

Digital Maturity and Sustainable Urban Logistics in the Transition Toward Smart City 4.0 in the Context of Polish and European Urban Experiences

First author (Sabina+Kauf)^a, Additional authors (Nataliia+Boichuk)^b,
(Iwona+Pisz)^b, (Sabina+Wyrwich-Płotka)^b, (Anna+Bruska)^{b,1}

^aOpole University, Ozimska 46a, Opole 45-052, Poland

^bOpole University, Ozimska 46a, Opole 45-052, Poland

Abstract

The transition toward Smart City 4.0 requires cities to combine technological advancement with environmental responsibility and new governance models shaping contemporary urban logistics. The study examines how digital maturity of cities shapes their capacity to implement sustainable urban logistics, and how this relationship manifests under the different institutional and technological conditions present in Polish and European urban contexts. Drawing on a multi-layered dataset - including surveys of residents in Polish voivodeship cities, a survey of local government representatives in Poland and Europe, and in-depth interviews with urban development and digital transformation decision-makers – the analysis uncovers a structural divergence between Polish and Western European urban cities. While Polish cities display high technological readiness and rapid deployment of standalone digital services, limited data consolidation, fragmented ICT systems and insufficient system analytical capacities constrain their ability to incorporate digital tools into strategic planning for sustainable urban logistics. In contrast, European cities operate on more advanced levels of digital transformation, where environmental monitoring systems, AI-based modelling, and interoperable platforms support both operational and strategic decision-making. The study also highlights the relevance of social factors: despite high ICT adoption, residents of Polish cities express notable concerns regarding data privacy and administrative transparency, which affect public trust in smart logistics initiatives. The article identifies conditions necessary to reduce the implementation gap between Poland and Europe, emphasising the need for stronger data integration, enhanced digital competences, participatory governance frameworks, and robust environmental monitoring as foundations for sustainable logistics strategies within Smart City 4.0.

Keywords: Smart City 4.0, Industry 4.0, digital maturity, sustainable urban logistics.

1. Introduction

Modern cities operate under conditions of increasing socio-economic complexity, rapid urbanization, climate pressures and rising expectations for efficient public services. In this context, digital transformation has become a key factor shaping the adaptability of urban systems, and their ability to manage risk and maintain quality of life. Research shows a clear evolution of the smart-city concept - from early technology-driven models to advanced approaches emphasizing systemic integration of data, governance, and sustainability objectives. This shift from Smart City 1.0 to Smart City 4.0 reflects a transition from isolated digital solutions to interoperable, analytically driven and institutionally embedded urban platforms supporting strategic planning and real-time management.

Mobility and urban logistics are areas where this systemic integration is particularly visible. Transport systems and freight flows are shaping emissions, energy efficiency, space availability and the quality of life of residents. In emerging Smart Mobility 4.0, the effectiveness of transport innovations depends not only on technology, but on institutional coordination, data integration and administrative analytical capacity. Studies increasingly show that transport technologies deployment often outpaces the development of governance structures, resulting in fragmented systems with limited systemic potential².

Industry 4.0 tools - Internet of Things (IoT), artificial intelligence (AI), and big data analytics - are becoming embedded in urban mobility and the environmental management, yet their use remains largely operational

¹ Corresponding author. Anna Bruska; e-mail address: abruska@uni.opole.pl

² Read more: Smart city 4.0 research reports [Raporty – Baza SCM](#)

(monitoring-focused), rather than strategic and predictive³, reinforcing the gap between technological potential and its systemic application. This gap highlights the relevance of digital-maturity models, which assess not only ICT deployment but also interoperability, data governance and the administrative ability to translate information into decisions. Digital maturity thus becomes a determinant of a city's capacity to move from pilot projects to integrated mobility and logistics management systems⁴.

Despite extensive research on Industry 4.0 and smart mobility, few studies examine these perspectives jointly. Urban logistics is often treated as a transport or environmental issue, rather than as a domain revealing the real level of a city's digital maturity. As a result, the relationship between the technology, data, governance and sustainable mobility flows, remains under-theorized.

Against this background, the article asks: How and to what extent does digital maturity determine a city's ability to implement sustainable urban logistics within the Smart City 4.0 model? The objective is to explain the relationship between digital maturity and the organization of sustainable mobility, with emphasis on data integration, analytical capacity and the use of Industry 4.0 technologies. This has both cognitive and practical significance, helping identify whether barriers stem from technological or institutional constraints.

