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TRANSPORTATION MANAGEMENT IN URBAN FUNCTIONAL AREAS

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ABSTRACT

Urban and suburban transport within Functional Urban Areas (FUAs) is now considered an integrated system. In these regions, many residents commute from the suburbs to the city daily for work, education, and social purposes. Transport planning must consider these dynamics to ensure consistent and convenient connections between the city and its suburbs. This article stresses the need for a standardized tool to collect data on transport management models in FUAs across 38 OECD-affiliated countries.

The proposed tool, a survey questionnaire, aims to gather information on how transport management models are organized and operate in these regions. The article discusses research conducted in the Olsztyn FUA, revealing significant variations in transport management methods among municipalities. The questionnaire is categorized into four themes: public transport, transport infrastructure, FUA transport strategy and innovation, and risks and monitoring, offering a comprehensive view of the transport management model.

The study also highlights varying development priorities among FUA municipalities; some focus on public transport, while others invest in road infrastructure. This study underscores the importance of a cohesive approach to transport management in FUAs, considering their diverse needs and requirements.

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1. Introduction

Transportation management (TM) in an urban Functional Urban Area (FUA) is a comprehensive process that involves planning, organizing, supervising, controlling, and improving traffic and transportation activities not only within the city but also in the surrounding suburbs and areas with strong functional connections. TM encompasses various objectives that define key aspects of the transportation system. These objectives include maintaining smooth traffic flow, optimizing the utilization of transportation infrastructure, ensuring traffic safety, and guaranteeing equal and equitable access to various modes of transportation. An important aspect of TM within the FUA is the promotion of environmentally friendly transportation modes, aligning with global development goals for sustainable transportation that safeguards the urban environment (United Nations, 2015). Integrating different types of transportation is crucial for facilitating seamless connectivity and convenient passenger transfers. Additionally, TM leverages advanced technologies such as smart traffic signals and traffic management systems to optimize traffic flow and enhance the overall transportation system. All these objectives contribute to the establishment of a favorable and user-friendly transportation environment, which, in turn, has an impact on the quality of life for residents and tourists, as well as on the environment. Implemented improvements and countermeasures should be monitored and evaluated since they may not always be effective enough, and further challenges may arise. TM within the FUA is a

complex endeavor, particularly when there is a lack of coordination in planning and organization among different regions, including within the FUA, making a coordinated approach challenging.

To date, various methods and tools have been employed to evaluate TM systems, such as surveys, interviews, traffic counts (Shafiei et al., 2015), GPS data analysis (Sekuła, 2022), ITS technologies (Guerrero-Ibáñez et al., 2018), and indexes, including cost-benefit analysis (Cartenì et al., 2018). TM is assessed through various indexes and indicators, such as the Transport Quality Index (TQI) (Falamarzi et al., 2021), Transportation Accessibility (Bhat et al., 2000; Tiznado-Aitken et al., 2021), Sustainable Mobility (Moeinaddini et al., 2015), Capacity (Gibson et al., 2002), Traffic Intensity (van Ruth, 2014), and Traffic Slowdown (Bunn et al., 2003). These methods allow for an objective assessment of the efficiency and quality of transportation systems. Additionally, relevant safety indicators (Marquez, 2016) and CO_2 emission indicators (Chen et al., 2020) are utilized by researchers, officials, and experts to analyze transportation systems and make decisions to improve traffic management in urban areas.

However, a literature review has revealed a gap in the development of a standardized methodological approach to evaluate the functioning of various transportation management models (TMMs) in urban functional areas (FUAs), which are considered "complex organisms" with multiple responsible and funding entities.

An FUA is defined as a geographic area containing one or more central cities and surrounding rural and urban areas, comprising separate administrative units with common economic, social, and infrastructure connections. In Poland, for example, the public transport organizer is composed of several entities, including the mayor of a municipality, the mayor or president of a city, the starost, the marshal of a province, and the minister of transport. Combining the interests of so many key decision-makers requires the implementation of different hierarchical-structural models.

Therefore, there is a need for a dedicated, standardized content of the questionnaire for gathering information about TMMs in FUAs. This necessity is particularly pronounced due to the diversity of TM systems worldwide, including in Poland (Masek et al., 2016; Patriksson, 2015; Soczówka, 2013; Tyan et al., 2003; Zhu et al., 2016). Given the multitude of TMMs in Poland, a long-standing member of the European Union (EU), it is crucial that this tool comprehensively considers all potential conditions, barriers, and opportunities while identifying individual systems. The specific form of these systems depends on numerous factors, including regulations governing public transport operations, demography, geography, economy, local policies, user preferences, the pace of technological development, and sources of funding in this sector. Depending on the availability and size of these funding sources, TMMs may vary in terms of service scope, operating frequency, accessibility to various social groups, and service quality. Therefore, there is a pressing need to create a universal tool, such as an interview or survey questionnaire, with the primary aim of collecting information about the organization and functioning of TMM in these regions.

This questionnaire may contribute to a better understanding of the existing differences in TM within FUAs, highlighting potential problems, challenges, and threats that public transport users encounter in their daily commutes. Additionally, the survey will facilitate the identification of possible inequalities and inconsistencies in the organization of public transportation in selected areas, including the identification of regions excluded from transportation services or at risk of exclusion, as well as problematic locations, such as areas with inadequate road infrastructure or existing traffic hazards.

Conducting the survey will enable the identification of areas that require more in-depth analysis and further research to optimize solutions in public TM. The survey will reveal both the strengths and weaknesses of the selected model. Consequently, decision-makers will be better equipped to make more informed choices regarding the further development of public transport. The data collected in the survey will help identify issues and highlight transportation challenges that may necessitate intervention by policymakers. TMMs are contingent upon existing threats in a given area or innovation (Kiani Mavi et al., 2022). Furthermore, the developed tool will support the assessment of management systems across entire regions, facilitating a comparative evaluation of individual segments. A comprehensive understanding of existing TMMs within various FUAs, in a structured and systematic approach, will facilitate the creation of integrated transport network management plans. Hence, a research hypothesis has been formulated that suggests the occurrence of threats in transport leads

to the implementation of innovative solutions in the TMM. The results obtained can serve as the foundation for validating current transport policies and their alignment with societal needs and expectations. Based on this, decision-makers can adjust policies to better meet the actual needs and preferences of residents.

