization. Therefore, it is very important that these transformations are accompanied by concurrent social development, which will allow us to take full advantage of all the available opportunities. The conducted survey has its limitations in terms of space or respondents’ representation and profile. For example, tourists could be taken into consideration in future studies. Simultaneously, this study could serve as a preliminary investigation for potential follow-up studies

regarding the influence of digital technologies on smart and sustainable mobility development throughout Poland and other medium-sized European cities.

Based on the analysis, the following contributions in terms of findings, novel observations, and recommendations for this urban area may be indicated:

1. The general assessment of public transport in Gdynia is good in light of the survey. Respondents positively assessed such transport requirements as punctuality, travel comfort, regularity, availability, frequency and directness of connections, speed, and access to information. The low cost of travel, which was rated as average, was the worst in this ranking. The Gdynia public transport system may become more competitive in the near future, or at least it has good grounds to do so. Overall, 77% of people traveling around the city by public transport buy e-tickets from various applications, which proves the increasing penetration of digitalization into everyday life. The high satisfaction with various aspects of public transport in Gdynia, coupled with the growing adoption of e-ticketing through digital applications, suggests a positive trend towards modernization and efficiency within the transportation system. By addressing the cost concerns and further leveraging digital technologies, Gdynia's public transport system has the potential to enhance its competitiveness and better meet the evolving needs of the city's residents and visitors.
2. When it comes to shared transport, at the moment we can observe a fairly low rate of use by survey participants (36%). Introducing an electric city bike to Gdynia city may significantly increase this indicator, which, in turn, may cause a change in the transport habits of the surveyed people, fostering a more sustainable and eco-friendly commuting culture. By providing a convenient and alternative, the availability of electric city bikes may encourage more individuals to opt for shared transportation options, contributing to reduced traffic congestion and emissions in the city, making it more sustainable.

The respondents have sufficient digital competencies, and they did not report any problems adapting to the digital reality. The percentage of people using applications to facilitate their mobility and enable the purchase of tickets is high, which allows us to look with optimism at the possible implementation of further modern solutions introduced in the area of Gdynia. The high level of digital competency among respondents, coupled with their seamless adaptation to digital tools for mobility, creates a favorable environment for the successful implementation of additional modern solutions in Gdynia's transportation sector. The readiness for digital innovation suggests promising prospects for future advancements that enhance convenience, accessibility, and efficiency in the city's mobility infrastructure.

Meanwhile, there are already opinions testifying that the concept of Industry 5.0 is already on the horizon, the main idea of which would be complete cooperation between a human and a robot, using the best qualities of both of them. Therefore, without the introduction and effective use of all the assumptions of Revolution 4.0, it will not be possible to fully use the potential of upcoming changes. Besides, it is important to consider other important impacts of the Fourth Industrial Revolution on urban development, especially concerning its adoption in order to face sustainable mobility challenges and to take into consideration transportation systems' resilience and vulnerabilities. Also, sustainable and smart transport operationalization goes through enhancing energy transition by pursuing sustainable energy sources, conserving energy, and enhancing energy efficiency. The abovementioned factors may constitute further interesting research paths in this field in the future.

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Received 07.11.2022; accepted in revised form 06.06.2024