The article first outlines the theoretical foundations linking digital maturity, Industry 4.0, and sustainable urban logistics. It then presents empirical findings from the 2024-2025 "City 4.0 - Universal Maturity Model" project, comparing Polish and European urban and incorporating both institutional and user perspectives.

2. Digital maturity as a condition for systemic mobility transformation

Contemporary smart city research increasingly adopts systemic perspectives, conceptualising cities as socio-technical ecosystems. In the classic six-dimensional smart city model (Giffinger et al., 2007), mobility is a core functional domain linked to economic performance, environmental quality, governance and quality of life. Later scholarship emphasises cities as systems of flows – of people, goods, energy and information – whose efficiency depends on real-time data and coordinated decision-making. In this sense, urban mobility and logistics are not only components of the urban system, but its backbone, determining the organisation of space, the level of emissions and the availability of services. (Giffinger et al., 2007) (Batty et al., 2012)

The evolution of the smart city paradigm - from early infrastructure-centric approaches to the Smart City 4.0 model - reflect a shift from automating isolated processes to integrating data, predictive analytics, and adaptive management. Earlier models often marginalised social and institutional dimensions; contemporary approaches emphasise data governance, system interoperability and administrative capacity. Smart City 5.0 further reinforces the human-centric orientation. This evolution indicates that the level of technological development is not synonymous with the level of systemic maturity of a city. (Hollands ,2008; Kitchin ,2015) (Fukuyama, 2018; Narvaez Rojas et al., 2021)

Industry 4.0 tools are essential for mobility and logistics. IoT, AI, and big data analytics enable a shift from reactive traffic management to predictive modeling and optimization of transport flows. Their effectiveness, however, depends on organizational coordination among public transport operators, shared service providers and mobility platforms, requiring common standards, institutional alignment, and administrative analytical skills. (Avci & Koca, 2024; Ma & Fang, 2022) (Ho & Tirachini, 2024)

Sustainable mobility – central to the Smart City 4.0 model – relies on access to high quality data on transport behavior and environmental impacts. Without systematic data analysis, mobility policies remain intuitive and short-term; predictive approaches, by contrast, support emissions reduction, route optimization, and better infrastructure planning. Mobility thus reveals the real ability of cities to integrate technology, data and management. (Winkler et al., 2023)

Smart-city maturity models assess not only ICT deployment, but also the capacity to operationalize data (Lombardi, Giordano, Farouh, & Yousef, 2012); (Pliatsios, Kotis, & Goumopoulos, 2023) integrate systems across sectors, and align technology with environmental and social goals. Digital maturity becomes a precondition for moving from fragmented, project-based technological deployments to integrated urban logistics management.

Synthesizing these strands leads to a key conclusion: urban logistics is a sensitive indicator of a city's systemic maturity. The ability to manage freight and transport flows predictively depends on Industry 4.0 technologies, interoperability, data-driven-governance, and administrative analytical capacity.

This reasoning justifies the development of a conceptual model that structures the relationship between digital maturity and sustainable urban logistics. The literature clearly shows that technologies, data, and governance structures operate not as isolated components but as sequential and interdependent layers. In the proposed model, Industry 4.0 technologies – IoT, AI, big data analytics, and intelligent transport systems – constitute the technological layer, enabling real-time monitoring, scenario modeling and partial automation of traffic processes. However, according to previous findings, "the mere presence of technology does not determine the city's ability

³ N. Boichuk, I. Pisz..., Maturity models in managing the development of smart cities – a systematic review of the literature (manuscript submitted to publication)

⁴ *ibid.*

to systematically manage mobility and logistics". (Batty et al., 2012; Lombards et al., 2012); (Avcı & Koca, 2024; Ma & Fang, 2022)

The organizational-institutional layer, corresponding to digital maturity mediates between technological potential and operational performance (Pliatsios et al., 2023). It encompasses data interoperability, data-driven-governance, interdepartmental coordination, and administrative analytical skills. Without this layer, cities remain trapped in fragmented, project-based implementations - as Hollands (2008) and Kitchin (2015) described.

The integration of the technological and organizational layer produces the operational layer, which reflects the city's ability to manage mobility predictively, optimize freight flows, reduce emissions, and coordinate multimodal systems. In this sense, urban logistics becomes an operational manifestation of digital maturity, and its performance reveals the degree of integration between technology, data, and governance.(Ho & Tirachini, 2024; Winkler et al., 2023)

The model therefore posits an indirect relationship: Industry 4.0 technologies influence sustainable urban logistics through the mediating role of digital maturity. Underdeveloped organizational-institutional capacity prevents technological investments from generating systemic effect. As a result, urban logistics can be treated as a precise (sensitive) indicator of a city's true digital maturity.