1.1. Transportation management model

TM is structured around key management levels, which include operational, tactical, and strategic levels (Okdinawati et al., 2015). At the operational level, the emphasis is on day-to-day management aspects such as traffic monitoring, infrastructure maintenance, and passenger service organization. The tactical level involves timetable planning, optimizing transport services, and efficiently managing the vehicle fleet. The strategic level encompasses long-term transportation policy development, infrastructure enhancement, and the establishment of cohesive transportation systems that integrate various modes of transportation to enhance accessibility, promote sustainable development, and mitigate disruptions, such as traffic congestion. These three management levels converge to form a comprehensive TMM, facilitating the effective and sustainable operation of transportation systems across various domains and scales.

Indicators have been assigned to each management level: operational, tactical, and strategic (Table 1). They elucidate the essence and objectives of each level of TM. At the operational level, indicators describe information availability for staff, infrastructure conditions, operational handling, maintenance of traffic order, and safety-related aspects. At the tactical level, the focus is on optimizing activities and adapting them to changing conditions. These indicators encompass timetable planning, route and connection efficiency, vehicle fleet maintenance, and cost management. At the strategic level, management centers on long-term vision and planning (Nguyen, 2022).

2. Material and methods

2.1. Methods

The methodological approach employed analytical methods, including the analysis of scientific and industry literature concerning the organization and operation of TMM, control reports, and indicators describing various models (Fig. 1).

The sequence of the planned research tasks was determined based on methodological assumptions aimed at assessing the utility of the interview questionnaire tool and validating the research hypothesis that the emergence of threats disrupting the effective functioning of transportation contributes to the introduction of innovative solutions in its management model. The developed tool, which allows for the identification of TMM within FUAs along with its determining factors, is comprehensive and complete. It can be used for diagnostic purposes related to TMM in FUAs in 38 highly developed countries associated with the Organization for Economic Cooperation and Development (OECD), including Poland, where its effectiveness was tested.

Table 1

Indicators for levels of TM

Management levels	Indicators	Group*	Literature
operating	Frequency and regularity of public transportation trips	1	(Cieśla et al., 2010)
	Availability of passenger information (timetables, delays)	1	(Cieśla et al., 2010)
	Technical condition of road surfaces	2	(Kurakina et al., 2020; Nguyen, 2022)
	Availability of bicycle paths and sidewalks	2	(Buehler & Pucher, 2012)
	Speed range and speed limits within the municipality	2	(Bylinko, 2015)
	Duration and side effects of road construction works	2	(Hyari et al., 2015)
	Condition of public transportation stops and platforms	2	(Zhu et al., 2016)
	Response time to incidents and traffic flow maintenance	3	(Debnath et al., 2014)
	Proportion of sustainable transportation modes (bicycling, walking) in traffic	4	(Buehler et al., 2017)
	Number of electric vehicle charging station.	4	(Sztafrowski & Kaznowski, 2022)
	Level of passenger satisfaction with transportation services	4	(Mikulska & Starowicz, 2015)
	Percentage of electronic ticket sales	1	(Lübeck et al., 2012)
	Use of renewable energy in transportation	4	(da Silva et al., 2008)

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	Intersection collisions	2	(Masek et al., 2016)
	Availability of parking lots and stops (number of parking spaces relative to demand)	2	(Aliniai et al., 2015)
tactical	Availability and utilization of cartographic studies and Intelligent Transportation Systems (ITS)	3	(Antoniou et al., 2011)
	The number of entities or units involved in transportation development planning within FUAs	3	(Ceder, 2016)
	Current status and availability of reserves for road infrastructure	3	(Nawir et al., 2023)
	Occurrence of transportation development initiatives within FUAs	3	(Wolny-Kucińska et al., 2017)
	Number of available connections between regions/Length of public transport routes, e.g., per capita	1	(Stead & Marshall, 2001)
	Frequency of trips during various hours of the day	1	(van Lint et al., 2010)
	Scheduling adjustments for different days of the week	1	(van Lint et al., 2010)
	Vehicle occupancy levels during peak hours	1	(Chavhan & Venkataram, 2020)
	Age and technical condition of vehicles	2	(Hudec et al., 2021)
	Route and connection efficiency index.	1	(Chavhan & Venkataram, 2020)
	Integration of ticketing within the transportation system	1,4	(Kamargianni et al., 2016)
	Number of new lines and routes planned for introduction	1	(Milakis & Athanasopoulos, 2014)
	Projected duration of modernization projects	2	(Rocha Filho et al., 2020)
	Assessment of passenger information quality and evaluation of accessibility for individuals with disabilities	4	(Beul-Leusmann et al., 2014)
	Infrastructure maintenance costs	2	(Yannis & Chaziris, 2022)
	Costs associated with maintaining transportation means and passenger services (personnel, tickets)	1	(Jajac et al., 2009)
	Assessment of investment priorities	3	(Andersson et al., 2018)
	Schedule adjustments due to increases or decreases in demand and as a result of breakdowns	1	(Middelkoop & Loeve, 2006)
	Incident delay rate (risks)	3	(Pradhananga et al., 2014)
	Adoption rate of new electronic payment solutions	4	(Kuo et al., 2023)
	Rate of adoption of innovative technologies in traffic management	4	(Kuo et al., 2023)
	Capability to adapt to seasonal changes in traffic	3	(Jenelius & Cebecauer, 2020)
strategic	The share of renewable energy in transport	3	(da Silva et al., 2008)
	Speed limits for vehicle traffic within the FUA area	3	(Kim & Jung, 2021)
	Exclusions of certain vehicles (e.g., banning diesel vehicles from entering cities)	3	(Töller, 2021)
	Indicators of the length and distribution of the road and railway network	2	(Milakis & Athanasopoulos, 2014)
	Number and efficiency of transfer hubs	2	(Nellore & Hancke, 2016)
	The share of bicycle paths and pedestrian paths in urban infrastructure and traffic	2	(Buehler et al., 2017)
	Number of integrated ticketing and fare systems	1	(Kamargianni et al., 2016)
	Number of implemented ITS technologies	4	(Damaj et al., 2021)
	Share of electric (public fleet) or low-emission vehicles in the fleet	1, 4	(Mugion et al., 2018)
	Number of research and innovation projects implemented in the field of transport	4	(Kitchen et al., 2019)
	Number of transport development strategies developed for specific years	3	(Diao, 2019)
	The degree of implementation of goals and strategic plans in the area of transport	3	(Diao, 2019)
	The degree of use of modern technology, such as GPS assistance and route management systems	3	(Damaj et al., 2021)
	Joint transport development initiatives in FUA	3	(Ki-moon, 2015; Wolny - Kucińska et al., 2017)

* 1. Public transport, 2. Infrastructure and maintenance, 3. TM and strategy, 4. Innovations, threats, and monitoring

Source: own study.