The conceptual model presented in Figure 1 synthesizes these relationships, offering a heuristic structure that organizes the interplay between technological, organizational-institutional (digital maturity) and operational dimensions.

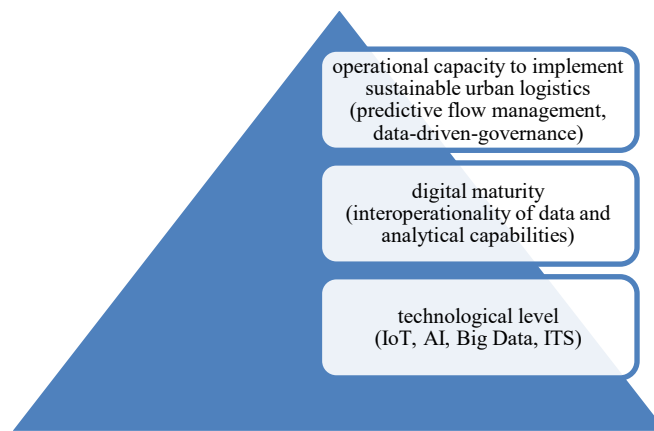


Fig. 1. Conceptual model of the relationship between digital maturity and sustainable urban logistics.
Source: Author's elaboration

Its purpose is to support the analysis of complex urban transformation processes by providing a coherent interpretative framework consistent with contemporary theoretical assumptions. This is particularly valuable in the study of complex urban systems, where interactions between technology, governance, and operational outcomes are multidimensional and context-dependent.

Within this framework, sustainable urban logistics is understood as an emergent property of digitally integrated mobility management. The capacity to monitor flows, model demand and coordinate multimodal systems through digital platforms becomes a prerequisite for reducing environmental pressures, improving energy efficiency, and mitigating the spatial impacts of transport on the urban fabric.

3. Architecture of the Urban Mobility and Logistics Survey

The methodology of this study was developed as a multi-stage, integrated diagnostic framework designed to capture the digital maturity of cities not as a collection of isolated technological deployments, but as a complex system of interdependencies among digital infrastructures, organizational and institutional arrangements, and the social context in which smart city solutions operate. Although the broader research project encompassed the full spectrum of smart city development, this article focuses specifically on urban mobility and logistics as a domain particularly suited to revealing the actual degree of integration between digital technologies, data ecosystems, and governance structures.

The impetus for undertaking the research was the need to construct a universal Smart City 4.0 maturity model capable of operationalizing the level of integration of ICT and Industry 4.0 technologies with urban management processes and with the everyday practices of urban space users. The study was conducted in 2025 as part of the project "City 4.0 – Universal Maturity Model", implemented by a research team at the University of Opole. Its methodological design followed the principle of triangulation across data sources, research methods, and analytical perspectives.

The research process unfolded sequentially through several complementary stages. First, a review of the literature and existing smart city assessment models was carried out, enabling the identification of key dimensions of digital maturity and informing the development of the research tools. Based on this foundation, a set of indicators was constructed, including – among others - data integration, system interoperability, the use of digital technologies in mobility and environmental management, governance models, and the extent to which data inform decision-making processes. In the subsequent stage, research tools were developed: standardized questionnaires for city administration representatives and for residents, as well as interview protocols for in-depth interviews with decision-makers responsible for smart city development and digital transformation. These tools underwent expert validation and pilot testing, which facilitated refinement of question wording and improved measurement accuracy.

The institutional component of the study encompassed both Polish and European cities. In Poland, the analysis covered all eighteen voivodeship capitals, ensuring full representation of the country’s highest-status administrative centers. The survey targeted local government officials responsible for city development, digital transformation, mobility, and data management. This quantitative material was complemented by in-depth interviews with decision-makers in selected cities, providing qualitative insights into organizational processes, implementation barriers, and data-use practices in urban management. In parallel, selected European cities – national capitals and major metropolitan areas with advanced smart city ecosystems – were included to enable comparative analyses across diverse institutional and technological contexts.