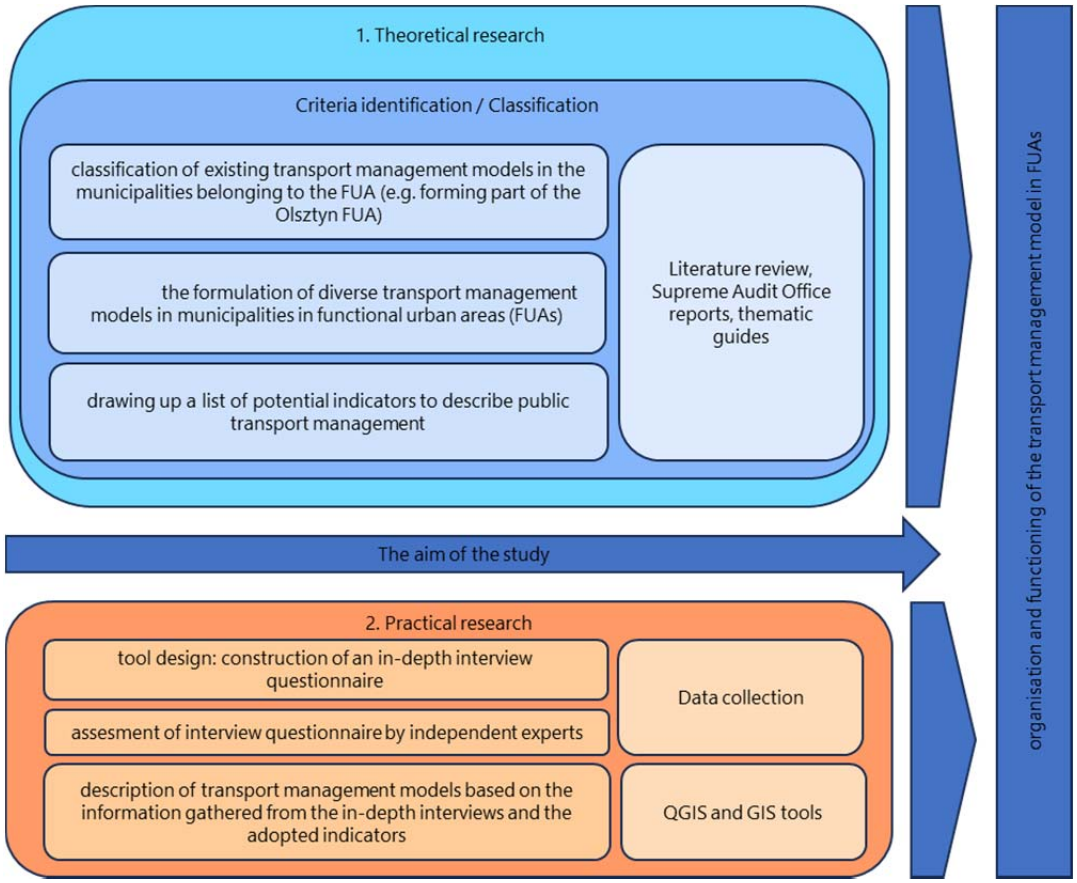

Fig. 1. Research steps and methods. *Source*: own study.

In the initial phase of the research, the identification and classification of TMMs in municipalities were conducted, and a list of potential indicators describing public TMMs was compiled based on a review of domestic and foreign literature, reports from the Supreme Audit Office, and industry studies. Selected indicators were used to develop interview questions as a data collection tool. The designed questionnaire was evaluated by independent experts and refined based on their feedback (Chapter 3.2). The expert groups included specialists with practical experience and knowledge in the field of transportation, such as experts in public transport, urban planners, transport engineers, and economists. Subsequently, the tool was tested in municipalities within the Olsztyn FUA, using the TMM.

In the subsequent stage of the research, the TMMs in FUAs were described based on the information collected from the questionnaire and using indicators describing TMMs in relation to spatial factors. The results of spatial analyses were presented in tables and cartograms, utilizing GIS tools, including QGIS software. The final stage of the study involved verifying the research hypothesis following the test in the context of the analyzed urban functional area of Olsztyn.

2.2. Interview questionnaire form

Based on the categorized indicators presented in Table 1 and the indicators of threats that influence on travel behavior (Dudzińska et al., 2023), a comprehensive electronic interview form was developed using the Google platform.

The direct interview method is a data collection technique employed in various fields such as social, psychological, marketing, and other research, involving direct interaction between the researcher and the respondent.

Responses to the questions can be categorized as open-ended (allowing respondents to provide free-form answers), closed-ended (where respondents select from predefined options), or semi-open-ended (offering respondents an alternative answer option while allowing them to clarify their response). A pilot test of the interview questionnaire was conducted with the participation of twelve experts who specialized in urban transport and transport infrastructure management, possessing professional experience in planning and organizing transportation systems within

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cities. The panel comprised four transportation engineers, three urban planners engaged in urban planning and public transport development, three experts in transport ecology, and two economists specializing in economic analysis related to urban transport activities. Among these experts, eight had professional experience exceeding 15 years, three had 10-15 years of experience, while the remaining experts had experience ranging from 5-10 years. The insights gathered from these experts were utilized to refine the questionnaire.

During the testing phase, experts observed that the questionnaire contained a large number of questions, making the interview process lengthy. They also identified three questions that were imprecise and unclear, necessitating clarification. These questions pertained to the quality of road infrastructure in the municipality, the prioritization of communication investments within the municipality's initiatives, and the potential for collaborative transport development initiatives spanning multiple municipalities within the FUA. It was evident that the latter question did not encompass all possible scenarios. Additionally, two questions redundantly inquired about the frequency of public transport services. Experts recommended changing the terminology in two questions and suggested grouping questions into thematic categories. Four groups were proposed: public transport, infrastructure and maintenance, TM and strategy, and innovation, threats, and monitoring. Alternatively, innovation and research were also suggested. Following the pilot study, the presented questionnaire was ultimately accepted.

The prepared tool in the form of a questionnaire ultimately consisted of four parts (Table 2). Finally, an open-ended question was added to identify other characteristic problem areas within a given municipality.

Table 2

Interview questionnaire to identify existing TMMs

	Group 1: Public transport
1	Please describe the current transportation network within the municipality. Kindly provide information on the number of bus routes operating in the area, including those in cooperation with the city (core routes) and those organized solely by the municipality. Please also specify if there are private bus lines with designated stops. This information should encompass both routes exclusive to your municipality and those that involve collaboration with neighboring municipalities. Do these routes serve all towns within the area? Identify the organizer responsible for these routes (including any private ones).
2	What is the frequency of bus services, and do they operate throughout the entire week?
3	Are there regular modifications to the bus timetable, such as seasonal adjustments or adaptations to changing demands? Do the buses have passenger counting systems on board?
4	Are there informational displays at bus stops indicating real-time arrivals, conventional timetables, or applications providing access to bus traffic updates?
5	What is the frequency of bus services during peak and off-peak hours? Is there any issue with overcrowding?
6	Is there a unified metropolitan transit ticket available, or is there a plan to implement one? Can tickets be purchased through mobile applications or websites?
7	Is the municipality considering the introduction of new bus routes or the expansion of existing ones?
8	What portion of the municipality's budget is allocated to the development of the transportation network and public transit?
9	What is the cost per kilometer for each vehicle?
	Group 2: Infrastructure and maintenance
1	How would you rate the quality of road infrastructure in the municipality on a 3-point scale? Please identify roads that require significant intervention due to surface conditions.
2	Is there a speed limit for vehicular traffic in the municipality?
3	Has there been any road construction or modernization, including bicycle paths, lasting longer than 3 months in the municipality? What were the traffic disruptions associated with the implementation of these projects?
4	Please provide information on the number and locations of bus stops in the municipality. Are bus stops consistent in design throughout the entire municipality, and what is their current condition? Are they shelters, posts, or of another type? Are there any plans to either decrease or increase the number of bus stops?
5	Are there locations within the municipality with a high incidence of traffic accidents, and if so, where are they situated? Have any measures been taken to reduce accidents, such as transforming intersections into roundabouts?
6	Is there sufficient parking available in the municipality? Are there plans to create new parking facilities or modernize existing ones in the near future?
7	What is the age and condition of the municipal rolling stock (vehicles)?
8	How many kilometers of roads and railway lines exist in the municipality, and how are they distributed throughout the area?
9	How many kilometers of bicycle paths and sidewalks are present in the municipality, and how are they distributed throughout the area?

	How many kilometers of new bicycle paths have been constructed in the last 3 years?
	Group 3: TM and strategy
1	Does the municipality have an effective TM system (e.g., ITS)? Please inform us about the procedures implemented in case of emergencies, such as capacity restrictions on a particular road due to an accident.
2	Does your municipality have maps that are used for sustainable TM?
3	How many units (departments) are involved in planning transport development within the municipality?
4	Do you currently have a transport development strategy (for which years)?
5	To what extent have the strategic goals of transport development been implemented?
6	Are there collaborative initiatives for transport development within the FUA or its subregions?
7	Is there monitoring of public transport vehicles, including GPS tracking, monitoring systems, and passenger counting devices on these vehicles?
8	Are there any road reserves within the municipality, and if so, how up-to-date are they, and is the route still accessible?
9	Which communication investments are considered most important in the municipality's activities? Please rank them in order of priority based on the available options: 1) Public transport development; 2) Improvement of road infrastructure; 3) Investments in cycling and pedestrian infrastructure; 4) Development of environmentally friendly, utility, and electric transport; 5) Integrated transport systems and mobile applications; 6) Other (please specify as appropriate).
10	Are there speed limits within the municipality, and are there any restrictions on certain vehicles (e.g., bans on diesel vehicles entering the city)?
	Group 4: Innovations, threats, and monitoring
1	Has research on mobility been conducted within the municipality, and if so, when was it conducted?
2	Is there infrastructure in place to support the use of electric vehicles? Are there electric vehicle charging stations available in the area, and if yes, how many?
3	Have passenger satisfaction surveys been conducted regarding transport services, and if they have, when were these surveys conducted?
4	Has the municipality acquired modern, environmentally friendly means of transportation (vehicles) or transport infrastructure, such as photovoltaic streetlights?
5	Have there been any unusual transportation delays in the municipality resulting from events such as road accidents, floods, snowstorms, or snowdrifts?
6	Have there been any situations in the municipality that caused disruptions in public transportation services, and if so, what measures were implemented to address these situations?
7	Please provide the number of transport-related innovations implemented in the last 3 years.

Source: own study.

A limitation of the field interviews was the fact that the organizational structure is different in each municipality and employees in thematically similar departments have different responsibilities. This causes difficulties in conducting interviews with only one person. On average, interviews were conducted with two officials in each of the analyzed municipalities. Most often, these were people who deal with municipal investments or the organization of public mass transportation. However, due to the different responsibilities of the employees, they often supplemented their knowledge through telephone consultations or by inviting other employees to participate in a selected parts of the interview. The exception was the municipality of Dobre Miasto, where one person was interviewed, because in its area the county is the organizer of public transport, and it was the source that the most information from this municipality was obtained. Another exception was the municipality of Stawiguda, where 3 employees took part in the interview and they additionally consulted some issues with more office staff by phone.

2.3. Study area

The study encompassed the FUA of Olsztyn, which is formed by the City of Olsztyn and its neighboring municipalities, including Barczewo, Dobre Miasto, Dywity, Gietrzwałd, Jonkowo, Pasym, Purda, Stawiguda, and Świątki. Factors influencing the spatial relationships between the settlement units within the Olsztyn FUA included, among others, the distance between individual municipalities. Olsztyn, as the primary agglomeration center, occupies a central location and is relatively equidistant from other settlement units within the FUA, with an average distance of 15.4 km. This allows for efficient travel to and from Olsztyn in a relatively short time, demonstrating the functional cohesion of the Olsztyn FUA. Olsztyn is recognized as a FUA of metropolitan significance (Fig. 2). In 2011, the European Commission and the Organization for Economic Co-operation and Development (OECD) developed a

standardized definition for a city and its commuting zone (Statistics Poland, 2022). Functional Urban Areas, often referred to as FUAs, encompass cities and their commuter zones. These FUAs consist of a densely populated city at the core and a commuter zone with lower population density, whose labor market is closely integrated with the core city. This positions this area among Poland's primary urban centers, which also exert influence within the broader international European context and play a significant socio-economic role at the local, regional, and national levels.

Olsztyn is a provincial city. It serves as the primary hub for work, education, services, and recreation for residents of nearby municipalities and is an attractive workplace for employees from neighboring FUAs. In 2016, Olsztyn served as the workplace for 13.9 thousand hired workers (Statistics Poland, 2016). The majority of these employees (92.1%) originated from municipalities within the Warmian-Masurian Voivodeship (Table 3). Over 65% of those arriving came from rural areas. The largest influx of hired workers came to Olsztyn from the municipalities surrounding the city. Olsztyn's transportation system is characterized by a radial network of national roads that facilitate easy travel in various directions. These roads (S51, DK16, S16, DK53) also serve to direct traffic out of the city towards the external transportation system. The radial system of national roads is complemented by provincial roads: DW 527 and DW 598 (Fig. 3). However, despite the presence of this network, the absence of alternative routes and the only partially completed city ring road contribute to some traffic congestion on the roads passing through the city center. This phenomenon is a result of the transit traffic load, which could be partially reduced or dispersed with the full implementation of the city bypass. Rail transportation in Olsztyn includes both long-distance and regional services. There are plans to create an agglomeration railway, but the progress of works is slow.