A crucial complement to the institutional perspective was the social dimension. A nationwide survey was conducted among residents of eighteen voivodeship cities, yielding a representative sample of 1 515 respondents selected through a quota sampling method reflecting population structure by sex, age, education, and employment status. The study was administered using the CAWI technique, allowing access to a diverse group of users of urban digital technologies. The questionnaire included thematic modules on awareness of the smart city concept, assessment of technological implementation levels, use of municipal applications, trust in authorities regarding data management, willingness to participate, and concerns related to privacy and information security. Five-point Likert scales and frequency scales were employed to capture the intensity of attitudes, and digital tool usage. The instrument demonstrated very high internal consistency (Cronbach $\alpha = 0.928$), confirming its reliability. The overall architecture of the research procedure - integrating conceptualization, operationalization, sampling, and multi-source data collection and analysis in the field of urban mobility - is illustrated in Figure 2.

The empirical material thus encompassed three complementary analytical levels: the systemic-institutional level (city administration), the organisational-operational level (data management and use practices) and the social level (city users). Quantitative data were subjected to descriptive and comparative analysis, including the identification of maturity levels, development patterns, and inter-city differentiation. Qualitative material was used to interpret organizational and contextual mechanisms. Given the diagnostic and exploratory character of the study, and the horizontal operationalizing the indicators, the analysis aimed to identify developmental configurations and systemic barriers rather than model causal relationships. This approach is methodologically appropriate for research on complex urban systems, where transformation processes are multidimensional, context-dependent, and deeply embedded in institutional structures.

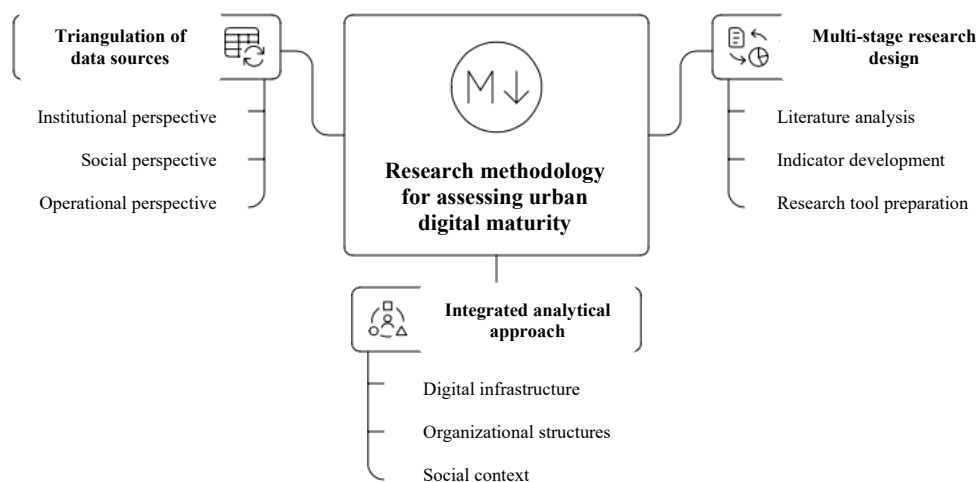


Fig. 2. Research methodology for assessing the digital maturity of cities
Source: Author’s elaboration using Napkin AI

All research procedures were conducted in accordance with ethical standards for social research, ensuring respondent anonymity and data confidentiality. The adopted methodology enabled the conceptualization of digital

maturity as a systemic phenomenon integrating technological, organizational, and social dimensions, forming the basis for subsequent analysis of results in relation to the proposed Smart City 4.0 conceptual model.

4. An empirical picture of the digital maturity of cities in the area of urban mobility

This section presents the empirical findings on the digital maturity of cities in the domain of urban mobility and logistics. The analysis follows the three interrelated dimensions of the adopted conceptual model: the technological layer, the organisational-institutional layer, and operational mobility-management practices. This structure enables a systemic interpretation of the data, capturing not only the state of digital infrastructure but also the administrative capacity to use data in decision-making and the experiences of users of urban mobility systems.

The smart mobility dimension refers to the application of digital technologies in the organisation, management, and planning of urban transport, with the aim of reducing emissions, improving accessibility and increasing the efficiency of mobility systems. Within the Smart City 4.0 framework, this area represents one of the most dynamic fields of urban transformation, where ICT solutions, data-analytics platforms, and artificial intelligence tools interact with sustainability goals and adaptive urban governance.

From a systems perspective, Smart Mobility encompasses the development of intelligent transport systems (ITS), the integration of public and shared mobility services, the deployment of traffic-monitoring and forecasting tools, and the expansion of infrastructure supporting electromobility and micromobility. A key component is the provision of real-time passenger information and the creation of integrated mobility platforms (Mobility as a Service – MaaS), which combine public transport, cycling, shared mobility, and pedestrian services into a coherent ecosystem.