3. Results

3.1. Field interview - Inventory of municipalities belonging to FUA Olsztyn

The interview participants included municipal employees working in departments responsible for TM in the municipality. Additionally, employees from the district office who actively participate in coordinating transportation for selected municipalities within the analyzed FUA were also invited for the interviews.

The interviews took place between May 4, 2023, and September 10, 2023. Two interviewers conducted the surveys at the offices where the interview participants were employed. The outcomes of the interviews were documented using an electronic version of the interview questionnaire designed for local government units within the FUA Olsztyn. Systematic data regarding the organization and operation of TMM in these areas were collected. The interview results were presented in Tables 4-7.

The FUA Olsztyn area offers a diverse range of bus lines (Table 4). Olsztyn itself boasts 35 bus lines, while Barczewo and Dywity have 11 and 10 public lines, respectively. Five municipalities feature 5 bus lines each. In contrast, Pasym municipality solely relies on privately operated bus lines (Fig. 4). Olsztyn collaborates in organizing public transport in 5 other municipalities, connecting them with a total of 12 bus lines. The Olsztyn district also serves as the coordinator for public transport in 5 municipalities (Fig. 4). The presence of a public transport organizer catering to multiple municipalities in the FUA management model simplifies passengers' use of public transport services, as they don't need to adapt to different organizational systems. This benefits both residents and enhances the efficiency of the transportation system. Only 3 municipalities (Świątki, Jonkowo, and Gietrzwałd) independently manage their public transport. Dywity collaborates in providing transportation for Dobre Miasto. Notably, there is no private transportation in 3 municipalities, including Olsztyn itself.

Therefore, in the analyzed municipalities, there is a co-organization of local government transport by various entities, including regional ones, as well as independent organization by individual municipalities. In the city of Olsztyn and the Gietrzwałd municipality, bus lines cover all villages, while in other municipalities, not all villages have bus service. Vehicle overcrowding during rush hours is a common issue in the municipalities, leading to increased bus frequencies during those times (except Świątki). Sunday bus services are available in 4 municipalities. Timetables are posted at bus stops and some municipalities provide information through mobile apps or websites, although a common agglomeration ticket is unavailable. Ticket prices vary by municipality, with most set at 4 PLN. The highest ticket price is in Pasym, which lacks government-organized transportation. Municipalities allocate 5% to 23% of their budgets for developing the transportation

network and public transport, with 15% being the most common allocation. Costs per vehicle kilometer vary significantly, ranging from 5.3 to 33 PLN (for Olsztyn trams).

Table 3

Characteristics of FUA Olsztyn

	Barczewo	Dobre Miasto	Dywity	Gietrzwałd	Jonkowo	Purda	Stawiguda	Świątki	Pasym	Olsztyn
Total area [ha]	32001	25869	16116	17233	16869	31812	22287	16415	14920	8833
Total population	18157	15214	13203	6838	7693	8886	14027	3746	5066	169251
of pre-working age	3655	2798	2803	1427	1593	1856	3630	760	930	28821
of working age	11026	9006	8134	4135	4784	5481	8712	2315	3106	99893
Population density [people/1 km2]	56,7	58,8	81,9	39,7	45,6	27,9	62,9	22,8	34	1916,1
Road accidents	13	10	9	12	9	1	11	13	5	130
Injured/including fatalities	19 (7)	10 (3)	10 (0)	13 (1)	11 (1)	1 (0)	12 (0)	14 (1)	8 (1)	145 (3)
Municipalities' budget expenses [mln PLN]	110.4	89.9	112.4	61.4	46.3	38.8	22.4	117.8	30.6	1.50 mld
Expenditure classification section: Transport and Communication [mln PLN]	11.1	16.2	25.9	14.0	4.2	2.7	9.6	27.3	1.7	127.5

Source: own study based on Poland in numbers (2022) and Statistics Poland (2021).

Fig. 2. FUA Olsztyn – location. *Source*: own study.

Fig. 3. The location of Olsztyn and its FUA in the transportation system of the region. *Source*: own study based on delimitation of OECD (Dijkstra et al., 2019).

Table 4

Group 1: Public transport

	Barczewo	Dobre Miasto	Dywity	Gietrzwałd	Jonkowo	Purda	Stawiguda	Świątki	Pasym	Olsztyn
Characteristics of the transport network										
Total number of bus lines	11	5	10	5	5	5	8	5	0	35
Number of bus lines in cooperation with the city (core)	2	0	3	3	0	1	3	0	0	-
Presence of private bus services within the municipality										
Range of bus lines										
Presence of at least one bus line serving all villages										

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Organizer of the bus lines										
Number of local government organizers for public bus lines	2	2	2	1	1	2	2	1	1	1
Bus frequency										
Presence of overcrowding on buses										
Higher bus frequency during rush hours										
Operation of buses on Saturdays and Sundays										
Changes in Timetable										
Are there regular schedule changes (seasonal/adjustment)										
Monitoring and Information										
Is timetable information available at the stops?										
Is there access to bus schedules through a mobile application or websites?										
Tickets and Fare System										
Is there a common agglomeration ticket										
Ability to purchase tickets through mobile apps or websites.										
Whether the prices of a regular ticket are the same for a paper ticket and in the app [PLN]	4/4	4/4	4/4	4/4	3.92	4/4	4/4	5	14	4/3.4
Development of the public transport network										
Consideration of introducing new bus lines or expanding existing lines										
Allocation of Budget for Public Transportation										
Percentage of municipal budgets allocated to the development of the transportation network and public transport [%]*	10	5	23	23	9	14	20	10	7	15
Budget expenditure on public roads [PLN/1 resident]*										
Provincial Public Roads	2.3	8.2	0	0	0	0.1	0	34.8	0	0
County Public Roads	51.1	6.4	184.5	0	0	56.3	207.5	0.8	9.9	16.8
Municipal Public Roads	319.5	170.4	472.6	1079.7	308.2	701.5	639.8	507.4	345.8	61.6
Cost per vehicle kilometer										
Cost per kilometer for haulers [PLN]	6.2/ 11.7	8.3	10.0/ 8.3	8.6	5.7	8.8	5.3	10.5	no data	33.0/ 11.5/ 10.6

where: yes no

Source: own study based on Statistics Poland (2022)* and the questionnaire.

Fig. 4. Ways of organizing transportation in FUA Olsztyn. *Source*: own study.

Table 5

Group 2: Transport infrastructure and maintenance

	Barczewo	Dobre Miasto	Dywity	Gietrzwałd	Jonkowo	Purda	Stawiguda	Świątki	Pasym	Olsztyn
Assessment of the quality of road infrastructure										
Assessment of the quality of road infrastructure in the municipality on a 3-point scale (1 - low, 3 - high).	2	2	2	2	2	2	2	2	2	2
Are there any roads in the municipality that require intervention due to the condition of the surface?										
Speed Limits										
Is there a speed limit for vehicular traffic in the municipality set at 30 km/h?										
Construction and Modernization of Roads										
Have there been any construction or modernization projects for roads, bicycle paths, etc., in the municipality that have lasted longer than 3 months?										
Number of roads built in the last 3 years										
Bus Stations*										
Total number of bus stops, including:	34	58	125	75	78	149	61	31	32	413
Owned or managed by the municipality	16	13	125	63	78	149	61	31	32	413
Owned or managed by an entity that is not a local government unit	12	15	0	0	0	0	0	0	0	0
Owned or managed by another local government unit	6	30	0	12	0	0	0	0	0	0
Length of Bus Lanes [km]	0	0	0	0	0	0	0	0	0	15.6
The appearance of stops and their condition, and whether they are consistent throughout the municipality.	plain	varied	varied	varied	varied	varied	varied	varied	varied	plain
Planned Changes in the Number of Bus Stops										as required
Indication of Collision Locations and Corrective Actions										
Occurrence of Road Collisions in the municipality										
Have any measures been taken to mitigate collisions, such as transforming intersections into roundabouts?					-			-	-	
Parking Lots										
Assessment of parking lots in the municipality	missing	enough	enough	enough	enough	enough	enough	enough	missing	missing
Are new or modernized parking lots planned?										
The count of parking facilities in the Park & Ride system	0	0	0	0	0	0	0	0	0	0
Condition of the municipal vehicle fleet										
Description of the age of municipal vehicles (newest and oldest vehicle)	up to 9 years	lack	5-10 years	up to 8 years	new and older	lack	up to 5 years	n/a	lack	new and older
Roads and railway stations										
Number of train stations and stops in passenger traffic experience	4	4	1	2	4	2	4	0	2	8
Municipal roads [km]*	149	126	85	144	67	154	186	31	77	521
Number of kilometers of roads in the municipality per municipality's surface area*	77.7	50.7	20.5	43.9	24.7	24	33.2	61.9	70.4	20.6
Bike paths [km]*										
Number of kilometers of bicycle paths in the municipality	3	1	8.8	5.6	8.3	2.2	19.1	0	6.2	106
under municipal management	3	0	5	5.6	2.1	1.3	12.5	0	6.2	102
under the management of the district administrator	0	0	3.1	0	6.2	0.7	0	0	0	0
under the management of the Marshal's Office	0	1	0	0	0	0	3.4	0	0	0
Bicycle paths per 100 square kilometers	0.9	0.3	5.0	3.2	4.9	0.6	7.1	0	4.2	115.4
Bicycle paths per 10 thousand inhabitants	1.6	0.7	6.1	8.2	10.8	2.2	11.3	0	12.2	6.0
Bike paths constructed in the last 3 years	0	0	0.7	0	6.2	0.2	3.2	0	0	4.9

where: yes no

Source: own study based on Statistics Poland (2022)* and the questionnaire.

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All municipalities have identified roads requiring intervention due to surface conditions when assessing the overall state of the road infrastructure, with an average rating (Table 5). In particular, municipalities have pointed out worse road surface conditions, especially on district roads. Over the past three years, road construction and renovation projects have been undertaken, some of which involved the addition of bicycle paths, often extending beyond three months. These investments aimed to improve the availability and quality of the transportation infrastructure but temporarily impacted network capacity.

In six surveyed municipalities, collision-prone areas were identified, leading five of them to take measures to reduce collisions. Examples include converting intersections into roundabouts on Bartąska Street in Stawiguda Municipality and installing traffic lights in Łęgajny, Barczewo Municipality.

Parking availability varies across municipalities. Three of them (Olsztyn, Barczewo, Pasym) reported inadequate or nonexistent parking spaces. Three of them have plans to create new parking lots or upgrade existing ones to improve parking availability. Unfortunately, there is no Park & Ride facility in FUA, which could reduce downtown car traffic.

Municipalities have different approaches to their stocks, ranging from modern vehicles meeting emission standards (Stawiguda) to older buses. Jonkowo purchased two buses in 2019 and owns three others, including a school bus acquired in 2022. Four municipalities lack their own fleet (Barczewo, Dobre Miasto, Purda, Pasym) and rely on external carriers. Some municipalities are considering new vehicle acquisitions, with a focus on electric vehicles to promote greener public transport.

The number of railway stations and operational passenger traffic points varies among municipalities. Some, like Świątki, lack railway stations, while Olsztyn, Stawiguda, Barczewo, Jonkowo, and Dobre Miasto, have more facilities. Stawiguda is currently in discussions about introducing an additional railway stop with PKP S.A.

The length of municipal roads varies, with Olsztyn having the most at 521.1 kilometers, and Świątki having the least at 30.9 km. Similarly, the number of kilometers of bicycle paths and pathways varies, with Stawiguda having the most at 19.1 kilometers and Pasym having none. It's worth noting that some municipalities have constructed new bicycle paths in the past three years, improving cyclist infrastructure availability.

All municipalities, except Olsztyn's core city, lack an effective TM system (Table 6). Olsztyn has implemented an ITS responsible for controlling street traffic, monitoring intersections, and enhancing public transport. Only Olsztyn has formal procedures for handling traffic-related situations, going beyond altering bus routes to include updating information boards through dispatchers. Other municipalities handle issues on an ad hoc basis, leading to inefficiencies. The absence of an action plan can also lead to delays in resolving traffic issues.