The analysis of the development of intelligent and integrated mobility (Fig. 3) shows that the digitisation of transport systems in Polish cities is currently as a stage of distributed consolidation. Medium and transitional maturity levels dominate, although some cities have reached advanced stages and a few demonstrate elements of full implementation. This indicates that digital tools – ITS modules, mobility applications, or electromobility solutions – are typically deployed as isolated components rather than as element of a fully interoperable mobility system.

Many implemented solutions remain project-based or pilot-oriented, which limits long-term integration and constrains the use of data for comprehensive traffic planning and management. In contrast, European cities demonstrate significantly higher levels of digital maturity. Advanced and full implementation levels prevail, suggesting that smart mobility is structurally embedded in urban strategies. Digital technologies are integrated into climate, spatial and social policies, and transport data is used not only operationally, but also predictively – to model traffic flows, plan infrastructure investments and optimise transport networks.

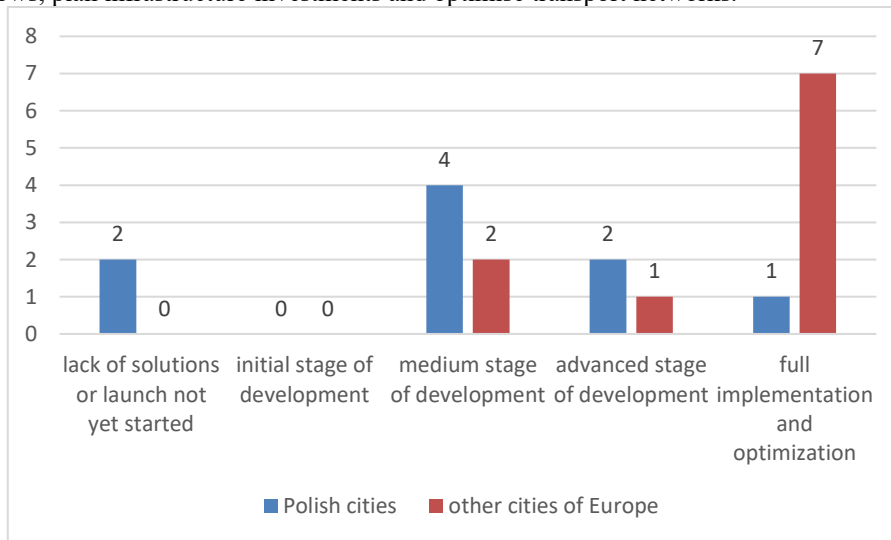


Fig. 3. Development of smart and integrated urban mobility
Source: Author's elaboration based on own research

A critical component of digital maturity is the use of data use and automation in urban transport management (Figure 4). In Polish cities, data collection is becoming more widespread, yet its operationalization remains limited. Barriers include insufficient systems interoperability, weak feedback loops between platforms, and the absence of specialized analytical units within city administrations. In European cities, telemetry systems, sensors, GPS data, and analytics platforms form a unified information infrastructure that enables real-time traffic management and the integration of mobility data into spatial planning. These differences have direct implications for sustainable

urban logistics: cities capable of integrating real-time data and applying predictive tools are better positioned to reduce congestion, optimise passenger and freight flows, and lower transport-related emissions.

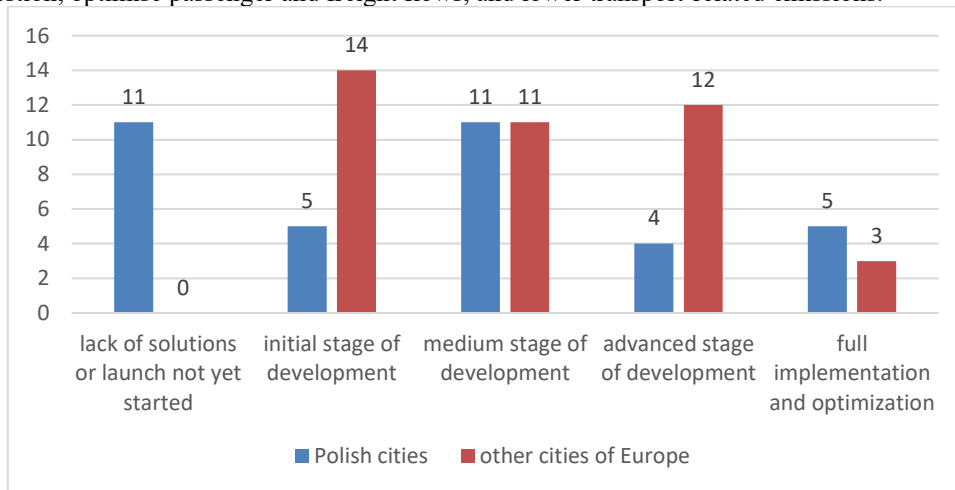


Fig. 4. Use of data and automation in urban transport management
Source: Author’s elaboration based on own research

These divergences are not only technological, but also organisational and institutional. In Poland, digital mobility solutions primarily serve a modernization function, improving existing processes. In European cities, they play a transformative role, contributing to the creation of integrated, adaptive mobility ecosystems.