Table 6

Group 3: TM and strategy at FUA

	Barczewo	Dobre Miasto	Dywity	Gietrzwałd	Jonkowo	Purda	Stawiguda	Świątki	Pasym	Olsztyn
TM system										
Do you possess an effective TM system, such as an ITS?										
Description of procedures in the event of an emergency, such as road capacity restrictions following an accident										
Are there speed limits within the municipality?										
Are there any restrictions on certain vehicles (e.g., bans on diesel vehicles entering the city)?										
TM maps										
Do you have maps utilized for managing sustainable transport?										
Transport development planning										
The number of units (units) participating in planning transport development in the municipality	1	1	1	2 + outsource	1	1	2	2	2	2
The existence of current transport development strategies and the years for which they are prepared										2016-2027
Implementation of strategic goals										
The extent to which strategic transport development goals	-	-	-	-	-	-	-	-	-	according to strategy

are realized in the municipality										
Joint initiatives for transport development										
Collaborative initiatives for transport development within the FUA or specific parts of the FUA										
Road reserves										
Availability of road reserves										
Key directions for TM development										
The most important directions for the development in the field of TM include: 1) Advancing public transportation. 2) Enhancing road infrastructure. 3) Investments in cycling and pedestrian pathways. 4) Development of eco-friendly, utility, and electric transportation. 5) Integrated transportation systems and mobile applications. 6) Other (please specify as appropriate).	1,2	2	1,2	2, 1, 3	1,5	2	1	1	2,3	1,2, 3,4,5
where: yes no										

Source: own study.

The municipalities, excluding Olsztyn, use publicly available maps for transport planning and development, lacking specialized maps. They often have one organizational unit overseeing these responsibilities, with rural municipalities typically having 1-2 individuals in charge. Olsztyn, on the other hand, has the Transport Department and the Department of Strategy and European Funds at the Olsztyn City Hall responsible for these tasks.

Olsztyn is the only municipality with a current transportation development strategy (2016-2027). Other municipalities integrate transportation planning and development into their municipal development strategies.

Collaborative transportation initiatives within the Olsztyn FUA are rare. The most notable one was the unified agglomeration ticket, but it only covered a portion of the FUA. However, this initiative concluded at this stage. Some municipalities collaborate with the city on urban transport within their areas, usually through separate agreements. For instance, Dobre Miasto collaborates with Dywity on a single bus route.

Municipalities have individual development directions for TM. Barczewo, Dywity, Jonkowo, Stawiguda, and Świątki focus on public transportation, while Purda, Pasym, Dobre Miasto, and Gietrzwałd prioritize road infrastructure improvement. Olsztyn is currently involved in an investment project to expand tram lines, develop public transport, enhance road and cyclist infrastructure, promote eco-friendly and utility transport, and integrate transportation systems and mobile applications.

Mobility research was conducted in Olsztyn and the immediately adjacent municipalities in 2018 as part of the SUMBA project (Table 7). While the FUA has not invested in electric vehicle infrastructure, only Olsztyn, Stawiguda, and Barczewo have AC charging stations for electric vehicles, with power ranging from 1.4 to 22 kW. Additionally, only Olsztyn and Barczewo have fast public DC stations with power ranging from 10 to 300 kW. Passenger satisfaction surveys were conducted exclusively in Olsztyn in 2017 and 2021.

When renewing their vehicle fleets, all municipalities prioritize eco-friendly options. Olsztyn opts for electric vehicles, while others choose low-emission vehicles.

The implementation of public transport within an FUA frequently encounters various challenges. In the analyzed municipalities, these challenges include unfavorable terrain (Stawiguda and Dywity), road renovations and modernizations that necessitate detours and cause substantial delays (Gietrzwałd, Jonkowo), adverse weather conditions such as excessively wet or icy surfaces (Olsztyn, Pasym), difficulties arising from improper parking of vehicles not affiliated with the public transport fleet (Olsztyn).

In the last three years, innovative projects were executed in the analyzed municipalities, including solar lighting, photovoltaic applications, and QR codes at public transport stops for real-time tracking. Olsztyn led in innovation, with onboard displays for passenger information and cultural event promotion, as well as the option to store tickets on a payment card. Municipal bus fleets are equipped with GPS and monitoring systems to some extent. Olsztyn, Dobre Miasto, and Purda have reserves for new road construction to expand existing infrastructure.

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Dobre Miasto - photovoltaic lighting

Olsztyn - charging station for electric vehicles, the option to store tickets on a payment card

Fig. 5. Innovations in Olsztyn's FUA. *Source*: own study.

Table 7

Group 4: Innovation, risks and monitoring

	Barczewo	Dobre Miasto	Dywity	Gietrzwałd	Jonkowo	Purda	Stawiguda	Świątki	Pasym	Olsztyn
Mobility Research										
Mobility research in the municipality, date	2018		2018	2018	2018	2018	2018			2018
Infrastructure for Electric Vehicles										
Public charging stations with alternating current (AC), with power ranging from 1.4 to 22 kW										
Fast, public DC stations with power levels ranging from 10 to 300 kW										
Passenger Satisfaction Surveys										
Passenger satisfaction surveys regarding transportation services, date										2017, 2021
Environmentally friendly means of transportation										
Modern, environmentally friendly means of transportation (vehicles) or transportation infrastructure, such as photovoltaic street lamps								-	-	
Innovations in the field of transport										
Have innovations in the area of transportation in the municipality been implemented in the last 3 years?										
Monitoring of public transport vehicles										
Monitoring of public transport vehicles, equipping vehicles with GPS, and monitoring and passenger counting gates	GPS	-	GPS	GPS	GPS	GPS	GPS			GPS
Threats										
Situations that have resulted in difficulties in public transportation										

where:
yes no GPS - GPS in buses - monitoring on buses - counting gates

Source: own study.

In June 2023, a hacker attack disrupted IT infrastructure responsible for passenger service and payments for public transport (Fig. 6). Traffic lights were reset, causing increased vehicular traffic, and mobile and stationary ticket machines were disabled. Limited paper tickets were available for purchase at selected stores and newsstands, but the supply was insufficient. Residents were compelled to use innovative solutions, including mobile apps, to buy tickets. The Olsztyn City Card couldn't be used to purchase monthly tickets, and the Roads, Greenery, and Transport Authority website remained non-operational until September 22, 2023. The dynamic passenger information system was also affected, with full functionality not restored until September 2023.