Other analysed areas of Smart Mobility – such as the availability of modern transport solutions for users, the influence of Industry 4.0 technologies on emerging mobility forms, and the use of digital tools to enhance transport efficiency – exhibit a similar pattern. European cities consistently achieve higher levels of technological and organizational integration, while Polish cities, are typified by phased, selective and often pilot-based applications.

To synthetically capture these differences, the results for the key components of Smart Mobility were compared in a cross-city perspective (Table 1). The comparison covers both the technological dimension (use of Industry 4.0 solutions, ITS systems, predictive tools) and the organizational-institutional dimension (data integration, system interoperability, analytical capacity of city administration). This approach makes it possible to identify dominant development levels in Polish and European cities and to highlight the systemic differences between the modernization-oriented and transformat-oriented models of digital mobility development.

Table 1. Comparative levels of digital maturity in Smart Mobility: Poland and Europe

Smart Mobility component	Poland – dominant level	Europe – dominant level	Key Systemic Difference
Integrated forms of mobility	Intermediate – Advanced	Advanced – full integration	Fragmented module-based solutions in Poland, vs. integrated MaaS ecosystems in Europe
Availability of digital transport services	Medium	Advanced – full implementation	Poland: mainly informational functions; Europe: real-time service coordination and management
Industry 4.0 technologies in mobility	Medium	Advanced	Poland: pilot-scale deployments; Europe: integrated sensor networks, AI and V2I systems
Use of transport data	Medium	Advanced	Limited interoperability and analytical capacity in Poland vs unified data infrastructures in Europe
Process automation and prediction	Initial – Medium	Advanced	Poland: lack of systemic coupling; Europe: predictive models embedded in traffic management
Smart Mobility development model	Developmental and selective stage	System integration stage	Poland: modernization trajectory; Europe: systemic transformative model

Source: Author’s elaboration based on own research

The maturity levels presented in Table 1 indicate that, in Polish cities, the development of smart mobility remains phased and selective, with digital solutions functioning primarily as instruments for improving isolated components of the transport system. In European cities, by contrast, development trajectories correspond to system-integration configurations, in which data, automation and predictive analytics constitute the operational backbone of mobility management. This divergence is structural: it reflects differences not merely in technological equipment, but above all in the institutional capacity to embed digital technologies within decision-making processes and spatial planning frameworks.

The institutional analysis was complemented by the perspective of transport-system users. Incorporating this dimension is methodologically significant, as urban mobility is an area in which a city’s digital maturity is directly reflected in residents’ everyday practices – how they plan trips, use applications, and evaluate the usefulness of ICT solutions in the mobility environment. This dual perspective enables multi-source triangulation allowing comparison between the declarative level of implementation reported by local governments and the perceptions and experiences of system users.

Survey results confirm that mobility is one of the most tangible and visible areas of urban digitization. The very high level of internet access among respondents (over 98%) creates favourable conditions for the widespread use of digital mobility tools, such as journey-planning applications, real-time passenger-information systems, and municipal e-service platforms. Residents emphasise that these technologies facilitate the organization of daily mobility, reduce the time needed to access information, improve navigation within the transport network and increase the predictability of travel. From the user perspective, smart mobility is hence not perceived as an abstract technological innovation, but as a practical enhancement of the city’s comfort, efficiency, and functionality.

At the same time, the findings reveal a notable tension between technological saturation and the relational dimension of mobility systems. As in other smart-city domains, a "relational gap" emerges: residents are willing to use digital services yet they participate only marginally in co-decision processes concerning the development of transport systems. Digital mobility thus functions predominantly as a service infrastructure rather than as a field for participatory co-creation of transport policy. From the standpoint of Smart Mobility maturity, this constitutes a significant limitation: full transformation requires not only technological implementation but also the active involvement of users in planning, consulting, and evaluation processes.

Residents’ statements also points an ambivalent attitude toward the technologization of mobility space. Alongside perceived benefits, concerns arise regarding privacy, data security, and the transparency of data-processing rules within public institutions. These issues are particularly salient in mobility, where location data and movement patterns are routinely collected. Acceptance of solutions such as traffic monitoring, sensor networks or predictive analytics is therefore conditional – dependent on trust in local authorities and on clear communication about the purpose and scope of data use. This underscores that the development of Smart Mobility is not solely a technological challenge, but also one of data ethics and social trust management.

From a social-structural perspective, the risk of digital exclusion in mobility is also significant. Although overall connectivity is very high, concerns persist regarding the accessibility of digital solutions for older residents, and individuals with limited technological competences. In practice, this may result in a situation where the growing importance of digital information channels is accompanied by limited ability among some users to benefit from them. The Smart Mobility dimension must therefore be assessed not only in terms of systemic efficiency, but also in terms of inclusiveness and social accessibility.

Incorporating the residents’ perspective thus enables a broader, relational interpretation of the institutional findings. While local governments tend to view digital mobility as an area of gradual technological integration, users already experience it as part of their everyday urban life, evaluated through the lenses of usability, trust, and accessibility. The comparison of these two levels suggests that the further development of Smart Mobility should focus not only on expanding ICT infrastructure and analytical systems, but also on establishing transparent data-management principles, strengthening residents’ digital competences, and enhancing participatory mechanisms in urban transport planning.

To complement the institutional perspective with the utility dimension, synthetic conclusions from the residents' survey regarding the functioning of digital mobility in everyday urban experience were compiled. Table 2 presents the key areas of Smart Mobility perception, illustrating the relationship between user practices and the systemic maturity of transport solutions. This interpretative approach links the technological advancement of mobility systems with their social reception, sensed usefulness, and level of trust in institutional data management.

Table 2. Digital mobility in residents’ perceptions as a social dimension of Smart Mobility maturity

Dimension of residents' perception	Empirical observations	Relevance for Smart Mobility Maturity
Use of digital mobility tools	Very high internet access; frequent use of journey-planning apps and real-time passenger information systems	Indicates strong user-side technological readiness and the system’s capacity to operationalize digital services
Usability of digital mobile solutions	Digital tools perceived as genuinely facilitating trip planning, and navigation	Confirms mobility as the most visible and functionally impactful area of smart-city digitisation
Participation in mobility planning	Limited resident involvement in co-decision processes regarding transport development	Reveals a relational gap between technological deployment and participatory co-management
Trust and data governance	Concerns about privacy, data security, and transparency of location-data processing	Acceptance of mobility technologies is conditional on institutional trust and clear communication
Digital inclusivity	Risk of exclusion among users with lower digital competence or limited access to technology	Highlights the need for socially accessible and competence-inclusive mobility systems

Source: Author's elaboration based on own research

The areas summarized in the table show that digital mobility is the dimension of smart city transformation most directly experienced by residents. They also highlight a clear tension between the high usability of technological solutions and the comparatively low levels of participation and trust in data-management practices. This indicates that the next stage of Smart Mobility development must strengthen its social component: involving users in more actively in planning processes, enhancing digital competences, and establishing transparent rules for data processing. Only by combining technological efficiency with social legitimacy can urban mobility systems achieve a mature, fully integrated form of smart-city development.

5. Discussion – digital maturity as a driver of systemic transformation in urban mobility

The empirical findings show that urban mobility is the domain in which a city's actual level of digital maturity becomes most visible. Bringing together institutional and user-centred perspectives demonstrates that digital technologies in transport are no longer experimental add-ons but have become embedded components of contemporary urban systems. From a sustainability standpoint, the results indicate that digital maturity constitutes a foundational condition for environmentally responsible urban logistics: only integrated data environments enable the shift from reactive traffic control to systemic optimization of mobility flows. At the same time, the analysis reveals a persistent gap between the presence of technological solutions and their systemic integration, a distinction with significant theoretical and practical implications.

Within the adopted conceptual model, the findings confirm that Industry 4.0 technologies, ITS systems and analytical tools influence the quality of urban mobility indirectly - through the organizational-institutional layer, that forms the core of digital maturity. In Polish cities, the technological layer is advancing more rapidly than the administrative capacity to integrate data, build interoperable systems and translate analyses into decision-making. As a result, technological potential remains only partially realised, and digital mobility continues to develop in a project-based rather than systemic logic.