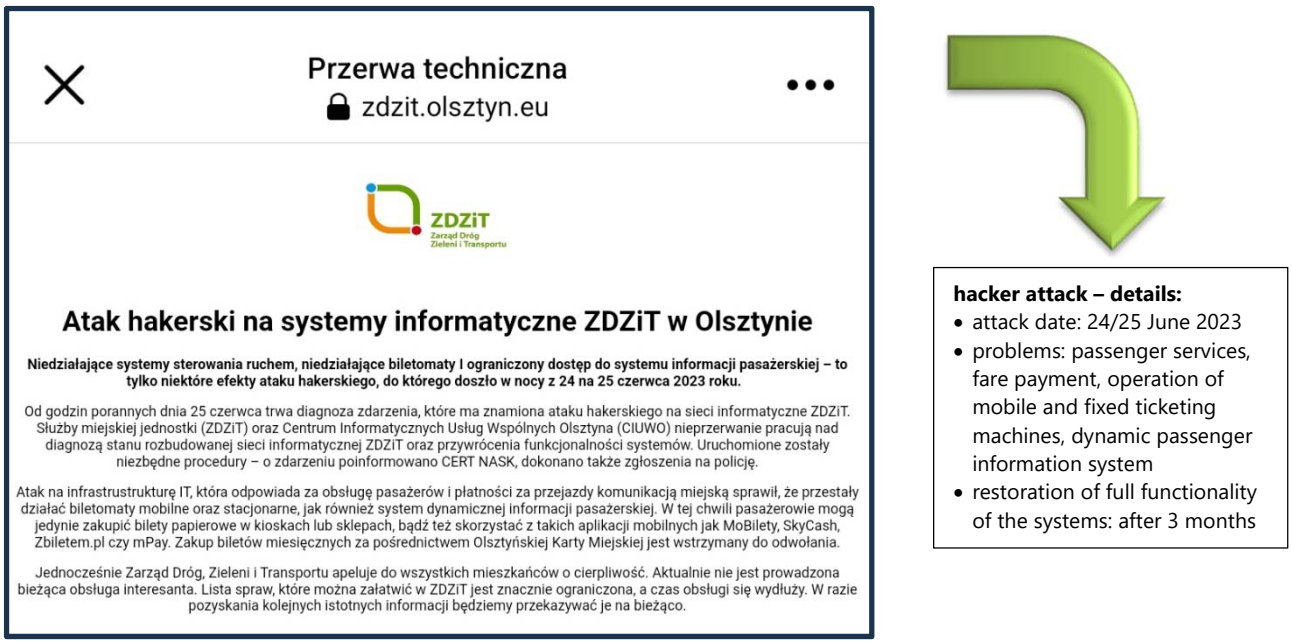

Fig. 6. Hacker attack. *Source*: own study.

4. Discussion

The research, conducted through a designed questionnaire, revealed significant differences in transportation management methods among FUA Olsztyn municipalities. They employ various models, with some being the sole organizers of public transport while others share this responsibility. Pasym, within the FUA, lacks local government public transport, raising concerns about potential transportation exclusion, as it has the highest ticket prices and limited service on weekends. The analysis showed that these municipalities commonly face similar challenges, primarily relating to road infrastructure quality, road and bicycle path scarcity, and the absence of Park & Ride facilities, noise along roads (Szopińska et al., 2022), congestion (Goetz, 2019; Rodrigue, 2020). All are committed to improving road conditions and implementing eco-friendly investments.

Additionally, the research highlighted the absence of comprehensive transport development initiatives covering the entire FUA area. Most initiatives involve 2-3 local government units, despite core city and Olsztyn district co-organizing transport in various municipalities. Recognizing the need for a unified system, it's crucial to consider the commuting patterns between the suburbs and the city. In addition, it should be noted that a territorial development tool, Integrated Territorial Investments, is being implemented in the FUA Olsztyn. This initiative is realized in the new financial perspective of the European Union for 2021-2027 (previously for 2014-2020). With the help of this tool, the city of Olsztyn and six municipalities (Barczewo, Purda, Stawiguda, Gietrzwałd, Jonkowo, and Dywity) are collaborating on joint projects encompassing various aspects, including mobility within the FUA (such as construction/ reconstruction of roads) and the promotion of electromobility (Olsztyn Municipal Office, 2023). However, it is important to note that not all municipalities in the FUA Olsztyn are participating in these activities - specifically, Dobre Miasto, Świątki,

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and Pasym.

The research also revealed varying development priorities among local government units, with some focusing on public transport and others on road infrastructure. It's essential to note that only the core city has established transport development strategies and an ITS.

The occurrence of a hacking attack on the ITS system of Olsztyn draws attention to how important cyber security is nowadays, especially because we create Smart Cities (Lévy-Bencheton & Darra, 2015a). There were 7 incidents from March 2021 to October 2022 in transport sector as a whole – in India, US, Taiwan, Philippines, Hong Kong, Latvia, Poland, Ukraine and one global incident. It is important to develop good practices and recommendations to avoid such situations (ENISA, 2023; Lévy-Bencheton & Darra, 2015a, 2015b).

5. Conclusions

The research objective has been achieved. The conducted research has enabled us to validate the research hypothesis that the emergence of transportation-related threats leads to the implementation of innovative solutions in TMM. This model underwent changes in Olsztyn in response to the threat of a hacker attack on the IT system of the unit engaged in TM in the municipality. These changes pertained to the method of purchasing tickets and the use of mobile applications. Similar research findings were also presented by (Pomykała, 2020), which indicate that the Covid-19 threat also led to an increased use of mobile applications in public transportation. Additionally, time-related risks result from difficulties associated with renovation, modernization, and investment projects, such as the expansion of tram lines in Olsztyn and the construction of a roundabout in Bartąg (Stawiguda municipality). Traffic disruptions motivate individuals to use applications and search for alternative routes that bypass problematic areas.

The designed interview questionnaire serves as a valuable tool for characterizing TMMs in FUAs. It has been divided into four thematic groups, namely public transportation, transport infrastructure, transport strategy within the FUA area, and innovations, threats, and monitoring. This categorization facilitates the acquisition of a more comprehensive understanding of TMM. The questions are clear, and respondents had no trouble understanding them. The division into these four thematic areas simplifies the oversight of responses and helps identify the specific aspects of transportation under analysis. Some questions allow for expanded responses, allowing the addition of supplementary information regarding TMM operation. However, the questionnaire's drawbacks include its length. Its completion demands a significant amount of time, but it represents a compromise between the volume of information gathered and its length. Several questions are highly technical or detailed, requiring respondents to possess specialized knowledge, proficiency in data analysis, or access to historical data, which prolonged the response time. It became apparent that certain questions pertained exclusively to specific towns or regions, necessitating the inclusion of "not applicable" as an option in the questionnaire. Questions like "Is there a speed limit for vehicles in the municipality?" and "Are there any road reserves within the municipality?" are of a general nature, primarily because the respondents, who are local government employees, lack precise technical information. They often supplemented their knowledge through telephone consultations or by inviting other employees to participate in a selected parts of the interview. The questions have been tailored to the level of information collected in local government units.

The authors, seeing how important the topic of TM in FUAs is, intend to analyze other FUAs in the future. The comparative analysis of implemented innovative solutions in response to different threats in different classes of FUAs is one of the next steps of the research. The content of the questionnaire can be used to apply to those analysis. If necessary, it may also be extended. TM requires more holistic approach (sustainable transport), which addresses all problems of all modes of transport (Christidis et al., 2022; Transport Policy Advisory Services (gtz), 2010; Vickerman, 2021).

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