European cities exhibit a contrasting configuration, in which technology, data and governance structures operate as a coupled system. Transport data is embedded in planning cycle, used predictively, and linked to climate, energy, and spatial policies. The findings therefore reinforce the argument that digital maturity is not equivalent to the level of ICT equipment; it is defined by the institutional capacity to convert data into operational knowledge and strategic decisions.

A further contribution of the study lies in incorporating the residents' perspective. This reveals that digital mobility is already deeply rooted in everyday practices, yet simultaneously marked by a relational deficit. High usability of technology does not automatically translate into trust in institutional data governance or active participation in mobility planning. The transformation of Smart Mobility is thus asymmetrical: technological progress outpaces the development of social and participatory dimensions. From the standpoint of systemic maturity theory, this confirms that social inclusion is a prerequisite for the stabilising digital transformation rather than a secondary outcome.

These findings contribute to the broader debate on the evolution of the smart-city concept from technology- or infrastructure-driven approaches toward systemic and human-centred models. Urban mobility – because it is closely tied to daily experience - becomes a testing ground for the real quality of digital transformation. Without integration into governance structures and without social legitimacy, transport technologies deliver operational improvements but fall short of enabling deeper transformation of the urban system.

From a practical perspective, the key challenge for cities in the transition is moving from isolated implementations to system consolidation. This requires building interoperable data platforms, strengthening analytical capacities within public administration, and involving users in mobility-policies design. In this sense, digital maturity is not an end in itself, but a condition enabling cities to pursue sustainable, adaptive, and socially legitimate mobility strategies.

The study therefore confirms the thesis that urban mobility functions as an operational indicator of a city's digital maturity. It is in this domain that it becomes evident whether technologies, data and governance structures form a coherent system capable of learning, adapting, and achieving environmental and social objectives - or whether they remain a collection of disconnected technological components.

6. Conclusions and implications for the development of Smart Mobility

The analysis demonstrates that urban mobility is the domain in which a city's digital maturity is most clearly expressed. The combined institutional and user-centred perspectives confirm that digital technologies in transport systems are now a stable feature urban functioning, yet their presence alone does not equate to systemic maturity. The key differentiator among the cities studied is the ability to integrate data, ensure system interoperability and operationalise analytical insights in decision-making.

In Polish cities, smart-mobility development remains predominantly modernization-oriented and incremental. ITS systems, digital tools and user-support applications are being deployed, but they often operate within a project-

oriented logic, without sustained integration into urban data platforms or governance structures. Consequently, the potential of Industry 4.0 technologies is not fully translated into predictive or adaptive mobility management.

European cities, by contrast, represent a model of system integration in which transport data, predictive analytics and process automation underpin operational flow management. Digital technologies are embedded in urban strategies and linked to climate, energy and spatial policies. The difference between the two groups of cities is therefore structural, rooted primarily in institutional capacities rather than technological availability.

The residents' perspective adds an important dimension: digital mobility is firmly embedded in everyday practices and perceived as a genuine convenience. Yet participation and trust in data governance remain limited. This suggests that the next phase of Smart Mobility development must strengthen the social dimension – enhancing transparency, improving communication, and involving users in planning processes.

Several practical implications emerge: (1) interoperable data platforms integrating transport, environmental and spatial information are essential, (2) analytical competencies within urban administrations must be expanded to support the shift from monitoring to predictive modeling, (3) Smart Mobility development should be more closely aligned with sustainability objectives, including emission reduction and improved quality of life, (4) participatory mechanisms and trust-building in data governance are critical for social legitimacy.

The study also contributes to theory by confirming that digital maturity is systemic and mediatic: technologies influence mobility outcomes through organisational, institutional and social layers. Urban mobility can therefore serve as an operational indicator of the integration of technology, data and governance within the Smart City 4.0 model.

The main limitation of the study is the relatively small sample of local-government respondents and the exploratory nature of the comparative analysis, which does not allow for statistical generalizations. The findings should be interpreted as identifying patterns and developmental tendencies. Future research should include larger samples, more extensive quantitative analyses, and refined indicators capturing the integration of data and decision-making processes in mobility systems.

In conclusion, the digital transformation of urban mobility is not merely a technological shift but a complex systemic process in which organisational integration, analytical capacity and social legitimacy play decisive roles. These factors determine whether cities can progress from isolated deployments to adaptive, sustainable and genuinely smart mobility systems. Urban mobility in the Smart City 4.0 model thus emerges as a domain where digital maturity, urban logistics and sustainable objectives converge into a shared platform for systemic urban transformation.

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